NORTH CAROLINA Wildlife RESOURCES COMMISSION

2015 NORTH CAROLINA

WILDLIFE ACTION PLAN

NCWILDLIFE.ORG

Recommended citation:
North Carolina Wildlife Resources Commission. 2015. North Carolina Wildlife Action Plan. Raleigh, NC.

An electronic version of the NC Wildlife Action Plan is available online:
http://www.ncwildlife.org/plan.aspx.

This program receives Federal financial assistance from the US Fish and Wildlife Service.

Design and layout by Robert Kern, TIPS Technical Publishing, Inc. (Carrboro, NC)
Cover design by Bryant Cole, NCWRC
Photographs (clockwise, from left) by:
Brook Floater (Alasmidonta varicosa), Brena Jones, NCWRC
Eastern Painted Bunting (Passerina ciris ciris), Kenneth Cole Schneider
Prescribed burning (an important land management tool), Melissa McGaw, NCWRC
Bog Turtle (Glyptemys muhlenbergii), Melissa McGaw, NCWRC

200 copies of this public document were printed at a cost of $1,665.84 or $16.66 per copy, April 2016.

RESOLUTION ENDORSING THE NORTH CAROLINA WILDLIFE ACTION PLAN 2015 REVISION

WHEREAS, the North Carolina Wildlife Resources Commission is the agency entrusted with the management and conservation of North Carolina's wildlife resources for the enjoyment of all people; and

WHEREAS, the North Carolina Wildlife Action Plan, a comprehensive fish and wildlife management plan, was developed in 2005 with appropriations by the United States Congress for the State Wildlife Grants Program; and

WHEREAS, the North Carolina Wildlife Action Plan, in conjunction with the North Carolina Wildlife Resources Commission's Strategic Plan, provides a conservation blueprint to guide and direct statewide wildlife diversity conservation priorities, emphasizing the use of best available science to keep common species common; and

WHEREAS, Congress has mandated that the state's eligibility for receiving State Wildlife Grants for management of non-game species is dependent upon maintaining the approved North Carolina Wildlife Action Plan and subsequent revisions; and

WHEREAS, the North Carolina Wildlife Action Plan has undergone revision by North Carolina Wildlife Resources Commission staff in concert with numerous federal, state and local partners and stakeholders;

NOW, THEREFORE, BE IT RESOLVED, that the North Carolina Wildlife Resources Commission endorses the revised North Carolina Wildlife Action Plan as the blueprint for comprehensive management of wildlife resources in North Carolina.

This resolution was introduced by Wildlife Commissioner Mark Craig and unanimously approved by acclamation by the Wildlife Resources Commission in its duly assembled meeting on August 27, 2015 in Raleigh, North Carolina.

John Litton Clark
Chairman

Gordon S. Myers
Executive Director

Notes and Acknowledgements

There were many people who contributed significant amounts of time to creating and reviewing the technical content of North Carolina's 2015 Wildlife Action Plan, often through long hours participating in work groups or on teams or committees. Their participation and efforts are recognized in the list of key participants and organizations provided in Appendix C. In addition, I would like to acknowledge the numerous people whose time, perspectives, advice, and expertise were invaluable for completing tasks and developing subject matter, determining priorities, and recommending actions. There were also many people, especially Commission staff, who provided various types of support throughout the revision effort that helped me herd cats and meet deadlines. You all have my sincerest thanks. For anyone not specifically mentioned by name, the oversight is unintentional and your help is appreciated.

Cindy Carr
Wildlife Action Plan Coordinator, NC Wildlife Resources Commission
Mailing Address: 1721 Mail Service Center, Raleigh, NC 27699-1721
office: 919-707-0227 // fax: 919-707-0028
ncwildlife.org/plan

NC Wildlife Resources Commission staff (too many to name)
Allison Weakley, NCNHP
Anita Goetz, USFWS
Anne Deaton, NCDMF
Austin Kane, NWF
Barry New, NCFS
Bill Crowell, APNEP
Bob Butler, USFWS
Braxton Davis, NCDCM
Bryan England, City of Raleigh Parks
Chuck Hunter, USFWS
Craig Watson, USFWS
Chris Matthews, Mecklenburg County Parks
Dave Penrose, Watershed Science
Dave Genereux, NCSU
David Griffin, NC Aquariums
David Jones, NC Zoo
David Welch, PCP
Dean Carpenter, APNEP
Don Hopkins, NCDOA Apiculture
Greg Cope, NCSU
Hilary Morris, SALCC
Holly Weyers, USGS
Ian McMillan, NCDWR
Jacob Leech, Piedmont Conservation Council
James Costa, WCU
Jamie Smith, NCMNS
Jason Cryan, NCMNS
Jay Levine, NCSU
Joe Stancar, DOD
John Ann Shearer, USFWS
John Finnegan, NCNHP
John Fridell, USFWS
John Stanton, USFWS
Julie Elmore, NRCS
Lee Thornhill, USFS
Les Hunter, NCFS
Lisa Tolley, NC Office of Environmental Education
Louise Vaughn, SALCC
Mark Endries, USFWS
Marty Korenek, DOD
Matthew Cimitile, AMJV
Mike LaVoie, EBCI
Mike Schafale, NCNHP
Misty Buchanan, NCNHP
Nancy Daly, NCDMS
Naomi Edelson, NWF
Nina Hall, UNC Asheville
Nora Deamer, NCDWR
Pat Harris, NCDS&WC
Peter Weigl, Wake Forest University
Rebecca Benner, TNC
Rich Hatfield, Xerces Society
Rua Mordecai, SALCC
Ryan Monello, NPS
Sally Palmer, TNC
Sean Brogan, NCFS
Stephanie Horton, NCDMS
Steve Williams, NCSU
Sue Cameron, USFWS
Tancrid Miller, NCDCM
Tom Augspurger, USFWS
Valerie True, Blue Ridge Forever
Veronica Fasselt, USEPA
Wayne Starnes, NCMNS
William Winner, NCSU

Contents

APPENDIXES

List of Figures

List of Tables

Introduction

1

FOR 75 YEARS, state fish and wildlife agencies across the United States have benefited from federal aid funds provided by the Wildlife Restoration Act (Pittman–Robertson or PR), Sport Fisheries Restoration Act (Dingell–Johnson or DJ), and the Wallop-Breaux Act, which support the conservation and management of game fish and wildlife species. These funds are generated through federal excise taxes collected at the manufacturers' level and have been critical to the establishment of long-term agency conservation planning related to game species.

Yet conservation efforts for nongame fish and wildlife species (those that are not hunted or fished) have historically been opportunistic and crisis-driven. This is largely because of limited resources, such as a lack of dedicated funding, and a lack of strategic approaches to species and habitat conservation. With nearly 600 wildlife species listed nationally on the federal endangered and threatened species list, the need for a complementary source of funding for nongame species remains critical for the continued conservation, protection, and restoration of the full array of North Carolina's wildlife species.

With North Carolina's population on the rise and the state's growth rate higher than the national average, natural habitats for wildlife are losing ground.

Nongame species have had the most to lose. There has been a steady decline in species that were once common, like the Golden-winged Warbler and Eastern Box Turtle.

The NCWRC and our partners are working hard to keep common animals common and to implement effective conservation measures to benefit declining species.

1.1 The Origin of Wildlife Action Plans

In the mid-1990s, the Teaming With Wildlife Coalition (TWW) was formed to continue a decade-long effort working to secure funding for the conservation of fish and wildlife species that were not covered by other programs or funding strategies. From their work with members of Congress, the Department of the Interior and Related Agencies Appropriation Act was developed and signed into law in 2002. This Act created the Wildlife Conservation and Restoration Program and the State Wildlife Grants Program (or SWG), which provides federal matching funds to all 50 states and territories (separate funding is provided to tribes through the Tribal Wildlife Grants Program). The funds are to be used for conservation efforts aimed at preventing wildlife from becoming endangered and keeping common species common.

The SWG program was designed to assist states with the conservation of nongame species by providing annual allocations to supplement, not duplicate, existing fish and wildlife programs. These matching funds support work that benefits species in greatest need of conservation; species indicative of the diversity and health of the states' wildlife; and species with low and declining populations, as designated by the states' fish and wildlife agencies. The Wildlife and Sport Fish Restoration Program, which is part of the US Fish and Wildlife Service (USFWS), administers the SWG program and apportions funds each year to state wildlife agencies.

1.2 State Wildlife Grants Eligibility and Requirements

To be eligible for SWG matching funds, each state was required to develop a comprehensive wildlife conservation plan, more commonly known as a state Wildlife Action Plan (WAP or Plan). Each Plan must address the Eight Required Elements (see Table 1.1) and, at a minimum, be revised at 10-year intervals. North Carolina's first WAP, which was developed to provide a foundation for state and federal agencies and other conservation partners to think strategically about their individual roles and coordinate prioritizing conservation efforts, was reviewed and approved by USFWS in 2005. Details about the development of the 2005 WAP are available in that document and an electronic copy of the document is available on the internet (www.ncwildlife.org/plan). The NC Wildlife Resources Commission (NCWRC or Commission) is responsible for managing the SWG program and implementing the WAP.

State funds are needed to match the federal SWG grants and are generated through several opportunities:

- North Carolina State Tax Checkoff for Nongame and Endangered Wildlife
- Wildlife Diversity Endowment Fund donations
- Purchases of the wildlife conservation special license plate from NC Department of Motor Vehicles
- State budget allocations
- In-kind contributions produced by the efforts of volunteers and state and local partners

1.3 From 2005 to 2015—Revision of North Carolina's Wildlife Action Plan

To fulfill a 10-year WAP revision mandate, every state is required to conduct a comprehensive review and revision of their Plan no later than the end of September 2015. Guidance from USFWS states that all state WAP documents must address the Eight Required Elements, outlined in Table 1.1, that are the framework for conducting the review and revision, and each element has been addressed in the chapters of this document. To accomplish the revision of this Plan, NCWRC staff worked with numerous federal, state, and local partners and stakeholders to complete a comprehensive review that began in 2010.

1.3.1 Incorporating Climate Change

In advance of the 10-year comprehensive review and revision deadline, USFWS sent a letter to state fish and wildlife agencies with guidance for review and revision of the Plans (USFWS 2007). Additional revision guidance was made available by the Association of Fish and Wildlife Agencies (AFWA) on evaluating climate change as an impact to fish and wildlife species during revision of WAPs (AFWA 2009). The recommendations outlined in their report Voluntary Guidance for States to Incorporate Climate Change into State Wildlife Action Plans and Other Management Plans are correlated to each of the eight elements required by USFWS for state WAPs (AFWA 2009).

Using this guidance, NCWRC staff worked collaboratively with climate scientists and biologists to evaluate how climate change may affect North Carolina's wildlife and habitats. The findings were published in 2010 in the report Understanding the Impacts of Climate Change on Fish and Wildlife in North Carolina (DeWan et al. 2010) and were presented at a September 2010 Climate Impacts Workshop hosted by NCWRC in Raleigh. The Executive Summary can be found in Appendix B and the entire report is available for download as a PDF document from the following web page: www.ncwildlife.org/Plan/Revision/September2010Workshop.aspx.

1.3.2 Revision Approach and Methods

This second version of the NC WAP is the result of the collaborative efforts of many federal and state agencies, local organizations, and citizens working on the revision. Similar to the process for developing the 2005 WAP, early efforts in the process were spent on planning and organization activities, including the development of committees, review of literature and guidance documents, review and revision of the species evaluation and prioritization process, and investigation of the technical publication resources. The collaborative efforts and extensive assistance from biologists and staff from many organizations and agencies across the state were involved in developing and expanding text, identifying supporting materials (i.e., maps, figures, tables, reports), and assimilating existing conservation planning resources. It is with great appreciation that we acknowledge their contributions. A copy of the USFWS letter acknowledging NCWRC's intent to comprehensively review and revised the WAP as well as a list of individuals and organizations involved in the revision process, key meeting dates, and important coordination efforts are provided in Appendix C.

A State Wildlife Action Plan Best Practices Working Group was created by the AFWA TWW Committee and tasked with identifying best practices that state fish and wildlife agencies could use when revising and implementing their plans. The guidance was published in the Best Practices for State Wildlife Action Plans (Best Practice Guide) and distributed to the states in late 2012. The best practices are intended to improve plan consistency among the states and territories, increase plan standardization, and enhance plan effectiveness with respect to prioritization, conservation delivery, and collaboration with partners and other states.

To the extent possible, NCWRC has incorporated many of these best practices, including developing ranking procedures to characterize risk and assess the conservation status and need of the state's wildlife species; utilizing spatial analysis tools to identify and map areas that offer the best opportunities for conservation of species and habitats, and providing GIS data that support these recommendations; and adopting standard language and classification hierarchies in describing threats and discussing conservation actions (AFWA 2012).

1.3.3 Report Organization and Format

The North Carolina WAP not only fulfills the requirements set forth by Congress, it also serves as a practical and essential resource for future fish and wildlife conservation planning in North Carolina. You will find many changes in this revised WAP, as the entire document was comprehensively reviewed and it has been updated in its entirety. It has also been formatted to improve readability and our ability to revise any section as needed. The new format will allow readers to access the document across multiple electronic formats. Since this revision contains new content and is structured in a new format, a road map outlining how the document is organized is provided below.

- **Chapter 1** provides background information on the SWG program, explains why we have a Wildlife Action Plan, outlines the revision process used to update the Plan, and describes the required information that is included in the document.

- **Chapter 2** provides a problem-and-need overview and highlights changes to wildlife and natural community resources, summarizes steps taken toward addressing conservation needs presented in the 2005 Plan, and and provides a case study that describes how implementing recommendations from the 2005 WAP have benefited conservation efforts for the Carolina Northern Flying Squirrel.

- **Chapter 3** defines wildlife statutes and outlines federal and state statutes governing wildlife resources. This chapter focuses on the process for evaluating and ranking wildlife to identify Species of Greatest Conservation Need (SGCN) and other species for which there are research and management priorities. The taxonomic groups evaluated were amphibians, birds, crayfish, freshwater fish, freshwater mussels, mammals, reptiles, and snails. The chapter also provides background information about these groups and individual species, species habitat associations, and conservation needs and recommendations specific to each group. Information provided by partners is included for marine species, pelagic birds, and certain rare and declining arthropods ('insects').

- **Chapter 4** contains descriptions of aquatic, wetland, and terrestrial communities based on four primary ecoregions with a list of priority natural communities for conservation. Descriptions cover 12 aquatic communities, 8 wetland communities, 21 terrestrial communities, and the 17 river basins in the state. The descriptions provide information on SGCNs associated with each community, the problems and threats that affect the communities, and anticipated climate change impacts, and outline recommendations for surveys, monitoring, research, conservation, or management actions specific to each community.

- **Chapter 5** provides information on several categories of threats that are likely to affect North Carolina's natural communities and wildlife during the 10-year planning horizon addressed by this document. Threat categories are based on the classification scheme supported by the International Union for Conservation of Nature (IUCN) Conservation Measures Partnership (IUCN 2012) and recommended by AFWA in the Best Practice Guide for states to use during the revision process.

- **Chapter 6** summarizes recommendations for conservation action and management applicable statewide. This information represents only a fraction of North Carolina's conservation needs and is intended to be part of the dialogue for implementing collaborative and cooperative discussions about conservation in the state. Recommendations can be used to guide the prioritization of conservation efforts within the context of a particular agency's or organization's mission. They can also be used to guide conservation or management decisions about a natural community or particular species in any habitat where that species occurs, no matter the size of the management area. Summary information about the agencies, organizations, and partnerships that have developed programs to address wildlife and habitat conservation issues is also included in this chapter.

- **Chapter 7** identifies monitoring needs and outlines strategies and actions that address those needs and provides information about monitoring activities con-ducted by NCWRC and many of our partners. The chapter includes information about species-specific and guild-level monitoring activities as well as habitat and natural community monitoring.

- **Chapter 8** discusses the next steps for working collaboratively with partners to accomplish the conservation measures identified in this document, provides information about products currently in development that will need to be incorporated as an addendum to this Plan, and plans to review and revise this Plan in an ongoing manner in an effort to keep the information up-to-date and relevant to current and emerging issues.

- **Appendices** provide supporting information and documents that are referenced throughout the Plan, beginning with a list of abbreviations and acronyms and a glossary of definitions (Appendix A) and including tables that provide information about species, habitats, and conservation measures. Refer to the Table of Contents for a complete list of all materials provided in the appendices.

The USFWS provided guidance to the states for Plan revision, including instructions to provide a roadmap that highlights the location of the Eight Required Elements. Table 1.1 outlines where information addressing each of the elements can be found in this revision and where the information was primarily provided in the 2005 Plan.

Table 1.1 Roadmap to the Eight Required Elements

Required Element	Where to find it in the Plan	
	2015 Revision	2005 Original Plan
1. Distribution and abundance of **species** of wildlife	Chapter 3 Wildlife Chapter 4 Habitats Appendices E, G, H, I, N, P	Chapter 2 Approach Chapter 5 Species and Habitat Assessments and Conservation Strategies Appendices D, E, G, H, K
2. Descriptions of locations and relative condition of key **habitats** and community types	Chapter 4 Habitats Appendices E, H, J	Chapter 5 Species and Habitat Assessments and Conservation Strategies Appendices F, J, K
3. Descriptions of **problems** and priority research and survey **efforts needed**	Chapter 2 Need for Conservation Chapter 3 Wildlife Chapter 4 Habitats Chapter 5 Threats Appendix G	Chapter 1 Introduction Chapter 3 State of the State Chapter 4 Statewide Conservation Strategies

Required Element	Where to find it in the Plan	
	2015 Revision	2005 Original Plan
4. Descriptions of **conservation actions** proposed **to conserve species and habitats**	Chapter 3 Wildlife Chapter 4 Habitats Chapter 6 Conservation Priorities Appendices K, L, M, O	Chapter 4 Statewide Conservation Strategies Chapter 5 Species and Habitat Assessments and Conservation Strategies Chapter 6 Synthesis of Conservation Priorities
5. **Monitoring plans** and adaptation of **conservation actions**	Chapter 3 Wildlife Chapter 4 Habitats Chapter 6 Conservation Priorities Chapter 7 Implementation and Monitoring Appendices L, M, O	Chapter 4 Statewide Conservation Strategies Chapter 5 Species and Habitat Assessments and Conservation Strategies Chapter 6 Synthesis of Conservation Priorities Chapter 7 Status and Trends Monitoring Chapter 8 Implementation Monitoring, Adaptive Management, and Review and Revision Procedures
6. **Procedures for review** of the Plan at intervals not to exceed 10 years	Chapter 8 Review, Coordination, Revision, and Next Steps	Chapter 8 Implementation Monitoring, Adaptive Management, and Review and Revision Procedures
7. Plans for **coordinating** the development, implementation, review, and revision of the Plan with federal, state, and local agencies and Indian tribes	Chapter 8 Review, Coordination, Revision, and Next Steps	Chapter 8 Implementation Monitoring, Adaptive Management, and Review and Revision Procedures
8. Documentation of **public participation** during development and implementation	Chapter 8 Review, Coordination, Revision, and Next Steps Appendix C	Chapter 2 Approach Chapter 8 Implementation Monitoring, Adaptive Management, and Review and Revision Procedures Appendices C, J

Problems affecting North Carolina's fish and wildlife species and natural communities and the priority conservation actions that focus on these problems are presented as recommendations in this Plan. These recommendations identify the surveys, monitoring, research, management practices, and partnerships and cooperative efforts that address the provisions of the Eight Requirement Elements. All recommendations are priority conservation actions and were developed through the collaborative efforts of NCWRC biologists, Taxa Team members, partners, and stakeholders during development of this NCWAP.

References

[AFWA] Association of Fish and Wildlife Agencies. 2009. Voluntary guidance for states to incorporate climate change into state Wildlife Action Plans & other management plans. Washington (DC): Teaming With Wildlife Committee and Climate Change Committee; [accessed 2015 August]. 50 p. http://www.fishwildlife.org/files/AFWA-Voluntary-Guidance-Incorporating-Climate-Change_SWAP.pdf.

[AFWA] Association of Fish and Wildlife Agencies. 2012. Best practices for developing state Wildlife Action Plans. Washington (DC): Teaming With Wildlife Committee, State Wildlife Action Plan (SWAP) Best Practices Working Group; [accessed 2015 August]. 85 p. http://www.fishwildlife.org/files/SWAPBestPractices.pdf.

DeWan A, Dubois N, Theoharides K, Boshoven J. 2010. Understanding the impacts of climate change on fish and wildlife in North Carolina. Washington (DC): Defenders of Wildlife; [accessed 2015 August]. 218 p. http://www.ncwildlife.org/Portals/0/Conserving/documents/ActionPlan/Revisions/FullReportDefendersofWildlifeUnderstandingtheimpactofclimatechangeNC.pdf.

Salafsky N, Salzer D, Stattersfield AJ, Hilton-Taylor C, Neugarten R, Butchart SHM, Collen B, Cox N, Master LL, O'Connor S, et al. 2008. A standard lexicon for biodiversity conservation: unified classifications of threats and actions. Conserv Biol. [accessed 2014 Dec];22(4):897–911. http://www.teaming.com/sites/default/files/A%20Standard%20Lexicon%20for%20Biodiversity%20Conservation.pdf.

[USFWS] US Fish and Wildlife Service. 2007. Guidance for Wildlife Action Plan (comprehensive wildlife conservation strategy) review and revision. Letter addressed to state fish and wildlife agencies and territory governors dated July 11, 2007. 8 p.

The Need for Conservation

2

2.1 Introduction

Using the best information available, North Carolina's 2005 Wildlife Action Plan (WAP) addressed local, regional, and state-wide concerns across key terrestrial and aquatic habitats and identified critical knowledge gaps and future data needs. This 2015 revision provides a comprehensive review of the need for conservation and problems that are likely to impact wildlife and natural communities. The revised Plan identifies significant wildlife resources and critical habitats across the state and outlines priority conservation actions for these resources.

This chapter highlights changes to wildlife and natural community resources that support the need for conservation action. A case study at the end of the chapter provides an example of how implementing recommendations from the 2005 WAP have improved our knowledge about Carolina Northern Flying Squirrels, leading to positive results from conservation efforts. These actions help us achieve the goals of the WAP.

2.2 Population Changes

A review of numerous economic forecast and development reports provide trend and prediction information about growth patterns for the southeast region and North Carolina. From US Census data, we know that the national population grew almost 10% from 2000 to 2010 (USCB 2010). Regionally, the South and the West had the highest growth rates in the US (around 14%) with half of the nation's growth occurring in the South. In comparison, North Carolina experienced the sixth highest population growth in the nation with an almost 19% increase in population from 2000 to 2010 (NCOSBM 2015).

Growth patterns and the quick pace of new and emerging technologies and markets influence economic development strategies and patterns, neighborhood and community structure, urban growth, transportation patterns, and infrastructure needs. Evidence can be seen in shifts away from manufacturing and industrial jobs to service- and technology-oriented jobs (Jacobsen and Mather 2010) and the growth of innovation hubs and cluster-based economic development strategies (NGA 2013).

Other indicators include commuting patterns that have changed significantly over the last three decades, with more people driving alone and longer distances between home and work and fewer using carpools or walking to work (Jacobsen and Mather 2010). Several reasons have been cited for this trend, including increases in car ownership, job growth in suburban and surrounding areas, and an increase in the need to combine trips between home and work with stops at the day care, grocery store, and other locations (Ungemah et al. 2007; Jacobsen and Mather 2010).

With continued population and development growth, we can expect continued changes to land uses and a persistent need for conservation and protection of important natural resources. Between 2000 and 2010, North Carolina gained almost 1.5 million residents to reach a total population of 9.5 million (Tippett 2013). Over this same period, North Carolina was the 6th fastest growing state in the nation. Its growth rate was 18.5%, nearly double the national rate of 9.7%. While its growth rate will slow, the state as a whole is projected to gain roughly 1 million residents each decade through 2014 and rise from being the 10th most populous state to the 8th by 2040. The number of state residents is projected to be approximately 10.6 million in 2020 and 11.6 million in 2030, an increase averaging 400 new residents per day (NCOSBM 2015).

Population growth around the state's major urban centers has been significant. For example, population growth in the Charlotte metropolitan area was about 32% from 2000 to 2010, which is about three times the national growth average (Chesser 2015). During this same period, Union County, adjacent to the Charlotte-Mecklenburg County urban area, had a 63% growth rate—the highest rate in North or South Carolina during that period (Chesser 2015). Projections indicate growth trends will continue around large urban centers while rural and less populated areas may experience low growth or population declines.

Figure 2.1 depicts projected population growth rates for 2030–2035 in North Carolina by county (OSBM 2015), and supports predictions that growth will center around major metropolitan areas.

Data for the Raleigh-Durham urban area shows that nearly 70% of the population growth in this urban area occurred in Wake County (USDHUD 2013), which includes the Cary, Wake Forest, Holly Springs, Morrisville, and Apex municipalities. Available housing in the area was projected to meet only 6% of projected demand based on expected population

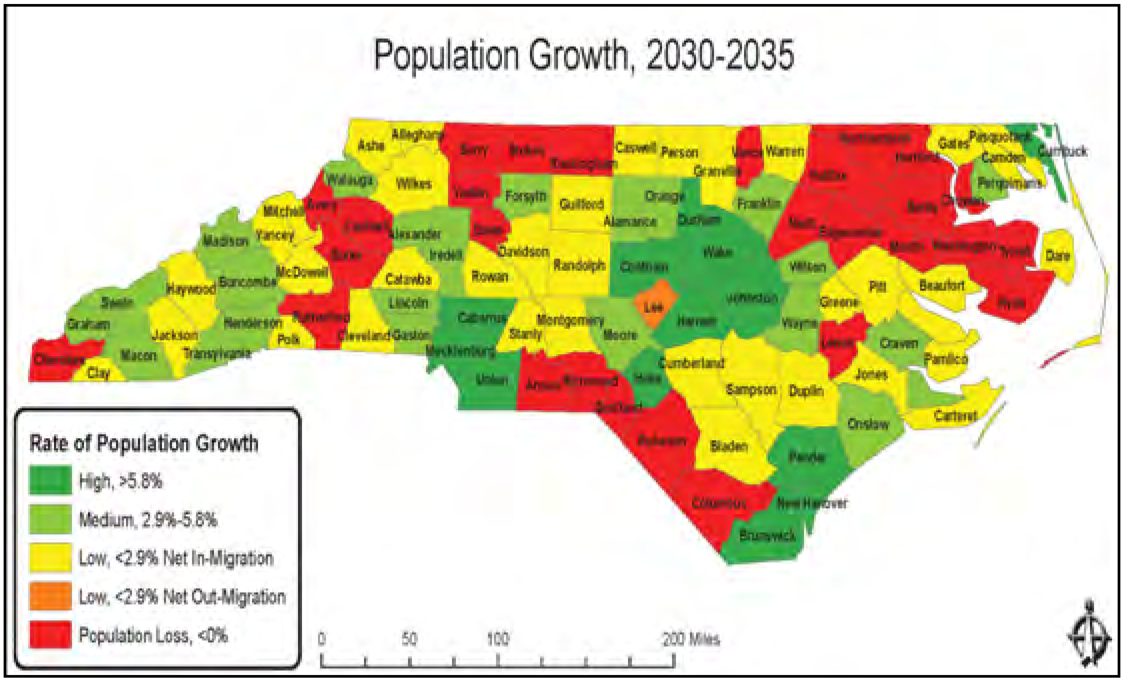


Figure 2.1 **Projected population growth by county, 2030–2035** (NCOSBM 2015)

growth. This rate of growth spurred a request by these municipalities for a 38% increase in water withdrawals from the Cape Fear River Basin for drinking water supplies. Growth around these urban areas also resulted in new roads, expanded highway capacity through widening, additional utility infrastructure, and increased commercial-, education-, and health-related development.

2.3 Natural Resources Changes

North Carolina has diverse fish and wildlife habitats statewide (see Chapter 4 for descriptions) that link North Carolina to neighboring states. The Natural Resources Inventory (NRI) periodically conducted by the US Department of Agriculture's (USDA) NRCS reports the status, condition, and trends in soil, water, and other natural resources on nonfederal lands in the US (USDA 2009added). The most recent inventory for North Carolina estimates the total surface area of the state, including freshwaters, to be more than 33 million acres (USDA 2009added). Based on estimates reported in the latest NRI, most land ownership in North Carolina is characterized as nonfederal rural lands, which means that nearly all land is in private, municipal, state, or tribal ownership (USDA 2013). The NC Forest Service reports approximately 86% of the farm and forest land holdings in North Carolina are privately owned land (NCFS 2013). This NRI is a key resource in consideration on private lands.

2.3.1 Land Cover and Land Use Changes

The forests, wetlands, farms and other natural communities that cover the land contribute to the health of our ecosystems, the state's economic prosperity, and the quality of life of North Carolina's citizens. However, rapid residential and commercial development in many areas of the state over the last several decades has resulted in the change of millions of acres of important land cover and land uses (Dutzik, Schneider 2012).

According to the Conservation Trust for North Carolina (2014), the state has led the nation in the loss of farmland, posing a threat to the estimated $78 billion (including $6 billion from forestry) per year contribution that agriculture provides to the state's economy. From 2010 to 2011, North Carolina lost 1,000 to 100,000 acres of farmland to development and continues to lose about 55 acres of farmland per day. At present, there are more than 9 million acres of farmland in North Carolina (CTNC 2014).

The recreation side of wildlife and habitat conservation also has a huge positive impact on the state's economy. More than $3.3 billion dollars were added to state and local coffers in 2011 alone, according to the US Fish and Wildlife Service's (USFWS) Survey of Fishing, Hunting, and Wildlife-Associated Recreation in North Carolina (USFWS and USCB 2011).

In spite of increased land development and population, North Carolina has made tremendous progress in protecting our most valuable and vulnerable watersheds, wildlife habitat, and working landscapes over the past decade. Thanks to a concerted effort by state and local governments, nonprofit groups, land trusts, agricultural organizations, and dedicated citizens across the state, North Carolina has ensured that hundreds of thousands of acres will endure for future generations. Between 1999 and 2009, more than 680,000 acres of land were permanently protected in North Carolina, increasing protected land in North Carolina by 24%. Between 2009 and 2011, an average of 29,580 additional acres per year was protected. In 2007, there were more than 164,000 acres of farmland in conservation or wetland reserve programs.

But by 2012, that number had dropped to 106,000 acres. The economic downturn beginning in 2011 brought a dramatic drop in land conservation in the state. The depressed housing market lowered land prices, making land conservation more affordable, but brought with it rising unemployment, pressure on government budgets, and cutbacks to conservation funding. The same economic pressures affecting the state government also affected many individuals and organizations engaged in land conservation. Landowners, local governments, and nonprofit organizations decreased conservation investments.

Figure 2.2 uses NRI data to compare land ownership changes from 1997 to 2010. A similar comparison was presented in the 2005 WAP (NCWAP 2005). Of note is the 3% increase in acres of nonfederal developed land over this 13-year period in North Carolina.

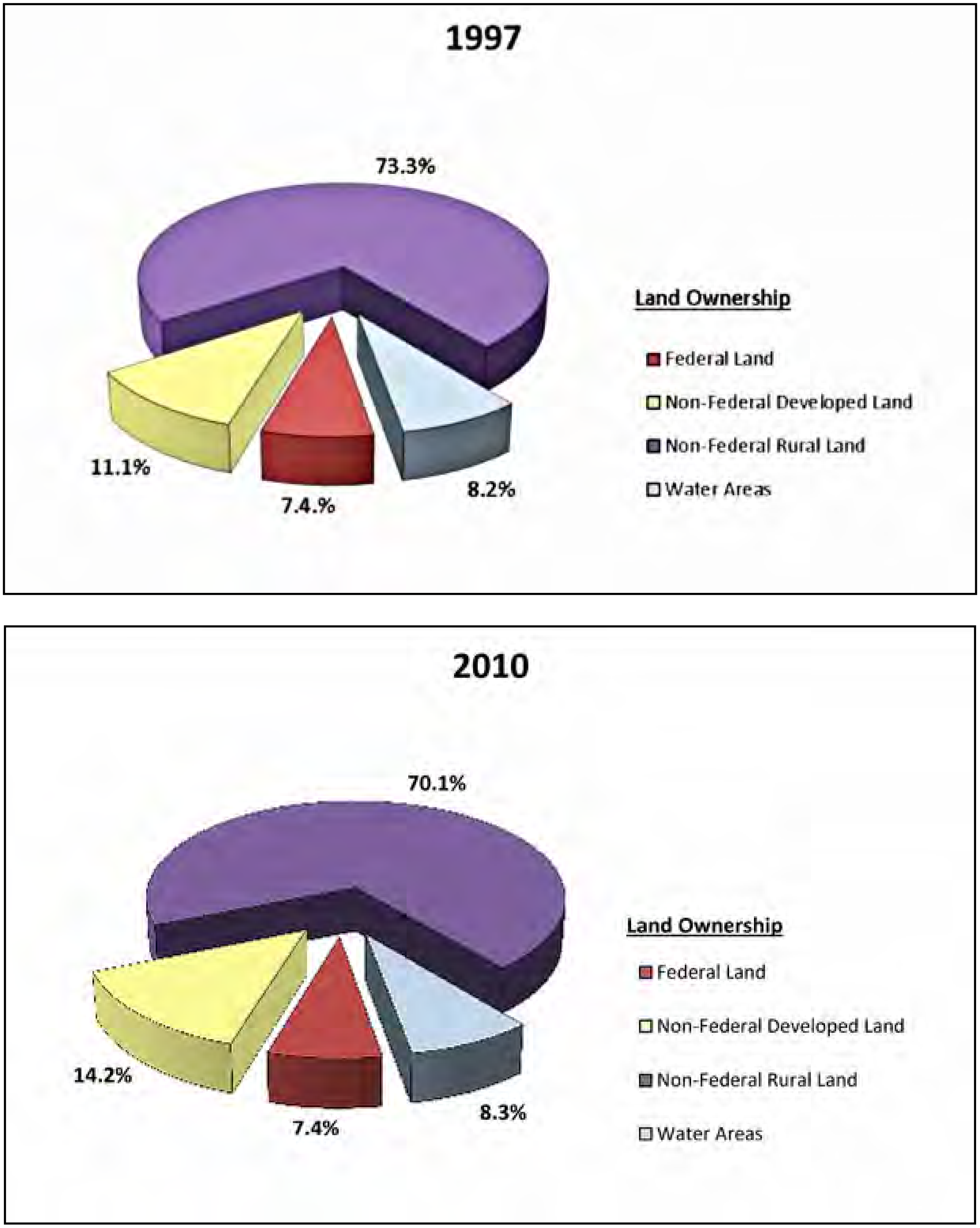


Figure 2.2 **Percent change in land ownership (based on acreage), 1997 to 2010 (USDA 2013)**

With this reported increase in developed lands, there is a corresponding decrease in land cover type over the same 13-year period (USDA 2013). As of 2010, there are 23,639,900 acres of nonfederal lands in the state and land use or cover is primarily forest land. Figure 2.3 uses NRI data to depict the change in percent of land cover for nonfederal lands used for crops, pasture, forest, and other rural land as well as land enrolled in the USDA Conservation Reserve Program (CRP) (USDA 2014). CRP is a federal program established under the Food Security Act of 1985 to assist private landowners who want to convert highly erodible crop land to vegetative cover for 10 years.

As depicted in Figure 2.3, cropland acreage decreased by 1.5%; pastureland decreased by 0.3%; forest land decreased by 1.6%; total rural land decreased by 3.2%; and CRP land decreased by 0.2% over the period between 1997 and 2010, while other rural land uses increased by 0.4% over this 13-year period.

2.3.2 Protected Species

Currently, there are 61 wildlife and plant species known to occur in North Carolina that are listed by USFWS for protection under the Federal Endangered Species Act of 1973 (ESA) (USFWS 2013). Of those listed for the state, 34 are fish, wildlife, insects and spiders, and the remaining 27 are plants. ESA protects species that are in danger of extinction. Of the protected species found in the state, 29 have recovery plans. Recovery plans are available online: http://www.fws.gov/endangered/species/recovery-plans.html.

In addition to the federally listed species, there are 109 species currently listed as endangered or threatened in North Carolina. Since th 2005 WAP was published, there have been several changes to the species protected under federal and state listings. State protected species are designated by NCWRC through legislative rule-making and published in the NC Administrative Code (NCAC) 15A NCAC 10I.0101 through .0105. All species listed for federal protection are also listed for protection under the State Endangered Species Act (NC General Statute 113-331 to 113-337). There are also 129 species of special concern in North Carolina. The current NCAC list includes both federally and state-listed species; however, any species that has been removed from federal listing will retain state listing status until removed through North Carolina legislative action. A record of state-listed species is available online: http://www.ncwildlife.org/Portals/0/Conserving/documents/protected_species.pdf.

Table 2.1 provides a comparison of species with a federal listing status that has changed while the state listing has been retained. Some of these listings differ from the status published in the 2005 WAP.

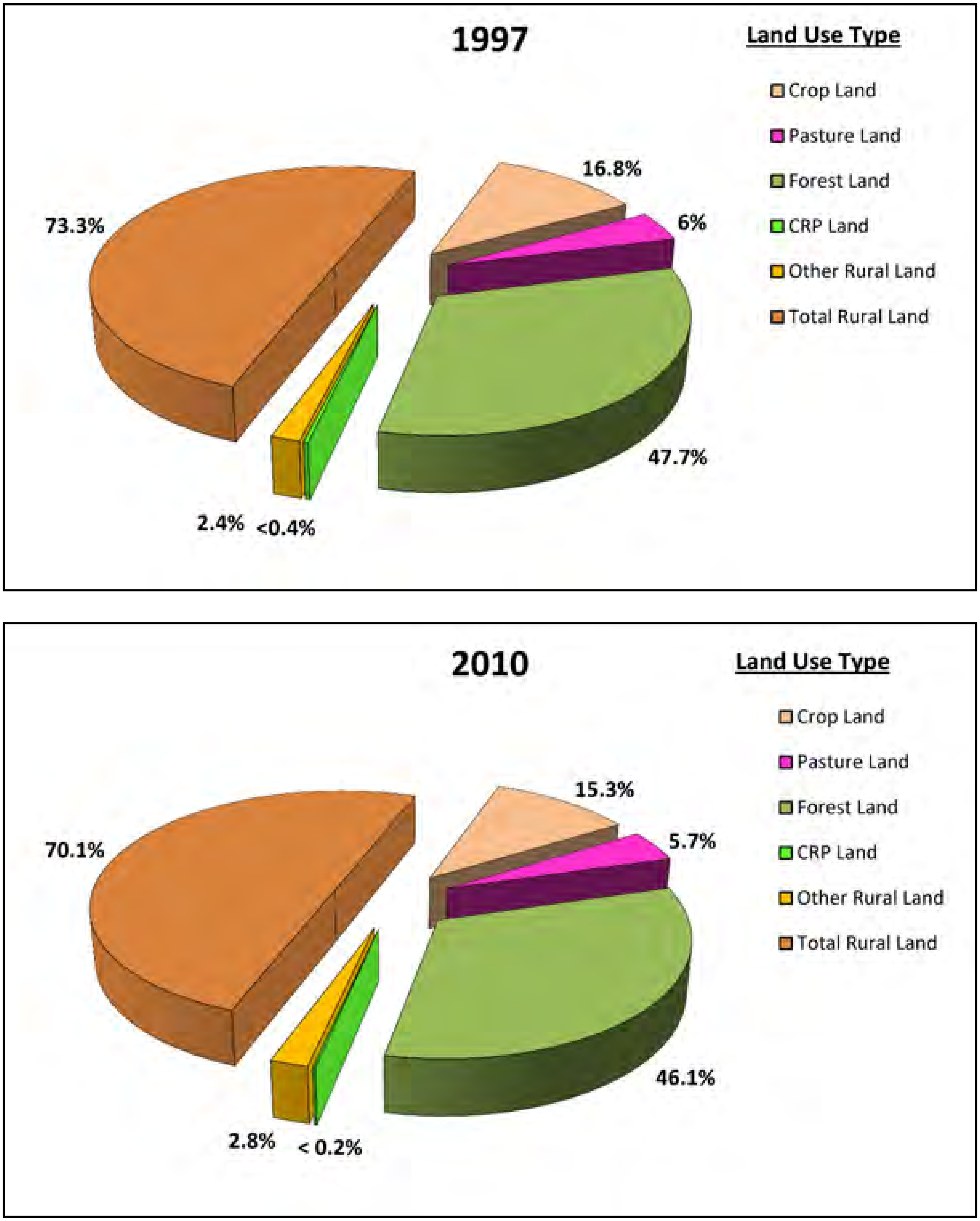


FIGURE 2.3 **Percent change in land use on nonfederal lands (based on acreage), 1997 to 2010** (USDA 2013)

Table 2.1 Changes since 2005, federal protection status (endangered and threatened) changes and corresponding state protection status

Common Name	Scientific Name	Federal Status	State Status
Bald Eagle	*Haliaeetus leucocephalus*	Delisted 8/8/2007 – Recovered	Threatened
Loggerhead Sea Turtle	*Caretta caretta*	Listed 10/24/2011 – Threatened (NW Atlantic Ocean populations)	Threatened
Atlantic Sturgeon	*Acipenser oxyrinchus oxyrinchus*	Listed 2/6/2012 – Endangered	Endangered (Pending status change from Special Concern)
Red Knot Rufa	*Calidris canutus rufa*	Listed 1/12/2015 – Threatened	Threatened (Pending status change)
Northern Long-eared Bat	*Myotis septentrionalis*	Listed 5/4/2015 – Threatened	Threatened (Pending status change)
Red Wolf	*Canis rufus*	Listed 11/19/1986 –Endangered	Threatened (Per USFWS agreement)

In addition to a listing status change for Loggerhead Sea Turtle, USFWS designated critical terrestrial (nesting) habitat for the Northwest Atlantic Ocean distinct population segment. In addition to a listing status change for Loggerhead Sea Turtle, the USFWS designated critical terrestrial (nesting) habitat for the Northwest Atlantic Ocean distinct population segment. This designation was published in a final rule that became effective on August 11, 2014. Coastal areas of North Carolina, from Boque Banks (Carteret County) south to Holden Beach/Shallotte Inlet (Brunswick County), are within the Northern Recovery Unit of this Loggerhead Sea Turtle critical habitat (FR 2014).

Candidate species for state protection are plants and animals for which USFWS has sufficient information on biological status and threats serious enough to propose them as endangered or threatened under ESA, but for which a proposed listing regulation is precluded by other priorities based on the magnitude and immediacy of threats and taxonomic uniqueness of the species (USFWS 2014). Candidate species receive no statutory protection under ESA. USFWS encourages cooperative conservation efforts for these species because they are, by definition, species that may warrant future protection under ESA. USFWS encourages cooperative conservation efforts for these species because they are, by definition, species that may warrant future protection under ESA. The current list of USFWS candidate species is available online: http://ecos.fws.gov/tess_public/SpeciesReport.do?listingType=C.

The National Marine Fisheries Service (NMFS), which has jurisdiction over most marine species, also maintains a list of "species of concern" for which more information is needed before they can be proposed for listing. The current list of NMFS candidate species is available online: http://www.nmfs.noaa.gov/pr/species/esa/candidate.htm.

As of late 2014, there are 27 federally listed endangered and threatened plant species in North Carolina that are protected by USFWS under ESA; however, this WAP does not address listed plant species. The NC Natural Heritage Program (NCNHP) tracks the occurrence and status of listed plant species through its own surveys and monitoring programs, and the occurrence and status of listed wildlife species through data shared by agencies and partners that conduct survey and monitoring programs. Both federally and state-listed plant species can be found on federal- or state-owned lands in many of the natural communities described in Chapter 4.

The Plant Conservation Program, a unit of the NC Department of Agriculture and Consumer Services (NCDACS), has regulatory responsibility for the 299 state-listed endangered and threatened plant species and the 118 plant species of special concern listed in the state for protection. This information is published in the NC General Statutes, Article 19B, Chapter 106, §202.12-22.

Implementation of ESA was enhanced in 2011 when a complementary agreement was reached in US District Court with the Center for Biological Diversity that reinforces the work plan developed by USFWS. The original multi-year listing work plan gives the agency six years to systematically review and address the needs of more than 250 species listed on the 2010 Candidate Notice of Review to determine if they should be added to the Federal Lists of Endangered and Threatened Wildlife and Plants. The complementary agreement includes additional scheduling commitments for a small subset of the actions in the work plan that is consistent with USFWS objectives and biological priorities.

These historic agreements allow USFWS to focus on providing the benefits of ESA more effectively to those imperiled species most in need of protection, while prioritizing its workload based on the needs of the candidate species and providing state wildlife agencies, stakeholders, and other partners more clarity and certainty about when listing determinations will be made. Response to both the needs of at-risk resources and the concerns of citizens will be consistent with land management objectives and need. The new tools provide regulatory assurance, technical assistance, and programs that provide landowners more recovery options.

2.3.3 Endangered Ecosystems

Forest ecosystems that support numerous species and essential ecological processes have high ecological value that might be compromised when the forest is impacted by stressors. The concept of 'endangered' forests is based on concerns that continuing losses and impacts from stressors such as land-use changes, invasive species, climate change, and industrial forestry practices will make it increasingly difficult to retain biodiversity in forest ecosystems. These systems may require protection from stressors that threaten their ability to function as complete and natural ecological communities (Forest Ethics et al. 2006).

Seven southeastern states (Florida, Georgia, North Carolina, South Carolina, Virginia, Alabama, and Tennessee) made the 'extreme risk' category in an assessment of risk to ecosystems in the United States based on number of endangered ecosystems, percentage of imperiled species by state, and development pressures. In addition to that distinction, eight of the top 21 endangered ecosystems in the United States can be found in North Carolina (Noss and Peters 1995) as indicated in Table 2.2.

Table 2.2 Endangered ecosystems in the southeast

Endangered Ecosystem	Rank
Southern Appalachian spruce-fir forests	2
Longleaf Pine and savanna	3
Eastern grasslands, savanna, and barrens	4
Coastal communities in the lower 48 states	7
Large streams and rivers in the lower 48 states	11
Cave and karst systems	12
Ancient eastern deciduous forest	16
Southern forested wetlands	21

NCWRC has developed conservation recommendations that can help local planning organizations and municipal governments conserve and manage terrestrial wildlife habitats, including six priority community types: wetlands, riparian and floodplain habitats, longleaf pine habitats, upland forests, early successional habitats, and rock outcrops, caves, and mines (NCWRC 2012).

2.3.4 Critical Areas for Freshwater Conservation

There have been several aquatic assessments undertaken by conservation organizations during the last several years that address freshwater biodiversity conservation at different scales. These assessments have largely built on the information gathered in previous efforts in order to identify significant regions and priority areas for freshwater conservation.

For example, The Nature Conservancy (TNC) quantified the distribution of freshwater systems and the condition of lands and waters surrounding them to generate a set of priorities for freshwater preservation, restoration, and further exploration (Burns et al.2012; Benner et al. 2014). TNC evaluated streams in the state by applying criteria that considered physical properties and condition characteristics to evaluate their degree of resilience or vulnerability. Resilient stream and river systems are those that have the greatest potential to continue supporting biodiversity into the future despite potentially severe, and often unpredictable, impacts from climate change (Benner et al. 2014). A resilient network is a structurally intact geophysical setting that sustains a diversity of species and natural communities, maintains basic relationships among ecological features and key ecological processes, and allows for adaptive change in composition and structure (Anderson et al. 2012; Benner et al. 2014).

The World Wildlife Fund (WWF) conducted a conservation assessment of freshwater ecoregions of North America (Abell et al. 2000). TNC also assessed small-scale watersheds across the country (Aldrich et al. 1998) and subsequently identified priority areas within four freshwater ecoregions in the Southeast (Smith et al.2002). All three efforts identify the Southeast as a key region for freshwater conservation efforts. Many of the critical areas identified in those efforts overlap North Carolina's borders:

- The entire South Atlantic freshwater ecoregion (southern Virginia through central Georgia) was identified by Abell et al. (2000) as a key region in which to focus aquatic conservation efforts in North America;
- Of the 327 key small watershed areas Aldrich et al. (1998) identified across the country, 21 are found in North Carolina;
- Smith et al. (2002) identified 70 sites for priority freshwater conservation in North Carolina (14 in the Tennessee-Cumberland Aquatic Region, 56 in the South Atlantic Aquatic Region).

2.4 Uncertainty of Future Conditions

Urban growth probability (as percent change) for the year 2020 to 2050 was projected by means of the Slope, Land use, Excluded, Urban, Transportation and Hillshade (SLEUTH) model, which uses cellular automata, terrain mapping, and land cover change modeling to address urban growth (Jantz et al. 2009; Project Gigapolis 2011). The SLEUTH model incorporates five parameters (Dispersion, Breed, Spread, Slope, and Road Gravity) into the growth rules that project future urbanization. The model simulates not only outward growth of existing urban areas but also growth along transportation corridors and new centers of urbanization. Figures 2.4 and 2.5 incorporate four growth rules (Spontaneous Growth, New Spreading Centers, Edge Growth, and Road-Influenced Growth) to model the predicted rate and pattern of urbanization. Figure 2.4 depicts the change based on 12-digit Hydrologic Unit Code (HUC) boundaries (see Chapter 4.5.1 for more information on HUCs).

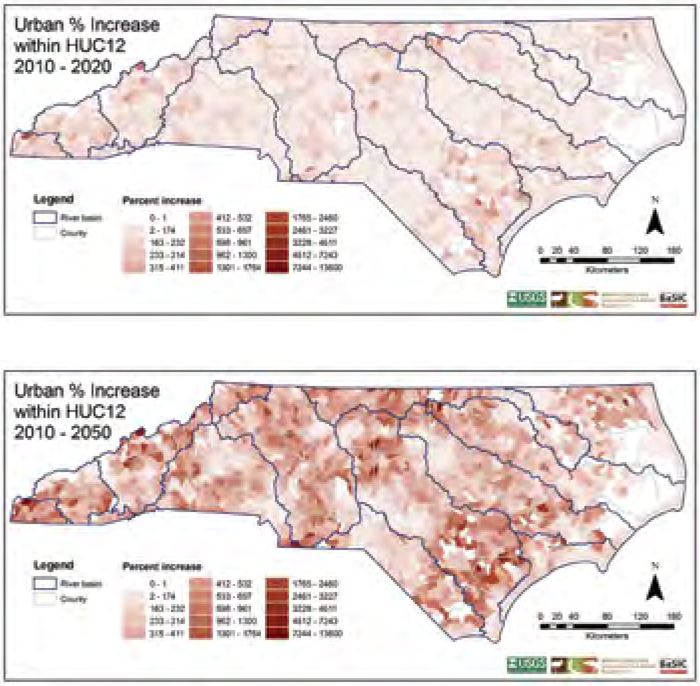


FIGURE 2.4 **Urban growth projections (as percent increase) for the period 2010–2020 in comparison with 2010–2050**

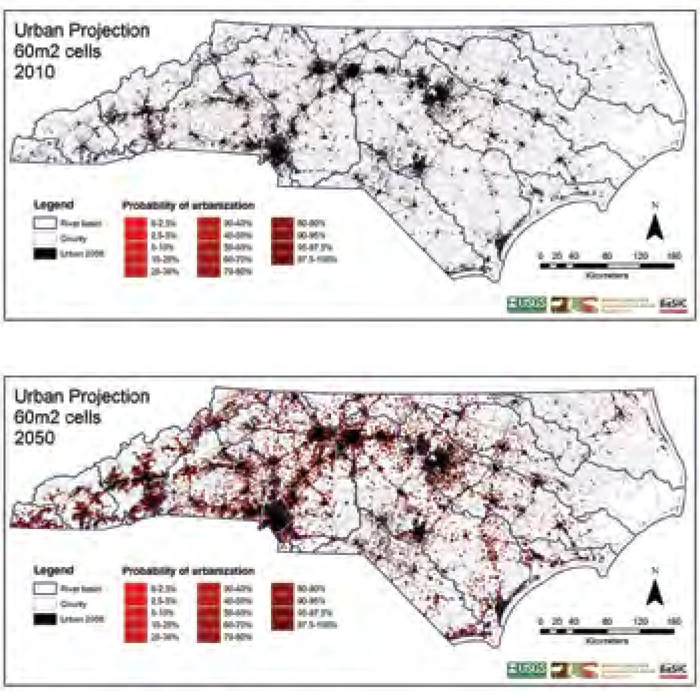


FIGURE 2.5 **Urban growth probabilities (as percent increase) for the period 2010–2020 in comparison with 2010–2050**

Similar results are shown in research conducted by the Spatial Analysis for Conservation and Sustainability SILVIS Lab, a cooperative effort led by the University of Wisconsin Forest and Wildlife Ecology Department and supported by numerous federal and state agencies and private conservation organizations. The rapid development around the edges of metropolitan areas and expansion into adjacent wildlands and in rural areas is depicted in wildlife–urban interface (WUI) maps. Two types of WUI maps are intended to illustrate where WUI was located in 1990, 2000, and 2010: intermix and interface. Intermix WUIs are areas where housing and vegetation intermingle; interface WUI are areas with housing in the vicinity of contiguous wildland vegetation. Geographic Information System (GIS) data that provide spatially detailed national assessment of WUI across the coterminous United States and for each state (including North Carolina) are available online: http://silvis.forest.wisc.edu/maps/wui/2010/download.

2.5 Conclusion

A myriad of factors affect the abundance and distribution of species and habitats including many human influences. The fact that management and implementation of conservation measures often fall under the jurisdiction of multiple agencies and organizations presents an obstacle to effective conservation. Natural resource agencies must work more closely with private landowners and nongovernmental organizations to identify common conservation goals and to work toward cooperative achievement of those goals. Considering the persistent limits to funding and manpower resources available for implementing conservation strategies, it is imperative to prioritize efforts and work collaboratively to implement the recommendations outlined in the Wildlife Action Plan. All of the recommendations outlined in this document are considered priority conservation actions and were developed to meet provisions of the Eight Required Elements.

The remaining chapters in this document provide information about the conservation and management needs of North Carolina's fish and wildlife and the natural communities that support them; prioritize recommendations for meeting those needs; and identify important partnerships and programs that work toward achieving conservation goals. An example of how conservation action and partnerships help protect an endangered species is provided in the following brief case study on Carolina Northern Flying Squirrel.

Case Study—How Conservation Action Helps Protect Species: Carolina Northern Flying Squirrel

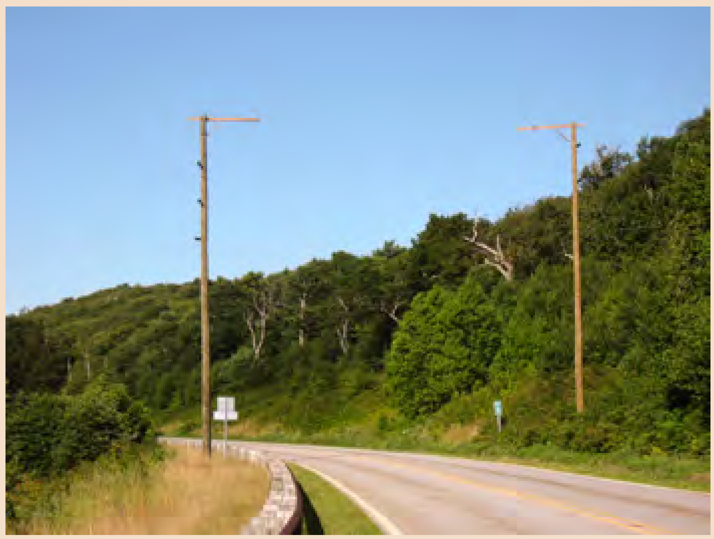
Carolina Northern Flying Squirrel (Christine Kelly/ NCWRC)

There are two species of flying squirrels in North Carolina—the Northern (*Glaucomys sabrinus coloratus*) and Southern (*Glaucomys volans*). Carolina Northern Flying Squirrels (CNFS) are found on high mountain peaks in southwest Virginia, western North Carolina, and eastern Tennessee in spruce-fir and northern hardwood forests. Flying squirrels are nocturnal, spending the day denning in tree cavities or dry nests filled with shredded Yellow Birch bark. At night, they forage principally on certain fungi and lichens, supplementing their diet with buds, catkins, fruits, sap, insects, small vertebrates, and eggs. CNFS was federally listed as endangered under the Endangered Species Act in 1985 and was identified as a priority species for conservation in the 2005 Wildlife Action Plan (WAP).

The 2005 WAP identified the need for surveys to determine the distribution, relative abundance, and status of wildlife species associated with northern hardwood and spruce-fir forests, including CNFS. Recommendations also called for use of monitoring programs to assess current population status and trend information; research studies on the population biology of wildlife species as well as the ecological relationships between the species, their habitats, and the biological, physical, and chemical habitat components; genetic studies to explore the degree of genetic isolation of species restricted to high elevations; and support of collaborative research with colleges and universities. To date, work has involved partnerships with USFWS, USFS, NPS, Eastern Band of Cherokee Indians (EBCI), NCDOT, Duke Energy, Southern Appalachian Spruce Restoration Initiative, Southern Highlands Reserve, Warren Wilson College, WildSouth, and Deltec Homes. Cooperative research efforts have involved NC State University, Auburn University, Virginia Polytechnic Institute and State University (Virginia Tech), and the University of NC at Wilmington.

Even before the 2005 WAP was published, annual survey and monitoring of CNFS populations was conducted within seven of the eight Geographic Recovery Areas identified by USFWS

(1990). Monitoring efforts began in 1997 with the installation of wooden squirrel boxes (designed by Dr. Peter Weigl of Wake Forest University) in apparently suitable habitat (Weigl et al. 1992; USFWS 1990, 2001), and includes conducting mark-recapture surveys. The low captures and recaptures from nest boxes do not generate meaningful population estimates. Therefore, nest box data are analyzed using occupancy models and additional monitoring techniques are recommended to better understand population status and trends of this rare and elusive species. Survey sites have since been expanded to include transects within additional areas of suitable habitat. Monitoring efforts now also include using radio-telemetry, acoustic detectors, and trail cameras, and genetic research to improve our understanding of this species.



Cherohala Skyway crossing structures (Christine Kelly/NCWRC)

Conservation and management efforts have focused on addressing the loss of conifer habitat and fragmentation that serves as a barrier to dispersal. Habitat loss has resulted primarily from extensive logging of the spruce-fir forest that occurred primarily between the 1880s and 1930s, followed by mortality of Fraser Fir due to Balsam Woolly Adelgid (*Adelges piceae*) and development (for recreation and second homes). In one recovery area, the only extant conifer species, Eastern Hemlock, has been lost due to Hemlock Woolly Adelgid (*Adelges tsugae*). Habitat improvement measures involve enhancing the conifer component in appropriate areas by planting Red Spruce (*Picea rubens*) seedlings or managing the forest canopy around existing spruce trees through timber cuts that 're-lease' existing spruce trees so the canopy is more open and they get more sunlight. In 2012, a multi-state effort, the Southern Appalachian Spruce Restoration Initiative, was established with the goal of achieving landscape scale restoration to benefit Northern Flying Squirrel populations as well as other priority species (Red Crossbill and Saw-whet Owl).

Fragmentation caused by the Cherohala Skyway corridor in the Unicoi Mountains resulted in a barrier to dispersal that impeded genetic mixing of populations. Road width is greater than gliding ability and road shoulders lack mature trees of sufficient height for the squirrels to successfully launch and glide across the corridor. Mitigation measures developed in 2007 and implemented in 2008 involved erecting artificial crossing structures along the Cherohala Skyway to facilitate road crossing and to reconnect populations. Radio telemetry monitoring and trail camera images indicate some flying squirrels have successfully used the crossing structures (Kelly et al. 2013). Priorities for additional work over the next 10-year planning cycle are outlined in Chapter 3.

References

Abell RA, Olsen DM, Dinerstein E, Hurley PT, Diggs JT, Erichbaum W, Walters S, Wettengel W, Allnutt T, Loucks CJ, et al. 2000. Freshwater ecoregions of North America: a conservation assessment. Washington (DC): Island Press.

Aldrich JR, Fries J, Haddock R, Ivey G, Lawson KJ, Laurenzi A, Lynett K, Myers J, Riordan RM, Vaughn C, et al. 1998. Rivers of life: critical watersheds for protecting freshwater biodiversity. Arlington (VA): The Nature Conservancy.

Anderson MG, Clark M, Olivero Sheldon A. 2012. Resilient sites for terrestrial conservation in the northeast and mid-atlantic region. Boston (MA): The Nature Conservancy, Eastern Conservation Science. 168 p.

Benner R, Barnett A, Olivero A, Hoenke K, Meitzen K, Fields M. 2014. North Carolina's freshwater resilience. Durham (NC): The Nature Conservancy. 33 p.

Burns CE, Peoples C, Fields M, Barnett A. 2012. Protecting North Carolina's freshwater systems: a state-wide assessment of biodiversity, condition and opportunity. Durham (NC): The Nature Conservancy.

Chesser, John 2012. Charlotte population growth: a clearer picture. Charlotte (NC): University of North Carolina at Charlotte; [accessed 2015 July]. http://ui.uncc.edu/display/charlotte-region-population-growth-census-tract.

[CTNC] Conservation Trust for North Carolina. 2014. Protecting farmland: preserving land for fresh and local foods. Raleigh (NC): Conservation Trust for North Carolina; [accessed 2015 July]. http://www.ctnc.org/protect/info-nc-landowners/land-protection-programs/protecting-farmland/.

Dutzik T, Schneider J. 2012. Securing North Carolina's future: a five-year plan for investing in our land, water and quality of life. Raleigh (NC): Land for Tomorrow.

[ERS] Economic Research Service. ERS State Fact Sheets: North Carolina Census of Agriculture. Washington (DC): US Department of Agriculture; [accessed 2015 May; updated 2015 May 8]. http://www.ers.usda.gov/statefacts/.

[FR 2014] Federal Register [internet]. 2014. Endangered and threatened wildlife and plants; designation of critical habitat for the Northwest Atlantic Ocean distinct population segment of the Loggerhead Sea Turtle. N.p.: US Fish and Wildlife Service; [accessed 2015 July] https://www.federalregister.gov/articles/2014/07/10/2014-15725/endangered-and-threatened-wildlife-and-plants-designation-of-critical-habitat-for-the-northwest.

Ford WM, Evans AM, Odom RH, Rodrigue JL, Kelly CA, Abaid N, Diggins CA, Newcomb D. Forthcoming 2015. Predictive habitat models derived from nest-box occupancy for the endangered Carolina Northern Flying Squirrel in the Southern Appalachians. Endanger Species Res.

Ford WM, Kelly CA, Rodrigue JL, Odom RH, Newcomb D, Gilley LM, Diggins CA. 2014. Late winter and early spring home range and habitat use of the endangered Carolina Northern Flying Squirrel in western North Carolina. Endanger Species Res. 23:73–82.

Forest Ethics, Greenpeace, Natural Resources Defense Council, Rainforest Action Network. 2006. Ecological components of endangered forests. N.p.: Greenpeace; [accessed 2015 May]. docs.nrdc.org/land/files/lan_06092001A.pdf.

Jacobsen LA, Mather M. 2010. U.S. economic and social trends since 2000. Popul Bull. 65(1).

Jantz CA, Goetz SJ, Donato D, Claggett P. 2009. Designing and implementing a regional urban modeling system using the SLEUTH cellular urban model. Comput, Environ, Urban Syst. 34(1):1–16.

Kelly CA, Diggins CA, Lawrence AJ. 2013. Crossing structures reconnect federally endangered flying squirrel populations divided for 20 years by road barrier. Wildl Soc Bull. 37(2):375–379.

[NCAC] North Carolina Administrative Code. SubChapter 10I Endangered and Threatened Species. N.p.: N.p.; [accessed 2015 July]. http://reports.oah.state.nc.us/ncac.asp

[NCWAP] NC Wildlife Action Plan. 2005. Raleigh (NC): NC Wildlife Resources Commission; [accessed 2015 July]. http://www.ncwildlife.org/plan.aspx.

[NCWRC] NC Wildlife Resources Commission. 2012. Conservation recommendations for priority terrestrial wildlife species and habitats in North Carolina. Raleigh (NC): NC Wildlife Resources Commission; [accessed 2015 May]. http://www.ncwildlife.org/Portals/0/Conserving/documents/ConservingTerrestrialHabitatsandSpecies.pdf.

[NCOSBM] NC Office of State Budget and Management. 2015. Socioeconomic data and population estimates and projections [webpage]. Raleigh (NC): NC Office of State Budget and Management; [accessed 2015 June]. http://www.osbm.nc.gov/facts-figures/demographics/

[NGA] National Governors Association. 2013. Top trends in state economic development. Washington (DC): National Governors Association; [accessed 2015 July]. http://www.nga.org/cms/center.

Noss RF, Peters RL. 1995. Endangered ecosystems: a status report on America's vanishing habitat and wildlife. Washington (DC): Defenders of Wildlife.

Project Gigapolis [webpage]. 2011. N.p.: National Center for Geographic Information and Analysis; [accessed 2015 July]. http://www.ncgia.ucsb.edu/projects/gig/index.html.

Smith RK, Freeman PL, Higgins JV, Wheaton KS, FitzHugh TW, Ernstrom KJ, Das AA. 2002. Priority areas for freshwater conservation action: a biodiversity assessment of the Southeastern United States. N.p.: The Nature Conservancy.

Tippett R. 2013. Population growth & population aging in North Carolina counties [Internet]. Chapel Hill (NC): UNC Carolina Population Center, Carolina Demography; [accessed 2015 May]. http://demography.cpc.unc.edu/2013/10/14/population-growth-population-aging-in-north-carolina-counties/.

Ungemah D, Goodin G, Dusza C. 2007. Examining incentives and preferential treatment of carpools on managed lane facilities. J Public Transp. 10(4):151–69.

[USCB] US Census Bureau. 2010. 2010 census data products: United States at a glance (version 2.8). N.p.: US Census Bureau; [updated 2015 May, accessed 2015 June]. http://www.census.gov/population/www/cen2010/glance/.

[USDA] US Department of Agriculture. 2009. Summary report: 2007 National Resources Inventory. Washington (DC: Natural Resources Conservation Service; Ames (IA): Center for Survey Statistics and Methodology, Iowa State University; [accessed July 2015]. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1041379.pdf.

[USDA] US Department of Agriculture. 2013. Summary report: 2010 National Resources Inventory. Washington (DC): Natural Resources Conservation Service; Ames (IA): Iowa State University; [accessed 2015 May]. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1167354.pdf.

[USDA] US Department of Agriculture. 2014. The 2010 NRI: changes in land cover/use. Washington (DC): Natural Resources Conservation Service; [accessed 2015 July]. http://www.farmlandinfo.org/sites/default/files/2010%20NRI%20Changes%20in%20Land%20Cover%20Useext_FIC%202014_0.pdf.

[USDHUD] US Department of Housing and Urban Development. 2013. HUC PD&R Housing Market profiles, Raleigh-Durham, North Carolina. N.p.: Office of Policy Development and Research; [accessed 2015 June]. http://www.huduser.org/portal/periodicals/USHMC/reg/RaleighNC_HMP_Nov13.pdf.

[USFWS] US Fish and Wildlife Service. 1990. Appalachian Northern Flying Squirrels (*Glaucomys sabrinus fuscus* and *Glaucomys sabrinus coloratus*) recovery plan. Newton Corner (MA): US Fish and Wildlife Service; [accessed 2015 June]. http://ecos.fws.gov/docs/recovery_plan/900924c.pdf.

[USFWS] US Fish and Wildlife Service. 2001. Appalachian Northern Flying Squirrels (*Glaucomys sabrinus fuscus* and *Glaucomys sabrinus coloratus*) recovery plan update. Hadley (MA): US Fish and Wildlife Service; [accessed 2015 June]. http://ecos.fws.gov/docs/recovery_plan/010906.pdf.

[USFWS] US Fish and Wildlife Service. 2013. Endangered and threatened species of North Carolina. Raleigh (NC): Raleigh Ecological Services Field Office; [updated 2013 December; accessed 2015 May]. http://www.fws.gov/raleigh/es_tes.html.

[USFWS] US Fish and Wildlife Service. 2014. Candidate species: section 4 of the Endangered Species Act. Fall Church (VA): US Fish and Wildlife Service, Endangered Species Program; [accessed 2015 July]. http://www.fws.gov/endangered/esa-library/pdf/candidate_species.pdf.

[USFWS & USCB] US Fish and Wildlife Service and US Census Bureau. 2011. National survey of fishing, hunting, and wildlife-associated recreation. N.p.: US Department of the Interior.

North Carolina's Wildlife

3

Required Element 1

Information on the distribution and abundance of species of wildlife, including low and declining populations as the state fish and wildlife agency deems appropriate, that are indicative of the diversity and health of the state's wildlife.

3.1 Introduction

Keeping common species common and preventing extinction are important actions, because any loss of species will reduce diversity in natural communities and will have unknown consequences for ecosystems' processes, functions, and services upon which we depend (Mace and Purvis 2008; Diaz et al. 2006). A loss of species diversity can also contribute to constraints in gene flow, which will influence the ability of a species to survive changing conditions and stressors (Mace and Purvis 2008; Myers and Knoll 2001).

Conservation efforts are often necessary to successfully reverse declining population trends and prevent the need for a species to be listed for protection under federal and state laws. While it could be justified to rank every species at the highest priority for conservation and management efforts, there are usually not sufficient resources to implement and achieve this level of effort. Time, staff, and budget constraints are resource limitations that must be factored into conservation planning in an effort to support more effective use of resources. It is important to focus efforts not only on the highest priorities but also on those measures that have the greatest impact, can achieve the most benefits, or are easiest to implement. It is also important to take advantage of opportunities to work synergistically with partners toward achieving common conservation goals.

This chapter identifies SGCN and other priority species as outlined in Required Element 1. However, discussions of problems affecting these species and recommendations for priority conservation actions found in this chapter address provisions outlined in each of the Eight Required Elements.

3.1.1 Regulatory Authority for Wildlife

The idea of wildlife as a "public trust" resource, meaning it is a resource shared as common property amongst all people, was the prevalent perspective during the Roman era. During the Middle Ages, common law tradition that emerged in England stated that wildlife species were legally owned by the king and not for private use (Organ and Mahoney 2007; UCB 2010). However, plants were not owned by the king and fish were subject to limited property rights dependent upon possession (Walrut 2004).

The legal system in the United States is based on English common law (UCB 2010); however, common usage and laws in the United States have reestablished fish and wildlife as public trust resources. By the beginning of the 20th century, overuse and extinctions led to the need for regulation, thus federal laws were established to protect and regulate the use of wildlife resources. One of the most important protective measures for wildlife conservation is the Endangered Species Act of 1973, designed to protect and recover endangered and threatened species of fish, wildlife, and plants within the United States and its territories.

While not inclusive of all current federal and state legislation, Table 3.1 provides a list of important federal and state laws that regulate and protect wildlife resources in North Carolina. The year federal laws became effective and dates of revision can be found online by visiting the federal resource laws digest webpage (http://www.fws.gov/laws/lawsdigest/Resourcelaws.html). Information about state regulations can be found online by visiting the North Carolina General Assembly webpage (http://www.ncga.state.nc.us/gascripts/Statutes/StatutesTOC.pl).

North Carolina has enacted legislation that states all marine, estuarine, and wildlife resources are public trust resources, establishes state jurisdictions and authorities for their use and management, and assigns stewardship of natural resources to certain state agencies. Legislation (see GS 143-24) states that public trust lands and waters are under stewardship authority of either the NC Wildlife Resources Commission (NCWRC) (freshwater and inland resources) or the Marine Fisheries Commission (marine and estuarine resources).

The General Statutes direct the NCWRC to manage, restore, develop, cultivate, conserve, protect, and regulate the wildlife resources of the state; to determine the requirements for conservation of protected wild animal species; and also grant the NCWRC authority to conduct investigations to determine whether a wild animal should be on a protected

Table 3.1 Selected state and federal laws that protect wildlife

Federal Resource Laws[1]	NC General Statutes[2]
• Bald and Golden Eagle Protection Act • Endangered Species Act • Federal Aid in Fish Restoration Act • Federal Aid in Sport Fish Restoration Act (Dingell–Johnson Act, Wallop–Breaux Act) • Federal Aid in Wildlife Conservation Act (Pittman–Robertson Act) • Fish & Wildlife Act • Fish & Wildlife Conservation Act (Nongame Act) • Fisheries Conservation & Management Act • Lacey Act • Land & Water Conservation Act • Magnuson–Stevens Fishery Conservation and Management Act • Marine Mammal Protection Act • Migratory Bird Conservation Act • Migratory Bird Treaty Act • Neotropical Migratory Bird Conservation Act • Protection of Migratory Game & Insectivorous Birds Migratory Bird Treaty • Whaling Convention Act • Wild Bird Conservation Act	Chapter 19A: Protection of Animals (includes protection of black bears) Chapter 77: Rivers, Creeks, and Coastal Waters (defines river basins, covers obstructions in streams, various lake management commissions, and clean water regulation) Chapter 104: US Lands (covers inland waterways, forest reserves, migratory bird sanctuaries, wildlife refuges, National Park system lands) Chapter 106: Agriculture (covers pest control, forestry services and development, prescribed burning) Chapter 113: Conservation and Development (covers state forests and park topics, fire control, game laws, trapping, conservation agencies, coastal fisheries, regulation of wildlife and fisheries, endangered and threatened species, species of special concern) Chapter 146: State Lands (covers land acquisition topics including wetland mitigation, public parks and forests, public waters access)

1. See http://www.fws.gov/laws/lawsdigest/Resourcelaws.html for enacted and revision dates
2. See http://www.ncga.state.nc.us/gascripts/Statutes/StatutesTOC.pl for enacted and revision dates

animal list (see GS113 and GS 143). These statutes also provide definitions covering fish, including freshwater, marine, and estuarine species, and wildlife resources, including game and migratory species. These include the following (as defined in NCGS 113, Article 12, §113-129):

> "*Wildlife* [is] all wild animals, wild birds, all fish found in inland fishing waters, and inland game fish."

> "*Wild Animal* means any native or once-native nongame amphibian, bird, crustacean, fish, mammal, mollusk, or reptile not otherwise legally classified by statute or regulation such as game and fur bearing animals, except those inhabiting and depending upon coastal fishing waters, marine and estuarine resources, marine mammals found in coastal fishing waters, sea turtles found in coastal fishing waters, and those declared

to be pests under the Structural Pest Control Act of North Carolina of 1955 or the North Carolina Pesticide Law of 1971."

"*Wildlife Resources* [are] all wild birds; all wild mammals other than marine mammals found in coastal fishing waters; all fish found in inland fishing waters, including migratory saltwater fish; all inland game fish; all uncultivated or undomesticated plant and animal life inhabiting or depending upon inland fishing waters; waterfowl food plants wherever found, except that to the extent such plants in coastal fishing waters affect the conservation of marine and estuarine resources the Department (Department of Environment and Natural Resources) is given concurrent jurisdiction as to such plants; all undomesticated terrestrial creatures; and the entire ecology supporting such birds, mammals, fish, plant and animal life, and creatures."

"*Marine and Estuarine Resources* [are] all fish, except inland game fish, found in the Atlantic Ocean and in coastal fishing waters; all fisheries based upon such fish; all uncultivated or undomesticated plant and animal life, other than wildlife resources, inhabiting or dependent upon coastal fishing waters; and the entire ecology supporting such fish, fisheries, and plant and animal life."

"*Nongame Animals* are all wild animals except game and fur-bearing animals; all wild birds except game birds; and all fish found in inland fishing waters other than inland game fish. Wildlife that are considered to be 'game' species are regulated and subject to special license requirements for harvesting them (e.g., fishing, hunting, trapping)."

In some instances, an animal may fall into more than one regulation or license category. For example, bobcats are classified as a fur-bearing animal subject to trapping regulations and as a game animal subject to hunting regulations. Information about which species are game animals in North Carolina and the regulations and license requirements for fishing, hunting, or trapping wildlife can be found online at the NCWRC web page (http://www.ncwildlife.org/Learning/Species.aspx) and in the Commission's rules and regulation digest, which is published annually.

With few exceptions, collection and possession of live animals from the wild is illegal and can be prosecuted under state law; with the exception authorizing the NCWRC to issue permits for wildlife collectors. This applies to all wildlife species and allows collection and possession when a permit has been issued by NCWRC. Permits are also required for scientific collection of any federal or state protected species for any reason (e.g., research, propagation). However, when a scientific collection permit is issued, possession of the animal must be temporary and the animal must be returned alive to the site where it was collected. Another exception has been made for collection and possession of amphibian or reptile species which allows for an individual to collect a limited number of animals without the need for a permit (NCGS n.d.c).

3.1.2 Evaluation and Identification of Priority Species

Conservation priorities need to include the greatest variety of biological diversity possible as a means of ensuring that genetic diversity and ecosystem services remain viable as our environment is changed by natural and man-made forces. One way to determine where to focus our conservation efforts is to evaluate what we know about the status of a species and prioritize where best to direct our efforts. Similar to the method used to identify the priority species listed in the 2005 Wildlife Action Plan (WAP or Plan), recommendations were developed by species experts and research authorities (Taxa Teams) and results were subject to peer-review evaluation. The taxa evaluation process and a list of participants involved in developing and implementing the taxa evaluation process are described in a white paper found in Appendix F.

The Taxa Teams were tasked with evaluating wildlife in eight taxonomic groups based on the jurisdictional authority outlined in Section 3.1.1 and traditional programmatic boundaries. The taxonomic groups are: amphibians, birds, crayfishes, freshwater fishes, freshwater mussels, mammals, reptiles, and snails. The review process identified and measured concerns, knowledge, and needs in three evaluation categories (conservation, knowledge, and management) and ranking scores were developed for each species. Each Taxa Team established threshold scores for the three evaluation categories using the Delphi method (Linstone and Turoff 2002) and considering statistical quartiles and weighting factors as deemed appropriate for the taxonomic group. Ranking scores were then used to prioritize levels of concern for species within each taxonomic group. The 2015 evaluation process was designed to be a more objective method of prioritizing species for conservation action, and is intended to be used in future Wildlife Action Plan revisions. Thus, future changes in prioritization status will reflect changes in conservation status.

During their evaluations, the Taxa Teams decided to exclude some species from their evaluations because they may occur at the extreme periphery of their range in the state; occur as accidentals or sporadic migrants that do not normally occur in the state; or have a conservation status or management objectives that have been developed through cooperative efforts of specific conservation partnerships (e.g., North American Bird Conservation Initiative) or are mandated under Federal authorities (e.g., regional Fisheries Management Councils, endangered and threatened species recovery plans). Information was provided for marine species and pelagic birds by conservation partners and can be found in Sections 3.10 and 3.11, respectively.

This Plan also includes a discussion about several groups of species in the phylum Arthropoda for which there is statewide or national concern regarding conservation status. Not all species in this phylum are true insects, but we use the common term “insects” in this document to collectively refer to these species. Generally, there is a significant lack of knowledge about insects in the state (e.g., population size, distribution, life history, and more), which increases the complexity and difficulty in determining conservation status or needs. Except for those identified as serious agricultural pests, there is also some ambiguity about which state agencies have regulatory or conservation authority over insects in North Carolina.

We convened an Arthropod Taxa Team of species and research experts to develop recommendations of species for which there should be conservation concern. The team limited their consideration to those insects that are generally considered important to pollination and certain food web cycles, are being tracked by the North Carolina Natural Heritage Program (NCNHP), or were identified by biologists, researchers, and other knowledgeable experts to be of national or state conservation concern. The insects identified as conservation and research priorities include important pollinator species (bees, butterflies, and moths only) and species with significant aquatic life stages (dragonflies, mayflies, stoneflies, and caddisflies only). These species are discussed in Section 3.12.

Sections 3.2 through 3.12 provide information on the eight taxonomic groups and three special categories considered in this version of the WAP. Tables with common and scientific names and evaluation results for all species evaluated by the Taxa Teams can be found in Appendix G. Copies of the tables also are available online and can be downloaded in Excel format from the WAP web page (http://www.ncwildlife.org/plan).

In most cases, common names are used throughout this document to identify a species. Exceptions include the first reference to a plant or pest species and species for which there is taxonomic uncertainty or when common practice is to use a form of the scientific name as the common name; in those instances, the scientific name may be used to identify the species.

3.1.2.1 Conservation Concern and Species of Greatest Conservation Need (SGCN)

The Conservation Concern category (Metrics 1 through 9) evaluated current understanding about biological vulnerability based on current status and trend data for the species reviewed, not only for where they occur in North Carolina, but also for their range-wide occurrence. Species that are currently rare or have been designated as at risk of extinction, those for which we have knowledge deficiencies that hamper conservation efforts, and those that have not received adequate conservation attention generally received the highest scores during the Taxa Team evaluations.

The species that scored above a threshold established by each Taxa Team for the Conservation Concern evaluation category have been designated as Species of Greatest Conservation Need (SGCN). All SGCN are considered a priority for use of State Wildlife Grant (SWG) Program funds. Any changes to the SGCN list to add or remove species will be reviewed and approved by the USFWS as a major revision to the NCWAP. In subsequent revisions, species that are newly listed for protection under the ESA, or that are petitioned for listing and for which the USFWS issues a positive 90-day finding, and newly described species will be prioritized for SGCN designation without need for evaluation by a Taxa Team. Appendix P contains a comprehensive list of all SGCN.

Sections 3.2 through 3.12 provide information about SGCN (arranged in alphabetical order by taxonomic group common name); a reference for the federal and state listing status abbreviations used in the species tables in these sections is provided in Table 3.2. A complete list of all SGCN and priority species is in Appendix G.

3.1.2.2 Knowledge Gaps and Research Needs

One of the obstacles to wildlife conservation and management is often a lack of scientific information about a species or taxon. A lack of information inhibits the ability to assess the risk of extinction for a species based on its distribution, population status, or other metric (IUCN 2012). A lack of data can also preclude preventative measures that protect a species or result in failure to restrict actions that will have a negative consequence for a species.

Changes that occur over long time periods may be hard to detect without monitoring data and the reasons for a species' decline may be difficult to discern when data are insufficient.

Table 3.2 Federal and state listing status abbreviations

Federal Listing Status	
E	Endangered; a taxon which is in danger of extinction throughout all or a significant portion of its range.
T	Threatened; a taxon which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.
C	Candidate; taxa for which the [Fish and Wildlife] Service has on file enough substantial information on biological vulnerability and threat(s) to support proposals to list them as endangered or threatened.
FSC	Federal Species of Concern; Those species that appear to be in decline or otherwise in need of conservation and are under consideration for listing or for which there is insufficient information to support listing at this time. Subsumed under the term 'FSC' are all species petitioned by outside parties and other selected focal species identified in USFWS strategic plans, State Wildlife Action Plans, or Natural Heritage Program Lists.
State Listing Status	
E	Endangered; any native or once-native species of wild animal whose continued existence as a viable component of the State's fauna is determined to be in jeopardy or listed as a federal endangered species.
T	Threatened; any native or once-native species of wild animal which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range or listed as a federal threatened species.
SC	Special Concern; any species of wild animal native or once-native to North Carolina which is determined to require monitoring but which may be taken under regulations adopted under State laws.

The lack of long-term data coupled with a need to develop policies that are often short-term responses can contribute to inefficient and ineffective conservation measures (Mace and Purvis 2008). Identifying where information is lacking or where uncertainty exists about the information available will improve decisions made about conservation needs and actions. Survey, monitoring, and research data are needed before we can develop conservation actions that benefit species and preserve biodiversity and ecosystem services (Arponen 2012).

The Knowledge Gap category (Metrics 10 through 14) prioritized research needs based on what can be achieved under existing programs or given available resources to develop new programs, over the next 10 years. The species that scored above the threshold established by the Taxa Teams for each taxon are considered priority species and are a priority for conducting survey, monitoring, and research activities.

A complete list of research priority species by taxonomic group can be found in Sections 3.2 through 3.12; a complete list of all SGCN and priority species is in Appendix G.

3.1.2.3 Management Concerns

There may be reasons, other than conservation concern or research needs, for a species to be considered a priority for some type of action. For example, one may be a species of recreational, commercial, or tribal importance that is vulnerable to local threats but has stable populations elsewhere. It may be a species for which we are unable to determine true status in the state because it is not monitored or is very difficult to monitor. Or, it may be a species for which there are concerns about the potential for disease to occur within a population, but for which there are no programs for disease monitoring or management.

In some cases, when population densities of common species (those found throughout the state) are concentrated to the extent they exert competitive pressures on local populations of rare species, intervention measures may be deemed necessary. Sometimes a species for which we have lower conservation concerns can be impacted by emerging threats or the synergistic effects of multiple threats can cause rapid declines to their populations and management action must be taken to mitigate the impacts. The Management Concern evaluation category (Metrics 15 through 20) was developed to evaluate both game and non-game species. The evaluation results can be used to identify populations with sustainability issues and areas where there may be a need for management action to mitigate impacts on a species.

Species that scored above the threshold set by the Taxa Teams have been recommended as a priority for decisions about habitat management, land protection, or other management actions. A complete list of management priority species by taxonomic group can be found in Sections 3.2 through 3.12; a complete list of all SGCN and priority species is in Appendix G.

3.1.3 Species and Habitat Associations

A discussion about species will necessarily require consideration for the natural communities that provide the habitats they occupy. To aid the discussion about conservation and management actions, we have developed species–habitat association information for SGCN. The resulting species–habitat matrix is organized by ecoregions of the state (Mountain, Piedmont, Sandhills, and Coastal Plain) for the aquatic, wetland, and terrestrial communities described in Chapter 4 and depicted in Figure 4.1.

Since natural communities are composed of many different species and trophic levels, information about the functional relationships between and amongst the species found in these communities are also discussed in Chapter 4. Groups of species that use the same resources but are not taxonomically related are often referred to as an ecological guild. The guild concept is often used to provide a framework for discussions about survey, research, and monitoring needs and conservation recommendations that benefit multiple species and the natural communities they occupy. A few important guilds and other types of species associations are discussed in Sections 3.2 through 3.12.

Tables showing associations between SGCN and the habitats described in Chapter 4 are provided in Appendix H for the eight taxonomic groups evaluated by Taxa Teams.

3.1.4 Population Objectives

As noted in the 2005 WAP, specific population objectives are difficult to assess for the majority of fish and wildlife in North Carolina due to data limitations and knowledge gaps that need to be filled. Survey, monitoring, and research efforts have since contributed to improving our knowledge base, but with little more than 10 years of data accumulated for many species, there is still much we do not know or understand about many of the species found in North Carolina.

Due to the mostly strategic (and not operational) nature of this Plan, we have not identified specific population objectives for each species mentioned herein. However, for some species, such as birds and marine fish, data to assess population level objectives developed through the cooperative efforts of specific conservation partnerships may be available. Examples of these partnerships include the North American Bird Conservation Initiative, Atlantic Coast Joint Venture, and the regional Fisheries Management Councils. Recovery plans for species on the federal threatened and endangered species list also identify

Table 3.3 Population target information for North Carolina

Group	Conservation Plan	Citation/ Resource
Endangered and Threatened species (federal)	Species recovery plans	USFWS Threatened and Endangered Species System Webpage (http://ecos.fws.gov/tess_public/)
Landbirds	Partners in Flight South-Atlantic Coastal Plain Bird Conservation Plan	Hunter et al. 2001b
	Cooperative Upland-habitat Restoration and Enhancement (CURE)	NCWRC 2013 (http://www.ncwildlife.org/CURE/CUREDecliningHabitatDecliningWildlife.aspx)
	South Atlantic Migratory Bird Initiative Implementation Plan	Watson and Malloy 2006
	Partners in Flight Piedmont Bird Conservation Plan	Demarest n.d.
	Partners in Flight Southern Blue Ridge Bird Conservation Plan	Hunter et al. 1999
	Partners in Flight North American Landbird Conservation Plan	Rich et al. 2004
	North American Bird Conservation Initiative (NABCI)	Southeast Region Conservation Planning Atlas (http://seregion.databasin.org/datasets/)
	National Bobwhite Conservation Initiative Biologist Ranking Index	Conservation Planning Atlas (http://seregion.databasin.org/datasets/)
Waterbirds	North American Waterbird Conservation Plan	Kushlan et al. 2002
	Southeast US Region Waterbird Conservation Plan	Hunter et al. 2006
Waterfowl	North American Waterfowl Management Plan	NAWMP 1998, 2004a, 2004b
Shorebirds	Southeastern Coastal Plain-Caribbean Regional Shorebird Plan	Hunter et al. 2005
Landbirds Waterbirds Waterfowl Shorebirds	South Atlantic Migratory Bird Initiative implementation plan	Watson and Malloy 2006
Coastal and Marine Fisheries	Fisheries Management Plans	Mid-Atlantic Fisheries Management Council (www.mafmc.org) South-Atlantic Fisheries Management Council (www.safmc.net)

population objectives related to species recovery thresholds. Priorities for other species groups have focused on collecting enough information to support valid population size estimates.

Table 3.3 provides a list of existing resources on population target information appropriate to North Carolina.

The following sections of this Chapter provide information about each of the eight taxonomic groups reviewed by the Taxa Teams and marine, pelagic bird, and arthropod species. A few species of particular concern have been highlighted and recommendations specific to certain species or guilds are provided in the discussion. Information about important natural communities in the state can be found in Chapter 4.

3.2 Amphibians

3.2.1 Introduction

Amphibians and reptiles are collectively known as herpetofauna and are commonly referred to as "herps" for short. They are often discussed as a group because they occupy many of the same habitats. In this document they are discussed as separate groups in order to present information about conservation and management concerns that are unique to each class of animals. Class Amphibia represents salamanders (including sirens and newts) and anurans (frogs and toads). The North Carolina Museum of Natural Sciences (NCMNS) includes 92 species of amphibians on their checklists of North Carolina amphibians (http://naturalsciences.org/research-collections/research-specialties/amphibians-reptiles).

The southern Appalachian region is the world's center for plethodontid salamander diversity (Ricketts et al. 1999). Gradients in elevation, aspect, slope, and rainfall contribute to a range of available niches and habitats. The North Carolina Herpetological Society (NCHS) (www.ncherps.org) notes there are more than 90 species of amphibians in the state. According to the Southern Appalachian Biodiversity Institute (SABI), nearly 10% of global salamander diversity and 10% of freshwater mussel diversity occur in this region.

Marbled Salamander (Patrick Coin, Flickr)
https://www.flickr.com/photos/pcoin/361937330/

Many amphibians depend on fishless ponds for breeding and, in many cases, breeding sites are restricted to upland ephemeral pools. Because of the porous nature of their skins, and the fact that many species require both terrestrial and aquatic habitats, amphibians are often considered indicator species of general environmental problems such as water pollution and habitat fragmentation. For many species, transitioning from aquatic to terrestrial habitat results in high mortality. This is due to high predation rates of juveniles, changing metabolic processes, and difficulty crossing roads.

In 2013, the Marbled Salamander was designated through legislative action as the State Salamander and the Pine Barrens Treefrog was designated as the State Frog. The Herp Taxa Team designated the Marbled Salamander as a priority for both research and management concerns because of the uncertainty about population size and distribution in North Carolina's Mountain ecoregion, and because the species is at risk for population decline due to disease and pathogens. The Pine Barrens Treefrog is found primarily in pine forest and acidic bogs in the Sandhills and lower Coastal Plain ecoregions and is considered significantly rare in the state. The Taxa Team designated it an SGCN in part due to its confined distribution within this small number of wetland types that are themselves rare on the landscape. Additionally, the Pine Barrens Treefrog, like the Marbled Salamander, was also designated a priority for both research and management concerns because of the uncertainty about population size and distribution in the Sandhills and Coastal Plain ecoregions of North Carolina, and because the species is at risk for population decline due to disease and pathogens.

Table 3.4 Amphibian SGCN

Family	Scientific Name	Common Name	Federal/ State Status*
ORDER: ANURA			
Bufonidae	*Bufo [Anaxyrus] quercicus*	Oak Toad	—
Hylidae	*Hyla andersonii*	Pine Barrens Treefrog	—
	Hyla versicolor	Northern Gray Treefrog	—
	Pseudacris brachyphona	Mountain Chorus Frog	—/SC
	Pseudacris nigrita	Southern Chorus Frog	—
	Pseudacris ornata	Ornate Chorus Frog	—
Ranidae	*Rana [Lithobates] capito*	Carolina Gopher Frog	FSC/T
	Rana [Lithobates] heckscheri	River Frog	—/SC
	Rana sylvatica [Lithobates sylvaticus] pop.3	Wood Frog—Coastal Plain pop.	—
ORDER: CAUDATA			
Ambystomatidae	*Ambystoma mabeei*	Mabee's Salamander	—
	Ambystoma talpoideum	Mole Salamander	—/SC
	Ambystoma tigrinum tigrinum	Eastern Tiger Salamander	—/T
Cryptobranchidae	*Cryptobranchus alleganiensis allaganiensis*	Eastern Hellbender	FSC/SC

Family	Scientific Name	Common Name	Federal/ State Status*
Plethodontidae	*Aneides aeneus*	Green Salamander	FSC/E
	Desmognathus aeneus	Seepage Salamander	FSC/—
	Desmognathus auriculatus	Southern Dusky Salamander	—
	Desmognathus conanti	Spotted Dusky Salamander	—
	Desmognathus folkertsi	Dwarf Black-bellied Salamander	—
	Desmognathus imitator	Imitator Salamander	—
	Desmognathus imitator pop.1	Imitator Salamander—Waterrock Knob pop.	—
	Desmognathus organi	Northern Pigmy Salamander	FSC/—
	Desmognathus santeetlah	Santeetlah Dusky salamander	—
	Desmognathus wrighti	Southern Pigmy Salamander	FSC/—
	Eurycea bislineata	Northern Two-lined Salamander	—
	Eurycea junaluska	Junaluska Salamander	FSC/T
	Eurycea longicauda longicauda	Long-tailed Salamander	—/SC
	Eurycea quadridigitata	Dwarf Salamander	—/SC
	Eurycea sp. 9	Sandhills Salamander	—
	Hemidactylium scutatum	Four-toed Salamander	—/SC
	Plethodon amplus	Blue Ridge Gray-cheeked Salamander	FSC/—
	Plethodon aureolus	Tellico Salamander	—
	Plethodon chattahoochee	Chattahoochee Slimy Salamander	—
	Plethodon cheoah	Cheoah Bald Salamander	FSC/—
	Plethodon glutinosus	Northern Slimy Salamander	—
	Plethodon jordani	Jordan's Salamander	—
	Plethodon longicrus [=yonahlossee pop. 1]	Crevice Salamander	—/SC
	Plethodon meridianus	South Mountain Gray-cheeked Salamander	FSC/—
	Plethodon richmondi	Southern Ravine Salamander	—
	Plethodon shermani	Red-legged Salamander	—
	Plethodon teyahalee	Southern Appalachian Salamander	—
	Plethodon ventralis	Southern Zigzag Salamander	—/SC
	Plethodon wehrlei	Wehrle's Salamander	—/T
	Plethodon welleri	Weller's Salamander	FSC/SC
	Plethodon yonahlossee	Yonahlossee Salamander	—
	Stereochilus marginatus	Many-lined Salamander	—
Proteidae	*Necturus lewisi*	Neuse River Waterdog	FSC/SC
	Necturus maculosus maculosus	Common Mudpuppy	—/SC
Sirenidae	*Siren intermedia intermedia*	Eastern Lesser Siren	—
	Siren lacertina	Greater Siren	—

* See Table 3.2 for abbreviations.

A list of amphibian SGCN is provided in Table 3.4 and the Taxa Team evaluation results can be found in Appendix G. River basin and habitat associations for these species can be found in Appendix H.

Conservation recommendations for the associated habitats have been incorporated into the natural community descriptions in Chapter 4. The following paragraphs provide information about a few of the amphibian species identified by the Taxa Team as SGCN or a priority species for research or management and for which work has been conducted to implement conservation and management recommendations.

3.2.1.1 Salamanders

The southeastern United States has the largest diversity of salamander species in the world. North Carolina is home to more than 60 species, many of which are located only in specific isolated habitats and a few of which are endemic to North Carolina.

Eastern Hellbender (NCWRC)

The Eastern Hellbender, one of only three giant salamanders from the family Cryptobranchidae, is one of the largest salamanders found in North Carolina and the United States. It was once more common throughout the mid-eastern United States, but has since disappeared from many streams because of declining water quality, over-collecting, barriers such as dams, and persecution. This species is state listed as Special Concern and has been designated an SGCN. Hellbenders are fully aquatic salamanders (they do not leave the water) that are found in habitats with swift running, fairly shallow, highly oxygenated waters. They feed on crayfish, fish, aquatic insects, and other amphibians (Mayasich et al. 2003). Because Hellbenders are sensitive to silt, sediment, and other pollution in their aquatic habitat, they are considered a biological indicator of water quality. Regional efforts have been undertaken to establish captive breeding programs to assist with recovery efforts through augmentation and restoration of populations in the wild (Reeves and Pfaffko 2013).

Neuse River Waterdog (Melissa McGaw, NCWRC)

The Neuse River Waterdog is another fully aquatic salamander that has been identified an SGCN and a species for which there are management concerns. Conservation recommendations include the need for survey, research, and monitoring efforts to determine the status and distribution of this salamander in the two river basins (Neuse, Tar-Pamlico) where it was historically found. During the last several years, status surveys have involved winter trapping to collect information for use in determining status trends for the species.

3.2.1.2 Frogs and Toads

North Carolina has 31 species of native frogs and toads, which includes a recently identified species, the Atlantic Coast Leopard Frog (Feinberg et al. 2014). Molecular DNA analysis, morphology, and bioacoustics identification techniques were used to examine the genetics and mating calls of related leopard frogs to positively determine the frog as a distinct species (Feinberg et al. 2014). Surveys have confirmed populations of the new species occur in North Carolina.

Carolina Gopher Frog (Jeff Humphries NCWRC)

The Carolina Gopher Frog (also referred to as the Gopher Frog) is state listed as a Special Concern species and is under review by the USFWS for listing under the ESA for protection. The Gopher Frog is listed on the International Union for Conservation of Nature IUCN Red List as "near threatened" (IUCN 2014). It is listed as endangered, threatened, or of special concern in all states within their range. In North Carolina, the Gopher Frog is an uncommon species found only in high-quality Longleaf Pine forests and is state listed as threatened. Gopher Frogs live in stumphole cavities in upland Longleaf Pine forests and breed in high-quality isolated ephemeral ponds during late winter. Historically, they are known from over 50 sites that represent over 30 populations. In recent years, extensive surveys throughout the known range of Gopher Frogs in North Carolina have shown substantial declines, and currently, only 6 populations remain active. Degradation, fragmentation, and outright loss of both wetlands and associated uplands are the causes. Fire on the landscape is an extremely important factor for this and many other coastal amphibians (and reptiles, for that matter). Seasonally appropriate fires (hot summer fires) are important to maintain both open grassy upland habitat and open-canopy, herbaceous wetlands. The Carolina Gopher Frog is an SGCN and the Taxa Team evaluation indicates it is the highest priority amphibian species. It is a management priority due to concerns for loss of breeding habitat and risk of mortality from a viral or bacterial disease.

The Mountain Chorus Frog is a state Special Concern species and an SGCN for which there are also knowledge gaps and management concerns. Little is known about the use of upland habitat by Mountain Chorus Frogs and their movements when away from breeding habitats. Nighttime visual encounter surveys conducted at aquatic breeding sites have been used to collect morphological data. Audio surveys for calling frogs, conducted since 2008, have collected distribution information in western North Carolina, and more than 20 new breeding habitats in south-central Cherokee County and western Clay County have been detected. Telemetry techniques could be used to find out more about their movements and habitat use in these areas.

3.2.2 Comparison of 2005 and 2015 Priority Species

The 2015 evaluation identified a total of 78 species as conservation concern, knowledge gap, or management concern priorities. Some species are a priority in more than one of the three evaluation categories. Of the 78 species, 49 were identified as SGCN and another 17 were designated research priorities.

In comparison, the 2005 WAP listed 41 amphibians as priority species, which may have included concerns for knowledge gaps. However, the 2005 Taxa Team evaluations did identify knowledge gaps or management concerns as separate priorities. These changes do not necessarily indicate a change in the concern status of these species; they are more likely a result of different evaluation methodologies from the 2005 process (see Appendix F) or reflect an increase in our knowledge base for the species.

There have been significant scientific advances in direct DNA sequencing methods that enabled tests of previous hypotheses of phylogenetic relationships (Amphibiaweb 2015). This new information has led to suggestions for taxonomic revisions such as those proposed by Frost et al. (2006) and others. However, newly published taxonomy should not be interpreted

TABLE 3.5 Amphibians: comparison of changes from 2005 WAP

2005		2015 Changes		
Common Name	Scientific Name	Common Name	Scientific Name	Comment
Oak Toad	*Bufo quercicus*	No Change	*Bufo [Anaxyrus] quercicus*	Taxonomists have proposed genus name changes that the 2015 Taxa Team has not adopted
Sandhills Salamander	*Eurycea* sp. *1*	No Change	*Eurycea sp. 9*	
Carolina Gopher Frog	*Rana capito*	No Change	*Rana [Lithobates] capito*	
River Frog	*Rana heckscheri*	No Change	*Rana [Lithobates] heckscheri*	

as a formal, mandatory change; it is simply an alternative that should be evaluated alongside other such proposals (Amphibiaweb 2014). In some cases, published literature will use both genus names in use to refer to the same species (*Rana* [*Lithobates*] *pipiens* Northern Leopard Frog).

Table 3.5 provides a comparison of changes since the 2005 WAP was published.

In the sections below, we highlight specific conservation issues related to SGCN and their habitats. This is not an exhaustive list of species-specific conservation concerns, but rather highlights some of the conservation concerns in the state. Recommendations for priority survey, monitoring, and research studies, conservation actions, and partnerships are outlined in Section 3.3.8.

3.2.3 Conservation Concerns

In general, protection and restoration of natural community composition and function and protection of surrounding natural areas are the best ways to conserve at-risk and sensitive populations. Riparian buffers and forest habitats adjacent to streams and wetlands provide cool and moist microclimate conditions which are beneficial to amphibians (Shoo et al. 2011). The following recommendations should be considered appropriate to implement for all amphibian species.

Long-term population and distribution trends can be difficult to assess. Actual declines can sometimes be difficult to separate from natural fluctuations in population numbers. Surveys and monitoring efforts often focus only on breeding sites (Storfer 2003) and may not be able to determine survival or recruitment information. However, scientists have been concerned with apparent worldwide declines in amphibian populations since the 1980s. More recently, a 2004 global assessment indicated a nearly 32% decline of amphibian species in the United States (Adams et al.2013). Climate change is recognized as a major threat to amphibian biodiversity and the Amphibian Conservation Action Plan identifies gaps in scientific knowledge and general management actions for amphibians in response to climate change (Gascon et al. 2007; Shoo et al. 2011).

The Taxa Team evaluation results indicate that distribution information is uncertain for Cope's Gray Treefrog, Northern Gray Treefrog, and River Frog (which is believed to be extirpated in the state). Current levels of knowledge about these amphibians are generally limited to published range maps or have been extrapolated from a few known population locations in the state. These species are high priorities for new status surveys to collect data that can be used to develop monitoring programs and future conservation recommendations.

The North Carolina Partners in Amphibian and Reptile Conservation (NCPARC) program coordinates the North Carolina Calling Amphibian Survey Program (CASP) that provides data to the North American Amphibian Monitoring Program (NAAMP) database. Frog call monitoring conducted by NCWRC biologists, partners, and citizen science volunteers has provided distribution information on many species of anurans, including Oak Toad, Barking Treefrog, and Ornate Chorus Frog. Monitoring results are used to understand occupancy of available wetlands, as well as guide future survey and inventory efforts for target species.

Other conservation recommendations for the habitats associated with amphibian species have been incorporated into the natural community descriptions in Chapter 4. Additional management information can be found in a PARC technical publication on habitat management for amphibians and reptiles in the Southeast (Bailey et al. 2006) and is available online: http://separc.files.wordpress.com/2013/04/se-hmg.pdf.

3.2.4 Knowledge Gaps

Inventories of amphibian species have been conducted statewide to help build datasets and improve understanding of population abundance and distribution in North Carolina. Knowledge gained from this work contributes to the design of research and conservation measures that support persistence of all amphibian species.

Studies are needed to assess the effectiveness of specific actions and application of general adaptation management principles (Shoo et al. 2011). Efforts should be targeted at high-risk areas and species as well as locations where species are most likely to persist or migrate toward new sites under changing climate conditions (Lawler et al. 2009; Blaustein et al. 2010; Killeen et al. 2007; Klein et al. 2009; Reilly et al. 2009; Shoo et al. 2010, 2011).

Green Salamander (NCWRC)

In addition to the SGCN listed in Table 3.4, the species for which the Taxa Team determined there are research priorities because of knowledge gaps are identified in Table 3.6.

Table 3.6 Amphibian knowledge-gap priority species

Family	Scientific Name	Common Name	Federal/ State Status*
ORDER: ANURA			
Hylidae	*Hyla chrysoscelis*	Cope's Gray Treefrog	—
	Pseudacris brimleyi	Brimley's Chorus Frog	—
Ranidae	*Rana [Lithobates] virgatipes*	Carpenter Frog	—
Scaphiopodidae	*Scaphiopus holbrookii*	Eastern Spadefoot	—
ORDER: CAUDATA			
Ambystomatidae	*Ambystoma maculatum*	Spotted Salamander	—
	Ambystoma opacum	Marbled Salamander	—
Amphiumidae	*Amphiuma means*	Two-toed Amphiuma	—
Plethodontidae	*Desmognathus marmoratus*	Shovel-nosed Salamander	—
	Eurycea chamberlaini	Chamberlain's Dwarf Salamander	—
	Plethodon chlorobryonis	Atlantic Coast Slimy Salamander	—
	Plethodon cinereus	Eastern Red-backed Salamander	—
	Plethodon cylindraceus	White-spotted Slimy Salamander	—
	Plethodon serratus	Southern Red-backed Salamander	—
	Pseudotriton montanus montanus	Eastern Mud Salamander	—
	Pseudotriton ruber	Red Salamander	—
Proteidae	*Necturus punctatus*	Dwarf Waterdog	—

* See Table 3.2 for abbreviations.

3.2.5 Management Needs

The Taxa Team indicated current levels of management for the Carolina Gopher Frog are not sufficient to maintain long-term viable populations. Encroachment by woody shrubs and invasive plants in areas not subject to prescribed burns has reduced the number and quality of ephemeral pools. Vegetation removal and maintenance of these areas will maintain and improve the condition of existing breeding habitats. Additionally, captive rearing of tadpoles, hatched from portions of egg masses, for release at existing sites should increase recruitment and eventually lead to more stable populations.

An example of successful amphibian habitat restoration is work being conducted by NCWRC biologists and partners in the Sandhills and Coastal Plain ecoregions targeting SGCN species such as Carolina Gopher Frogs, Ornate Chorus Frogs, and Eastern Tiger Salamanders, although many other amphibian and reptile species also benefit. These SGCN require open-canopied, herbaceous ephemeral ponds for successful reproduction. Some upland ephemeral pools are maintained as open-canopy emergent wetlands because of naturally long hydroperiods that prevent the colonization of trees and shrubs (e.g., limestone sinks with a groundwater connection). However, many upland, isolated wetlands would have historically been maintained as open, “grassy” ponds through a combination of hyrdoperiod and fire regime processes (De Steven and Toner 2004). Because of historic fire exclusion, or problems with the timing of prescribed fire, many isolated ponds that were once open-canopied have become forested. Dense canopy in these ponds reduces herbaceous vegetation needed for amphibian egg attachment, changes the pond’s pH, and can drastically alter the hydroperiod such that ponds dry out too early in the year for amphibian larval development to be completed.

Restoration efforts in wetlands have included removal of organic and woody debris by mechanical means, as well as the use of prescribed fire. Typically, greater numbers of species of amphibians utilize ponds following restoration. For example, two wetlands restored in the Sandhills exhibited greater numbers of species after restoration than before. One pond supported only 3 species of amphibians prior to restoration efforts, and none were SGCN. After management work was conducted, 12 species of amphibians were detected using the wetland, including 2 SGCN species (Pine Barrens Treefrog and Eastern Tiger Salamander). Another pond also supported only 3 species (none SGCN) prior to work, and 9 species after, including 2 SGCN species (Pine Barrens Treefrog and Oak Toad).

Management recommendations include the need to protect known breeding sites as well as nearby and surrounding uplands; restore degraded sites and maintain existing sites through application of prescribed fire during appropriate seasons and at required intervals; protect corridors connecting nearby and adjacent breeding sites; investigate captive breeding methods and opportunities for population augmentation and restoration; and monitor populations for evidence of disease and pathogens so that protective measures can be designed and implemented when needed.

Logs, tree falls, and other woody debris can provide microhabitat and shelter that can protect amphibians from high temperatures and govern dehydration rates that can occur during the hottest and driest times of the year (Shoo et al.2011). Retention of down wood reduces desiccation and promotes amphibian survival in modified landscapes such as harvested forests (Rittenhouse et al. 2008, Shoo et al.2011). Studies are needed to increase understanding of microhabitat requirements of amphibians and to investigate artificial shelter or burrows use (Lettink and Cree 2007; Arida and Bull 2008; Shoo et al. 2011).

Another example of important conservation measures that benefit amphibian species include protection and restoration of ephemeral ponds and wetlands on Sandhills Game Lands and within Croatan National Forest. Success of these restoration projects was demonstrated by the large number of Eastern Tiger Salamanders and Eastern Spadefoots that used the restored wetlands during the first breeding season after restoration work was finished.

3.2.6 Threats and Problems

Chapter 5 describes 11 categories of threats the Taxa Team considered during the evaluation and ranking process to identify SGCN; information about the expected scope and severity of the impacts from these threats is available in Appendix G. Evaluation results for Metric 9 indicate the most likely threats to create significant impacts to amphibian populations in North Carolina over the next 10 years include the following:

- residential and commercial development
- energy production (e.g., drilling, mining, quarrying, and renewal energy production)
- natural system modifications (e.g., fire suppression, land management activities)
- transportation and service corridors (e.g., habitat fragmentation or being run over by vehicles)
- climate change impacts, especially drought
- disease and pathogens

Research related to these threats and their impacts on certain amphibian species was ranked as a high priority. Anthropogenic impacts that create habitat loss and degradation are one of the most important threats to amphibian populations (Willson and Dorcas 2003). Amphibian declines may correlate with declines of other species, especially those utilizing wetlands. Amphibians are also indicators for anthropogenic stressors that can have broader health and biodiversity implications to an ecosystem (Lannoo 2005; Bosch and Rincon 2008).

3.2.7 Additional Information

The USFWS has proposed including the Eastern Hellbender in Appendix III of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), including live and dead whole specimens, and all readily recognizable parts, products, and derivatives. Listing in Appendix III of CITES would allow for adequate monitoring of international trade in the taxon; to determine whether exports are occurring legally with respect to state laws; and to determine whether further measures under CITES or other laws are required to conserve the species (and any subspecies) (Congressional Record 2011).

The US Geological Survey (USGS) established the ARMI to document changes in the number of amphibian populations rather than the change in species abundance (Adams et al. 2013). The ARMI analysis indicates a trend in amphibian declines that includes common species for which there has traditionally been low conservation concern and these declines are occurring on lands protected and managed for conservation.

Another online database is the Carolina Herp Atlas, developed by the Davidson College Herpetology Laboratory. This program tracks county-level distribution information for native species in North and South Carolina and is available online at http://www.carolinaherpatlas.org. Davidson College also maintains an online identification and information guide, Amphibians and Reptiles of North Carolina (http://www.herpsofnc.org).

Information on habitat management for herp species can be found in the Partners in Amphibian and Reptile Conservation (PARC) technical publication on habitat management for amphibians and reptiles in the Southeast (Bailey et al. 2006), available online here: http://separc.files.wordpress.com/2013/04/se-hmg.pdf.

Important conservation measures that benefit amphibian species include protection and restoration of ephemeral ponds and wetlands on the Sandhills and Holly Shelter game lands and within Croatan National Forest. Encroachment by woody shrubs and invasive plants in areas not subject to prescribed burns had reduced the number and quality of ephemeral pools. Vegetation removal and maintenance of these areas has resulted in additional breeding sites being available and has improved the condition of existing breeding habitats. Success of these restoration projects has been demonstrated by the increase in number and diversity of species of amphibians using these sites after restoration work was finished.

Taxonomic classification and agreement on naming conventions for some species is likely to be unsettled until scientific evidence supporting any recommended changes becomes widely accepted. Resources for information about changes in classification include the Society for the Study of Amphibians and Reptiles (SSAR) and the Center for North American Herpetology (CNAH). SSAR is a nonprofit organization established to advance research, conservation, and education concerning amphibians and reptiles; is the largest international herpetological society; and is recognized worldwide for having the most diverse program of publications, meetings, and other activities. SSAR's Committee on Standard English and Scientific Names produces a circular every few years with suggestions for standard taxonomy and can be found here: http://ssarherps.org/publications/north-american-checklist/. CNAH is an organization that serves as a data bank for information about North American amphibians, turtles, reptiles, and crocodilians. Published research literature documenting taxonomic changes is available online (www.cnah.org). The CNAH webpage also provides a link to peer-reviewed articles published in the *Journal of North American Herpetology* and access to articles in the *Contemporary Herpetology* journal archives. Another resource for amphibian taxonomy is the American Museum of

Natural History Amphibian Species of the World online reference database: http://research.amnh.org/vz/herpetology/amphibia.

3.2.8 Recommendations

In general, protection and restoration of natural community composition and function and protection of surrounding natural areas under current conditions are the best ways to ensure that suitable habitats are available for amphibian species. Measures that protect a large and diverse pool of populations are the best way to ensure that species are able to survive future stressors and adapt to changing climate conditions.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Conduct distributional surveys for priority species, especially the Mudpuppy, Neuse River Waterdog, Junaluska Salamander, Longtail Salamander, Wehrle's Salamander, and Mole Salamander.

- Conduct surveys (and monitoring) on all amphibian species associated with small wetland communities, especially the Mabee's Salamander, Mole Salamander, Four-toed Salamander, Eastern Tiger Salamander, Oak Toad, Dwarf Salamander, Ornate Chorus Frog, Southern Chorus Frog, Pine Barrens Treefrog, and Carolina Gopher Frog.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species.. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Use inventory and monitoring efforts to build historical data that can be compared over time to identify population trends.

- Conduct herpetofauna monitoring to track population trends for species of concern. Particular attention should be paid to Four-toed Salamanders.

- Continue to support CASP and other monitoring programs and participate in partnerships where possible.

- Monitor populations for evidence of disease and pathogens so that protective measures can be designed and implemented when needed. For example, NCWRC biologists and partners have been collecting and analyzing skin swabs from more than 30 different salamander and six frog species in the Mountain ecoregion as a means of detecting the presence of the *Batrachochytrium dendrobatidis* (Bd) chytrid fungus. Additional disease monitoring will focus on the salamander equivalent of *Bd*, called *B. salamandrivorans* (*Bsal*), as well as ranaviruses.

- Continue annual inventory and monitoring surveys for Neuse River Waterdog, Pine Barrens Treefrog, Gopher Frog, Mole Salamander, and Ornate Chorus Frog and develop new surveys for other priority species.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- NCWRC is working cooperatively with the NC Zoo to propagate Eastern Hellbenders at fish hatchery facilities. Support and expand captive breeding and propagation programs that benefit hellbenders and other priority species.

- Investigate sites and identify opportunities for population augmentation and restoration for all priority species, especially Gopher Frogs, Ornate Chorus Frogs, and Pine Barrens Treefrogs.

- Determine minimum upland buffers required to sustain at-risk amphibian populations.

- Investigate meta-population dynamics and land management effects on Green Salamanders.

- Investigate Mountain Chorus Frog upland habitat use.

- Investigate land use and urbanization effects, habitat augmentation and restoration effects, and larval ecology of Eastern Hellbender.

- Conduct genetic investigations and species' range delineations for plethodontid salamanders, for example, endemic Gray-cheeked Salamander complex (Cheoah Bald, Blue Ridge, South Mountain Gray-cheeked Salamander) and Slimy Salamander complex (Chattahoochee Slimy, Northern Slimy, Tellico Salamander).

- Conduct genetic work on Gopher Frog populations to determine extent of genetic diversity within each population.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital.

- Restore, create, and protect habitats for all priority species, especially seasonal wetlands, especially degraded wetland systems, riparian zones, and maintain habitat connectivity with uplands.
- Protect known breeding sites as well as nearby and surrounding uplands. Protect corridors and hydrologic connections between nearby and adjacent breeding sites.
- Restore degraded sites and maintain existing sites through application of prescribed fire during appropriate seasons and at required intervals.
- When feasible, remove populations in immediate danger of destruction from land use changes (e.g., transportation projects, development).
- Where fish have invaded amphibian breeding sites, such as from flooding from nearby streams, remove them as a means of protecting amphibian eggs and juveniles.
- Manage high-elevation forests for old growth vegetation.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protection measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but overall can promote ecosystem resilience.

- Identify high-quality examples of habitat for SGCN and attempt to acquire, or seek alternative conservation actions.
- Continue to support programs that limit collection of priority species, including permit requirements, law enforcement oversight, and legislative action that protects species.
- Implement the state listing process by routinely evaluating conservation status and recommending legislative updates to revise the state species lists.

- Support land trusts and conservation easements as a means to protect amphibian habitat.
- Utilize programs such as the Wildlife Conservation Lands Program and others to protect, manage, and restore habitat on private lands.
- Support citizen science and volunteer efforts to monitor species and habitats.
- Utilize partnerships and research collaborations with local universities and education programs to implement conservation, research, and management actions.
- Develop education, outreach, and technical guidance programs for the public.

3.3 Birds

3.3.1 Introduction

North Carolina hosts more than 460 species of birds (Piephoff et al. 2013; CBC 2014), of which roughly 360 species are seen at some point during the year. Managers and researchers have better knowledge and understanding of many of our bird species compared to other taxonomic groups, largely because of the popularity of bird-watching and subsequent ability to collect data from researchers and the public alike. Citizen science is a continuing force in the collection of bird data (e.g., eBird, Nest Watch, Christmas Bird Count, Great Backyard Bird Count, and Yard Map). Much of the population trend data driving conservation priorities are derived from nationwide citizen science programs like the USGS Breeding Bird Survey (BBS) (Sauer et al. 2013) and the Audubon Christmas Bird Count (CBC) (Dunn et al. 2005).

Northern Saw-whet Owl (NCWRC)

The conservation needs of birds in North Carolina center mainly on habitat management, restoration, and protection, especially of spruce–fir forest, bottomland hardwood forest, quality early successional habitats, Longleaf Pine communities, riparian and bottomland habitats, and coastal beach and estuarine habitats. Community descriptions in Information on pelagic bird species is provided in Section 3.11 of this chapter.

A list of bird SGCN is provided in Table 3.7 and the Taxa Team evaluation results can be found in Appendix G. Habitat associations for these species can be found in Appendix H.

Table 3.7 SGCN bird species

Family	Scientific Name	Common Name	Federal/ State Status*
Accipitridae	*Circus cyaneus*	Northern Harrier	—
	Elanoides forficatus	Swallow-tailed Kite	—
	Haliaeetus leucocephalus	Bald Eagle	—/T
Anatidae	*Anas rubripes*	American Black Duck	—
	Anas strepera	Gadwall	—
	Aythya valisineria	Canvasback	—
	Branta bernicla	Brant	—
	Chen caerulescens	Snow Goose	—
	Clangula hyemalis	Long-tailed Duck	—
	Cygnus columbianus	Tundra Swan	—
	Melanitta fusca	White-winged Scoter	—
	Melanitta perspicillata	Surf Scoter	—
Ardeidae	*Botaurus lentiginosus*	American Bittern	—
	Egretta caerulea	Little Blue Heron	—/SC
	Egretta thula	Snowy Egret	—/SC
	Egretta tricolor	Tricolored Heron	—/SC
	Ixobrychus exilis	Least Bittern	—/SC
	Nyctanassa violacea	Yellow-crowned Night-heron	—
	Nycticorax nycticorax	Black-crowned Night-heron	—
Cardinalidae	*Passerina ciris ciris*	Eastern Painted Bunting	FSC/SC
Charadriidae	*Charadrius melodus*	Piping Plover	**T, E/T
	Charadrius wilsonia	Wilson's Plover	—/SC
	Pluvialis squatarola	Black-bellied Plover	—
Ciconiidae	*Mycteria americana*	Wood Stork	T/E
Corvidae	*Corvus corax*	Common Raven	—
Emberizidae	*Ammodramus caudacutus*	Saltmarsh Sparrow	—
	Ammodramus henslowii	Henslow's Sparrow	***—/SC
	Ammodramus leconteii	Le Conte's Sparrow	—
	Ammodramus maritimus	Seaside Sparrow	—
	Ammodramus nelsoni	Nelson's Sparrow	—
	Melospiza lincolnii	Lincoln's Sparrow	—

Table 3.1 SGCN bird species (cont.)

Family	Scientific Name	Common Name	Federal/ State Status*
Emberizidae (cont.)	*Passerculus sandwichensis*	Savannah Sparrow	—
	Peucaea aestivalis	Bachman's Sparrow	FSC/SC
	Pooecetes gramineus	Vesper Sparrow	—/SC
	Spizella pallida	Clay-colored Sparrow	—
Falconidae	*Falco columbarius*	Merlin	—
	Falco peregrinus	Peregrine Falcon	—/E
	Falco sparverius	American Kestrel	—
Fringillidae	*Coccothraustes vespertinus*	Evening Grosbeak	—
	Loxia curvirostra	Red Crossbill	***—/SC
Haematopodidae	*Haematopus palliatus*	American Oystercatcher	—/SC
Hirundinidae	*Riparia riparia*	Bank Swallow	—
Icteridae	*Dolichonyx oryzivorus*	Bobolink	—
	Euphagus carolinus	Rusty Blackbird	—
	Euphagus cyanocephalus	Brewer's Blackbird	—
Laniidae	*Lanius ludovicianus*	Loggerhead Shrike	—/SC
Laridae	*Gelochelidon nilotica*	Gull-billed Tern	—/T
	Hydroprogne caspia	Caspian Tern	—
	Larus argentatus	Herring Gull	—
	Larus marinus	Great Black-backed Gull	—
	Rynchops niger	Black Skimmer	—/SC
	Sterna antillarum	Least Tern	—/SC
	Sterna forsteri	Forster's Tern	—
	Sterna hirundo	Common Tern	—/SC
	Thalasseus maximus	Royal Tern	—
	Thalasseus sandvicensis	Sandwich Tern	—
Odontophoridae	*Colinus virginianus*	Northern Bobwhite	—
Parulidae	*Helmitheros vermivorus*	Worm-eating Warbler	—
	Limnothlypis swainsonii	Swainson's Warbler	—
	Oreothlypis ruficapilla	Nashville Warbler	—
	Parkesia motacilla	Louisiana Waterthrush	—
	Protonotaria citrea	Prothonotary Warbler	—
	Setophaga cerulea	Cerulean Warbler	FSC/SC
	Geothlypis formosa	Kentucky Warbler	—

Family	Scientific Name	Common Name	Federal/ State Status*
Parulidae (cont.)	*Setophaga discolor*	Prairie Warbler	—
	Setophaga dominica	Yellow-throated Warbler	—
	Setophaga fusca	Blackburnian Warbler	—/SC
	Setophaga virens waynei	Wayne's Black-throated Green Warbler	FSC/—
	Vermivora chrysoptera	Golden-winged Warbler	FSC/SC
Pelecanidae	*Pelecanus occidentalis*	Brown Pelican	—
Phalacrocoracidae	*Phalacrocorax auritus*	Double-crested Cormorant	—
Phasianidae	*Bonasa umbellus*	Ruffed Grouse	—
Picidae	*Melanerpes erythrocephalus*	Red-headed Woodpecker	—
	Picoides borealis	Red-cockaded Woodpecker	E/E
Rallidae	*Coturnicops noveboracensis*	Yellow Rail	—
	Gallinula galeata	Common Gallinule	—
	Laterallus jamaicensis	Black Rail	FSC/SC
	Rallus elegans	King Rail	—
	Rallus limicola	Virginia Rail	—
	Rallus crepitans [R. longirostris]	Clapper Rail	—
Recurvirostridae	*Recurvirostra americana*	American Avocet	—
Scolopacidae	*Arenaria interpres*	Ruddy Turnstone	—
	Calidris alba	Sanderling	—
	Calidris canutus rufa	Red Knot	T/T
	Calidris maritima	Purple Sandpiper	—
	Calidris pusilla	Semipalmated Sandpiper	—
	Limosa fedoa	Marbled Godwit	—
	Numenius phaeopus	Whimbrel	—
	Tringa semipalmata	Willet	—
Sittidae	*Sitta pusilla*	Brown-headed Nuthatch	—
Strigidae	*Aegolius acadicus*	Northern Saw-whet Owl	—/T
Threskiornithidae	*Eudocimus albus*	White Ibis	—
	Plegadis falcinellus	Glossy Ibis	—/SC
Turdidae	*Catharus fuscescens*	Veery	—
	Catharus guttatus	Hermit Thrush	—

Table 3.1 SGCN bird species (cont.)

Family	Scientific Name	Common Name	Federal/ State Status*
Tyrannidae	*Contopus cooperi*	Olive-sided Flycatcher	—
	Empidonax alnorum	Alder Flycatcher	—
	Empidonax virescens	Acadian Flycatcher	—
Tytonidae	*Tyto alba*	Barn Owl	—

* See Table 3.2 for abbreviations.

** The USFWS has listed two separate populations of Piping Plover for protection under the ESA. The Great Lakes population (interior population) is listed as an endangered (E) species and the Northern Great Plains and Atlantic coast population is listed as a threatened (T) species. Birds from both populations may occur in North Carolina; however, the USFWS Region 4 office has indicated the Northern Great Plains and Atlantic coast population occurs in the state during breeding season. For more information see the USFWS Piping Plover species profile (http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=B079). North Carolina's protected species list includes the breeding population as a threatened species.

*** Bird subspecies designated by USFWS as a Federal Species of Concern (FSC) are recognized by use of a trinomial scientific name or other identifier for specific population segments. Examples include Eastern Henslow's Sparrow (*Ammodramus henslowii susurrans*), Southern Appalachian Red Crossbill (*Loxia curvirostra* pop. 1), and Northern Saw-whet Owl – Southern Appalachian population (*Aegolius acadicus* pop. 1). Other populations of these species may not carry the FSC designation.

Conservation recommendations for the associated habitats have been incorporated into the natural community descriptions in Chapter 4. Additional recommendations can be found in the river basin descriptions (Section 4.5). The following sections provide information about birds the Taxa Team identified as SGCN or a priority for research or management.

3.3.2 Comparison of 2005 and 2015 Priority Species

The 2015 Taxa Team evaluation identified a total of 164 species as conservation concern, knowledge gap, or management concern priorities. Some species are a priority in more than one of the three evaluation categories (see Appendix G). Of the 164 priority species, 99 were identified as SGCN and another 38 were designated as research priorities.

In comparison, the 2005 WAP identified 92 priority species which may have included concerns for knowledge gaps. However, the 2005 Taxa Team evaluation did not identify knowledge gaps or management concerns as separate priorities. These changes do not necessarily indicate a change in the concern status of these species; they are more likely a result of different evaluation methodologies from the 2005 process (see Appendix F) or reflect an increase in our knowledge base for the species.

When research data improve scientific understanding about relationships among and between species, the taxonomic classification of a species may warrant change. This new information often leads to suggestions for taxonomic revisions, such as those proposed by Frost et al. (2006) or published in the American Ornithologist's Union Check-list of North

American Birds (Chesser et al. 2014). Table 3.8 provides a comparison of changes since the 2005 WAP was published.

Other revisions since 2005 include the following changes to listing status under the ESA:

- The Bald Eagle was removed from protection under the ESA (delisted); however, it continues to be protected under the Bald and Golden Eagle Protection Act.
- The listing status for Wood Stork was changed from endangered to threatened (downlisting).
- The listing status for Red Knot was changed from candidate status to threatened (uplisting).

Table 3.8 Birds: comparison of changes from 2005 WAP

2005		2015		
Common Name	Scientific Name	Common Name	Scientific Name	Comment
Common Moorhen	*Gallinula chloropus*	Common Gallinule	*Gallinula galeata*	Common name and Species change
Bachman's Sparrow	*Aimophila aestivalis*	No change	*Peucaea aestivalis*	Genus change
Blue-winged Warbler	*Vermivora pinus*	No change	*Vermivora cyanoptera*	Species change
Canada Warbler	*Wilsonia canadensis*	No change	*Cardellina canadensis*	Genus change
Caspian Tern	*Sterna caspia*	No change	*Hydroprogne caspia*	Genus change
Cerulean Warbler	*Dendroica cerulea*	No change	*Setophaga cerulea*	Genus change
Chestnut-sided Warbler	*Dendroica pensylvanica*	No change	*Setophaga pensylvanica*	Genus change
Chuck-will's-widow	*Caprimulgus carolinensis*	No change	*Antrostomus carolinensis*	Genus change
Gull-billed Tern	*Sterna nilotica*	No change	*Gelochelidon nilotica*	Genus change
Hooded Warbler	*Wilsonia citrina*	No change	*Setophaga citrina*	Genus change
Kentucky Warbler	*Oporornis formosus*	No change	*Geothlypis formosa*	Genus change
Magnolia Warbler	*Dendroica magnolia*	No change	*Setophaga magnolia*	Genus change
Pine Siskin	*Carduelis pinus*	No change	*Spinus pinus*	Genus change
Prairie Warbler	*Dendroica discolor*	No change	*Setophaga discolor*	Genus change
Wayne's Black-throated Green Warbler	*Dendroica virens waynei*	No change	*Setophaga virens waynei*	Genus change

In the sections below, we highlight specific conservation issues related to SGCN and their habitats. This is not an exhaustive list of species-specific conservation concerns, but rather highlights some of the conservation concerns in the state. Recommendations for priority survey, monitoring, and research studies, conservation actions, and partnerships are outlined in Section 3.3.8.

3.3.3 Conservation Concerns

Shorebirds

North Carolina's 3,375 miles of tidal shoreline (NOAA 1975) plays a key role in the life cycle of many migratory shorebirds; thus, conservation activities directed at shorebird stopover, wintering, or breeding habitats (primarily beach, dune, estuarine, and coastal marsh habitats) can have a substantial impact on shorebird conservation throughout the Atlantic Flyway (Winn et al. 2013). In addition, coastal areas are often heavily populated, and balancing the needs of conservation and tourism can be challenging without accurate life history data.

Red Knot (USFWS) http://digitalmedia.fws.gov
Used under license CC BY-NC-SA 2.0

There is national concern about the decline of many shorebird populations, including species found in North Carolina. The American Oystercatcher, Wilson's Plover, Red Knot, and Piping Plover are shorebird species with stabilized or declining populations in North Carolina. The International Shorebird Survey protocol is followed biannually to obtain population estimates of these and other migratory shorebirds (Howe et al. 1989). In response to recent monitoring and research attention on the American Oystercatcher, its population has stabilized over the last 10 years (personal correspondence, Schulte 2013, 2014, unpublished data). Specific projects have been completed to estimate numbers of American Oystercatcher and Wilson's Plover during the breeding season (Davis et al. 2001; DeRose-Wilson et al. 2013), and of American Oystercatcher during winter (Brown et al. 2005), but more detailed information is needed on breeding habits to inform coastal management where species conservation and tourism interests often conflict. The Wilson's Plover is much less studied; hence, its population trend is not as well understood in North Carolina, but is declining elsewhere (Butcher and Niven 2007; NABCI 2009).

The Red Knot was federally listed as threatened in 2014 (USFWS 2014), and its abundance and distribution in North Carolina during migration periods and winter are poorly understood. The Piping Plover is a state-listed threatened species and is federally listed both as an endangered (interior population) species and threatened (Atlantic Coast population) species. Piping plover is well monitored and studied, and its population trend is stabilized, but not meeting recovery goals (USFWS 2011a).

Colonial Waterbirds

Wading birds often nest in multispecies colonies in trees and shrubs, referred to as rookeries (or heronries), and terns, pelicans, gulls, and skimmers nest on the ground in colonies. Since the mid-1970s, multistate surveys have been conducted to collect information on colonial waterbird nesting sites (Hunter et al. 2006), and in North Carolina, every 2 to 3 years, surveys are conducted to collect data on the location and status of existing colonies and document new colonies. Ground surveys of colonial waterbirds have also been conducted in North Carolina every two to three years since the late 1970s (Wilson and Henson 1993). Colonial waterbirds nest on North Carolina's barrier islands, dredged-material islands, and marsh islands in estuaries. Aerial surveys of inland heronries are conducted every 10 years within select portions of river basins located in Coastal Plain and Piedmont regions.

Aerial surveys of Wood Stork colonies and potential sites have been conducted annually since 2005. Wood Storks nesting in North Carolina are the most northern nesting population in the United States. This northward expansion and their adaptability have led to their being down-listed by USFWS from endangered to threatened in 2014. Data from surveys are stored in the online colonial waterbird database and used to assess population trends, status, and distribution.

Snowy Egret (USFWS) http://digitalmedia.fws.gov
Used under license CC BY-NC-SA 2

The Snowy Egret, Tricolored Heron, Little Blue Heron, and Glossy Ibis are small wading birds that nest in North Carolina's coastal region. Population trends of these species indicate a decline in numbers of nesting pairs, and nesting population sizes do not meet the state's management goals (Shields and Parnell 1990; Kushlan et al. 2002; Hunter et al. 2006). The Common Tern and Gull-billed Tern also nest in the coastal region, selecting nearly bare sandy areas on barrier and dredged-material islands. Numbers of nesting pairs of both species have declined continuously for more than five years. The Black Skimmer often nests in or near these tern colonies and, while coast-wide surveys illustrate an increase in skimmer nesting pairs since 2007, their population continues to remain below the state goal.

Marshbirds

Many secretive birds, such as rails, are dependent on coastal marshes. The Black Rail in particular has experienced significant population declines in North Carolina and elsewhere (Delany and Scott 2002). The King Rail is declining in many areas where freshwater marshes are receiving increased saltwater intrusion (Cooper TR 2007). Relatively little is known about the limiting factors of these species because of the hidden and inaccessible nature of their nesting habitats. The North American Marsh Bird Monitoring Program was designed to develop and beta-test standardized protocols to be used in a national or continental monitoring effort. Information about the status and population trends of many species of secretive marsh birds is limited. This general lack of knowledge is the product of inconsistencies in survey methodology that make it difficult to compare data from local and regional survey efforts. Current broad-scale monitoring efforts (e.g., BBS) lack adequate coverage of wetland habitat to provide statistically significant results on marsh bird trends. Currently data available through the program is managed by the USGS Patuxent Wildlife Research Center (Maryland), in cooperation with the University of Arizona and the USFWS Office of Migratory Birds. Access to data is through the Marsh Birds Population Assessment and Monitoring Project: http://www.pwrc.usgs.gov/point/mb/.

Songbirds

North Carolina plays a key role in the life cycle of many migratory landbirds for all stages of their life cycle (breeding, wintering, and migration stopover habitats). Songbirds comprise the largest bird species group, and accordingly are found in every habitat type across the state.

Breeding bird surveys and monitoring of priority species and habitats have been conducted on state-owned game lands and other public lands, on conservation partnership lands (e.g., NCWRC's Cooperative Upland-habitat Restoration and Enhancement program) and on private lands, especially on early successional habitats. Data from these survey efforts have improved our understanding of distribution, relative abundance, and population trends for migratory songbirds, but are not adequate to assess larger population parameters (Alder and Least Flycatcher, Blackburnian Warbler, Kentucky Warbler, Louisiana Waterthrush, Prairie Warbler, Rose-breasted Grosbeak, Vesper Sparrow, and others).

The Golden-winged Warbler has experienced one of the steepest declines of any North American songbird (GWWG 2013; Sauer et al. 2013), and is currently being petitioned for listing under the Endangered Species Act. It is threatened by loss of high-elevation successional community habitats, exacerbated by hybridization with the Blue-winged Warbler. In North Carolina, a range-wide spatially balanced monitoring effort led by Cornell Laboratory of Ornithology and supplemental surveys and monitoring have improved overall understanding of the species. The Golden-winged Warbler Working Group (GWWG 2013) developed best management practices for Golden-winged Warbler which identifies habitat and population goals and includes habitat supplements dedicated to specific habitat types most important to Golden-winged Warbler in the Appalachian Mountains (e.g., Deciduous Forests, Abandoned Farmlands).

Golden-winged Warbler (Caleb Putnam, Flickr)
https://www.flickr.com/photos/27846187@N07/

The Cerulean Warbler is declining at a rate of 3% annually (Sauer et al. 2013) and current population estimates represent a >75% decline compared to population estimates in 1966 (Buehler et al. 2008). Western North Carolina's core populations have been monitored biennially since 2012, and recent efforts have begun to delineate populations in the black- and brownwater floodplains of eastern North Carolina. Resources developed for managing habitat for the Cerulean Warbler in the Appalachian Mountains include *Management Guidelines for Enhancing Breeding Habitat in Appalachian Hardwood Forests* (Wood et al. 2013) and "Enhancing Cerulean Warbler Habitat in the Appalachians: A Guide for Foresters" (AMJV n.d.).

Many species that breed in the riparian areas of the Piedmont and Coastal Plain of North Carolina are under-represented by traditional bird surveys (e.g., Swainson's Warbler, Acadian Flycatcher, Kentucky Warbler, Yellow-billed Cuckoo). While surveys of these riparian areas have been completed in recent years, continued effort will be needed to assess long-term trends. Red Crossbill and Southern Appalachian Black-capped Chickadee (also referred to as Black-capped Chickadee) inhabit the imperiled spruce–fir forests of western North Carolina. The Red Crossbill's nomadic habits make it difficult to monitor. The Black-capped Chickadee occurs in the Great Smoky Mountains and Plott Balsam Range, and hybridizes with Carolina Chickadee in the Great Balsam Range. The logging boom of the 1880s–1930s reduced the southern Blue Ridge's spruce–fir forests by half, and Balsam Woolly Adelgid subsequently caused extensive mortality of mature Fraser Fir forest.

The Eastern Painted Bunting inhabits the maritime forests and successional community habitats of eastern North Carolina (see community descriptions in Chapter 4). Population numbers have declined in the state and remain low (Sauer et al. 2013). Monitoring of the species is adequate, but little is known about habitat parameters influential to survival.

The Bachman's Sparrow is closely associated with dense, herbaceous ground cover and is therefore well-suited as a primary indicator of a healthy Longleaf Pine ecosystem that is managed with frequent prescribed burning. Recent studies have made significant progress towards determining the current distribution and habitat requirements of this species in North Carolina (Taillie et al. in review, 2015). The Sandhills region contains the most contiguous habitat, specifically the Longleaf Pine forests of Fort Bragg and Sandhills Game Land, and was found to support the highest densities of sparrows. In addition, sparrows were found throughout the southern Coastal Plain but were more widely distributed on or near large public lands such as Croatan National Forest, Marine Corps Base Camp Lejeune, Holly Shelter Game Land, and the Green Swamp Preserve. Continued efforts to maintain fire return intervals of less than four years, promote herbaceous ground cover, and restore fire-suppressed forests will help to maintain and expand Bachman's Sparrow populations (Taillie et al. 2015). Furthermore, Bachman's Sparrow occupancy was found to be highly influenced by the amount of suitable habitat available within three kilometers, underscoring the importance of habitat connectivity (Taillie et al. 2015).

Bachman's Sparrow (Jeff Marcus NCWRC)

Henlsow's Sparrow is considered one of the most vulnerable nongame species found in eastern North America (Hunter et al. 2001a). It is currently designated as a species of state special concern in North Carolina, and the NC Nongame Wildlife Advisory Committee Scientific Council on Birds has recommended that it be elevated to a state status of threatened. They are known to reliably breed at only two locations in the southeastern United States, both of which occur in eastern North Carolina: Voice of America (VOA) sites A and B. These populations have persisted since their discovery in the early 1980s because of the large, contiguous size of both sites and the regular control of woody vegetation through annual mowing. Recent surveys suggest that VOA site A supports a more stable population than that of site

Henslow's Sparrow (John Carpenter, NCWRC)

B; however, the overall number of birds detected and their distribution at both locations has steadily declined over the last two decades. Evidence suggests that grassland size and isolation are limiting factors for Henslow's Sparrow and many other grassland bird species (Johnson 2001). The NCWRC is actively pursuing opportunities to develop a comprehensive and consistently administered management plan at VOA site A.

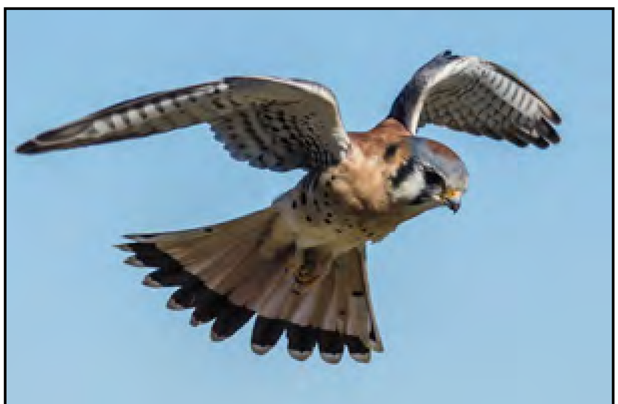
Other Land Birds

The Red-cockaded Woodpecker is a federally listed endangered species native to Longleaf Pine habitats in the Sandhills, Piedmont, and Coastal Plain ecoregions. It also uses other natural communities such as the wet pine stands found in Dare, Tyrrell, and Hyde counties, and Pond Pine–dominated pocosins found on Holly Shelter Game Land. Intense recovery efforts, including annual monitoring and excavation of supplemental artificial cavities, have allowed many managed lands to meet their goals for population recovery. However, continued management of Longleaf Pine and other habitats where it is found is necessary to continue recovery of this species.

The Eastern Whip-poor-will has averaged a 2.8% annual decline since 1966 (Sauer et al. 2013). Because of its nocturnal habits, this species is not well documented through traditional surveys, and thus little is known about its current status. In 2007, the Nightjar Survey Network (nightjars.org) began monitoring this species and other nightjars using volunteers to run survey routes. These data will be important to better assess the status of these cryptic species.

Birds of Prey

Birds of prey include various species of hawks, falcons, eagles, vultures, and owls that occur in North Carolina. Since the conclusion in 1996 of North Carolina's efforts to reintroduce the Peregrine Falcon, a subset of nests has been monitored annually. Territory occupancy, nest success, and productivity remain at or below the national average. A total of 16 territories have been documented; however, a dozen territories are documented most years.



American Kestrel (Jayaretea Snaps, flickr)
https://www.flickr.com/photos/jayaretea-snaps/15285883569/in/album-72157626618408956/

Barn Owls and American Kestrels are two raptor species of open habitats with suspected declines in North Carolina and documented declines elsewhere (Smallwood et al. 2009). Loss of nesting and foraging habitat has been attributed to development and clean farming practices. Both species have responded to installation of nest boxes in western North Carolina.

Understanding of the Golden Eagle's migration and winter range in the Appalachians has greatly improved with efforts of the Eastern Golden Eagle Working Group. Since 2013, studies of Golden Eagles using camera surveys and GPS tracking have revealed the importance of the North Carolina mountains as overwintering grounds for this species.

The Northern Saw-whet Owl breeds in North Carolina's spruce–fir and northern hardwood forests but its population trends are unknown. The logging boom of the 1880s–1930s reduced North Carolina's spruce–fir forests by half, and Balsam Woolly Adelgid subsequently caused extensive mortality of mature Fraser Fir forest. The species also occurs in Coastal Plain habitats in the winter, but the importance and extent of this area is unknown.

The Bald Eagle continues its recovery after being delisted from the endangered species list by the US Fish and Wildlife Service in 2007. Periodic efforts to monitor populations are continuing to ensure future positive population trends.

3.3.4 Knowledge Gaps

Much of our distribution and population trend knowledge gaps stem from those species that are not well-surveyed by traditional road-based methods (i.e., USGS Breeding Bird Surveys, Audubon Christmas Bird Count). In many cases, more research into the life history traits and habitat requirements of species is required to properly inform habitat management practices, identify areas for conservation, and resolve human–animal conflicts.

There have been few studies of the Wilson's Plover population in North Carolina; thus, the population trend is poorly understood, although survey data have been collected during surveys focusing on other species such as American Oystercatcher and Piping Plover (Ray 2011; DeRose-Wilson et al. 2013). Other beach-nesting species exhibiting declines, including Common and Gull-billed Terns, have not been studied to identify threats to their nest-site selection and nesting success. Further, although Erwin (2005) and others provide suggestions for buffer or set-back distances that reduce impacts of human activities to nesting colonies of terns and skimmers, there have been no studies of this threat in North Carolina; hence, buffer distances are based on studies in other locations and under different circumstances.

North Carolina provides foraging grounds for the Red Knot during fall and spring migrations, as well as during winter. There has been no systematic survey protocol developed to monitor Red Knot distribution and abundance in North Carolina. Further, although it is known that Red Knots specialize in foraging on small clams such as *Donax* spp. found in the intertidal zone, impacts of continued beach nourishment (fill) projects and beach driving along the North Carolina coast on the forage base for Red Knots has not been studied (Cohen et al. 2010; Sturbois et al. 2015).

The decline of nesting populations of Snowy Egret, Tricolored Heron, Little Blue Heron, and Glossy Ibis in North Carolina has not been examined to elucidate threats and causes. Recent surveys of colonial waterbirds in Virginia also detected declines in these nesting populations (Watts and Paxton 2014). Better management of regional data for migratory colonial waterbirds will allow better assessment of populations at the flyway scale. Currently, however, it is unknown what factors are bringing about declines in these small, colonially nesting wading birds.


Great Blue Heron (Melissa McGaw, NCWRC)

Each shorebird and colonially nesting waterbird species of concern in North Carolina is dependent on coastal estuaries and beaches. Modeling studies of potential sea level rise and climate change indicate change and loss of these habitats (Morris et al. 2002; FitzGerald et al. 2008). The challenges these species will face, especially given areas of hardened structures on the coast (e.g., commercial and residential buildings, roads, groins, jetties), are not fully understood. Data for modeling studies are available and additional data can be obtained to populate informative, predictive models. Secretive marsh birds (e.g., Black Rail) will also benefit from informative models and increased monitoring efforts.

Among raptors, there is need for further study of Barn Owl, American Kestrel, and Peregrine Falcon's post-fledging dispersal, adult and juvenile survival, migratory habits, and vulnerability to contaminants. Very little is known about the abundance and distribution of several of North Carolina's raptor species. There is a need for further study of the Barn Owl, American Kestrel, and Northern Saw-whet Owl's use of habitat and population trends and of Golden Eagle winter abundance and distribution.

While it is assumed that habitats throughout North Carolina are likely to be significant to species that migrate through, the importance of these habitats has yet to be determined, making prioritization of habitat conservation, especially in the rapidly urbanizing Piedmont, difficult. Furthermore, the impact of lighting on buildings and other tall structures on migrating songbirds is unknown. More effort into monitoring migrating and post-breeding songbirds is warranted.

Nonnative predators such as feral and free-ranging cats have been implicated as a major source of direct mortality to birds in general (Loss et al. 2013). There is a lack of understanding of predator communities and the increase of many species found along the coastline (e.g., ghost crabs, large-bodied gulls, Raccoons, foxes, Coyotes) about the effect they are having on coastal bird populations. However, species-specific vulnerability is unknown, as is their overall impact of predators to bird populations.

In addition to the SGCN listed in Table 3.7, the species for which there are research priorities because of knowledge gaps are identified in Table 3.9.

Table 3.9 Bird knowledge-gap priority species

Family	Scientific Name	Common Name	Federal/ State Status*
Accipitridae	*Accipiter cooperii*	Cooper's Hawk	—
	Aquila chrysaetos	Golden Eagle	—
	Ictinia mississippiensis	Mississippi Kite	—
Anatidae	*Mergus merganser*	Common Merganser	—
Ardeidae	*Butorides virescens*	Green Heron	—
	Egretta rufescens	Reddish Egret	—
Cardinalidae	*Pheucticus ludovicianus*	Rose-breasted Grosbeak	—
	Spiza americana	Dickcissel	—
Certhiidae	*Certhia americana*	Brown Creeper	—/SC
Charadriidae	*Charadrius semipalmatus*	Semipalmated Plover	—
Cuculidae	*Coccyzus erythropthalmus*	Black-billed Cuckoo	—
Fringillidae	*Spinus pinus*	Pine Siskin	—
Gaviidae	*Gavia immer*	Common Loon	—
Hirundinidae	*Tachycineta bicolor*	Tree Swallow	—
Motacillidae	*Anthus rubescens*	American Pipit	—
Paridae	*Poecile atricapillus*	Southern Appalachian Black-capped Chickadee	FSC/SC
Parulidae	*Oreothlypis peregrina*	Tennessee Warbler	—
	Oreothlypis celata	Orange-crowned Warbler	—
	Setophaga castanea	Bay-breasted Warbler	—
	Setophaga coronata	Yellow-rumped Warbler	—
	Setophaga magnolia	Magnolia Warbler	—
	Setophaga tigrina	Cape May Warbler	—
	Vermivora cyanoptera	Blue-winged Warbler	—
Picidae	*Sphyrapicus varius*	Yellow-bellied Sapsucker	—

Family	Scientific Name	Common Name	Federal/ State Status*
Podicipedidae	*Podiceps auritus*	Horned Grebe	—
	Podilymbus podiceps	Pied-billed Grebe	—
Rallidae	*Porzana carolina*	Sora	—
Regulidae	*Regulus satrapa*	Golden-crowned Kinglet	—
Scolopacidae	*Actitis macularia*	Spotted Sandpiper	—
	Limnodromus griseus	Short-billed Dowitcher	—
	Limnodromus scolopaceus	Long-billed Dowitcher	—
	Scolopax minor	American Woodcock	—
	Tringa flavipes	Lesser Yellowlegs	—
	Tringa melanoleuca	Greater Yellowlegs	—
Sittidae	*Sitta canadensis*	Red-breasted Nuthatch	—
Strigidae	*Asio flammeus*	Short-eared Owl	—
Sulidae	*Morus bassanus*	Northern Gannet	—
Troglodytidae	*Cistothorus palustris*	Marsh Wren	—
	Cistothorus platensis	Sedge Wren	—
	Troglodytes troglodytes	Winter Wren	—
Turdidae	*Catharus minimus*	Gray-cheeked Thrush	—
	Catharus ustulatus	Swainson's Thrush	—
Tyrannidae	*Empidonax minimus*	Least Flycatcher	—
	Empidonax traillii	Willow Flycatcher	—
Vireonidae	*Vireo gilvus*	Warbling Vireo	—
	Vireo philadelphicus	Philadelphia Vireo	—

* See Table 3.2 for abbreviations.

3.3.5 Management Needs

Bird populations are affected by human activities, predator populations, and habitat characteristics. These factors are not independent from one another, thus, management actions on one are likely to affect another and this interaction must be understood. Recommendations for priority management actions are outlined in Section 3.3.8.

Depending on species, timing, type of disturbance, and habituation to human activities, many shorebirds and colonial waterbirds are sensitive to disturbance from human-related activities (Erwin 2005; Meyers 2005). Many of the colonial waterbirds found in North Carolina that are SGCN are also management-need priority species. Posting nesting areas with symbolic fencing, which consists of informative signs placed 50 meters apart with string tied between posts, reduces disturbance to nesting colonies by recreationists (Erwin 1989). The addition of education and outreach programs during the nesting season, and enforcement of leash and trespass laws, provides greater protection.

Buffer or set-back distances between nests and recreationists that prevent impacts to nesting colonies differ by species, stage of nesting (nest initiation, egg-laying, incubation, hatching, and brooding chicks), and type of disturbance activity (e.g., pedestrian, all-terrain-vehicle, off-road-vehicle, boat). Buffer distances between nests and posted signs (and, therefore, recreationists) are recommended by Erwin (2005) for Least Tern, Black Skimmer, Common Tern, Gull-billed Tern, Royal Tern, and Sandwich Tern. For American Oystercatcher, buffers are also recommended (Sabine et al. 2008). Once chicks are present, they are particularly vulnerable to recreationists until they have fledged. Alternatively, stewards or seasonal technicians should identify and protect broods from pedestrian and vehicular traffic that might travel closer than the optimal buffer distance.

In North Carolina, shorebirds and colonial waterbirds nest and roost on many state-owned dredged-material islands in rivers, sounds, and the Atlantic Intracoastal Waterway. The type and percentage of cover provided by vegetation on these islands should vary to provide habitat for diverse waterbird species. Vegetation management should be implemented using varied tools such as wetland-approved herbicides, prescribed burning, hand-pulling, mechanical equipment, and placement of beach-quality sand from dredging operations. Such vegetation management should be used to enhance land and marsh bird habitats on state-owned lands and on private lands enrolled in conservation programs.

Continued collection of population data from standardized survey protocol (e.g., colonial waterbird nesting surveys, Piping Plover census window counts, winter Piping Plover surveys, International Shorebird Surveys, point count surveys, marsh bird surveys, etc.) will provide critical data for population status, trend, and distribution evaluation. These data will demonstrate effectiveness of conservation management in North Carolina for SGCN. Shorebird and colonial waterbird data are managed in online databases managed by NCWRC; however, for migratory bird species, knowledge of population status at flyway and regional scales is necessary for conservation decision-making. Migratory bird data should be shared among conservation partners using the East Coast node of the Avian Knowledge Network data management system (Eastern Avian Data Center, available online at http://data.pointblue.org/partners/eadc).

Continued management of game lands and other conservation lands for successional habitats (particularly Longleaf Pine Savanna) through fire and other disturbance methods appears to be vital to the continued persistence of many species (e.g., Bachman's Sparrow, Northern Bobwhite, Prairie Warbler). Recent studies indicate that lands managed for conservation harbor the bulk of occurrences in North Carolina (Taillie et al. in review). Development of alternative habitat management practices suitable for both timber or pine straw management and nesting habitat for Bachman's Sparrow may help expand the already contracted range of this species.

Management of disturbance at Peregrine Falcon nest sites is accomplished through technical guidance to land owners and should continue. Examples of disturbance at a nest site include rock climbing, manned or unmanned (e.g., drone) aircraft operation, and building construction near a nest site.

Where the Barn Owl and American Kestrel are nest-site limited, nest boxes can be posted. Land management practices that support rodent populations provide foraging habitat for these two raptors.

Barn Owl (Joe Tomcho NCWRC)

Restoration of high elevation forests used by Northern Saw-whet Owl, Red Crossbill, and Black-capped Chickadee is underway through the efforts of the Southern Appalachian Spruce Restoration Initiative and should continue.

3.3.6 Threats and Problems

North Carolina's human population is expected to increase significantly in the next decade, with most development expected to be in the Piedmont region. In addition to traditional conservation land protection, development patterns can be affected through local and regional land managers. In 2010, NCWRC initiated the Green Growth Toolbox program, designed to proactively educate and inform development planning to minimize the impact of human development on wildlife. NCWRC will continue to evaluate and modify this program as needed.

In 2012, NCWRC published "Conservation Recommendations for Priority Terrestrial Wildlife Species and Habitats in North Carolina," a guide to development and habitat management practices to best protect priority species and habitats (NCWRC 2012). Simple recommendations are accompanied by an extensive appendix of backing research for each. The NCWRC will continue to promote these practices and update the guide as needed.

Conversion of farmlands to residential developments is a particular threat to Barn Owl and American Kestrel. Fragmentation of large forest blocks by conversion to non-forest is an increasing threat to a variety of songbirds and raptors in the Mountains and can exacerbate problems with hybridization (e.g., Golden-winged and Blue-winged Warbler) and nest parasitism.

Because North Carolina provides important nesting, migration stopover, and wintering habitat for numerous shorebird and waterbird species, any loss of this important habitat is a threat that can have significant impacts on populations. Loss of habitat can occur from land-use impacts (e.g., development, inlet relocation and management, beach nourishment projects, recreation activities) or environmental processes (e.g., storm events, saltwater intrusion) (NABCI 2009; Delany et al. 2010). Waterbird rookeries are vulnerable to development activities, especially land clearing and construction activities that destroy nesting habitat and intrusion or disturbance impacts from development sites that are located near rookeries. High winds or other severe weather events can uproot trees and impact entire nesting colonies. Saltwater intrusion can cause die-off of forest vegetation that needs freshwater resources.

Increased human population density within North Carolina's coastal region increases challenges associated with garbage and pet food that attract mammalian and avian predators in larger numbers. Raccoons, foxes, free-ranging cats, coyotes, crows, and gulls all prey on bird adults, eggs, chicks, and fledglings. Such predation pressures have population-level impacts on bird species, and especially significant effects on small, declining populations.

Energy development from wind farms, solar panels, or offshore oil rigs may affect migratory bird populations directly through collisions with infrastructure or being coated with oil from spills. Indirect effects may include avoidance of large areas used by energy development, thus loss of habitat.

Climate change and sea level rise will alter coastal environments. Loss of freshwater marsh habitat to saltwater intrusion will adversely affect several rail species, many of which we know little about already. Loss of marsh islands in estuaries will affect Forster's Tern, Willet, Clapper Rail, American Oystercatcher, and other species dependent on these sites for nesting, feeding, and roosting. Strong coastal storms create overwash pans and inlets that benefit many shorebirds, terns, and skimmers. Barrier islands may decrease in area, thus, dredged-material islands may play an increased role in providing nesting, roosting, and feeding habitats.

Clapper Rail (Dominic Sherony, flickr)
https://www.flickr.com/photos/9765210@N03

Habitat management on private lands continues to be important to maintaining viability of bird populations in the Piedmont and Coastal Plain. In particular, providing and administering programs to encourage beneficial agricultural practices (e.g., use of prescribed fire, native vegetation retained along field edges and in riparian buffers) practices, and promote field borders of native herbaceous and shrub species should continue to be supported through the NCWRC Wildlife Conservation Lands Program and similar programs. In other landscapes, increase the use of fire as a management tool, mitigate loss of canopy cover in key dispersal corridors (for species like the Red-cockaded Woodpecker), and manage invasive species causing reduction of insect prey populations.

3.3.7 Additional Information

North Carolina is committed to the full life cycle conservation of migratory bird species. Through the Southern Wings Program of the Association of Fish and Wildlife Agencies, NCWRC is supporting conservation work for the Piping Plover on its wintering grounds in the Bahamas. The Bahamas National Trust (BNT) and National Audubon Society (NAS) are conducting surveys of wintering Piping Plover to determine abundance and distribution, and to locate significantly important habitat. The BNT is working to put such habitat into conservation protection status. Additionally, current banding programs will provide further information about the migration of Piping Plover between the North Carolina coast and the Bahamas.

The International Partners in Flight is developing full life cycle plans for habitats across North America and associated wintering grounds in Central and South America. The NCWRC and other partners will continue to work on these plans to develop flyway-wide conservation priorities (e.g., Caribbean/Eastern Upland Hardwoods Conservation Business Plan).

Information on waterfowl and other migratory birds is collected through work conducted under cooperative agreements such as the Atlantic Coast Joint Venture (ACJV), Appalachian Mountains Joint Venture (AMJV), South Atlantic Migratory Bird Initiative (SAMBI), Atlantic Flyway Council, and South Atlantic Landscape Conservation Cooperative, and through management of PIF Bird Conservation Regions (BCRs).These efforts provide long-term trend data that are critical to assess population changes.

The AMJV currently has three main natural communities that are a focus for their conservation efforts. Bird species that are closely associated with these communities have been identified as priorities for their conservation work. The AMJV priorities include Golden-Winged Warblers and their association with young forests and old fields (successional community types); Cerulean Warbler and Wood Thrush and their association with mature deciduous forests (cove, montane, and oak forests); and Saw-whet Owl, Black-capped Chickadee, and Red Crossbill and their association with high elevation forests (northern hardwood and spruce–fir forests). Conservation of open pine communities and wetlands are another priority area for the AMJV.

North Carolina contains portions of three Bird Conservation Regions (BCRs)—Southeastern Coastal Plain BCR27, Piedmont BCR29, and Appalachian Mountains BCR28—as defined by US NABCI (2000) to encourage and facilitate conservation with ecological rather than political boundaries. Each BCR has conservation plan(s) outlining conservation actions specific to the species and habitats contained therein (see list in Appendix I).

Audubon has identified 95 Important Bird Areas (IBAs) in North Carolina (see web page: http://netapp.audubon.org/iba/Reports), 30 of which are recognized as globally important. The IBA program is a global effort to identify and conserve areas that are vital to birds and other biodiversity. The IBA reports associated with each site provide a description of habitats available and a list of species occurring in the IBA, identify threats likely to impact the site or species, and provide recommendations for conservation action.

The Carolina Bird Club (see webpage: http://www.carolinabirdclub.org) maintains well-documented records of birds in North and South Carolina, and through a quarterly ornithological journal, *The Chat*, publishes scientific articles, reports of bird counts, and general notes about bird sightings. An online searchable database of material published in *The Chat* provides occurrence data spanning 1971 to present day.

Citizen science efforts such as eBird have also become an important source of information. Each year, NABCI, in partnership with 18 other organizations, issues a “State of the Birds” report, which combines information from eBird and other sources to illustrate a high-level view of bird conservation across the country (NABCI 2014).

In 2012, NCWRC published “Conservation Recommendations for Priority Terrestrial Wildlife Species and Habitats in North Carolina,” a guide to development and habitat management practices to best protect priority species and habitats (NCWRC 2012). Simple recommendations are accompanied by an extensive appendix of backing research for each. NCWRC will continue to promote these practices and update the guide as needed.

3.3.8 Recommendations

In general, protection and restoration of natural community composition and function and protection of surrounding natural areas under current conditions are the best ways to ensure suitable habitats are available for bird species. Measures that protect a large and diverse pool of populations are the best way to ensure that species are able to survive future stresses and adapt to changing climate conditions. Data needs to be collected using standardized, accepted protocols that can be used by others and should be entered into the Avian Knowledge Network (appropriate node).

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Conduct surveys of secretive marsh birds such as the Black Rail, King Rail, Virginia Rail, Least Bittern, and American Bittern to determine the status and distribution of all marsh birds (Legare et al. 1999; Gibbs and Melvin 1997; Conway et al. 2004). Use survey data to estimate population status, trends, and distribution. Document distribution, past and present, using survey data and mapping efforts.

- Conduct surveys of SGCN birds in riparian habitats not covered well by traditional surveys such as Breeding Bird Surveys (Swainson's Warbler, Cerulean Warbler, Kentucky Warbler, Acadian Flycatcher, Prothonotary Warbler, Louisiana Waterthrush, etc.).

- Survey for grassland birds that are considered to be steeply declining, are not tracked well by typical survey methods, or have poorly understood distribution and status in the region (e.g., Barn Owl, Grasshopper Sparrow, Vesper Sparrow, Savannah Sparrow, Lark Sparrow, Eastern Meadowlark, Eastern Kingbird, Bobolink, Dickcissel, Loggerhead Shrike).

- Survey for birds that may be declining in Longleaf Pine habitats, such as Bachman''s Sparrow.

- Determine population and distribution status for other species not covered well by traditional surveys: American Kestrel, Merlin, Loggerhead Shrike, Barn Owl, Rusty Blackbird, Worm-eating Warbler, Seaside Sparrow, Nelson's Sparrow, Saltmarsh Sparrow, Sedge Wren, Northern Harrier, and Short-eared Owl.

- Determine breeding status/distribution of Sharp-shinned and Cooper's Hawks. Because of their secretive nature, traditional bird surveys do not adequately track these populations.

- Conduct migration surveys statewide to determine the extent of use of successional and other habitats by post-breeding and migratory birds.

- Determine the breeding and roosting status and distribution of Chimney Swift in natural conditions along major floodplains with appropriate habitat conditions (e.g. older, hollow trees).

- Survey for potential nesting birds in caves and on cliffs and rock outcrops, such as Turkey Vulture, Black Vulture, and Common Raven.

- Determine the status and distribution of Wayne's Black-throated Green Warbler.

- Determine the status and distribution of Swallow-tailed Kite, Mississippi Kite, Yellow-crowned Night-heron, and Anhinga (as well as other colonial nesting waterbirds).
- Conduct surveys in Mountain hardwood forests for Northern Saw-whet Owl.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Continue support for regular colonial waterbird surveys during the breeding season (currently conducted coast-wide every three years on average).
- Evaluate whether Breeding Bird Survey routes or point counts may need to be established in selected areas or habitats and more attention paid to the migration period and wintering ecology of birds using early successional habitats. Additional Monitoring Avian Productivity and Survivorship stations could also be beneficial, as well as migration banding stations.
- Monitor Henslow's Sparrow population and distribution at Voice of America sites in eastern North Carolina to determine population trends.
- Continue annual monitoring of Peregrine Falcon nest cliffs to monitor and assess population status.
- Continue long-term monitoring and banding work (currently being done by the USGS) on Eastern Painted Buntings and support the goals and objectives of the Painted Bunting Working Group that involves Florida, Georgia, South Carolina, and North Carolina.
- Continue long-term monitoring of active Bald Eagle territories, successful breeding pairs, and fledged eagles.
- Continue long-term monitoring of birds that use early successional habitats on game lands, national and state forests, and National Wildlife Refuges.
- Continue montane bird population monitoring (Northern Saw-whet Owl, Brown Creeper, Yellow-bellied Sapsucker, Rose-breasted Grosbeak, Cerulean Warbler,

Golden-winged Warbler, and others that may be found at the upper or lower ranges of this habitat).

- Continue regular, periodic heronry surveys in the Piedmont and Coastal Plain.
- Continue shorebird surveys for breeding, wintering, and migratory birds throughout the year to document population status, trends, and distribution, especially for Piping Plover, American Oystercatcher, Wilson's Plover, and Red Knot. Document distribution, past and present, using survey data and mapping efforts.
- Continue support for long-term monitoring of SGCN landbirds (i.e., early successional species in the Piedmont, longleaf associated species, riparian species, etc.)
- Establish long-term monitoring for all marsh birds (Gibbs and Melvin 1997; Benoit and Askins 2002; Bogner and Baldassarre 2002; Conway et al. 2004).
- Expand monitoring frameworks to account for species that are not suited to traditional long-term monitoring protocols (e.g. hawks, nightjars, owls), or for species missed under systematic monitoring due to small population sizes or limited ranges in North Carolina (e.g. Alder Flycatcher, Brown Creeper, Black-capped Chickadee).
- Initiate long-term monitoring of breeding and wintering birds in pocosin habitats on public lands and industrial forestland (Karriker 1993; Wilson and Watts 2000).
- Initiate long-term monitoring related to snag ecology and cavity-nesting birds during different seasons (e.g., Northern Flicker, Red-headed Woodpecker, and Brown-headed Nuthatch) (Wilson and Watts 1999; Kreisel and Stein 1999).
- Monitor status and reproductive success of Gull-billed Tern, Common Tern, Least Tern, Black Skimmer, Piping Plover, and Caspian Tern.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration.

- Identify causal factors responsible for low beach-nesting bird reproductive success; initiate predator impact studies (e.g., ghost crabs, fire ants, gulls, foxes, raccoons, feral cats, coyotes, crows).

- Conduct monitoring to estimate American Oystercatcher, Gull-billed Tern, Black Skimmer, and Wilson's Plover reproductive success, especially needed for the Wilson's Plover due to scant data available. Studies should examine direct and indirect factors affecting reproductive success, including effects of different levels of human disturbance.

- Conduct research on foraging strategies and energy budget allocations of migrating shorebirds, especially the Red Knot.

- Conduct life history studies of colonial waterbirds, especially SGCN.

- Examine the effectiveness of diverse vegetation control methods for beach-nesting birds that require early successional habitat.

- Examine impacts of coastal engineering actions on benthic macro-invertebrates on which migratory shorebirds feed, especially the Red Knot.

- Assess the impacts of changes mandated by the Federal Energy Regulatory Commission in water releases at hydroelectric dams on high-priority species.

- Conduct bird nest productivity studies, including nest-searching and spot mapping, and studies of predator effects on bird nest productivity.

- Conduct genetics research to determine if the coastal Worm-eating Warbler is a separate subspecies.

- Conduct genetics studies of the breeding subspecies of American Kestrel in the Sandhills ecoregion.

- Conduct genetics studies on the Henslow's Sparrow at Voice of America sites.

- Conduct studies of small wading birds (e.g., Snowy Egret, Tricolored Heron, Little Blue Heron, Glossy Ibis) using miniature GSM transmitters to obtain habitat selection, migration, energetics, and survival estimates.

- Use GIS mapping and modeling capabilities to study change in coastal bird habitats relative to past and predicted storm events, including natural barrier islands, marsh islands, and dredged-material islands. Use models to provide guidance for long-term habitat management for continued population viability.

- Conduct research on habitat management techniques to maintain suitable habitat for disturbance-tolerant species such as Golden-winged Warbler.
- Conduct studies on the nesting ecology of Mountain birds such as Hermit Thrush and Red Crossbill.
- Conduct studies on American Kestrel and Peregrine Falcon's post-fledging dispersal, adult and juvenile survival, migratory habits, and vulnerability to contaminants. Conduct studies of the Barn Owl, American Kestrel, and Northern Saw-whet Owl's use of habitat and population trends and of Golden Eagle winter abundance and distribution.
- Conduct studies about nesting success, productivity, and survival of floodplain birds in buffers of different widths; this could provide some insight into population declines and help to guide management recommendations for buffer width (Swainson's Warbler, Cerulean Warbler, Acadian Flycatcher, Kentucky Warbler, Wood Thrush).
- Conduct research into the potential effects of renewable energy development, including species-specific vulnerability and effectiveness of methods to reduce mortality (waterfowl, Bald Eagle, Golden Eagle, etc.).
- Determine if the southeastern subspecies of the American Kestrel breeds and/or winters in habitats in North Carolina.
- Determine the effects of clear-cut stand size on shrubland birds (Krementz and Christie 2000).
- Document the habitat selection and competition factors related to Indigo Bunting and Eastern Painted Bunting in these maritime forests (Kopachena and Crist 2000).
- Examine causes of declines among nightjars on industrial forestland.
- Examine Cowbird parasitism impacts on bird productivity in small versus large habitat patches.
- Examine habitat use and conduct nesting habitat research on the Black Rail using telemetry and then on other marsh birds (Bogner and Baldassarre 2002).
- Assess the importance of stopover habitats in North Carolina using aeroecology (radar) technologies.
- Conduct studies on contaminants in avian populations.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Annually post signs around perimeter of colonial waterbird nesting sites to prohibit human intrusion before the nesting season; signs should be posted at sufficient distance to minimize disturbance from activities in nearby areas.

- Maintenance of dredged-material islands created with sand dredged from channels is important to the continued viability of nesting sites for colonial waterbirds. Placement of dredged sand on the islands once every 7 to 10 years may be sufficient to maintain the habitats (Important Bird Areas 2013).

- Conduct predator management as needed at important bird nesting sites, especially of introduced and invasive species (e.g., Nutria, Coyotes, Red Fox, feral cats, large-bodied gulls).

- Continue to proactively promote planning efforts incorporating conservation measures for priority species via the Green Growth Toolbox program and in accordance with Conservation Recommendations for Priority Terrestrial Wildlife Species and Habitats in North Carolina (NCWRC 2012).

- Close public access to cliffs and rock outcrops with Peregrine Falcon nests. Continue to provide technical guidance on cliff closures to protect nesting Peregrine Falcons.

- Where appropriate, use prescribed fire to maintain fire-adapted communities.

- Continue to excavate artificial nest cavities for Red-cockaded Woodpeckers.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Work with owners and managers of buildings on which Least Terns nest to increase reproductive success while allowing owners/managers to maintain good public relations.

- Work with private lands biologists to identify conservation strategies and programs for important waterbird nesting and roost sites (e.g., Wood Stork, Great Egret, Snowy Egret, Little Blue Heron, Tri-colored Heron, Black-crowned Night-heron, Great Blue Heron, Anhinga) that occur on private lands

- Continue participation in Partners in Flight (International) efforts to develop international conservation business plans (e.g., Caribbean/Eastern Upland Hardwoods Conservation Business Plan).

Wood Storks (NCWRC 2007)

- Continue promotion and participation of private landowner incentive programs (e.g., Wildlife Conservation Lands Program, USFWS Partners for Fish & Wildlife)

- Continue active participation in international, national, regional, and species-specific partnerships. Examples include (but are not limited to):

  - International Partners in Flight (www.partnersinflight.org)
  - Southeast Partners in Flight (www.sepif.org)
  - Atlantic Coast Joint Venture (acjv.org)
  - Appalachian Mountains Joint Venture (amjv.org)
  - Atlantic Flyway Council (including the Game and Non-Game Migratory Bird Technical Sections)
  - Atlantic Flyway Shorebird Initiative
  - North American Bird Conservation Initiative (nabci-us.org)
  - Golden-winged Warbler Working Group (www.gwwa.org)
  - Loggerhead Shrike Working Group
  - International Wood Thrush Conservation Alliance (https://griffingroups.com/groups/profile/25137/international-wood-thrush-conservation-alliance)
  - Eastern Golden Eagle Working Group (egewg.org)
  - American Oystercatcher Working Group (amoywg.org)

- Eastern Atlantic Painted Bunting Working Group
- American Oystercatcher Business Plan
- Piping Plover Recovery Plan
- Wood Stork Recovery Plan
- South Atlantic Landscape Conservation Cooperative
- Others as appropriate
- NC Waterbird Management Committee and Plan
- USFWS Integrated Waterbird Management and Monitoring Program
- Southern Appalachian Spruce Restoration Initiative
- Southern Wings program of AFWA

- Continue efforts to improve coordination, collaboration, cooperation between biologists and researchers within the state and regionally through meetings, webinars, newsletters, and other electronic media (NC Partners in Flight Initiative). Continue to support and contribute data to the Eastern Avian Data Center (data.pointblue.org/partners/eadc), an initiative centered on greater data sharing.

3.4 Crayfishes

3.4.1 Introduction

Crayfishes, commonly referred to as crawfish or crawdads, are native to every continent except Africa and Antarctica and inhabit a wide diversity of habitats that range from rivers, lakes, streams, and wetlands, to caves, hillside seeps and springs, roadside ditches, and underground burrows in backyards (Taylor and Schuster 2004; Reynolds and Souty-Grosset 2012). North American crayfishes are classified into two taxonomic families (Astacidae, Cambaridae) that contain nearly 390 native species (Simmons and Fraley 2010). Approximately 98% of all species native to North American are classified as cambarids and the majority of this diversity (90%) occurs east of the Rocky Mountains, primarily in the southeastern United States (Pflieger 1996; Taylor and Schuster 2004) making the southeastern United States home to the greatest diversity of crayfish in the world (Schuster 1997; Welch and Eversole 2006).

Crayfishes are large, highly mobile, abundant invertebrates that utilize a wide variety of aquatic habitats and assume important roles in freshwater food webs (Pflieger 1996; Lodge et al. 2000a; Holdich 2002; Nystrom 2002). They are epitomized as keystone species because of their ability to manipulate their physical surroundings, process detritus, change macrophyte biomass, and influence the abundance and structure of invertebrate communities (Chambers et al. 1990; Hanson et al. 1990; Holdich 2002; Statzner et al. 2003; Stenroth and Nystrom 2003). Further, they represent a substantial portion of biomass within streams, thereby providing a forage base for numerous aquatic and terrestrial predators (Rabeni 1992; Rabeni and Smale 1995; Pflieger 1996).

Burrowing crayfish spend significant portions of their lives in subterranean burrows ranging from simple linear shafts to elaborate systems of multiple tunnels and chambers (Hobbs 1981; Taylor et al. 1996). Burrowers may use areas without standing water or inhabit open water during wet seasons (Hobbs 1942, 1981; Welch 2006). Nonburrowing crayfish live in permanent waters and may make shallow excavations or simple tubes under rocks or in the substrate for refuge (Taylor et al. 1996).


Red Burrowing Crayfish (Steve Fraley NCWRC)

Several crayfishes in the state are known from the work of John Cooper at the NC Museum of Natural Sciences during the last two decades (Cooper and Cooper 1995; Cooper 1998, 2000a, 2000b, 2006a, 2006b, 2007, 2010, 2011; Cooper and Schofield 2002; Cooper and Cooper 2003; Cooper and Russ 2013). Within North Carolina, 47 described crayfishes are currently recognized, including 12 endemic species and 4 nonindigenous species (Simmons and Fraley 2010). Our described native crayfish fauna is dominated by the genus *Cambarus* (30 species), but also includes species from the genera *Procambarus* (7 species), *Orconectes* (5 species), and *Fallicambarus* (1 species). In addition, North Carolina is home to several undescribed species that await taxonomic resolution and scientific description. Baseline surveys and relatively recent assessments have been completed for many species in the mountains, including new occurrence records for Sickle, Chattahoochee, Upland Burrowing, and Knotty Burrowing crayfishes (Simmons and Fraley 2010).

In 1996, the American Fisheries Society (AFS) Endangered Species Committee, Subcommittee on Crayfishes assessed the conservation status of crayfishes in the United States and Canada and subsequently reassessed statuses in 2007 (Taylor et al. 1996, 2007). To evaluate conservation status of crayfishes, Taylor et al. (1996, 2007) assessed status based on criteria known to impact aquatic taxa that included (1) existing or potential destruction or alteration of a species' habitat or distribution, (2) overutilization, (3) disease, (4) other natural or anthropogenic factors (e.g., hybridization or invasive species introduction), and

(5) restricted range. Results from the reassessment indicate that the overall conservation status of crayfishes has changed little since the first comprehensive review.

Specifically, nearly half of the 363 crayfishes remained categorized as possibly extinct, endangered, threatened, or vulnerable; however, it should be noted that at least 25 taxa were downgraded due to increased research efforts and 27 new crayfish species were described after the 1996 assessment (Taylor et al. 2007). Of the described native crayfishes in North Carolina, the conservation status of 24 species remained the same after reassessment, 7 species were downgraded to a lower priority status, 12 species were described after the 1996 assessment, and no species were upgraded to a higher threat category. Specifically, the 2007 assessment ranked the aforementioned 43 species as follows: 1 (2%) species is listed as endangered; 4 (9%) are threatened; 9 (21%) are vulnerable; 28 (65%) are currently stable; and 1 species was described subsequent to AFS assessments.

~~Chowanoke Crayfish (Tyler Black, NCWRC)~~

A list of crayfish SGCN is provided in Table 3.10 and the Taxa Team evaluation results can be found in Appendix G. River basin and habitat associations for these species can be found in Appendix H.

Conservation recommendations for the associated habitats have been incorporated into the natural community descriptions in Chapter 4. Additional recommendations can be found in the river basin descriptions (Section 4.5). The following paragraphs provide information about species identified by the Taxa Team as SGCN or a priority species for research or management, and for which work has been conducted to implement conservation and management recommendations.

3.4.2 Comparison of 2005 and 2015 Priority Species

The 2015 evaluation identified 30 crayfishes as conservation concern, knowledge gap, or management concern priorities. Some species are a priority in more than one of the three evaluation categories (see Appendix G). In comparison, the 2005 WAP listed 21 crayfishes as priority species, which may have included concerns for knowledge gaps. However, the 2005 Taxa Team did not identify knowledge gaps or management concerns as separate priorities. These changes do not necessarily indicate a change in the concern status for the species; they are more likely a result of different evaluation methodologies from the 2005 process or reflect an increase in our knowledge base for the species. Table 3.11 provides a comparison of changes since the 2005 WAP was published.

Table 3.10 Crayfish SGCN

Family	Scientific Name	Common Name	Federal/ State Status*
Cambaridae	*Cambarus acanthura*	Thornytail Crayfish	—
	Cambarus aldermanorum	Needlenose Crayfish	—
	Cambarus brimleyorum	Valley River Crayfish	—
	Cambarus carolinus	Red Burrowing Crayfish	—
	Cambarus catagius	Greensboro Burrowing Crayfish	—/SC
	Cambarus chaugaensis	Chauga Crayfish	FSC/SC
	Cambarus eeseeohensis	Grandfather Mountain Crayfish	FSC/—
	Cambarus georgiae	Little Tennessee Crayfish	FSC/SC
	Cambarus lenati	Broad River Stream Crayfish	—/SC
	Cambarus nodosus	Knotty Burrowing Crayfish	—
	Cambarus parrishi	Hiwassee Headwater Crayfish	FSC/SC
	Cambarus reburrus	French Broad River Crayfish	FSC/—
	Cambarus spicatus	Broad River Spiny Crayfish	FSC/SC
	Cambarus tuckasegee	Tuckasegee Stream Crayfish	—
	Orconectes virginiensis	Chowanoke Crayfish	FSC/SC
	Procambarus ancylus	Coastal Plain Crayfish	—
	Procambarus blandingii	Santee Crayfish	—
	Procambarus braswelli	Waccamaw Crayfish	—/SC
	Procambarus medialis	Pamlico Crayfish	—

* See Table 3.2 for abbreviations.

Table 3.11 Crayfishes: comparison of changes from 2005 WAP

2005		2015		
Scientific Name	Common Name	Scientific Name	Common Name	Comment
Cambarus davidi	Carolina Ladle Crayfish	—	—	No longer a conservation priority
Cambarus hiwasseensis	Hiwassee Crayfish	—	—	No longer a conservation priority
Cambarus hystricosus	Sandhills Spiny Crayfish	—	—	No longer a conservation priority
Orconectes carolinensis	North Carolina Spiny Crayfish	—	—	No longer a conservation priority
Orconectes sp. 1	Unnamed crayfish	*Orconectes (Procericambarus)* cf. *spinosus*	'Cheoah' Crayfish	Putative species; pending description.
Procambarus plumimanus	Croatan Crayfish	—	—	No longer a conservation priority

3.4.3 Conservation Concerns

Crayfish are one of the most threatened freshwater taxa assessed according to the 2010 update to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Richman et al. 2015; Reynolds and Souty-Grosset 2012). Nineteen species are considered SGCN and the majority are either NC endemics, have a small range-wide distribution, or have a nominal part of their distribution in the state (Cooper 2010). Extinction risk is often attributed to small range size and degradation of freshwater habitats, especially from urban development and pollution (Crandall and Buhay 2008; Richman et al. 2015). Lodge et al. (2000b) consider invasive nonnative crayfishes as the primary threat facing crayfish populations. Taylor et al. (2007) note five broad factors that can affect crayfish populations, including habitat destruction, overutilization, disease, introduction of exotic species, and restricted range.

Endemic species that are of conservation concern include the Broad River Stream, French Broad River, Grandfather Mountain, Greensboro Burrowing, Pamlico, Tuckasegee Stream, and Valley River crayfishes.

3.4.4 Knowledge Gaps

An understanding of crayfish taxonomy, ecology, distribution, and abundance is necessary for resource managers to determine relative conservation status and to develop effective monitoring and management strategies (Simmons and Fraley 2010). For some North American crayfishes, there is a lack of ecological knowledge and contemporary distributional information (Taylor et al. 2007). A recent evaluation of crayfish life history studies by Moore et al. (2013) substantiates the contemporary lack of knowledge and reports that only 12% of North American crayfishes have life history studies that have been published. These statistics are somewhat surprising considering the influence that crayfishes have on aquatic and terrestrial ecosystems. However, much work has been done in North Carolina over the last decade to address knowledge gaps about species in our state (Simmons and Fraley 2010).

In the late 1990s, the NCWRC began a focused effort to inventory and establish baseline data for the majority of crayfishes in the state. In-depth status assessments have been completed for several species considered SGCN, including Chauga, Grandfather Mountain, Little Tennessee, Hiwassee Headwater, Broad River Stream, French Broad River, Broad River Spiny, and Chowanoke crayfishes (Simmons and Fraley 2010; Thoma 2012; Russ and Fraley 2014). Eleven of the remaining species need baseline or updated status assessments to better understand their contemporary status and improve distributional knowledge within North Carolina. And while the general distribution for many crayfish species in the state is known, additional surveys are needed to refine their range in the state. Updated status assessments are needed for all but one of the species ranked as Knowledge Gap priority species.

Life history research is a conservation priority for all native crayfishes in North Carolina because this research forms the foundational knowledge base for evaluating threats and impacts from non-indigenous species, planning conservation activities, and guiding temporal aspects of environmental impacts. Nine of the SGCN species are high conservation priorities because of their NC endemic status, restricted range, taxonomic relationship, or lack of basic biological knowledge.

Genetic analysis is needed for seven of the SGCN to identify areas with high genetic diversity, resolve taxonomic relationships, and clarify species distributions. The results of genetic analysis studies will provide the knowledge needed to assess long-term monitoring priorities and direct conservation activities. An understanding of genetic diversity at the population level coupled with long-term monitoring will provide better information to conserve species.


Chattahoochee Crayfish (TR Russ, NCWRC)

Taxonomic descriptions need to be developed for currently undescribed species in the state. Within the past 10 years, the Carolina Foothills, Rocky River, and Sandhills Spiny crayfishes were described out of the *Cambarus* (*Puncticambarus*) sp. *C* species complex. Currently, there are still several suspected species from 10 different river basins that need to be described in this complex. The Chattahoochee Crayfish is currently considered part of another species complex that includes crayfishes found in the Broad and Catawba River basins and the South Fork Catawba River subbasin. Recently, *Cambarus* (*Cambarus*) sp. *A*, which is found in the Hiwassee and New River basins, was identified as a species that closely resembles the Common Crayfish and Chattahoochee Crayfish.

Six species considered SGCN are in need of long-term monitoring to assess long-term population trends, identify management actions, and update conservation status. A recent status assessment of Broad River Stream Crayfish, Hiwassee Headwater Crayfish, French Broad River Crayfish, and Broad River Spiny Crayfish found that some of these species have restricted ranges or declining populations, and specific monitoring recommendations were suggested (Russ and Fraley 2014), thereby warranting frequent monitoring of these species. For example, the Grandfather Mountain Crayfish is a SGCN for which monitoring is a high priority because it has a small range that is increasingly threatened by development, the potential threat of nonnative Virile Crayfish in the lower Linville River, and population trends that are not well known.

Other needs include monitoring to detect the spread of nonnative species and the status of native sympatric species. Species that have a small native range and are threatened by present or foreseeable habitat disturbance and those that may be declining should be monitored to detect population trends. Investigations on the factors associated with global climate change and deposition of atmospheric pollutants that may affect rare and endemic species found at high elevations, and land-use changes occurring in rapidly developing areas are needed. Research on the habitat requirements and the tolerance of individual species to physical and chemical changes to their habitats is another priority (Simmons and Fraley 2010). For instance, the Broad River Stream Crayfish appears to be vulnerable to excess sediment and is a priority for monitoring efforts (Simmons and Fraley 2010).

In addition to the SGCN priorities listed in Table 3.10, Table 3.12 lists the species for which the Crayfish Taxa Team determined there are research priorities because of knowledge gaps.

3.4.5 Management Needs

Five crayfish species considered nonnative and/or invasive have been identified in North Carolina and pose significant threat to native crayfish species: Coosa River Spiny, Kentucky River, Rusty, and Virile crayfishes, and the Red Swamp Crawfish. Except for the Coosa River Spiny Crayfish, each was ranked as a management priority by the Crayfish Taxa Team.

One native species, the White River Crawfish, is considered a management priority. It is native to the Piedmont and Coastal Plain but has been introduced to several basins in the Mountain region (likely through bait bucket dumps). Its effect on native crayfish

Table 3.12 Crayfish knowledge-gap priority species

Family	Scientific Name	Common Name	Federal/ State Status*
Cambaridae	*Cambarus davidi*	Carolina Ladle Crayfish	—
	Cambarus howardi	Chattahoochee Crayfish	—
	Cambarus hystricosus	Sandhills Spiny Crayfish	—
	Cambarus johni	Carolina Foothills Crayfish	—
	Procambarus pearsei	Carolina Sandhills Crayfish	—
	Procambarus plumimanus	Croatan Crayfish	—

* See Table 3.2 for abbreviations.

populations is not known. Measures to address impacts from these introduced populations should be considered for the drainages where they have been introduced.

The Red Swamp Crawfish is native to the lower Mississippi River Basin but is currently being raised as an aquaculture product in North Carolina. In 2012, five aquaculture farms in North Carolina produced approximately 8,685 pounds of this crayfish for consumption. It has been introduced to waters throughout the state and could pose a significant threat to native crayfish populations.

The Kentucky River Crayfish has recently been introduced to western North Carolina where it has been found in the Little Tennessee River Basin. The Rusty Crayfish is another introduced species found in the Broad and Catawba River basins. Both species could pose a significant threat to native crayfish populations. The Virile Crayfish has been introduced in the Roanoke, Catawba, and Broad River basins and its effect on native crayfish populations is unknown. Long-term monitoring of the spread of this crayfish should be a high priority.

3.4.6 Threats and Problems

Over the next several decades, invasive species are predicted to increase extinction rates of native species significantly (Lodge et al. 2000a; Shochat et al. 2010). Introduced nonnative crayfish (i.e., the Coosa River Spiny, Kentucky River, Rusty, and Virile crayfishes, and the Red Swamp Crawfish) are a primary threat, followed by habitat loss, degradation, or alteration (Taylor et al. 2007; Simmons and Fraley 2010). Nonnative crayfish have cleared streams of vegetation, eliminated insect larvae (macrobenthics) and other native organisms through predation, and contributed to problems with turbidity in otherwise clear water in small streams (Davidson et al. 2010). Although eradication or control of invasive species can be economically more expensive than the cost of prevention, measures or programs that address invasive species proactively are usually underfunded (Leung et al. 2002; Allendorf and Lunquist 2003; Ricciardi et al. 2011; Withrow et al. 2015).

Problems and uncertainty with taxonomy for numerous species need to be addressed in order to better understand abundance and distribution better and to develop conservation measures for native species. Research related to these threats and their impacts on certain species was ranked as a high priority.

Chapter 5 describes 11 categories of threats the Taxa Team considered during the evaluation and ranking of priority species, and provides information about the expected scope and severity of their impacts to wildlife in North Carolina (see Appendix G). Results of Metric 9 evaluations indicate the threats most likely to create significant impacts to crayfish populations in North Carolina over the next 10 years include the following:

- Pollution
- Invasive and other problematic species
- Residential and commercial development
- Natural system modifications
- Climate change and severe weather
- Transportation and service corridors
- Biological resource use

In their book on freshwater biodiversity management, Reynolds and Souty-Grosset (2012) identify fungal crayfish plague (*Aphanomyces astaci*) as another reason for concern with nonnative crayfish. This pathogen is listed by the IUCN as one of the world's 100 worst invaders (Lowe et al. 2000; Reynolds and Souty-Grosset 2012) because once a watershed is infected, control of its spread is almost impossible. While the disease has not been detected in the United States at this time, indirect evidence from laboratory studies indicates Red Swamp Crawfish can harbor the fungus and act as a vector for translocation of the pathogen (Evans and Edgerton 2002). There have been no investigations conducted in the United States about the fungus's mortality impacts to native species.

The ecological benefits of dam removal are well documented in research literature, and discussion about negative effects often focuses on downstream transport of sediments, nutrients, and toxic materials and upstream movement of introduced fish (Lieb et al. 2011). Dams may protect imperiled crayfishes by preventing the upstream spread of nonnative or invasive crayfishes, and regulatory agencies that manage dam removals need to consider this potential when considering dam removal projects (Lieb et al. 2011).

Thermal conditions in a watershed may also limit the spread of invasive species (Lieb et al. 2011). However, factors that can increase water temperatures (e.g., urbanization, climate change, increasing groundwater temperatures) can facilitate movement of invasive species into waters not previously occupied (Eggleston et al. 1999; Mohseni et al. 1999; Steffy and Kilham 2006; Kaushal et al. 2010; Lieb et al. 2011).

3.4.7 Additional Information

The AFS Endangered Species Committee, Subcommittee on Crayfishes published a reassessment of the conservation status of crayfishes in the United States and Canada (Taylor et al. 2007) that is available online from the US Geological Survey's Southeast Ecological Science

Center website (http://fl.biology.usgs.gov/afs_crayfish/index.html). This website provides lists of crayfishes by freshwater ecoregion, state, or province boundary, and plot distributions of crayfishes by ecoregions or political boundaries. Information is provided for both native and introduced species.

The International Association of Astacology (IAA) is dedicated to the study, conservation, and wise utilization of freshwater crayfish. The IAA publishes a peer-reviewed scientific journal (*Freshwater Crayfish*) to distribute information on aquaculture, life history, conservation, ecology, and research topics.

The NCWRC webpage (http://www.ncwildlife.org/Learning/Species.aspx#5528114-crustaceans) provides detailed species information, photographs, and distribution maps for crayfishes found in the state.

3.4.8 Recommendations

In general, protection and restoration of natural community composition and function and protection of surrounding natural areas under current conditions are the best ways to ensure suitable habitats are available for crayfish species. Measures that protect a large and diverse pool of populations are the best way to ensure that species are able to survive future stresses and adapt to changing climate conditions.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Conduct status assessments for the Coastal Plain, Greensboro Burrowing, Needlenose, Pamlico, Red Burrowing, Santee, Thornytail, Tuckasegee Stream, Valley River, and Waccamaw crayfishes.
- Conduct surveys prior to dam removal projects to detect presence of nonnative species; barrier removal may facilitate upstream movement of introduced crayfish (Lieb et al. 2011).

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Establish long-term monitoring for Broad River Spiny, Broad River Stream, French Broad River, Grandfather Mountain, and Hiwassee Headwater crayfishes.

- Monitoring the spread of nonnative species (e.g., Kentucky River, Rusty, Coosa River Spiny, Virile crayfishes, and Red Swamp Crawfish) is a high priority.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Perform genetic analysis for Broad River Stream, Broad River Spiny, Chauga, French Broad River, Greensboro Burrowing, and Tuckasegee Stream crayfishes.

- Genetic analysis of tissue samples, available from Carnegie Museum of Natural History, is needed to evaluate the closeness of the relationship between Grandfather Mountain Crayfish and Common Crayfish (Thoma 2012).

- Obtain life history and ecology information for nearly all crayfish species in North Carolina, most specifically for Broad River Stream, Chowanoke, Greensboro Burrowing, Little Tennessee, Needlenose, Pamlico, Red Burrowing, Tuckasegee Stream, and Valley River crayfishes.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Develop programs that emphasize the prevention of nonnative species introductions.

- Utilize education and outreach efforts to make the public aware of problems associated with bait bucket releases.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Implement recommendations developed by the Aquatic Nuisance Species Management Plan Committee (NCANSMP 2015).

3.5 Freshwater Fish

3.5.1 Introduction

The freshwater fish fauna of the southeastern United States is among the most diverse fauna in North America and one of the most imperiled because of pollution, flow alteration, habitat loss, and fragmentation of freshwater systems (Ashton and Layzer 2010). Freshwater communities are likely the most threatened ecosystems in the world, making aquatic organisms important indicators of degraded ecological conditions (Leidy and Moyle 1998; Jelks et al. 2008). Habitat loss, degradation, and fragmentation resulting from anthropogenic activities can have the most significant impact to natural communities at the landscape level. Flow modifications, introduction of nonnative species, and overuse also have significant impacts at the local and regional level.

Piedmont Shiner (TR Russ, NCWRC)

During the last two decades, several assessments considered the imperilment of freshwater fish species including those found in North Carolina. The 2005 WAP (Chapter 5B) referred to reports published by Etnier (1997) and Warren et al. (1997) that identified patterns of imperilment of fish by family and major habitat preference and a report by Butler (2002) that assessed conservation priorities for fishes in the Southern Appalachian Ecoregion. More recently, the AFS has published an updated assessment of the conservation status of imperiled freshwater and diadromous fishes of North America (Jelks et al. 2008). More information is available on the USGS website http://fl.biology.usgs.gov/afs/index.html.

As part of the updated assessment, the AFS Endangered Species Committee (AFS-ESC) developed a map of freshwater ecoregions that represented modifications of earlier ecoregional maps used by Maxwell et al. (1995), Abell et al. (2000, 2008), and others. The AFS-ESC map for North America indicates the southeastern United States has three ecoregions with especially large numbers of imperiled fishes. North Carolina is located within two of these ecoregions. The South Atlantic ecoregion (Atlantic Complex) has 34 species considered imperiled and the Tennessee ecoregion (Mississippi Complex) has 58 species considered imperiled. The report noted that the Tennessee River ecoregion has the greatest number of imperiled fishes in comparison with other US ecoregions (Jelks et al. 2008).

The AFS assessment states that approximately 39% of described fish species in North America are imperiled: 280 extant taxa are considered endangered, 190 are threatened, and 230 are vulnerable. Additionally, though they may survive in captive populations, 61 taxa are presumed extinct or extirpated from the wild (Jelks et al.2008). Habitat degradation and restricted range appear to be the primary factors associated with imperilment of North American fishes.

The National Park Service (NPS) assessed the status of freshwater fish biodiversity in the southeastern United States (Long et al. 2012). The NPS assessment used fish assemblage data for noncoastal park system locations (Long et al. 2012) and included four NPS sites in North Carolina: Blue Ridge Parkway, Carl Sandburg Home National Historic Site, Great Smoky Mountains National Park, and Guilford Courthouse National Military Park. Many of the same species identified by AFS (Jelks et al. 2008) as imperiled have been found within these sites. Human disturbance, especially urbanization, was noted to be the most important impact to freshwater fish in the park units. Linear park units such as the Blue Ridge Parkway have numerous nonnative species that represent a high threat to native species (Long et al. 2012).

A list of freshwater fish SGCN is provided in Table 3.13 and the Freshwater Fish Taxa Team evaluation results can be found in Appendix G. River basin and habitat associations for these species can be found in Appendix H.

Conservation recommendations for the associated habitats have been incorporated into the natural community descriptions in Chapter 4. Additional recommendations can be found in the river basin descriptions (Section 4.5). The following paragraphs provide information about species identified by the Freshwater Fish Taxa Team as SGCN or a priority species for research or management, and for which work has been conducted to implement conservation and management recommendations.

3.5.2 Comparison of 2005 and 2015 Priority Species

The 2015 evaluation identified 161 species as conservation concern, knowledge gap, or management concern priorities. Some species may be considered a priority in more than one of the evaluation categories (see Appendix G). Of these priority species, 69 were identified as SGCN and another 40 were designated research priorities. In comparison, the 2005 WAP listed 84 freshwater fishes as priority species, which may have included concerns for knowledge gaps. However, the 2005 Taxa Team did not identify knowledge gaps or management concerns as separate priorities. These changes do not necessarily indicate a change in the concern status of these species; they are more likely a result of different evaluation methodologies from the 2005 process (see Appendix F) or reflect an increase in our knowledge base for the species.

TABLE 3.13 Freshwater fish SGCN

Family	Scientific Name	Common Name (Population)	Federal/ State Status*
ORDER: Acipenseriformes			
Acipenseridae	*Acipenser brevirostrum*	Shortnose Sturgeon	E/E
	Acipenser oxyrinchus	Atlantic Sturgeon	E/E
ORDER: Atheriniformes			
Atherinopsidae	*Menidia extensa*	Waccamaw Silverside	T/T
ORDER: Cypriniformes			
Catostomidae	*Carpiodes carpio*	River Carpsucker	—/SC
	Carpiodes cyprinus	Quillback	—
	Carpiodes sp. cf. cyprinus	a carpsucker	—
	Carpiodes sp. cf. velifer	Atlantic Highfin Carpsucker	—/SC
	Hypentelium roanokense	Roanoke Hog Sucker	—
	Moxostoma ariommum	Bigeye Jumprock	—/T
	Moxostoma breviceps	Smallmouth Redhorse	—
	Moxostoma carinatum	River Redhorse	—
	Moxostoma pappillosum	V-lip Redhorse	—
	Moxostoma robustum	Robust Redhorse	FSC/E
	Moxostoma sp 2	Sicklefin Redhorse	C/T
	Moxostoma sp.1 (carolina)	Carolina Redhorse	FSC/T
	Thoburnia hamiltoni	Rustyside Sucker	FSC/E
Cyprinidae	*Clinostomus sp.*	Smoky Dace	—FSC/SC
	Cyprinella sp.1 (cf. zanema)	Thinlip Chub	—/SC
	Erimonax monachus	Spotfin Chub	T/T
	Erimystax insignis eristigma	Southern Blotched Chub	FSC/—
	Exoglossum laurae	Tonguetied Minnow	—
	Exoglossum maxillingua	Cutlips Minnow	—/SC
	Hybopsis rubifrons	Rosyface Chub	—/T
	Notropis bifrenatus	Bridle Shiner	FSC/E
	Notropis chalybaeus	Ironcolor Shiner	—
	Notropis lutipinnis	Yellowfin Shiner	—/SC
	Notropis mekistocholas	Cape Fear Shiner	E/E
	Notropis volucellus	Mimic Shiner (Neuse, Tar-Pam)	—
	Semotilus lumbee	Sandhills Chub	FSC/SC
ORDER: Cyprinodontiformes			
Fundulidae	*Fundulus cf. diaphanus*	Lake Phelps Killifish	FSC/—
	Fundulus waccamensis	Waccamaw Killifish	FSC/SC
Poeciliidae	*Heterandria formosa*	Least Killifish	—/SC
ORDER: Osteoglossiformes			
Hiodontidae	*Hiodon tergisus*	Mooneye	—/SC

Table 3.13 Freshwater fish SGCN (cont.)

Family	Scientific Name	Common Name (Population)	Federal/ State Status*
ORDER: Perciformes			
Centrarchidae	*Ambloplites cavifrons*	Roanoke Bass	FSC/—
	Enneacanthus chaetodon	Blackbanded Sunfish	—
	Enneacanthus obesus	Banded Sunfish	—
Elassomatidae	*Elassoma boehlkei*	Carolina Pygmy Sunfish	FSC/T
	Elassoma evergladei	Everglades Pygmy Sunfish	—
Percidae	*Etheostoma acuticeps*	Sharphead Darter	FSC/T
	Etheostoma collis	Carolina Darter (Piedmont pop.)	FSC/SC
	Etheostoma inscriptum	Turquoise Darter	—/T
	Etheostoma kanawhae	Kanawha Darter	—
	Etheostoma mariae	Pinewoods Darter	FSC/SC
	Etheostoma perlongum	Waccamaw Darter	FSC/T
	Etheostoma simoterum	Tennessee Snubnose Darter	—/SC
	Etheostoma thalassinum	Seagreen Darter	—
	Etheostoma vulneratum	Wounded Darter	FSC/SC
	Percina burtoni	Blotchside Logperch	FSC/E
	Percina caprodes	Logperch	—/T
	Percina gymnocephala	Appalachia Darter	—
	Percina nigrofasciata	Blackbanded Darter	—/T
	Percina oxyrhynchus	Sharpnose Darter	—/SC
	Percina rex	Roanoke Logperch	E/E
	Percina squamata	Olive Darter	FSC/SC
Sciaenidae	*Aplodinotus grunniens*	Freshwater Drum	—/SC
ORDER: Petromyzontiformes			
Petromyzontidae	*Lampetra aepyptera*	Least Brook Lamprey	—/T
	Lethenteron appendix	American Brook Lamprey	—/T
ORDER: Salmoniformes			
Salmonidae	*Salvelinus fontinalis*	Brook Trout (Native)	—
ORDER: Scorpaeniformes			
Cottidae	*Cottus caeruleomentum*	Blue Ridge Sculpin	—/SC
	Cottus carolinae	Banded Sculpin	—/T
ORDER: Siluriformes			
Ictaluridae	*Ameiurus brunneus*	Snail Bullhead	—
	Ameiurus platycephalus	Flat Bullhead	—
	Noturus eleutherus	Mountain Madtom	—/SC
	Noturus flavus	Stonecat	—/E
	Noturus furiosus	Carolina Madtom	FSC/T
	Noturus gilberti	Orangefin Madtom	FSC/E
	Noturus sp. 2	Broadtail Madtom	FSC/SC

* See Table 3.2 for abbreviations.

Freshwater Fish Taxa Team members separated populations of Carolina Darter and Mimic Shiner by river basin or ecoregion to allow consideration of basin-specific threats and concerns. However, because ranking results for the central and eastern Piedmont ecoregion populations of Carolina Darter were similar, the evaluation results are presented as one population. Evaluation results for Mimic Shiner populations indicate populations in different river basins are either of conservation concern or a priority to address knowledge gaps. Mimic Shiner populations in the Neuse and Tar–Pamlico river basins are included as SGCN, while populations in the French Broad and New river basins are research priorities.

Table 3.14 provides a comparison of changes since the 2005 WAP was published.

Table 3.14 Freshwater fishes: comparison of changes from 2005 WAP

2005		2015 Changes		Comment
Scientific Name	Common Name	Scientific Name	Common Name	
		Carpiodes sp. cf. *cyprinus*	a carpsucker	Putitive species; pending description
Carpiodes velifer	Highfin Carpsucker	*Carpiodes* sp. cf. *velifer*	Atlantic Highfin Carpsucker	Common and scientific name change
Erimyzon sucetta	Lake Chubsucker			No longer a conservation priority
Etheostoma collis	Carolina Darter	*Etheostoma collis pop. 1*	Carolina Darter	Evaluated separate populations by ecoregion (Central Piedmont)
Etheostoma collis	Carolina Darter	*Etheostoma collis pop. 2*	Carolina Darter	Evaluated separate populations by ecoregion (Eastern Piedmont)
Etheostoma nigrum	Johnny Darter			No longer a conservation priority
Etheostoma podostemone	Riverweed Darter			No longer a conservation priority
Etheostoma vitreum	Glassy Darter			No longer a conservation priority
Fundulus diaphanus	Banded Killifish			No longer a conservation priority
Fundulus lineolatus	Lined Topminnow			No longer a conservation priority
Ichthyomyzon greeleyi	Mountain Brook Lamprey			No longer a conservation priority
Ictiobus bubalus	Smallmouth Buffalo			No longer a conservation priority
Labidesthes sicculus	Brook Silverside			No longer a conservation priority
Lepomis marginatus	Dollar Sunfish			No longer a conservation priority

Table 3.14 Freshwater fishes: comparison of changes from 2005 WAP (cont.)

2005		2015 Changes		Comment
Scientific Name	Common Name	Scientific Name	Common Name	
Lepomis punctatus	Spotted Sunfish			No longer a conservation priority
Luxilus chrysocephalus	Striped Shiner			No longer a conservation priority
Lythrurus matutinus	Pinewoods Shiner			No longer a conservation priority
Moxostoma collapsum	Notchlip Redhorse			No longer a conservation priority
Moxostoma macrolepidotum	Shorthead Redhorse			No longer a conservation priority
Moxostoma spp 2	Carolina redhorse	*Moxostoma* sp. *carolina*	Carolina Redhorse	Scientific name modification
Moxostoma spp. 1	Sicklefin Redhorse	*Moxostoma sp. 2*	Sicklefin Redhorse	Scientific name modification
Notropis amoenus	Comely Shiner			No longer a conservation priority
Notropis maculatus	Taillight Shiner			No longer a conservation priority
Notropis photogenis	Silver Shiner			No longer a conservation priority
Notropis rubellus	Rosyface Shiner	*Notropis* sp. cf. *rubellus*	Kanawha Rosyface Shiner	Scientific name modification
Notropis volucellus	Mimic Shiner	*Notropis volucellus*	Mimic Shiner	Evaluated separate populations by river basin (Neuse, Tar-Pamlico)
Percina aurantiaca	Tangerine Darter			No longer a conservation priority
Petromyzon marinus	Sea Lamprey			No longer a conservation priority
Phenacobius teretulus	Kanawha Minnow			No longer a conservation priority
Pimephales notatus	Bluntnose Minnow			No longer a conservation priority

3.5.3 Conservation Concerns

Of the SCGN fish species, 40% are suckers and minnows (order Cypriniformes) and 24% are darters (order Perciformes). According to Jelks et al. (2008), the Cyprinidae family is the most species-rich of freshwater fishes in North America. Within this family, Ironcolor Shiner is noted to be one of the most widespread because it occurs in multiple ecoregions (Jelks et al.2008). However, based on statewide surveys conducted by NCWRC biologists since the 1960s this fish is noted to be a vulnerable species. Recent surveys conducted in locations where it was previously detected only a small number of fish.

Anadromous and catadromous fish species migrate between inland freshwaters and coastal brackish and salt waters during their life cycles. Many native migratory fish populations have sharply declined over the last several decades. A recent assessment of southeastern Atlantic coast diadromous fish stocks (Burke and Rohde 2015) provides information about numerous species for which there are population concerns, including the federally listed Atlantic Sturgeon and Shortnose Sturgeon. As noted in the report, American Eel and two river herring species that are found in North Carolina rivers and coastal waters have been petitioned for listing as endangered species (USFWS 2011b; NMFS 2011; Burke and Rohde 2015). Degraded freshwater and estuarine habitats that serve as nursery and spawning grounds and the vulnerability of anadromous fishes to exploitation during migration into coastal rivers contribute to a large number of diadromous species being included on lists of marine endangered and threatened fishes (Burke and Rohde 2015). Principle causes of population declines have traditionally been attributed to dammed rivers, habitat loss, overfishing, and pollution but other contributing factors include climate change, nonnative species, and aquaculture (NMFS 2012; Burke and Rohde 2015).


Cape Fear Shiner (NCWRC)

Additional information on rare and listed freshwater fishes relevant to the river basin systems where they are found is provided in Chapter 4.

3.5.4 Knowledge Gaps

There are 67 species identified as research priorities because there are knowledge gaps, of which 29 are also considered SGCN (see Table 3.13). Table 3.15 represents only those species considered a knowledge-gap priority. It should be noted that fish in the order Cypriniformes (suckers and minnows) make up more than half of the list.

3.5.5 Management Needs

Multiple collaborations and partnerships have formed to design and implement conservation activities that benefit migratory fish species as well as other native aquatic species (CFRP 2013). For example, in 2013, a rock arch fish passage ramp was built at Cape Fear River Lock & Dam No. 1, located 32 miles upstream from Wilmington. The structure improves passage for several species. Although construction of the rock arch ramp is complete, USACE's Lock and Dams No. 2 and No. 3 remain and continue to block spawning runs to the Smiley Falls area near Erwin in the middle of the Cape Fear River Basin. Access to the Deep River and historic spawning habitats in the upper Cape Fear River basin is currently

Table 3.15 Freshwater fish knowledge-gap priority species

Family	Scientific Name	Common Name (Population)	Federal/ State Status*
ORDER: Cypriniformes			
Catostomidae	*Ictiobus niger*	Black Buffalo	—
	Moxostoma cervinum	Blacktip Jumprock	—
Cyprinidae	*Chrosomus oreas*	Mountain Redbelly Dace	—
	Cyprinella labrosa	Thicklip Chub	—
	Cyprinella spiloptera	Spotfin Shiner	—
	Cyprinella zanema	Santee Chub	—
	Hybopsis amblops	Bigeye Chub	—
	Luxilus chrysocephalus	Striped Shiner	—/SC
	Nocomis platyrhynchus	Bigmouth Chub	—
	Nocomis raneyi	Bull Chub	—
	Notropis micropteryx	Highland Shiner	—
	Notropis photogenis	Silver Shiner	—
	Notropis rubricroceus	Saffron Shiner	—
	Notropis scabriceps	New River Shiner	—
	Notropis sp. cf. rubellus	Kanawha Rosyface Shiner	—
	Notropis telescopus	Telescope Shiner	—
	Notropis volucellus	Mimic Shiner (New and French Broad River basins)	—
	Phenacobius crassilabrum	Fatlips Minnow	—
	Phenacobius teretulus	Kanawha Minnow	FSC/SC
	Pimephales notatus	Bluntnose Minnow	—
ORDER: Cyprinodontiformes			
Fundulidae	*Fundulus chrysotus*	Golden Topminnow	—
	Fundulus diaphanus	Banded Killifish	—
Poeciliidae	*Gambusia affinis*	Western Mosquitofish	—
ORDER: Lepisosteiformes			
Lepisosteidae	*Lepisosteus osseus*	Longnose Gar	—
ORDER: Perciformes			
Percidae	*Etheostoma chlorobranchium*	Greenfin Darter	—
	Etheostoma gutselli	Tuckasegee Darter	—
	Etheostoma podostemone	Riverweed Darter	—/SC
	Etheostoma rufilineatum	Redline Darter	—
	Etheostoma swannanoa	Swannanoa Darter	—
	Etheostoma vitreum	Glassy Darter	—
	Percina aurantiaca	Tangerine Darter	—
	Percina evides	Gilt Darter	—
	Percina nevisense	Chainback Darter	—
	Percina roanoka	Roanoke Darter	—
	Sander canadensis	Sauger	—
ORDER: Petromyzontiformes			
Petromyzontidae	*Ichthyomyzon bdellium*	Ohio Lamprey	—
	Ichthyomyzon greeleyi	Mountain Brook Lamprey	—
	Petromyzon marinus	Sea Lamprey	—

* See Table 3.2 for abbreviations.

blocked by Buckhorn Dam on the Cape Fear River and Lockville Dam near the mouth of the Deep River. Fish passage around these obstructions is needed for migratory fish to reach historic spawning sites in the Deep River. Restoring migratory fish access to historic spawning and nursery habitats will help rebuild currently depressed populations to support healthy ecosystems and sustainable recreational and commercial fisheries (CFRP 2013).

Management activities differ depending on the type of habitat involved. Many large rivers have one or more hydropower operations so a main concern is maintaining a natural flow regime. On small streams, bank stability is a major concern. Fish passage is an issue of both large and small streams. Reservoirs are typically managed differently than natural lakes. Reservoirs are usually managed for sport fisheries to provide recreation. Participation in the Federal Energy Regulatory Commission (FERC) relicensing process will facilitate negotiation of more natural flow regimes in regulated rivers and help identify opportunities to mitigate negative impacts from hydropower development. Natural lakes such as Lake Waccamaw and Lake Phelps are managed for both recreational fisheries and native species.

Spotfin Chub (SJ Fraley, NCWRC)

Advancements in propagation techniques and hatchery facilities have contributed to the successful raising of Robust Redhorse and Spotfin Chub in captivity at NCWRC fish hatcheries. Partners such as Conservation Fisheries, Inc., have reared Sicklefin Redhorse and the state of Tennessee is propagating Lake Sturgeon. These captivity-raised fish have been used for augmentation stocking in areas with appropriate habitat and extant populations. Management needs include improvements to and expansion of fish hatchery facilities in order to support a successful propagation program.

There are numerous instances of nonnative fish species being introduced into NC waters and for some of these species, there are significant concerns. For example, the Flathead Catfish is an obligate piscivore (fish-eating species) that has been associated with declines of native fish populations in areas where it has been introduced.

3.5.6 Threats and Problems

There are water quality concerns beyond turbidity and sedimentation. The presence of endocrine-disrupting chemicals (EDCs), even at very low concentrations, can disrupt normal development and lead to reproductive problems. Many fishes, especially piscivores, bioaccumulate and bioconcentrate (retain in tissue) heavy metals such as mercury and arsenic, as well as many chemical pollutants, via predation on other fish that have absorbed these contaminants. Smallmouth Bass can be an environmental indicator and long-term monitoring of populations can identify where there are problems with heavy metals in fish tissue or the presence of EDCs (Brewer and Orth 2015). Immune suppression can be detected through presence of fin and skin erosions, lesions, and partial fish kills (Ripley et al. 2008; Blazer et al. 2010; Brewer and Orth 2015).

Aquatic weeds and invasive species are serious problems in many freshwater systems, especially reservoirs and lakes. Nuisance species such as Hydrilla and Water Milfoil can be transferred between aquatic habitats when water craft (boats, jetskis), trailers, and gear (rods, tackle) are not washed after being used in a location with these species.

3.5.7 Additional Information

Tangerine Darter (TR Russ, NCWRC)

The Robust Redhorse Project is part of a collaborative sampling effort with the Robust Redhorse Conservation Committee (www.robustredhorse.com), which collected individuals for use in the captive breeding program that has successfully stocked thousands of young fish in the Pee Dee River Basin downstream of Blewett Falls Dam. Spawning areas have been documented in the Pee Dee River and adjacent lands are protected by the NCWRC and Duke Energy. Participation and commitment of the Robust Redhorse Conservation Committee partners has resulted in conservation success and mitigated the need to list the species as endangered or threatened under the ESA.

3.5.8 Recommendations

Protection and restoration of natural community composition and function and protection of surrounding natural areas under current conditions generally are the best ways to ensure suitable habitats are available for freshwater fishes. Measures that protect a large and diverse pool of populations are the best ways to ensure that species are able to survive future stresses and adapt to changing climate conditions.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities. Distribution surveys are needed for all SGCN and other priority species.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible. Conduct long-term monitoring to identify population trends for all priority species.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. Studies should provide recommendations for mitigation and restoration when appropriate. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed. Descriptions of other research needs are outlined below.

- Support completion of species descriptions for undescribed taxa.
- Conduct research to facilitate appropriate conservation actions. Research should focus on life history studies of priority species.
- Determine the distribution of nonnative fishes and how they are affecting native species.
- Conduct surveys to assess potential Atlantic and Shortnose sturgeon spawning habitat above and below existing barriers in Cape Fear River (CFRP 2013).

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources, protect native populations and their habitats, and improve degraded habitats so they support native populations.

- Reintroduce or augment rare fish populations in areas where water quality and stream habitats have recovered sufficiently to support them.
- Support incentive and information programs that help reduce sedimentation/erosion, minimize pesticide and herbicide use, and modernize wastewater treatment facilities.
- Develop strategies to mitigate Flathead Catfish impacts to native species, including education and outreach programs to educate the public about the impacts of introduced species.

- Protect fish habitat from channel impacts caused by activities such as snag removals and where feasible, restore fish access to habitat by removing blockages. (CFRP 2013).

- Protect instream fish habitat from channel impacts caused by activities such as snag removals (CFRP 2013).

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation serves numerous purposes in the face of anticipated climate change, but most importantly, promotes ecosystem resilience.

- Support establishing riparian buffers along streams, and implement low-impact development and better stormwater management (e.g., secondary and cumulative impacts) through program coordination, cooperative projects, and technical guidance (NCWRC 2002, 2012).

- Support stream protection/restoration by working collaboratively with other organizations. Reintroduce or augment rare fish populations in areas where water quality and stream habitats have recovered sufficiently to support them.

- Support incentive and information programs that help reduce sedimentation/erosion, minimize pesticide and herbicide use, and modernize wastewater treatment facilities.

- Support targeted protection actions for priority spawning areas identified by the Cape Fear River Partnership (CFRP 2013).

3.6 Freshwater Mussels

3.6.1 Introduction

Freshwater bivalve mollusks, or mussels, are filter feeders with a diet that varies across habitats and among species but primarily consists of microscopic particulate matter such as phytoplankton, zooplankton, bacteria, and organic detritus (Vaughn and Hakenkamp 2001; Haag 2012). North America has the richest mussel fauna with more than 300 species distributed among approximately 50 genera that are members of the family Unionidae (Haag 2012).

Mussels live most of their lives burrowed in the bottom of a stream or lake, and depending on species and season, they may be closer to the substrate surface (warm seasons) or burrow more deeply during colder seasons (Amyot and Downing 1991, 1997; Watters et al. 2001; Schwalb and Pusch 2007; Haag 2012). When population density is high, mussels can be the dominant biomass and exert control over the structure of an aquatic community (Vaughn and Hakenkamp 2001), as demonstrated in locations that have large populations of the nonnative Asian Clam.


Brook Floater (Brena Jones, NCWRC)

Most mussel species have a complex life history that includes a reproductive process dependent on an obligate larva parasite on fish called a glochidium, which has important ramifications for many aspects of mussel ecology and conservation (Layzer and Scott 2006). Recolonization is dependent on the successful parasitizing of a host fish and subsequent movement of the infected host fish into water that provides suitable habitat for the mussel (Layzer and Scott 2006). Many freshwater mussels have undergone drastic declines and many are predicted to go extinct in the next few decades (Eckblad and Lehtinen 1991; Bogan 1993; Neves 1993; Shannon et al. 1993; Wilson et al. 1995; Neves et al. 1997; Vaughn and Taylor 1999; Vaughn and Hakenkamp 2001).

A list of freshwater mussel SGCN is provided in Table 3.16 and the Mussell Taxa Team evaluation results can be found in Appendix G. River basin and habitat associations for these species can be found in Appendix H.

Conservation recommendations for the associated habitats have been incorporated into the natural community descriptions in Chapter 4. Additional recommendations can be found in the river basin descriptions (Section 4.5). The following paragraphs provide information about species identified by the Mussel Taxa Team as SGCN or a priority species for research or management, and for which work has been conducted to implement conservation and management recommendations.

3.6.2 Comparison of 2005 and 2015 Priority Species

The 2015 evaluation identified a total of 49 species as conservation concern, knowledge gap, or management concern priorities. Some species may be considered a priority in more than one of the evaluation categories (see Appendix G). Of those species, 31 were identified as SGCN and another 12 were designated research priorities. In comparison, the 2005 WAP listed 43 freshwater mussels as priority species, which may have included species for which there were knowledge gaps. However, the 2005 Taxa Team evaluations did not identify knowledge gaps or management concerns as separate priorities.

Table 3.16 Freshwater mussel SGCN

Scientific Name	Common Name	Federal/ State Status*
Family: Unionidae		
Alasmidonta heterodon	Dwarf Wedgemussel	E/E
Alasmidonta raveneliana	Appalachian Elktoe	E/E
Alasmidonta sp. 2	a freshwater bivalve	—
Alasmidonta undulata	Triangle Floater	—/T
Alasmidonta varicosa	Brook Floater	FSC/E
Alasmidonta viridis	Slippershell Mussel	—/E
Anodonta couperiana	Barrel Floater	—/E
Anodonta implicata	Alewife Floater	—/T
Cyclonaias tuberculata	Purple Wartyback	—/E
Elliptio dilatata	Spike	—/SC
Elliptio lanceolata	Yellow Lance	FSC/E
Elliptio marsupiobesa	Cape Fear Spike	—/SC
Elliptio steinstansana	Tar River Spinymussel	E/E
Elliptio waccamawensis	Waccamaw Spike	FSC/T
Fusconaia masoni	Atlantic Pigtoe	FSC/E
Fusconaia subrotunda	Longsolid	FSC/—
Lampsilis cariosa	Yellow Lampmussel	FSC/E
Lampsilis fullerkati	Waccamaw Fatmucket	FSC/T
Lampsilis sp. 2	Chameleon Lampmussel	—
Lasmigona decorata	Carolina Heelsplitter	E/E
Lasmigona subviridis	Green Floater	FSC/E
Pegias fabula	Littlewing Pearlymussel	E/E
Pleurobema collina	James Spinymussel	E/E
Pleurobema oviforme	Tennessee Clubshell	FSC/E
Pleuronaia barnesiana	Tennessee Pigtoe	FSC/E
Toxolasma pullus	Savannah Lilliput	FSC/E
Villosa constricta	Notched Rainbow	—/SC
Villosa delumbis	Eastern Creekshell	—
Villosa iris	Rainbow	—/SC
Villosa vaughaniana	Carolina Creekshell	FSC/E

* See Table 3.2 for abbreviations.

Table 3.17 provides a comparison of changes since the 2005 WAP was published. These changes do not necessarily indicate a change in the concern status of these species; they are more likely a result of different evaluation methodologies from the 2005 process (see Appendix F) or reflect an increase in our knowledge base for the species. For some, the 2015

TABLE 3.17 Freshwater mussels: comparison of changes from 2005 WAP

2005		2015 Changes		
Scientific Name	Common Name	Scientific Name	Common Name	Comment
Alasmidonta robusta	Carolina Elktoe			No longer a conservation concern
Elliptio cistellaeformis	Box Spike			No longer a conservation concern
Elliptio congaraea	Carolina Slabshell			No longer a conservation concern
Elliptio folliculata	Pod Lance			No longer a conservation concern
Elliptio icterina	Variable Spike			No longer a conservation concern
Elliptio roanokensis	Roanoke Slabshell			No longer a conservation concern
Fusconaia barnesiana	Tennessee Pigtoe	*Pleuronaia barnesiana*	Tennessee Pigtoe	Scientific name change
Lampsilis fasciola	Wavyrayed Lampmussel			No longer a conservation concern
Lampsilis radiata conspicua	Carolina Fatmucket			No longer a conservation concern
Lampsilis radiata radiata	Eastern Lampmussel	*Lampsilis radiata*	Eastern Lampmussell	Scientific name revision
Lasmigona holstonia	Tennessee Heelsplitter			Periphery of range; not detected in NC.
Leptodea ochracea	Tidewater Mucket			No longer a conservation concern
Ligumia nasuta	Eastern Pondmussel			No longer a conservation concern
Villosa trabalis	Cumberland Bean			Periphery of range; not detected in NC.
Villosa vanuxemensis	Mountain Creekshell			Periphery of range; not detected in NC.

Mussel Taxa Team determined North Carolina is the periphery of their range and results from surveys indicate they are not present in the state.

3.6.3 Conservation Concerns

Haag (2012) notes that because the conservation status of many species remains poorly known, high conservation concern stems from the expectation that future imperilment will exceed current imperilment. Freshwater mussels are among the most globally imperiled freshwater organisms, with about 75% of those historically found in the southeastern United States thought to be extinct now or at risk of extinction (Williams et al. 1993; Bogan 1996;

Neves et al. 1997; Gangloff et al. 2009). The synergistic effects of numerous point and nonpoint source impacts that affect water and habitat quality are likely causes of these declines, with changes to the physical and chemical variables in a stream believed to be principle factors for this decline (Neves et al. 1997; Brim-Box and Williams 2000; Gillies et al. 2003; Lydeard et al. 2004; Gangloff et al. 2009).

3.6.4 Knowledge Gaps

Progress toward species recovery depends on knowledge about species distribution patterns as well as a clear understanding of habitat and life history requirements of species (Flebbe and Herrig 2000). We have limited knowledge and data regarding freshwater mussels compared to other taxa. Accurate distribution information is still lacking for some species, as is work related to fish host identification, ecology (both of individual species and among communities of organisms), and basic systematics (genetics, taxonomy, and morphology). Extensive monitoring of populations is generally lacking.

A rigorous phylogenetic study based on quantifiable, heritable attributes such as DNA sequence data is needed for scientifically defensible estimates of North American mussel diversity (Roe and Lydeard 1998). Such efforts have already yielded surprising departures from traditional classifications. Molecular studies have uncovered a high degree of cryptic variation not reflected by shell morphology. These studies show that several currently recognized species include multiple evolutionary units (Mulvey et al. 1997; Roe and Lydeard 1998; King et al. 1999; Jones et al. 2006; Serb 2006), suggesting that diversity of North American mussels has been underestimated. Taxonomic difficulties have yet to be resolved for several genera, most notably *Elliptio*. There is an extreme knowledge deficit regarding the pea clams. Attaining information on their distributions should be pursued whenever possible.

About 50 species of mussels currently can be found in the wild in North Carolina. Protecting a rich fauna of mussels from environmental contamination requires an understanding of mussel sensitivity to diverse toxicants. The vast majority of mussel species remain untested for most toxicants, and estimating safe environmental concentrations is a critical need, especially for the protection of rare, threatened, or endangered species. Freshwater mussel toxicology still lacks full identification of pollutants that may limit mussel survival, recruitment, and recovery. Few of the compounds that mussels encounter in the wild have been evaluated in the lab. Also, toxicity tests seldom address mussel reproduction, and tests are still short relative to mussel lifespans. In particular, there is a need to test previously unevaluated contaminants of emerging concern using long-term exposures that more closely mimic natural conditions, and to evaluate more ecologically relevant endpoints such as mussel health and recruitment.

Several publications over the last decade have noted the absence or under-protectiveness of national water quality criteria for particular pollutants to which mussels are known to be sensitive (Augspurger et al. 2003; Wang et al. 2010; Haag and Williams 2014; Haag 2012). To facilitate habitat evaluation, work is needed to better characterize chemical and contaminated sediment exposure and provide benchmarks to define acceptable pollutant concentrations. Researchers at NC State University, University of Georgia, and US Geological Survey have started work on testing additional classes of chemicals (Bringolf et al. 2010; Hazelton et al. 2012, 2013; Wang et al. 2012). The US Environmental Protection Agency (EPA) has been an active participant in designing and funding these studies, but more are needed. Publication of recommended benchmarks for pollutants of concern (e.g., metals, major ions) will be useful in developing water quality regulations.

In addition to the SGCN priorities listed in Table 3.16, the species for which the Mussel Taxa Team determined there are research priorities because of knowledge gaps are identified in Table 3.18.

Table 3.18 Freshwater mussel knowledge-gap priority species

Scientific Name	Common Name (Population)	Federal/ State Status*
Corbicula fluminea	Asian Clam [Exotic]	—
Elliptio fisheriana	Northern Lance	—
Elliptio icterina	Variable Spike	—
Elliptio roanokensis	Roanoke Slabshell	—/T
Lampsilis radiata	Eastern Lampmussel	—/T
Ligumia nasuta	Eastern Pondmussel	—/T
Pyganodon cataracta	Eastern Floater	—
Pyganodon grandis	Giant Floater	—
Strophitus undulatus	Creeper	—/T
Taxolasma parvum (parvus)	Lilliput [Exotic]	—
Uniomerus carolinianus	Florida Pondhorn	—
Utterbackia imbecillis	Paper Pondshell	—

* See Table 3.2 for abbreviations.

3.6.5 Management Needs

Restoring mussels into areas where they have been extirpated is a high priority because degraded habitat is being reclaimed and restored in some watersheds. Propagation and release of mussels to augment existing populations will help reduce the risk of extinction and may increase genetic diversity among small populations. Removing barriers and other impediments to host fish movement will allow natural recolonization of suitable habitats and facilitate gene flow between populations.

Freshwaters that support populations of SGCN mussels must be monitored to detect changes in water quality. Water quality ratings (poor to excellent) determined by the NC Division of Water Resources (NCDWR) Water Sciences Section inform several other aspects of state water quality programs. For example, some waters with excellent quality can be petitioned for additional protection, and waters rated as poor may be listed as impaired, thereby making them subject to restoration planning. Not all waters are monitored, so having important mussel habitat included in a long-term monitoring program is an important step in having access to other water quality management tools.

Wavyrayed Lampmussel marked for Cheoah River restoration project (Melissa McGaw, NCWRC)

Waters rated as excellent and which have outstanding resources values (as defined in water quality statutes) can be petitioned for designation as Outstanding Resource Waters (ORW) or High-Quality Waters (HQW). Those designations afford additional protections to ensure that water quality and associated resources are maintained. The process is not automatic and starts when NCDWR is petitioned to provide the additional designation and associated protections. Resource agencies should identify the waters important for mussel conservation, which are eligible for ORW or HQW designations, and petition for those protections.

Cooperation between NCDWR and partners (i.e., state and federal agencies, conservation organizations) is needed to develop site-specific water quality restoration plans under NC Administrative Code (see NCAC 15A 02b.0110) which outlines rules for considering federally listed threatened or endangered aquatic species. For example, through collaborative efforts, NCWRC, along with NCNHP, USFWS, and NCDWR, developed the technical basis for a site-specific water quality management plan for Goose Creek (Yadkin—Pee Dee River Basin). However, there are other waters with federally listed aquatic species and water quality concerns in need of additional site-specific restoration plans.

3.6.6 Threats and Problems


Tar River Spinymussel (Melissa McGaw, NCWRC)

Invasive and nonnative species can create competitive pressures on food resources. Further, their burrowing activity can uproot native mussels in sandy sediments (Vaughn and Hakenkamp 2001; Bogan et al. 2011). In 2007, the first location in the state of the nonnative Lilliput was discovered at Falls Lake in Wake County and was confirmed through DNA analysis (Bogan et al. 2011). Asian Clam can be found throughout the state, often in such large quantities that they decrease available oxygen (Belanger et al. 1990; Leff et al. 1990; Bucci 2007) and create high levels of ammonia in streams that can negatively affect native mussels.

Extinction of North American unionoid bivalves can be traced to impoundment and inundation of riffle habitat in major river basins of the central and eastern United States. Dams are a barrier to host fish and the loss of obligate hosts, coupled with increased siltation, and various types of industrial and domestic pollution have resulted in the rapid decline in the unionoid bivalve fauna in North America (Bogan 1993). Hypolimnion water discharged from behind a dam will be colder and have less oxygen than downstream receiving waters (Neves and Angermeier 1990). Participation in the Federal Energy Regulatory Commission (FERC) relicensing process will facilitate negotiation of more natural flow regimes in regulated rivers and help identify opportunities to mitigate negative impacts from hydropower development.

Contaminants and water pollution are a significant threat to all aquatic species, especially mussels. Point source discharges from municipal wastewater that contains monochloramine and unionized ammonia compounds are acutely toxic to freshwater mussels and may be responsible for glochidial mortality that results in local extirpation of mussels (Goudreau et al. 1993; Gangloff et al. 2009). However, given the transient nature of flowing systems (e.g., a water continuum) and the potential for dilution at any point along the system, it is especially difficult to detect not only origin points but also concentration levels in the water column (Fleming et al. 1995). A die-off event affecting Tar River Spinymussel populations was detected in the Swift Creek watershed (Nash County) as it occurred and was attributed to anticholinesterase poisoning related to organophosphorus and carbamate pesticides used in agricultural applications (Hill and Fleming 1982; Fleming et al. 1995).

Since the publication of Kolpin et al. (2002) on the extent and diversity of chemicals present in the nation's waters, there has been increased concern about the biological relevance of the mix of chemicals to which mussels and other aquatic organisms are exposed, including pharmaceuticals, personal care products, and agrochemicals. Many pollutants detected in streams have never been evaluated for their impacts to mussels (2015 email from T Augspurger to the authors; unreferenced, see "Notes").

Given their burrowing nature and consumption of detritus and particulate matter, mussels may be more susceptible to trace metal exposure and uptake of contaminants than other aquatic animals (Wilson 2008; Jarvis 2011). Sediments from upstream, especially hydroelectric impoundments, can be a source of sediments laden with trace metals (Jarvis 2011). A decline in Appalachian Elktoe populations in the Upper Little Tennessee River watershed may be related to concentrations of trace metals, especially copper and zinc, found in stream sediments (Jarvis 2011). In urbanized areas, a lack of riparian vegetation and increased impervious areas contributes to higher sediment loads from erosion that carry fertilizers, pesticides, herbicides, and many other chemical compounds (Gangloff et al. 2009).

Lab studies indicate freshwater mussels are more sensitive than most aquatic animals to toxicity from sodium chloride and potassium chloride (Gillis 2011; Wang et al. 2012). As sea levels rise and salt water moves upstream into freshwater habitats, it could be predicted that mussels would be particularly vulnerable. Field confirmation of the estimated limits of tolerance predicted by the lab tests is important in determining the significance of this threat and in design of ameliorative measures (2015 email from T Augspurger to the authors; unreferenced, see "Notes").

Climate change, mining, hydraulic fracturing, and other energy developments will bring additional stressors that need to be evaluated for mussels. In addition to specific pollutants that may be introduced into the aquatic environment, the interactions of pollutants and temperature (from climate change), salinity (related to sea level rise), and lower dilution (from altered flows) will need to be considered (2015 email from T Augspurger to the authors; unreferenced, see "Notes").

Impervious areas in urbanized watersheds contribute to high water levels, even during short rainfall events, which can result in flash flooding. These high or flashy flow events contribute to increased sediment loads, turbidity throughout the water column, and stream bed movements that stress mussel populations (Gangloff et al. 2009).

3.6.7 Additional Information

The Southern Appalachian Man and the Biosphere program, in partnership with several federal and state agencies, conducted the Southern Appalachian Assessment, which was designed to be a regional assessment of all resources in 132 counties in mountain areas of North and South Carolina, Georgia, Alabama, Tennessee, and Virginia (Flebbe et al. 1996b). The ecological, social, and economic data collected and analyzed by the project facilitates an ecosystem-based approach to management of the natural resources on public lands within the assessment area and are presented in four separate technical reports (SAMAB 1996a). The aquatic technical report compiles existing region wide information on aquatic resource status and trends, riparian condition, impacts of various land management or human activities, water laws, aquatic resource improvement programs, and water uses. The report discusses the distribution of aquatic species, identifies impacts on aquatic resources and water quality, identifies cooperative opportunities for citizens, businesses, and government agencies, and identifies future data needs for aquatic resources (SAMAB 1996b).

The NC Museum of Natural Sciences hosts a collection of aquatic invertebrate specimens focused on mollusks, especially freshwater bivalves. Collection composition is 83% freshwater species (mussels, fingernail clams, and snails), 10% marine species, and 7% terrestrial snails. The Invertebrates Collection is worldwide in scope, with emphasis on localities in the eastern United States. The holdings are comprised of collections acquired from state agencies (e.g., NCWRC), the Institutes of Marine Sciences (IMS), and a private collection from Herbert D. Athearn, Tennessee, which contained over 23,000 lots of freshwater mollusks. The collection contains specimens from over 100 countries, and currently contains of over 2.3 million specimens (NCMNS n.d.).

3.6.8 Recommendations

In general, protection and restoration of natural community composition and function and protection of surrounding natural areas under current conditions are the best ways to ensure suitable habitats are available for mussels. Measures that protect a large and diverse pool of populations are the best way to ensure that species are able to survive future stresses and adapt to changing climate conditions. Basin-specific recommendations are provided in Chapter 4 Habitats, Section 4.5 River Basins.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities. Continue species distribution surveys for all SGCN and priority species.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible. Conduct long-term monitoring to identify population trends for SGCN and priority species.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Support taxonomic resolution with completion of species descriptions for undescribed taxa and resolution of species complexes using DNA research.
- Conduct research to facilitate appropriate conservation actions. Research should focus on life history studies of priority species.
- Make pea clam species a research priority because there is little knowledge about them in North Carolina.
- Determine appropriate areas of suitable habitat for augmentation or restoration activities.
- Develop propagation techniques and protocols.
- Investigate host fish relationships for all SGCN and priority species.
- Research into the impact of chemicals, especially pharmaceuticals, personal care products, and agrochemicals and their interaction, to all mussel life stages. Test chemical selection should be guided by chemical occurrence and class (representative compounds from various classes of pharmaceuticals, for example) (2015 email from T Augspurger to the authors; unreferenced, see “Notes”).
- Evaluate the influence of suspended sediment and its associated contaminants, especially metals, on mussels. Develop a standard test method for evaluating the quality of sediment on mussel survival, growth, and reproduction (2015 email from T Augspurger to the authors; unreferenced, see “Notes”).
- Investigate the interactions of pollutants and temperature (climate change), salinity (sea level rise), and lower dilution (altered flows) (2015 email from T Augspurger to the authors; unreferenced, see “Notes”).
- Support genetic studies to help improve our understanding of the mussel genus *Elliptio*.
- Determine vulnerability of SGCN to guide permit regulations (moratoria).

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Develop propagation techniques and production capacity for SGCN and other priority fish and mollusk species.
- Conduct population augmentations and restorations using hatchery-reared and translocated mussels.
- Promote BMPs on Commission-owned game lands and other state lands (parks, recreation areas, forests, preserves).

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, promotes ecosystem resilience.

- Continue to work with partners, such as NCSU and propagation facilities from other states, to facilitate a robust production and augmentation program.
- Pursue voluntary approaches or local, regional, and state land-use ordinances to encourage riparian buffers, because not all waters of the state have buffer rules. Riparian buffers are recognized as important in maintaining suitable in-stream physical and chemical habitat quality.

3.7 Mammals

3.7.1 Introduction

Carolina Northern Flying Squirrel (Christine Kelly, NCWRC)

Mammals are distinguished from other warm-blooded vertebrates by the secretion of milk from the mammary glands of females to nourish their young and the occurrence of hair that covers some portion of their body. North Carolina has an impressive diversity of mammalian fauna, and they are an important component of the natural landscape. Mammals have the ability to influence vegetative communities, play a significant role in nutrient cycling, and contribute to ecosystem integrity.

The general public is often familiar with our larger, more visible species, like the White-tailed Deer and American Black Bear, but it is our species of bats, shrews, rodents, and other small mammals that comprise most of our mammalian diversity. North Carolina is ranked 11th in the country in mammalian diversity (Stein 2002). A 2013 guide to the mammals of North Carolina (LeGrand and Howard 2013), prepared by the NC Natural Heritage Program (NCNHP) and the NC Division of Parks and Recreation (NCDPR), noted that there are 121 mammal species in the state; however, several of those accounts represent rare, introduced, or extirpated species.

Mammals can occupy a variety of habitats and are distributed from the mountains to the coast, including marine habitats. Some species, such as the Coyote, are extremely adaptable and are found in a variety of habitat types throughout the state. Other species, like the Carolina Northern Flying Squirrel, are more restricted in their distribution, having very specific habitat requirements, and therefore only exist in isolated areas.

The conservation needs of mammals in North Carolina are addressed mainly through habitat management, restoration, and protection. However, disease, particularly white-nose syndrome in bats, is also a major conservation issue that requires ongoing surveillance and research. The community descriptions in Chapter 4 provide information on conservation recommendations for mammal species.

A list of mammal SGCN is provided in Table 3.19 and the Taxa Team evaluation results can be found in Appendix G. Habitat associations for these species can be found in Appendix H.

Conservation recommendations for mammal species and their associated habitats have been incorporated into the natural community descriptions in Chapter 4. The following paragraphs provide information about species identified by the Mammal Taxa Team as SGCN or a priority for research, and for which work has been conducted to implement conservation and management recommendations from the 2005 WAP.

3.7.2 Comparison of 2005 and 2015 Priority Species

The 2015 evaluation identified 56 species as conservation concern, knowledge gap, or management concern priorities. Some species are a priority in more than one of the three evaluation categories (see Appendix G). In comparison, the 2005 WAP listed 38 mammals as priority species, which may have included species for which there were knowledge gaps. However, the 2005 Taxa Team evaluations did not identify knowledge gaps or management concerns as separate priorities. These changes do not necessarily indicate a change in the

Table 3.19 Mammal SGCN

Order	Scientific Name	Common Name	Federal/ State Status*
Artiodactyla	*Cervus elaphus*	Elk	—/SC
Carnivora	*Canis rufus*	Red Wolf	E/T
Chiroptera	*Corynorhinus rafinesquii*	Rafinesque's Big-eared Bat	—
	Corynorhinus rafinesquii macrotis	Rafinesque's Big-eared Bat — Coastal Plain pop.	FSC/SC
	Corynorhinus rafinesquii rafinesquii	Rafinesque's Big-eared Bat — Mountain pop.	FSC/T
	Corynorhinus townsendii	Townsend's Big-eared Bat	—
	Corynorhinus townsendii virginianus	Virginia Big-eared Bat	E/E
	Lasiurus intermedius	Northern Yellow Bat	—/SC
	Myotis austroriparius	Southeastern Bat	FSC/SC
	Myotis grisescens	Gray Myotis	E/E
	Myotis leibii	Eastern Small-footed Bat	FSC/SC
	Myotis lucifugus	Little Brown Bat	—
	Myotis septentrionalis	Northern Long-eared Bat	T/T
	Myotis sodalis	Indiana Bat	E/E
	Perimyotis subflavus	Tricolored Bat	—
Rodentia	*Glaucomys sabrinus coloratus*	Carolina Northern Flying Squirrel	E/E
	Microtus chrotorrhinus	Rock Vole	—
	Microtus chrotorrhinus carolinensis	Southern Rock Vole	FSC/SC
	Neotoma floridana floridana	Eastern Woodrat —Coastal Plain pop.	—/T
	Neotoma floridana haematoreia	Southern Appalachian Woodrat	FSC/—
	Neotoma magister	Allegheny Woodrat	FSC/SC
	Peromyscus leucopus buxtoni	Buxton Woods White-footed Deermouse	FSC/SC
	Peromyscus leucopus easti	Pungo White-footed Deermouse	—/SC
	Peromyscus polionotus	Oldfield Deermouse	—/SC
Soricomorpha	*Sorex sp. 1*	an undescribed shrew	—
Sirenia	*Trichechus manatus*	West Indian Manatee	E/E

* See Table 3.2 for abbreviations.

concern status for the species; they are more likely a result of different evaluation methodologies from the 2005 process or reflect an increase in our knowledge base for the species. Table 3.20 provides a comparison of changes since the 2005 WAP was published.

These changes do not necessarily indicate a change in the concern status of these species; they are more likely a result of different evaluation methodologies from the 2005 process (see Appendix F) or reflect an increase in our knowledge base for the species. The Taxa

Table 3.20 Mammals: comparison of changes from 2005 WAP

2005		2015 Changes		
Scientific Name	Common Name	Scientific Name	Common Name	Comment
Condylura cristata pop. 1	Star-nosed Mole	*Condylura cristata*	Star-nosed Mole	No longer a conservation priority. Evaluated Coastal Plain population as distinct segment
Corynorhinus rafinesquii	Rafinesque's Big-eared Bat	*Corynorhinus rafinesquii macrotis*	Rafinesque's Big-eared Bat	Evaluated Coastal Plain population as distinct segment.
		Corynorhinus rafinesquii rafinesquii	Rafinesque's Big-eared Bat	Evaluated Mountain population as distinct segment
Cryptotis parva	Least Shrew			No longer a conservation priority.
Lasionycteris noctivagan	Silver-haired Bat			No longer a conservation priority.
Lasiurus cinereu	Hoary Bat			No longer a conservation priority.
Lasiurus seminolus	Seminole Bat			No longer a conservation priority.
Microtus pennsylvanicus	Meadow Vole			No longer a conservation priority.
Mustela frenata	Long-tailed Weasel			No longer a conservation priority.
Mustela nivali	Least Weasel			No longer a conservation priority.
Napaeo zapus insignis	Woodland Jumping Mouse			No longer a conservation priority.
Neotoma floridana	Eastern Woodrat			No longer a conservation concern
		Neotoma floridana floridana	Eastern Woodrat	Evaluated Coastal Plain population as distinct segment
		Neotoma floridana haematoreia	Southern Appalachian Woodrat	Evaluated Mountain population as distinct segment
Parascalops brewer	Hairy-tailed Mole			No longer a conservation priority.
Peromyscus gossypinu	Cotton Mouse		Cotton Deermouse	No longer a conservation priority.
Peromyscus leucopus easti	White-footed Mouse	*Peromyscus leucopus easti*	Pungo White-footed Deermouse	Common name changed from White-footed Mouse to denote distinct segment
Scalopus aquaticus	Eastern Mole			No longer a conservation priority.

2005		2015 Changes		
Scientific Name	Common Name	Scientific Name	Common Name	Comment
Sciurus niger	Eastern Fox Squirrel	*Sciurus niger niger* and *Sciurus niger pop. 1*	Eastern Fox Squirrel	No longer a conservation priority.. Evaluated Eastern NC population and Mountain population as distinct segments.
Sorex cinereus	Masked Shrew			No longer a conservation priority.
Sorex dispar	Rock Shrew			No longer a conservation priority.
Sorex fumeus	Smoky Shrew			No longer a conservation priority.
Sorex hoyi winnemana	Southern Pygmy Shrew			No longer a conservation priority.
Sorex palustris	Water Shrew	*Sorex palustris*	American Water Shrew	No longer a conservation priority. Common name changed to denote distinction from Southern Water Shrew.
		Sorex palustris punctulatus	Southern Water Shrew	Evaluated as distinct population from American Water Shrew
Spilogale putoriu	Eastern Spotted Skunk			No longer a conservation priority.
Sylvilagus palustris	Marsh Rabbit			No longer a conservation priority.
Synaptomys cooperi helaletes	Southern Bog Lemmin	*Synaptomys cooperi helaletes*	Dismal Swamp Southern Bog Lemming	No longer a conservation priority. Common name changed to denote distinction from Southern Bog Lemming
		Synaptomys cooperi stonei	Southern Bog Lemming	Evaluated Mountain population as distinct segment.
Zapus hudsonicus	Meadow Jumping Mouse			No longer a conservation priority.

Team evaluations also considered and evaluated distinct populations for certain species. There have also been taxonomic name revisions since the 2005 Plan was published.

3.7.3 Conservation Concerns

Habitat loss and fragmentation are two of the most pervasive threats to North Carolina's wildlife. This is underscored by the fact that the results of the Taxa Team's evaluation of threats to mammal species in which it ranked residential and commercial development as one of the greatest threats for many of the species for which there is conservation concern.

Many of our bat species within North Carolina are of conservation concern due in large part to the relatively recent spread of white-nose syndrome (WNS), a fungal disease affecting hibernating bats that has devastated many bat populations in the eastern United States. The NCWRC has developed a WNS Surveillance and Response Plan to coordinate a strategy for monitoring bat populations, documenting the occurrence and spread of this disease, and conducting research (NCWRC and USFWS 2013).

Little Brown Bat infected with White-nose Syndrome (USFWS) http://digitalmedia.fws.gov
Used under license CC BY-NC-SA 2.0

3.7.4 Knowledge Gaps

In general, most of the species noted as knowledge-gap priorities are listed because we lack information regarding statewide distribution and abundance, we have few programs in place to monitor the species, or there are questions regarding what factors affect the population size and distribution of these species. For example, studies are needed to assess the occurrence of Allegheny Woodrat and the Eastern Woodrat (coastal and mountain populations) and see if there is any overlap in the distribution of the mountain populations. Additionally, similar information is needed for the Eastern Spotted Skunk due to concerns regarding the suspected decline of this species in North Carolina. Suspected factors impacting Eastern Spotted Skunk populations may include habitat alteration associated with modern agricultural and forestry practices, predation, and disease (i.e. rabies) but it is unclear if or how these factors have impacted the abundance of this species.

Virginia Big-eared Bats (USFWS)
http://digitalmedia.fws.gov
Used under license CC BY-NC-SA 2.0

Research is needed to better understand bat presence, abundance, and distribution in the Piedmont and Coastal Plain, especially for those mountain species that are at-risk due to WNS and have populations living in other parts of the state that may serve to rescue mountain populations in the future. There is a need to identify where these Coastal and Piedmont populations are roosting and foraging, so that we can protect these habitats. Long-term survey sites for mist-netting bats have been established in the Mountain region of North Carolina, but much less information is known about the distribution and abundance of bats in the Piedmont and Coastal Plain.

There is a knowledge gap regarding the abundance and trends in abundance of Carolina Northern Flying Squirrel due to low captures and recaptures. Acoustics surveys are relatively new and a protocol is still being developed. An acoustic call filter and classifier are needed. A robust, long-term monitoring approach using appropriate survey techniques (e.g., nest box surveys and acoustic surveys to monitor occupancy over time) is needed. Research is needed to test for heavy metals and other contaminants in Carolina Northern Flying Squirrel (USFWS 1990). It is also not known how pervasive the *Strongyloides robustus* nematode is in the Carolina Northern Flying Squirrel population.

In addition to the SGCN priorities listed in Table 3.19, species for which the Taxa Team determined there are research priorities because of knowledge gaps are identified in Table 3.21

Table 3.21 Mammal knowledge-gap priority species

Order	Scientific Name	Common Name	Federal/ State Status*
Carnivora	*Mustela nivalis*	Least Weasel	—
	Spilogale putorius	Eastern Spotted Skunk	—
Chiroptera	*Lasiurus cinereus*	Hoary Bat	—
	Lasiurus seminolus	Seminole Bat	—
Rodentia	*Microtus pennsylvanicus nigrans*	Dismal Swamp Meadow Vole	—
	Ochrotomys nuttalli	Golden Mouse	—
	Microtus pennsylvanicus nigrans	Dismal Swamp Meadow Vole	—
	Ochrotomys nuttalli	Golden Mouse	—
	Reithrodontomys humulis	Eastern Harvest Mouse	—
	Sylvilagus obscurus	Appalachian Cottontail	FSC/ —
	Synaptomys cooperi	Southern Bog Lemming	—
	Synaptomys cooperi helaletes	Dismal Swamp Southern Bog Lemming	—
	Tamiasciurus hudsonicus	Red Squirrel	—
	Zapus hudsonius	Meadow Jumping Mouse	—
Soricomorpha	*Condylura cristata*	Star-nosed Mole	—
	Condylura cristata pop. 1	Star-nosed Mole	—/SC
	Parascalops breweri	Hairy-tailed Mole	—

* See Table 3.2 for abbreviations.

3.7.5 Management Needs

The Mammal Taxa Team indicated that current management levels for many of our bat species are not sufficient to maintain long-term, viable populations. Many laboratories and state and federal biologists are investigating the cause of bat deaths to document the spread of WNS. Research is currently being conducted to investigate the dynamics of the fungal infection and transmission, and determine a way to control the disease.

Carolina Northern Flying Squirrel populations have been monitored annually since 1996 via winter nest box surveys. Data are stored in NCWRC's flying squirrel database. Acoustic surveys have been underway since 2009 and take place in the spring, summer, and fall. A reference library of flying squirrel calls provides known calls of Northern and Southern Flying Squirrels (Gilley 2013). Radio-telemetry studies have provided additional insight into habitat use, in particular the Northern Flying Squirrel's use of conifers (Ford et al. 2014). A predictive model of Carolina Northern Flying Squirrel habitat has been developed for GIS analysis and can be used by researchers as a first approximation of species distribution (Ford et al 2015). Management recommendations for the Carolina Northern Flying Squirrel include the need to restore high-elevation forest habitat (Ford et al. 2014).

3.7.6 Threats and Problems

Chapter 5 describes 11 categories of threats the Mammal Taxa Team considered during evaluation and ranking process to identify SGCN; information about the expected scope and severity of these threats is available in Appendix G. Evaluation results for Metric 9 indicate the most likely threats to have significant impacts on mammal populations in North Carolina over the next 10 years include the following:

- Residential and commercial development (e.g., land use change)
- Disease and pathogens (e.g., WNS)

Land-use change, especially from undeveloped land into developed uses, is a critical threat to SGCN mammals. Fire suppression negatively impacts species associated with Longleaf Pines, such as Eastern Fox Squirrels and Southeastern Bat. Many small mammal populations are threatened by loss of early successional habitat across the state due to clean agriculture and timber practices. Loss of suitable roosts for bats is another important concern due to a decrease in snags in forested areas.

White-nose syndrome has emerged as a significant threat to bat populations in the state. Continued monitoring of bat populations in the Piedmont for WNS, especially in the Uwharrie region, is important to understanding the spread of the disease. Bats are also impacted by wind turbines. It is foreseeable that increased wind farm development in North Carolina will have adverse impacts on local and migratory bat populations.

Rafinesque's Big-eared Bat (USDA Forest Service)
https://www.flickr.com/photos/usdagov/12838157104/

The high-elevation forests inhabited by Carolina Northern Flying Squirrel are threatened by climate change and mortality of Fraser Fir and Eastern Hemlock. The Southern Flying Squirrel has crept upslope, threatening to infect populations of the Carolina Northern Flying Squirrel because it is a vector of the *Strongyloides robustus* nematode (Weigl 2007). There is the threat of hybridization between Northern and Southern Flying Squirrel where they overlap (Garroway et al. 2010). Open corridors through forests, such as roads with a width that exceeds the gliding ability of a flying squirrel, can inhibit dispersal (Kelly et al. 2013). In some areas, Carolina Northern Flying Squirrels are threatened by residential development.

Residential and commercial development ranked high as a research priority for many species, but especially for the Southern Appalachian Woodrat, the Southern Bog Lemming, Buxton Woods White-footed Deermouse, and the Southeastern Bat. The impacts from disease also ranked high in the threat category for the Eastern Small-footed Bat, Little Brown Bat, Northern Long-eared Bat, Indiana Bat, and Tricolored Bat.

3.7.7 Additional Information

Currently, the USFWS Red Wolf Recovery Program is under internal review. Interbreeding with the Coyote (a species not native to North Carolina) has been recognized as the most significant and detrimental threat affecting restoration of Red Wolves (USFWS 2015). Coyotes are found in all 100 counties of the state and pose a predatory threat to pets, livestock and native wildlife. On March 18, 2015, the NCWRC adopted a permanent rule to list the Red Wolf as a threatened species.

The NCWRC worked collaboratively with USFWS and other partners to develop a surveillance and response plan for WNS in bats (NCWRC and USFWS 2013). The plan objective is to coordinate the conservation community's strategy for addressing WNS as it relates to disease surveillance and response, population monitoring, and research in North Carolina.

Bat Conservation International (BCI) is an organization that was developed to conserve bat species and their habitats. It works with local, regional, national, and multinational public and private partners to respond rapidly and effectively to bat conservation crises, to prevent the extinction of threatened bats and the extirpation of globally significant populations of bats. For example, conservation strategies developed by Lacki and Bayless (2014) for Rafinesque's Big-eared Bat and Southeastern Bat are available through BCI's website. Online resources for bat conservation also can be found at www.batcon.org.

Information on the ecology of mammals in the South and habitat management techniques to promote conservation can be found in "The Land Manager's Guide to Mammals of the South," a publication developed through collaboration between US Department of Agriculture and The Nature Conservancy (Trani et al. 2007).

3.7.8 Recommendations

In general, protection and restoration of natural community composition and function and protection of surrounding natural areas under current conditions are the best ways to ensure that suitable habitats are available for these species. Measures that protect a large and diverse pool of populations are best for ensuring that species are able to survive future stresses and adapt to changing climate conditions.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Prioritize surveys of bats species impacted by WNS: Big Brown Bat, Eastern Small-footed Bat, Gray Bat, Little Brown Bat, Northern Long-eared Bat, Tricolored Bat, and Indiana Bat.
- Prioritize surveys for Southern Appalachian, Allegheny, and Eastern woodrats.
- Prioritize surveys for the Appalachian Cottontail to determine the current distribution and abundance of the population in NC.

Monitoring. Monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Continue monitoring bat populations in the mountains with roost, hibernacula, and ANABAT (ANABAT Detection System) surveys. Efforts to bring these monitoring programs to the rest of the state should be expanded.

- Continue monitoring of Carolina Northern Flying Squirrel populations using a variety of survey techniques.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration.

- Examine winter behavior of bats in the Piedmont.

- Conduct genetic research to understand distributions of the Southern Appalachian and Allegheny Woodrats better to determine where these species occur and if their ranges overlap.

- Test for evidence of hybridization between Southern and Carolina Northern Flying Squirrels in North Carolina.

- Study competition and disease transmission in areas of overlap between Southern and Carolina Northern Flying Squirrels.

- Test for heavy metals (e.g., bioaccumulation) in Carolina Northern Flying Squirrel.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Protect bat roosting sites for all priority bat species, particularly those that are known roost sites for species affected by WNS.

- Restore high-elevation forests for Carolina Northern Flying Squirrels.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protection measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation serves numerous purposes in the face of anticipated climate change, but most notably, promotes ecosystem resilience.

- Use programs such as the Wildlife Conservation Lands Program to protect, manage, and restore habitat on private lands.

- Implement the state listing process by routinely evaluating conservation status and recommending legislative updates to revise the state species lists.
- Support citizen science and volunteer efforts to monitor species and habitat.
- Utilize partnerships and research collaborations with local universities and education programs to implement conservation, research, and management actions.
- Develop education, outreach, and technical guidance programs for the public.

Eastern Fox Squirrel (Left: gray phase. Right: black phase) (Jeff Beane, NCMNS)

3.8 Reptiles

3.8.1 Introduction

The southeastern United States, especially the Coastal Plain, has a high diversity of reptiles, and the state of North Carolina is no exception. North Carolina harbors more than 70 native species of reptiles, including snakes, lizards, turtles, and the American Alligator. Reptiles, like many amphibians, are often very difficult to find and even the best available survey techniques may have limited success for detecting many species. This makes it essential to conduct survey and monitoring efforts over many years to collect sufficient information to understand the population status of each of the state's native reptile species.

North Carolina is also home to numerous imperiled species of reptiles, ranging from the Bog Turtle in the western part of the state to the Eastern Diamondback Rattlesnake, Southern Hognose Snake, Northern Pine Snake, and many others in the Sandhills and Coastal Plain. Some of these species, like the Bog Turtle, rely on small, interspersed, very specific habitats, such as mountain bogs, for survival. Other species, like the Eastern Diamondback Rattlesnake and Northern Pine Snake, require very large tracts of intact, high-quality Longleaf Pine forests—those managed with fire to maintain an open and diverse understory.

Northern Pine Snake (Melissa McGaw, NCWRC)

Many species of reptiles remain common in North Carolina, and appear to be able to tolerate some levels of urbanization. Examples of urban-tolerant species include the Green Anole and Eastern Rat Snake. Some species, such as Eastern Diamondback Rattlesnake and Southern Hognose Snake, are generally intolerant of urbanization and the conversion of natural habitat to other uses. Still other species of reptiles, however, have been little studied because of their rarity or secretive nature. Some examples of understudied species include Mimic Glass Lizard, Coal Skink, and Eastern Coral Snake. It is important to continue efforts to survey the state for reptiles, and conduct research and monitoring to increase our knowledge of the status of reptiles in North Carolina, for both common and uncommon species.

A list of reptile SGCN is provided in Table 3.22 and the Taxa Team evaluation results can be found in Appendix G. Habitat associations for these species can be found in Appendix H.

Conservation recommendations for the associated habitats have been incorporated into the natural community descriptions in Chapter 4. The following paragraphs provide information about a few of the reptile species identified by the Taxa Team as priority species for research or management, and for which work that has been conducted to implement conservation and management recommendations.

3.8.1.1 Lizards

Eleven species of native lizards occur in North Carolina, with the highest diversity in the Sandhills and Coastal Plain regions. Lizards, in general, have not been the focus of intensive survey, monitoring, or research in North Carolina. Some species appear to be quite common (e.g., Green Anole, Five-lined Skink), while others are very difficult to detect, or occur in apparently low numbers (e.g., Slender Glass Lizard, Mimic Glass Lizard). New locality records for the Slender Glass Lizard have recently been detected, but few surveys specifically aimed at lizards have been conducted.

Table 3.22 Reptile SGCN

Family	Scientific Name	Common Name	Federal/ State Status*
ORDER: Crocodilia			
Alligatoridae	*Alligator mississippiensis*	American Alligator	T(S/A)/T
ORDER: Testudines			
Cheloniidae	*Caretta caretta*	Loggerhead Sea Turtle	T/T
	Chelonia mydas	Green Sea Turtle	T/T
	Eretmochelys imbricata imbricata	Atlantic Hawksbill Sea Turtle	E/E
	Lepidochelys kempii	Kemp's Ridley Sea Turtle	E/E
Dermochelyidae	*Dermochelys coriacea*	Leatherback Sea Turtle	E/E
Emydidae	*Clemmys guttata*	Spotted Turtle	—
	Glyptemys muhlenbergii	Bog Turtle	T(S/A)/T
	Deirochelys reticularia reticularia	Eastern Chicken Turtle	—
	Graptemys geographica	Northern Map Turtle	—
	Malaclemys terrapin	Diamondback Terrapin	FSC/SC
	Pseudemys rubriventris	Northern Red-bellied Cooter	—
	Terrapene carolina carolina	Eastern Box Turtle	—
	Trachemys scripta troostii	Cumberland Slider	—
Kinosternidae	*Kinosternon baurii*	Striped Mud Turtle	—
	Sternotherus minor peltifer	Stripe-necked Musk Turtle	—/SC
Trionychidae	*Apalone spinifera aspera*	Gulf Coast Spiny Softshell	—
	Apalone spinifera spinifera	Eastern Spiny Softshell	—/SC
ORDER: Squamata			
Colubridae	*Cemophora coccinea copei*	Northern Scarlet Snake	—
	Farancia erytrogramma erytrogramma	Common Rainbow Snake	—
	Heterodon simus	Southern Hognose Snake	FSC/SC
	Lampropeltis calligaster rhombomaculata	Mole Kingsnake	—
	Lampropeltis getula sticticeps	Outer Banks Kingsnake	—/SC
	Lampropeltis elapsoides [*triangulum elapsoides*]	Scarlet Kingsnake	—
	Lampropeltis triangulum temporalis	Coastal Plain Milk Snake	—
	Lampropeltis triangulum triangulum	Eastern Milk Snake	—
	Masticophis [*Coluber*] *flagellum flagellum*	Eastern Coachwhip	—
	Nerodia sipedon williamengelsi	Carolina Water Snake	—/SC
	Opheodrys vernalis	Smooth Green Snake	—/SC
	Pituophis melanoleucus melanoleucus	Northern Pine Snake	FSC/SC
	Regina rigida rigida	Glossy Crayfish Snake	—
	Regina septemvittata	Queen Snake	—
	Rhadinaea flavilata	Pine Woods Litter Snake	—
	Seminatrix pygaea paludis	Carolina Swamp Snake	—
	Thamnophis sauritus sauritus	Common Ribbon Snake	—
	Virginia valeriae valeriae	Eastern Smooth Earth Snake	—
Elapidae	*Micrurus fulvius*	Eastern Coral Snake	—/E
Scincidae	*Eumeces* [*Plestiodon*] *anthracinus*	Coal Skink	—
Viperidae	*Crotalus adamanteus*	Eastern Diamondback Rattlesnake	FSC/E
	Crotalus horridus	Timber Rattlesnake	—/SC
	Sistrurus miliarius miliarius	Carolina Pigmy Rattlesnake	—/SC
Anguidae	*Ophisaurus attenuatus longicaudus*	Eastern Slender Glass Lizard	—
	Ophisaurus mimicus	Mimic Glass Lizard	FSC/SC

* See Table 3.2 for abbreviations.

3.8.1.2 Snakes

There are 37 species of snakes native to North Carolina. Snakes can be found from the mountains to the coast, but the highest diversity and the most imperiled species occur in the Sandhills and Coastal Plain. Most species are quite secretive. Some remain abundant (e.g., Eastern Worm Snake), while others are becoming increasingly rare (e.g., Northern Pine Snake). Six snake species in the state are venomous, including three species of rattlesnakes, the Eastern Cottonmouth, the Copperhead, and the Eastern Coral Snake.

Inventory and monitoring surveys for reptile species are conducted statewide, at both historical and new locations. These survey efforts have yielded new occurrence records for many reptile species, including the Timber Rattlesnake, Corn Snake, Mole Kingsnake, and several others. Several species are the focus of more intense survey, research, and monitoring efforts in addition to passive surveys, including the Eastern Diamondback Rattlesnake, Southern Hognose Snake, and Northern Pine Snake.

Timber Rattlesnake (Jeff Hall, NCWRC)

Eastern Diamondback Rattlesnakes are listed as State endangered in North Carolina. This species once occurred throughout much of the Coastal Plain, but populations have been drastically reduced. Historically, Eastern Diamondback Rattlesnakes were found in 13 counties, but since 2005, detections have only come from three counties, with all but three specimens found in a single county. Habitat loss and fragmentation due to development and silviculture are some of the biggest reasons for these declines, as well as road mortality and outright killing.

Another significant issue for the Eastern Diamondback Rattleskake is limited refugia. Refugium sites are limited to tree stumps, as many of the other refugia used by this species in other parts of its range are absent in North Carolina—no Gopher Tortoise, armadillo, or Pocket Gopher burrows. Stumps that are large enough for use by an Eastern Diamondback Rattlesnake are uncommon across the landscape. Winter temperatures are likely an important factor in limiting the distribution of the Eastern Diamondback Rattlesnake. Thus, any limits on potential refugia may have an even bigger impact on the species. Recent work on stump-dependent species has shown great promise in the creation of artificial stump holes, and this work will continue.

Monitoring of Southern Hognose Snakes, a State Species of Special Concern, has been ongoing for more than 25 years in the Sandhills and Coastal Plain. These snakes are strongly tied to sandy soils and large tracts of well-managed Longleaf Pine forests. They are extremely secretive during most of the year, but can be monitored by finding them crossing roads when they become more active in the fall. A recent publication suggests that no discernable trend in the captures of Southern Hognose Snakes was found over a long-term study in the Sandhills (Beane et al. 2014). However, outside the Sandhills, this species is extremely rare and infrequently encountered. Many coastal counties with historical records of the Southern Hognose Snake have no records within the last 20 years, despite considerable effort to detect the species.

Additionally, a mark-recapture study of five species of snakes on Sandhills Game Land is currently being conducted by NCWRC biologists and volunteers. Species targeted for this research include Northern Pine Snake, Eastern Coachwhip, Carolina Pigmy Rattlesnake, Corn Snake, and Southern Hognose Snake. This research is aimed at determining population size, relative abundance of each species, and other natural history aspects, such as movements and population status over time.


Southern Hognose Snake (Jeff Hall, NCWRC)

3.8.1.3 Turtles

North Carolina is home to 21 species of turtles, ranging from the terrestrial Eastern Box Turtle to numerous aquatic species, five sea turtles, and the estuarine Diamondback Terrapin. Some species, like the Yellow-bellied Slider, are generalists, using a wide variety of wetland habitats and as such, are common throughout the state. Others, such as the Bog Turtle, are highly specialized, relying on very specific habitat types, and are, accordingly, quite rare and difficult to find. The natural history and distribution of some species have been extremely well-studied, while others are in need of increased survey, research, and monitoring work.

Bog Turtles are the smallest turtle in North America. There are two distinct US population segments—one in the Northeast (MD to New England) and one in the Southeast (GA to VA). In North Carolina, Bog Turtles have been found in 22 counties along the western edge of the Piedmont and Mountain


Bog Turtle juvenile (NCWRC)

ecoregions. Their habitats include scattered small, grassy, herbaceous wetlands, spring-fed wetlands with little canopy and soft mucky substrates, and small riparian systems, often associated with pastureland or open fields (Somers et al. 2007). Roughly 75% of all Bog Turtle habitat in the Southeast is located on private lands, making partnerships with private landowners an integral component of conservation efforts for this species (Herman 2003). Project Bog Turtle is a North Carolina Herpetological Society conservation initiative supported by numerous state, federal, and private partners. The initiative supports inventory surveys, population density studies, and habitat conservation and restoration actions (http://projectbogturtle.org/).

The Eastern Box Turtle is the only terrestrial turtle species native to North Carolina, and was designated the state reptile in 1979. A collaborative of wildlife professionals, scientists, and educators from several state agencies and two universities initiated the Box Turtle Connection—a project designed to collect statewide data on Box Turtles. The project was initiated in response to concerns that this once common and widespread species may be experiencing population declines, due to habitat loss and fragmentation, and pressures from other anthropomorphic impacts (Somers and Matthews 2006). The Eastern Box Turtle is listed on the Conference of the Parties to the Convention on International Trade in Endangered Species of Wildlife Fauna and Flora (CITES) Appendix II list of species that are not currently threatened with extinction, but may become threatened unless international trade is closely controlled.

In early 2013, three turtle species that are native to North Carolina were added to the CITES Appendix II list because they are harvested for commercial trade: Diamondback Terrapin, Spotted Turtle, and Common Snapping Turtle.

- The Diamondback Terrapin is found in brackish waters of the Atlantic Coast, and is protected in North Carolina as a Species of Special Concern.
- The Spotted Turtle and Common Snapping Turtle are freshwater species commonly found in ponds and lakes.
- Only the Common Snapping Turtle can be harvested commercially in North Carolina, although a wildlife collection license must be obtained from NCWRC for this activity, and take is limited to 10 animals per day and 100 animals per year. However, the CITES listing provides an international focus on conservation concerns for these species.

There are five marine turtle species found in North Carolina's coastal region: Loggerhead, Green, Hawksbill, Leatherback, and Kemp's Ridley sea turtles. More information on marine species can be found in Section 3.10 of this chapter. Jurisdiction over sea turtle activity is divided between the USFWS (land) and the NOAA Fisheries (marine) because sea turtles are federally protected species that use both land and sea. The NCWRC has cooperative agreements with both USFWS and NMFS in order to monitor sea turtle activity in the state. All data collected by NCWRC biologists and permitted volunteers are shared with the appropriate federal agency.

The North Carolina Sea Turtle Program coordinates a network of more than 1,000 volunteers and collaborators that work to monitor sea turtle nesting and stranding activities along the state's coastline. Four species of sea turtle nest along North Carolina's beaches: Loggerhead, Green, Leatherback, and Kemp's Ridley. Volunteer groups monitor beaches daily from May to August and mark sea turtle nests. They monitor these nests throughout incubation and inventory each nest after it has emerged to determine hatching success. The Sea Turtle Stranding and Salvage Network collects data including species, carapace measurements, location, and probable cause of stranding from all reported sea turtle strandings.

Loggerhead Sea Turtle release (NCWRC)

Other turtle survey efforts have taken place in various parts of the state. These included recent trapping efforts in the mountains, where NCWRC biologists have detected Stripe-necked Musk Turtles, Eastern Spiny Softshells, and River Cooters in aquatic habitats where they were not previously documented. Surveys of streams in the Uwharrie Mountains, found in the Piedmont region of North Carolina, have recently documented additional and relatively large numbers of Gulf Coast Spiny Softshell Turtles in several drainages. Additionally, a new citizen science initiative called the Terrapin Tally has been formed to increase our knowledge of Diamondback Terrapins. Designed to help estimate population numbers, the Terrapin Tally is a joint project with the North Carolina Coastal Reserve and National Estuarine Research Reserve and the NCWRC.

3.8.1.4 Crocodilians

The American Alligator is the only crocodilian species found in North Carolina, occurring throughout much of the Coastal Plain. Once extremely rare in the state, alligators have increased in numbers since being federally listed under the Endangered Species Act, allowing them to be removed from endangered status in 1987. Trade of this species is still regulated by the US Fish and Wildlife Service, because of "similarity of appearance" to American Crocodiles, which are federally listed as threatened. Recent survey work (2014–2015) has been conducted jointly between NCWRC and NCSU to determine the status of the species in the state. Results of this research are currently being analyzed.

3.8.2 Comparison of 2005 and 2015 Priority Species

The 2015 evaluation identified a total of 61 species as conservation concern, knowledge gap, or management concern priorities. Some species are a priority in more than one of the three evaluation categories (see Appendix G). Of the 61 species, 43 were designated SGCN and another 14 were designated research priorities. In comparison, the 2005 WAP listed 43 as priority species, which may have included concerns for knowledge gaps. However, the 2005 Taxa Team evaluations did not identify knowledge gaps or management concerns as separate priorities.

There have been scientific advances in direct DNA sequencing methods that enabled tests of previous hypotheses of phylogenetic relationships (Amphibiaweb 2015). This new information has led to suggestions for taxonomic revisions such as those proposed by Frost (et al. 2006) and others. However, newly published taxonomy should not be interpreted as a formal, mandatory change; it is simply an alternative that should be evaluated alongside other such proposals (Amphibiaweb 2015).

Table 3.23 provides a comparison of changes since the 2005 WAP was published. These changes do not necessarily indicate a change in the concern status of these species; they are more likely a result of different evaluation methodologies from the 2005 process (see Appendix F) or reflect an increase in our knowledge base for the species.

3.8.3 Conservation Concerns

The conservation concerns for reptiles are many and are summed up well by Gibbons et al. (2000). This paper notes that although amphibians are often thought of as much more imperiled, reptiles are also experiencing drastic declines worldwide and face numerous threats to their conservation status. Some of the major concerns that may affect the abundance or distribution of reptile species include habitat loss and alteration, poor habitat management (e.g., lack of appropriate fire regimes), environmental pollution, unsustainable use, emerging diseases, and invasive species.

Most of the reptiles in North Carolina are affected by not one, but many issues related to their habitats. Sea turtles in particular are species that have experienced declines because

Table 3.23 Reptiles: comparison of changes from 2005 WAP

2005		2015		
Scientific Name	Common Name	Scientific Name	Common Name	Comment
Clemmys muhlenbergii	Bog Turtle	*Glyptemys muhlenbergii*		Genus name changed.
Deirochelys reticularia	Eastern Chicken Turtle	*Deirochelys reticularia reticularia*		Added trinomial to species name
Elaphe guttata guttata	Corn Snake			No longer a conservation priority.
Eumeces anthracinus	Coal Skink	*Plestiodon anthracinus*		Genus name changed.
Eumeces laticeps	Broad-headed Skink	*Plestiodon laticeps*		Genus name changed. No longer a conservation priority.
Farancia abacura abacura	Eastern Mudsnake			No longer a conservation priority.
Heterodon platirhinos	Eastern Hog-nosed Snake			No longer a conservation priority.
Lampropeltis getula getula	Eastern Kingsnake			No longer a conservation priority.
Lampropeltis Triangulum elapsoides	Scarlet Kingsnake	*Lampropeltis elapsoides*		Species name changed.
Masticophis flagellum	Eastern Coachwhip	*Coluber flagellum flagellum*		Genus name changed. Added trinomial species name.
Regina rigida	Glossy Crayfish Snake	*Regina rigida rigida*		Added trinomial species name
Seminatrix pygaea	Black Swamp Snake	*Seminatrix pygaea paludis*	Carolina Swampsnake	Common name changed; Added trinomial to species name
Sistrurus miliarius	Pygmy Rattlesnake	*Sistrurus miliarius miliarius*	Carolina Pigmy Rattlesnake	Common name changed, Added trinomial species name.
Sternotherus minor	Loggerhead Musk Turtle			Removed from species evaluation list.
		Sternotherus minor peltifer	Striped-necked Musk Turtle	Added to species evaluation list.
Tantilla coronata	Southeastern Crowned Snake			No longer a conservation priority.

of a multitude of factors, especially factors that affect beach nesting, but also numerous threats that affect them once they are in the ocean.

Some turtle species have experienced high levels of collection from the wild, and this type of activity may be unsustainable for certain species. Climate change may be another issue that affects the status of reptiles, though this has been relatively understudied. Additional threats faced by reptiles include road mortality and the invasion of nonnative plants and animals, such as Fire Ants.

Many species of reptiles have been heavily affected by the loss of habitat throughout North Carolina. Large snakes and those species that are associated with very specific habitat types likely have been most affected by habitat loss and fragmentation. Eastern Diamondback Rattlesnakes have been affected by numerous factors, now limiting them to only a small population in the Coastal Plain. Bog Turtles have been drastically affected by the loss of mountain bogs and by the lack of management in the bogs that remain. Conservation recommendations for the habitats associated with reptiles have been incorporated into the natural community descriptions in Chapter 4.

3.8.4 Knowledge Gaps

The current status of many reptile species is poorly known in North Carolina. Inventories using appropriate survey techniques are important for understanding the distribution of species, status of populations, effects of stressors on populations, and the effects of harvest. For instance, biologists lack information about locations and statuses of populations of Rainbow Snake and Mimic Glass Lizard. Some species are more difficult to survey than others, and novel techniques should be developed to make surveys more effective. There are significant knowledge gaps about Bog Turtles, including how they use the landscape outside of bogs (i.e., rivers, forests) as they move across the landscape between wetlands.

In addition to SGCN listed in Table 3.22, species for which the Taxa Team determined there are research priorities because of knowledge gaps are identified in Table 3.24.

3.8.5 Management Needs

Management needs for reptile species vary widely depending on each species' habitat use and natural history traits. In general, terrestrial reptiles often require specific habitat types, often in very large tracts of high-quality, well-managed habitat. Reptiles that rely on fire-maintained pine habitat are drastically affected by the lack of sound management, including prescribed fire. Management of these types of habitats needs to take place on a large scale to preserve reptile diversity.

Table 3.24 Reptile knowledge-gap priority species

Family	Scientific Name	Common Name	Federal/ State Status*
Anguidae	*Ophisaurus ventralis*	Eastern Glass Lizard	—
Colubridae	*Farancia abacura abacura*	Eastern Mud Snake	—
	Lampropeltis getula getula	Eastern Kingsnake	—
	Nerodia erythrogaster	Red-bellied Water Snake	—
	Nerodia taxispilota	Brown Water Snake	—
	Elaphe guttata [*Pantherophis guttatus*]	Corn Snake	—
	Tantilla coronata	Southeastern Crowned Snake	—
	Virginia striatula	Rough Earth Snake	—
Emydidae	*Graptemys kohnii*	Mississippi Map Turtle – High Rock Lake pop. [Exotic]	—
	Trachemys scripta elegans	Red-eared Slider [Exotic]	—
Gekkonidae	*Hemidactylus turcicus*	Mediterranean Gecko [Exotic]	—
Kinosternidae	*Sternotherus odoratus*	Eastern Musk Turtle	—
Phrynosomatidae	*Phrynosoma cornutum*	Texas Horned Lizard [Exotic]	—
Polychrotidae	*Anolis sagrei*	Brown Anole [Exotic]	—

* See Table 3.2 for abbreviations.

Lack of fire, fire suppression, and the conversion of open pine habitat to industrial forests have led to the decline of many habitat specialists such as Northern Pine Snakes, Southern Hognose Snakes, and Chicken Turtles. Information on habitat management for herp species can be found in the PARC technical publication on habitat management for amphibians and reptiles in the Southeast (Bailey et al. 2006).

Diverse reptile populations continue to persist in large, soundly managed tracts of Longleaf Pine forests in the Sandhills region. Working with land managers to emphasize the need for management to maintain diverse forests using prescribed fire is extremely important for maintaining diverse reptile populations.

Bog Turtle conservation efforts are another example of implementing management to maintain or increase populations of reptiles. This species is now restricted to very small mountain bogs that are easily shaded out by thick vegetation if active management is not undertaken (Somers et al. 2000). Though sometimes difficult to implement, current efforts to maintain bogs in an open-canopied state are contributing to the conservation of this rare species.

There are several species of sea turtles that use both aquatic and terrestrial habitats along North Carolina's coast and extremely intensive management is necessary to maintain or increase these populations. Additional information about priority conservation actions that benefit sea turtle species is provided in Section 3.10 Marine Species and Section 4.2.14 Estuarine Aquatic Communities. Turtle nests must be caged to keep predators away, nests are monitored to determine each species' status, and the numerous threats young and adult turtles face need to be managed from a fisheries perspective.

3.8.6 Threats and Problems

Chapter 5 describes 11 categories of threats the Taxa Teams considered during the evaluation and ranking process to identify SGCN; information about the expected scope and severity of the impacts from these threats is available in Appendix G. Evaluation results for Metric 9 indicate that the threats most likely to create significant impacts to reptile populations in North Carolina over the next 10 years include the following:

- natural system modifications (e.g., fire suppression, land management activities)
- biological resource use (e.g., harvesting and collection)
- pollution (e.g., point and nonpoint sources of wastes and effluents, contaminants)
- climate change impacts, especially drought

Research related to these threats and their impacts on certain reptile species was ranked as a high priority. Habitat loss, modification, and mismanagement should be a focus of efforts to reduce threats to many species of reptiles.

Three introduced species have been documented in the state, including Texas Horned Lizard, Mediterranean Gecko, and Brown Anole, but none of the populations of these species appear to be widespread. Breeding populations exist for both Texas Horned Lizard and Mediterranean Gecko, but no breeding activity has yet been detected for Brown Anoles in the state. Of the three nonnatives, the Brown Anole represents the highest threat to native species, because its ability to outcompete the Green Anole has been documented in Florida and elsewhere.

3.8.7 Additional Information

Management information can be found in a Partners in Amphibian and Reptile Conservation (PARC) technical publication on habitat management for amphibians and reptiles in the Southeast (Bailey et al. 2006) and is available online at https://separc.files.wordpress.com/2013/04/se-hmg.pdf.

Programs and information from the North Carolina Herpetological Society (NCHS), the USGS ARMI, and NCPARC are important resources for conservation of North Carolina's native reptile species.

An online database for tracking reptiles is the Carolina Herp Atlas, developed by Davidson College Herpetology Laboratory. This program tracks county-level distribution information for native species in North and South Carolina and is available online at www.carolinaherpatlas.org. Davidson College also maintains an online identification and information guide, Amphibians and Reptiles of North Carolina (www.herpsofnc.org).


Diamondback Terrapin (Melissa McGaw, NCWRC)

Taxonomic classification and agreement on naming conventions for some species are likely to be unsettled until scientific evidence supporting any recommended changes becomes widely accepted. Resources for information about changes in classification include the Center for North American Herpetology (CNAH), an organization that serves as a data bank for information about North American amphibians, turtles, reptiles, and crocodilians. Published research literature documenting taxonomic changes is available online at www.cnah.org. The CNAH web page also provides a link to peer-reviewed articles published in the *Journal of North American Herpetology* and access to articles in the *Contemporary Herpetology* journal archives. Another resource for amphibian taxonomy is the American Museum of Natural History Amphibian Species of the World online reference database, available online at http://research.amnh.org/vz/herpetology/amphibia.

3.8.8 Recommendations

In general, protection and restoration of natural community composition and function, and protection of surrounding natural areas under current conditions are the best ways to ensure suitable habitats are available for these species. Measures that protect a large and diverse group of populations are the best way to ensure that species are able to survive future stresses and adapt to changing climate conditions. Table 3.24 lists the species for which there are research priorities.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Conduct distributional surveys of Longleaf Pine habitat specialists. Some of these include Eastern Diamondback Rattlesnake, Northern Pine Snake, Southern Hognose Snake, Eastern Coachwhip, Eastern Coral Snake, and Chicken Turtle.

- Conduct surveys for aquatic or semi-aquatic species of snakes including Rainbow Snake, Black Swamp Snake, and Glossy Crayfish Snake.

- Continue to conduct surveys on aquatic turtle species in the mountains, where relatively little is known about turtle assemblages compared to other parts of the state.

- Survey habitat for Timber Rattlesnakes in the mountains and Piedmont to determine overwintering locations to protect and monitor these sites.

- Conduct surveys for Diamondback Terrapins to determine where healthy populations still occur, and implement conservation efforts accordingly.

- Focus survey efforts on learning more about the distribution and population status of glass lizards, both in the Coastal Plain and in the Piedmont.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Monitor priority reptile species that are perceived as declining or rare, especially upland snake species such as Southern Hognose Snakes, Northern Pine Snakes, Eastern Diamondback Rattlesnakes, and Timber Rattlesnakes.

- Continue to monitor Bog Turtle populations annually using mark-recapture and intensive habitat surveys.

- Continue to monitor sea turtles and Diamondback Terrapins using appropriate techniques.

- Monitor snake populations for signs of emerging diseases that could be detrimental to populations.

- Continue the statewide Box Turtle Connection program, forming a long-term database of the status of the Eastern Box Turtle throughout the state.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration.

- Continue mark-recapture program to determine status, life history, and population sizes of Bog Turtles. Telemetry work should also aid in understanding population dynamics.
- NCWRC biologists recently began a mark-recapture study on upland snakes throughout the Sandhills Game Land to determine the status of priority species.
- Conduct research on the movements and habitat use of upland snake species in the Sandhills and Coastal Plain to guide land use and protection. If possible, radio telemetry on certain species would be useful in elucidating habitat associations and limiting factors for these species.
- Conduct mark-recapture surveys on Eastern Box Turtles throughout the state to track population trends and determine differences in populations in relation to land use.
- Continue research on aspects of sea turtle biology, ecology, and recovery along the coast.
- Determine the effects of harvest on the conservation status of aquatic and semi-aquatic turtles.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. We will

- Promote appropriate prescribed fire regimes to maintain open, diverse habitat that supports abundant upland snake populations.
- Continue to manage mountain bogs using appropriate techniques, and promote habitat restoration and maintenance on mountain bogs.
- Restore lands where lack of fire, or fire suppression, has altered pine-dominated forests.
- Determine "hot spots" for road mortality and assess ways of alleviating issues, including underpasses or other techniques.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, promotes ecosystem resilience.

- Continue to support programs that limit collection of priority species, including permit requirements, law enforcement oversight, and legislative action that protects species. Implement the state listing process by routinely evaluating conservation status and recommending legislative updates to revise the state species lists.
- Support land trusts and conservation easements as a means to protect amphibian habitat.
- Utilize programs such as the Wildlife Conservation Lands Program and others to protect, manage, and restore habitat on private lands.
- Support citizen science and volunteer efforts to monitor species and habitats.
- Utilize partnerships and research collaborations with local universities and education programs to implement conservation, research, and management actions.
- Develop education, outreach, and technical guidance programs for the public. Work with private landowners to promote habitat that supports a high diversity of reptiles.

3.9 Snails

3.9.1 Introduction

Snails are members of the phylum Mollusca and are in the taxonomic class Gastropoda (commonly gastropods). This class also includes slugs. With about 40,000 snail species identified, they are the largest group of living mollusks. Gastropods are protected under state law in North Carolina and the NCNHP program collects data on rare gastropod species.

Gastropods have a muscular foot used for movement, and in some species it is modified for swimming or burrowing. Snails respire using a lung (group Pulmonata) or gills (several taxonomic groups) (Brusca and Brusca 1990; Hickman et al. 2000). They occupy both wetland and dry landscapes as well as fresh and marine waters; however, only freshwater and terrestrial gastropods are addressed in this version of the WAP.

Most snails have a single spirally coiled shell, whereas slugs lack a shell. Snails also have a mantle that covers internal organs and extends outward to attach to the shell, a well-developed head with eyes and either one or two pairs of tentacles, and a concentration of nervous tissue and cerebral ganglia that forms a primitive brain. Shells may have an operculum, a horny plate that seals the opening when the snail withdraws its body into the shell.

Noonday Globe (USFWS Asheville NC Field Office)
http://www.fws.gov/asheville/htmls/listed_species/Noonday_globe.html

Most use a radula (a horny, ribbonlike structure found in the mouth) in some aspect of their feeding behavior, which includes grazing, browsing, or feeding on plankton. They may also be scavengers or detritivores. Snails found in North Carolina include carnivores that prey on other snails and slugs, such as the Gray-foot Lancetooth and the Rosy Wolfsnail, and herbivores or detritivores, such as the Flamed Tigersnail and Mountain Disc.

All land snails and slugs are hermaphrodites, producing both spermatozoa and ova so all individuals have the potential to lay eggs. Some freshwater snails (e.g., Apple Snail) and marine species (e.g., Periwinkles) have separate sexes.

3.9.1.1 Freshwater Snails

There are about 650 different species of freshwater snails in North America with the greatest species richness being associated with flowing (lotic) waters (Johnson 2009). The southeastern United States is recognized as having a high diversity of freshwater gastropods (Lydeard and Mayden 1995; Brown et al. 1998; Lysne et al. 2008). Approximately 52 species of freshwater snails, representing eight taxonomic families, are found in North Carolina (Adams 1990; Mottesi and Savacool 1997). Many are endemics with very small geographic ranges, often isolated to a single location or geographically restricted drainage. According to the AFS, 74% of all freshwater snails in the United States and Canada are currently imperiled (Johnson et al. 2013).

The taxonomy of gastropods was revised by Bouchet and Rocroi (2005) using the concept of clades (a grouping that includes a common ancestor) to naturally group-related species based on molecular phylogenetics in comparison with other schemes that rely on morphological features. Under this system native freshwater snails in the United States belong to three main clades: Neritimorpha, Caenogastropoda, and Heterobranchia (Bouchet and Rocroi

2005; Johnson et al. 2013). Snails in the Neritimorpha clade are restricted to coastal river environments (Johnson et al. 2013).

Most freshwater snails have an operculum, use gills to breathe, mature slowly, and are long-lived dioecious species with internal fertilization. Operculate snails comprise about two-thirds of all North American freshwater snails. Freshwater snails with an operculum are descended from marine ancestors and extract oxygen from the water with a single gill. They have separate sexes and a short reproductive season, are slow-growing and long-lived, and very sensitive to environmental changes (Johnson 2009). Eggs are attached to firm substrates between late spring and early summer.

Aquatic snails can dominate benthic stream communities in numbers (Hawkins and Furnish 1987; Johnson and Brown 1997; Johnson et al. 2013) and can comprise more than 90% of the macroinvertebrate species in wetland habitats (Suski et al. 2012); can significantly influence algal primary productivity (Brown and Lydeard 2010; Johnson et al. 2013); and play a pivotal role in aquatic food webs and nutrient cycles (Covich et al. 1999; Johnson et al. 2013). Most freshwater species graze on algae and biofilms and some are suspension or deposit feeders. None are predatory (Burch 1989; Brown and Lydeard 2010; Johnson et al. 2013).

Snails are prey for numerous fishes from the families Acipenseridae, Cyprinidae, Catostomidae, Ictaluridae, Centrarchidae, and Percidae (Boschung and Mayden 2004; Johnson et al. 2013), as well as other aquatic and terrestrial species (e.g., Map Turtles, Snail Kites, and Muskrats) (Cagle 1952; Vogt 1981; Neves and Odum 1989; Bourne 1993; Johnson et al. 2013).

A list of freshwater snail SGCN is provided in Table 3.25 and the Taxa Team evaluation results can be found in Appendix G. River basin and habitat associations for these species can be found in Appendix H.

Table 3.25 Freshwater snail SGCN

Family	Scientific Name	Common Name	Federal/ State Status*
Amnciolidae	*Amnicola sp. 1*	Waccamaw Snail	—/SC
Hydrobiidae	*Cincinnatia (Floridobia) sp.*	Waccamaw Siltsnail	—/SC
Lithoglyphidae	*Somatogyrus sp. 1*	a hydrobid snail	—
	Somatogyrus virginicus	Panhandle Pebblesnail	FSC/—
Planorbidae	*Helisoma eucosmium*	Greenfield Rams-horn	FSC/E
	Planorbella magnifica	Magnificent Rams-horn	C/E
Pleuroceridae	*Elimia christyi*	Christy's Elimia	FSC/E
	Leptoxis virgata	Smooth Mudalia	FSC/—

* See Table 3.2 for abbreviations.

3.9.1.2 Land Snails

Not all land (terrestrial) snails are completely terrestrial. Some move between land and freshwater or saltwater habitats. A majority of land snails have a lung for respiration and are pulmonates, but there are some that live in moist habitats that have a gill and use an operculum to seal the shell.

Due to extremely limited data and a scarcity of biologists who work on the taxa, little is known about the 200+ species of native terrestrial gastropods known to exist in the state or the 30+ introduced species of land snails or slugs. Numerous land snails were identified as SGCN and are listed in Table 3.26. Taxa Team evaluation results can be found in Appendix G and some habitat associations for these species can be found in Appendix H.

TABLE 3.26 Land snail SGCN

Family	Scientific Name	Common Name (Population)	Federal/ State Listing*
ORDER: Basommatophora			
Carychiidae	*Carychium clappi*	Appalachian Thorn	—
	Carychium exiguum	Obese Thorn	—
	Carychium nannodes	File Thorn	—
ORDER: Stylommatophora			
Helicodiscidae	*Helicodiscus bonamicus*	Spiral Coil	—/SC
	Helicodiscus fimbriatus	Fringed Coil	—/SC
	Helicodiscus triodus	Talus Coil	—
Polygyridae	*Euchemotrema fasciatum*	Mountain Pillsnail	—
	Fumonelix archeri	Ocoee Covert	—
	Fumonelix cherohalaensis	Roan Covert	—
	Fumonelix jonesiana	Big-tooth Covert	—/T
	Fumonelix langdoni	Talus Covert	—
	Fumonelix orestes	Engraved Covert	—/T
	Fumonelix roanensis	Rock-loving Covert	—
	Fumonelix wheatleyi	Cinnamon Covert	—
	Fumonelix wheatleyi clingmanicus	Clingman Covert	—
	Inflectarius downieanus	Dwarf Globelet	—
	Inflectarius ferrissi	Smoky Mountain Covert	—/T
	Inflectarius subpalliatus	Velvet Covert	—/SC
	Inflectarius verus	a covert snail	—
	Mesodon altivagus	Wandering Globe	—
	Mesodon andrewsae	Balsam Globe	—
	Mesodon mitchellianus	Sealed Globelet	—
	Patera clarki clarki	Dwarf Proud Globe	—/SC
	Patera clarki nantahala	Noonday Globe	T/T

Family	Scientific Name	Common Name (Population)	Federal/ State Listing*
Polygyridae (cont.)	*Praticolella lawae*	Appalachian Shrubsnail	—
	Stenotrema depilatum	Great Smoky Slitmouth	—/SC
	Stenotrema pilula	Pygmy Slitmouth	—
	Triodopsis soelneri	Cape Fear Threetooth	FSC/T
	Xolotrema caroliniense	Blunt Wedge	—
Pupillidae	*Gastrocopta pellucida*	Slim Snaggletooth	—
	Vertigo bollesiana	Delicate Vertigo	—
	Vertigo parvula	Smallmouth Vertigo	
	Vertigo sp. 3	a vertigo snail	—
Succineidae	*Catinella hubrichti*	Snowhill Ambersnail	—
	Catinella pugilator	Weedpatch Ambersnail	—
	Catinella waccamawensis	Waccamaw Ambersnail	—/T
	Oxyloma effusum	Coastal-plain Ambersnail	—
	Succinea campestris	Crinkled Ambersnail	—
	Succinea unicolor	Squatty Ambersnail	—
	Succinea wilsonii	Golden Ambersnail	—
Valloniidae	*Vallonia excentrica*	Iroquois Vallonia	—
Zonitidae	*Glyphyalinia clingmani*	Fragile Glyph	FSC/E
	Glyphyalinia junaluskana	Dark Glyph	—/SC
	Glyphyalinia luticola	Furrowed Glyph	—
	Glyphyalinia ocoae	Blue-gray Glyph	—
	Glyphyalinia pentadelphia	Pink Glyph	—/SC
	Hawaiia alachuana	Southeastern Gem	—
	Mesomphix capnodes	Dusky Button	—
	Mesomphix latior	Broad Button	—
	Mesomphix pilsbryi	Striate Button	—
	Paravitrea clappi	Mirey Ridge Supercoil	—/SC
	Paravitrea lacteodens	Ramp Cove Supercoil	—/SC
	Paravitrea placentula	Glossy Supercoil	—/SC
	Paravitrea reesei	Round Supercoil	—
	Paravitrea ternaria	Sculpted Supercoil	FSC/T
	Paravitrea umbilicaris	Open Supercoil	—/SC
	Paravitrea varidens	Roan Supercoil	FSC/T
	Pilsbryna nodopalma	Oar Tooth Bud	—
	Pilsbryna vanattai	Honey Glyph	—/SC
	Ventridens arcellus	Golden Dome	—
	Ventridens lasmodon	Hollow Dome	—
	Ventridens suppressus	Flat Dome	—
	Zonitoides patuloides	Appalachian Gloss	—/SC

* See Table 3.2 for abbreviations.

Conservation recommendations for the associated habitats have been incorporated into the natural community descriptions in Chapter 4. Additional recommendations can be found in the river basin descriptions (Section 4.5). The following paragraphs provide information about species identified by the Taxa Team as SGCN or a priority species for research or management, and for which work has been conducted to implement conservation and management recommendations.

3.9.2 Comparison of 2005 and 2015 Priority Species

The 2015 evaluation identified eight freshwater snails and 63 land snails as SGCN. Numerous species were identified as knowledge-gap and management concern priori-ties. Some species are a priority in more than one of the three evaluation categories (see Appendix G). In comparison, the 2005 WAP listed 10 freshwater snails as priority species, which may have included concerns for knowledge gaps. However, the 2005 Taxa Team evaluations did not identify knowledge-gaps or management concerns as separate priorities. These changes do not necessarily indicate a change in the concern status of these species; they are more likely a result of different evaluation methodologies from the 2005 process (see Appendix F), an indication of increased knowledge about certain species, or a reflection of the lack of knowledge that forms the need for research.

Table 3.27 provides a list of changes from the 2005 priority species list.

TABLE 3.27 Aquatic and land snails: comparison of changes from 2005 WAP

2005		2015 Changes		
Common Name	Scientific Name	Common Name	Scientific Name	Comment
Blackwater Ancylid	*Ferrissia hendersoni*	-	-	No longer a conservation priority
Seep Mudalia	*Leptoxis dilatata*	-	-	No longer a conservation priority
Rotund Mystery Snail	*Viviparus intertextus*	-	-	No longer a conservation priority

In the sections below, we highlight specific conservation issues related to SGCN and their habitats. This is not an exhaustive list of species-specific conservation concerns, but rather highlights some of the concerns in the state. Recommendations for priority survey, monitoring, and research studies, conservation actions, and partnerships are outlined in Section 3.9.8.

3.9.3 Conservation Concerns

While efforts to protect healthy aquatic habitats benefits all aquatic species, including aquatic snails, efforts directed specifically to conserve freshwater gastropods have lagged behind efforts to conserve other freshwater species (Lysne et al. 2008). Very little research has addressed gastropods found in large river systems but snails in these systems are subject to the same threats in regulated waters as protected mussel species (Brown et al. 1998; Haynes et al. 1999; Brown 2001, 2001; Greenwood and Thorp 2001).

Published research on freshwater gastropods has focused on their effects on algae in small-order streams or have focused on pulmonate snails (snails that have a lung and are hermaphroditic) which are rare in large river systems (Greenwood and Thorp 2001). Because prosobranch species do not disperse over land, habitat fragmentation, such as the presence of dams, can isolate populations and increase the risk for local extirpation or extinction (Greenwood and Thorp 2001).

Saltwater intrusion poses a significant threat to species in freshwater coastal systems.

3.9.4 Knowledge Gaps

We have many knowledge gaps for snails in the state. Limitations include staff time and resources devoted to this taxon. The first step in a successful gastropod conservation program is to gain an understanding of the diversity of taxa that exist (Perez and Minton 2008; Lysne et al. 2008). The need for adequate inventories of extant taxa and an understanding of distributional trends of those taxa is urgent (Lydeard et al. 2004; Wilson 2005; Lysne et al. 2008). Dispersal abilities, life histories, and habitat requirements are not well understood for most species in North Carolina.

There is a great deal of taxonomic uncertainty as well. Many of the land snails in the family Zonitidae (glass snails) have not been described and very little has been published about their ecology, reproductive biology, or egg laying behavior. As new data are gathered and new species are described taxonomic knowledge databases need to be updated. Molecular/DNA studies can aid in taxonomic clarification and species detection. Simultaneously providing a description of community composition will provide ecological context that will benefit conservation planning (Lysne et al. 2008). There is uncertainty regarding the effects of pollutants on populations of freshwater snails, which continuing research help to clarify.

In addition to the SGCN priorities listed in Table 3.26, the species for which the Taxa Team determined there are research priorities because of knowledge gaps are identified in Table 3.28.

3.9.5 Management Needs

Captive propagation and reintroduction of imperiled snails continues to be explored as a conservation measure. Techniques include rearing snails in captivity for subsequent release into known historic range or other refugia. Other techniques may include relocation or translocation of eggs, juveniles, or adults from viable populations to augment extant

TABLE 3.28 Aquatic and land snail knowledge-gap priority species

Family	Scientific Name	Common Name	Federal/ State Status*
Aquatic Snails			
Viviparidae	*Cipangopaludina japonica*	Japanese Mystery Snail [Exotic]	—
	Cipangopaludina chinensis	Chinese Mystery Snail [Exotic]	—
Pomatiopsidae	*Pomatiopsis lapidaria*	Slender Walker	—
Land Snails			
Arionidae	*Arion circumscriptus*	Brown-banded Arion [Exotic]	—
	Arion fasciatus	Orange-banded Arion [Exotic]	—
	Arion subfuscus	Dusky Arion [Exotic]	—
Bulimulidae	*Bulimulus tennuissimus*	a terrestrial snail [Exotic]	—
	Bulimulus tennuissimus puellaris	a terrestrial snail [Exotic]	—
Cionellidae	*Cochlicopa lubrica*	Glossy Pillar	—
Haplotrematidae	*Haplotrema kendeighi*	Blue-footed Lancetooth	—/SC
Helicarionidae	*Guppya sterkii*	Sterki's Granule	—
	Helicodiscus notius	Tight Coil	—
	Helicodiscus parallelus	Compound Coil	—
	Lucilla scintilla	Oldfield Coil	—
Polygyridae	*Allogona profunda*	Broad-banded Forestsnail	—
	Appalachina chilhoweensis	Queen Crater	—/SC
	Appalachina sayanus	Spike-lip Crater	—
	Daedalochila postelliana	Coastal Liptooth	—
	Euchemotrema fraternum	Upland Pillsnail	—
	Fumonelix jonesiana	Big-tooth Covert	—
	Inflectarius kalmianus	Brown Globelet	—
	Lobosculum pustuloides	Tiny Liptooth	—
	Mesodon clausus	Yellow Globelet	—
	Mesodon elevatus	Proud Globe	—
	Mesodon normalis	Grand Globe	—
	Mesodon thyroidus	White-lip Globe	—
	Mesodon zaletus	Toothed Globe	—
	Neohelix albolabris	Whitelip	—
	Neohelix dentifera	Big-tooth Whitelip	—

Family	Scientific Name	Common Name	Federal/ State Status*
Polygyridae (Cont.)	*Neohelix major*	Southeastern Whitelip	—
	Neohelix solemi	Coastal Whitelip	—
	Patera appressa	Flat Bladetooth	—
	Patera laevior	Smooth Bladetooth	—
	Patera perigrapta	Engraved Bladetooth	—
	Polygyra cereolus	Southern Flatcoil	—
	Stenotrema altispira	Highland Slitmouth	—
	Stenotrema barbatum	Bristled Slitmouth	—
	Stenotrema barbigerum	Fringed Slitmouth	—
	Stenotrema hirsutum	Hairy Slitmouth	—
	Stenotrema magnafumosum	Appalachian Slitmouth	—
	Stenotrema stenotrema	Inland Slitmouth	—
	Triodopsis affinis	a pinhole threetooth	—
	Triodopsis burchi	Pittsylvania Threetooth	—
	Triodopsis fallax	Mimic Threetooth	—
	Triodopsis fulciden	Dwarf Threetooth	—/ SC
	Triodopsis hopetonensis	Magnolia Threetooth	—
	Triodopsis juxtidens	Atlantic Threetooth	—
	Triodopsis messana	Pinhole Threetooth	—
	Triodopsis obsoleta	Nubbin Threetooth	—
	Triodopsis pendula	Hanging Rock Threetooth	—
	Triodopsis tridentata	Northern Threetooth	—
	Xolotrema denotatum	Velvet Wedge	—
Punctidae	*Punctum blandianum*	Brown Spot	—
	Punctum minutissimum	Small Spot	—
	Punctum smithi	Lamellate Spot	—
	Punctum vitreum	Glass Spot	—
Pupillidae	*Columella simplex*	a column	—
	Gastrocopta armifera	Armed Snaggletooth	—
	Gastrocopta contracta	Bottleneck Snaggletooth	—
	Gastrocopta corticaria	Bark Snaggletooth	—
	Gastrocopta pentodon	Comb Snaggletooth	—
	Gastrocopta procera	Wing Snaggletooth	—
	Gastrocopta riparia	Gulf Coast Snaggletooth	—
	Gastrocopta rupicola	Tapered Snaggletooth	—
	Gastrocopta tappaniana	White Snaggletooth	—
	Pupoides albilabris	White-lip Dagger	—
	Vertigo alabamensis	Alabama Vertigo	—
	Vertigo gouldii	Variable Vertigo	—
	Vertigo malleata	Malleated Vertigo	—

Table 3.28 Aquatic and land snail knowledge-gap priority species (cont.)

Family	Scientific Name	Common Name	Federal/ State Status*
Pupillidae (Cont.)	*Vertigo milium*	Blade Vertigo	—
	Vertigo oralis	Palmetto Vertigo	—
	Vertigo oscariana	Capital Vertigo	—
	Vertigo ovata	Ovate Vertigo	—
	Vertigo teskeyae	Swamp Vertigo	—
Spiraxidae	*Euglandina rosea*	Rosy Wolfsnail	—
Strobilopsidae	*Strobilops aeneus*	Bronze Pinecone	—
	Strobilops labyrinthicus	Maze Pinecone	—
	Strobilops texasianus	Southern Pinecone	—
Subulinidae	*Allopeas clavulinum*	Spike Awlsnail [Exotic]	—
Succineidae	*Catinella oklahomarum*	Detritus Ambersnail	—
	Catinella vermeta	Suboval Ambersnail	—
	Novisuccinea ovalis	Oval Ambersnail	—
	Succinea forsheyi	Spotted Ambersnail	—
	Succinea indiana	Xeric Ambersnail	—
Valloniidae	*Vallonia pulchella*	Lovely Vallonia	—
Zonitidae	*Gastrodonta interna*	Brown Bellytooth	—
	Glyphyalinia carolinensis	Spiral Mountain Glyph	—
	Glyphyalinia cumberlandiana	Hill Glyph	—
	Glyphyalinia indentata	Carved Glyph	—
	Glyphyalinia praecox	Brilliant Glyph	—
	Glyphyalinia rhoadsi	Sculpted Glyph	—
	Glyphyalinia sculptilis	Suborb Glyph	—
	Glyphyalinia solida	Solid Glyph	—
	Glyphyalinia umbilicata	Texas Glyph	—
	Glyphyalinia wheatleyi	Bright Glyph	—
	Mesomphix andrewsae	Mountain Button	—
	Mesomphix cupreus	Copper Button	—
	Mesomphix perlaevis	Fragile Button	—
	Mesomphix rugeli	Wrinkled Button	—
	Mesomphix subplanus	Flat Button	—
	Oxychilus alliarius	Garlic Glass-snail [Exotic]	—
	Paravitrea andrewsae	High Mountain Supercoil	—/SC
	Paravitrea capsella	Dimple Supercoil	—
	Paravitrea lamellidens	Lamellate Supercoil	—/SC
	Paravitrea multidentata	Dentate Supercoil	—
	Striatura ferrea	Black Striate	—
	Striatura meridionalis	Median Striate	—
	Ventridens acerra	Glossy Dome	—

Family	Scientific Name	Common Name	Federal/ State Status*
Zonitidae (Cont.)	*Ventridens cerinoideus*	Wax Dome	—
	Ventridens coelaxis	Bidentate Dome	—/SC
	Ventridens collisella	Sculptured Dome	—
	Ventridens decussatus	Crossed Dome	—
	Ventridens demissus	Perforate Dome	—
	Ventridens gularis	Throaty Dome	—
	Ventridens intertextus	Pyramid Dome	—
	Ventridens lawae	Rounded Dome	—
	Ventridens ligera	Globose Dome	—
	Ventridens pilsbryi	Yellow Dome	—
	Ventridens theloides	Copper Dome	—
	Vitrinizonites latissimus	Glassy Grapeskin	—
	Zonitoides arboreus	Quick Gloss	—
	Zonitoides elliotti	Green Dome	—

* See Table 3.2 for abbreviations.

populations or establish new populations in suitable habitats. None of these approaches are without risks, such as reduction of genetic material and inbreeding, introduction of disease from individuals released into the wild, and loss of species held captive from human error or equipment failure (Snyder et al. 1996; USFWS 2000; Lysne et al. 2008), but these must be balanced against the extremity of threat to both the species in question and the taxon as a whole.

3.9.6 Threats and Problems

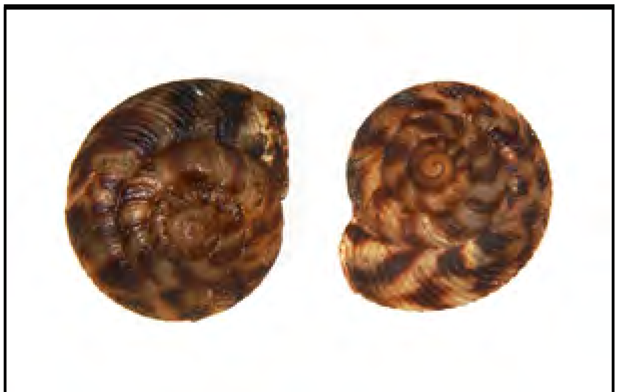
Chapter 5 describes 11 categories of threats the Taxa Team considered during the evaluation and ranking process to identify SGCN; information about the expected scope and severity of the impacts from these threats is available in Appendix G. Since there is a significant lack of information about aquatic and land snails in the state, the evaluation results for Metric 9 do not adequately assess anticipated impacts from threats for nearly all species considered during the evaluations. The results do indicate the threats most likely to create significant impacts on populations of Magnificent Rams-horn and Greenfield Rams-horn in North Carolina over the next 10 years include the following:

Magnificent Rams-horn (Andy Wood, Coastal Plain Conservation Group)

- residential and commercial development
- agriculture and aquaculture
- transportation and service corridors
- human intrusions and disturbance
- natural system modifications
- pollution
- climate change and severe weather

Acid deposition from air pollution can affect soil calcium levels, which in turn may affect snails. An association has been made between snail abundance and diversity and availability of calcium (from soil cations, detritus, plants) for regulation of bodily processes, reproduction, and shell building (Burch 1962; Fournie and Chetail 1984; Nekola 1999; Nekola and Smith 1999; Kalisz and Powell 2003; Hickman et al. 2003; Dourson 2013). Snails play a critical role in concentrating calcium (in shells) which then becomes available to species in higher trophic levels, especially birds that need calcium for egg shells (Skeldon et al. 2007). Some research suggests that snail abundance and diversity can serve as an indicator for the effects of acid deposition (Hamburg et al. 2003; Skeldon et al. 2007).

Contamination of freshwater habitats by chemicals, sediments, heavy metals and other substances has been recognized as a serious ecological impact to wildlife. Chemicals that affect survival and persistence (e.g., EDCs) in vertebrates and other mollusks can also affect freshwater snails (Fox 2005; Iguchi and Katsu 2008). There is also growing concern for salinization of freshwater systems from man-made sources such as road deicing, wastewater and mining effluents, oil and gas extraction methods, agricultural practices (Suski et al. 2012), and upstream encroachment of salt water (salt wedge) facilitated by increased navigational dredging and sea level rise.



Flamed Tigersnail (Phil Myers, Museum of Zoology, University of Michigan-Ann Arbor)
http://www.biokids.umich.edu/critters/Mollusca/pictures/resources/contributors/phil_myers/ADW_molluscs3_4_03/Anguispira_alternata3972/
Used under license CC BY-NC-SA 3.0

Species invasions have a demonstrated detrimental effect on the biodiversity of all mollusks, including snails (Lydeard et al. 2004; Lysne et al. 2008), directly through competition for resources, such as food and space, and indirectly through changes in ecosystem function (Hall et al. 2003; Richards 2004; Kerans et al. 2005; Lysne et al. 2008).

Many species of terrestrial gastropod, including those found throughout North Carolina, are known to be a vector for common parasites. For instance, the Flamed Tigersnail is known to be an intermediary host for *Parelaphostrongylus tenuis*, a common meningeal nematode parasite of White-tailed Deer and other ungulate species (Lankester and Anderson 1968; Anderson and Prestwood 1981; Garvon and Bird 2005).

North Carolina is home to the only known population of the state-listed endangered Greenfield Rams-horn, a large planorbid snail historically found only in Greenfield Lake and Orton Pond. Likewise, the Magnificent Rams-horn was historically known from two freshwater ponds in Brunswick County. When populations are so small, confined to specific landscapes, or associated with unique habitats, they are at extreme risk of extinction from any threat but moreso from transportation, utility, and development (Mallin 2010).

3.9.7 Additional Information

In 2013, the AFS Endangered Species Committee on freshwater gastropods developed a list of snails in Canada and the United States found in freshwater habitats. The Committee's assessment indicates that about 64% of freshwater snails are in some level of imperilment, including 53 species found in North Carolina, and another 10% are considered extinct. More information is available on the USGS website: http://fl.biology.usgs.gov/afs_snail/index.html.

Collections on land snails can be found at a number of museums around the country. Review of those collections will be critical to better verify species identifications and distributions for records pertaining to North Carolina. Collections are available at the

- NC Museum of Natural Sciences, Raleigh, NC. The Invertebrates Collection is worldwide in scope, with emphasis on localities in the eastern United States. The core of the holdings are collections acquired from state agencies (e.g., NCWRC), the Institutes of Marine Sciences (IMS), and a private collection from Herbert D. Athearn, Tennessee, which contains over 23,000 lots of freshwater mollusks: http://www.naturalsciences.org/research/invertebrates-collection.

- Field Museum of Natural History, Chicago, IL. The collections of L. Hubricht are available on the web.

- Academy of Natural Sciences, Philadelphia, PA. The collections of H. A. Pilsbry are housed here, which form the basis for the monograph of land snails of North America (see key references).

- Florida Museum of Natural History, Gainesville, FL. John Slapcinsky is conducting work on the family Zonitidae of western North Carolina; computerized collections.
- Carnegie Museum of Natural History, Pittsburgh, PA. Tim Pearce has a very large land snail collection which should be reviewed for North Carolina records.
- Ohio State Museum of Zoology. Tom Watters has a computerized collection of land snails that may contain information on western North Carolina species.

The Freshwater Mollusk Conservation Society (molluskconservation.org) is dedicated to the conservation of and advocacy for freshwater mollusks, North America's most imperiled taxon. The organization publishes *Walkerana: The Journal of the Freshwater Mollusk Conservation Society*, newsletters, and reports.

A recent publication by Dourson (2013) provides an inventory of the land snails found in the Great Smoky Mountains National Park and Southern Appalachians. Other published resources include older materials such as:

- Bayard Burch J. 1962. *How to know the eastern land snails. Picture-keys for determining the land snails of the United States occurring east of the Rocky Mountain Divide*. Dubuque (IA): William C. Brown Co.
- Bayard Burch J, Shrader Van Devender A. 1980. *Identification of eastern North American land snails. The Prosobranchia, Opisthobranchia and Pulmonata (Actophila)*. Ann Arbor (MI): University of Michigan.
- Bayard Burch J. 1982. *Freshwater snails (Mollusca: Gastropoda) of North America*. EPA-600/3-82-026. Cincinnati (OH): US Environmental Protection Agency, Environmental Monitoring and Support Laboratory.
- Hubricht L. 1985. *The distributions of the native land mollusks of the eastern United States. FieldianaZoology*, new ser. no. 24. Available online at http://www.biodiversitylibrary.org/bibliography/3329#/summary.

3.9.8 Recommendations

In general, protection and restoration of natural community composition and function and protection of surrounding natural areas under current conditions are the best ways to ensure suitable habitats are available for this taxon. Measures that protect a large and diverse pool of populations are the best way to ensure that species are able to survive future stresses and adapt to changing climate conditions.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Conduct a thorough statewide survey to confirm species distributions beyond river basin and county inventories.
- Continue species distribution surveys for SGCN and knowledge-gap priority species.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Conduct long-term monitoring to identify population trends.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Review existing collections to verify NC species records.
- Conduct much-needed taxonomic review on most snails, especially those in family Zonitidae.
- Focus research on life history of SGCN and knowledge gap priority species, including habitat use/preference, fecundity, population dynamics, feeding, competition, and vulnerability to predation.
- Continue to investigate captive-propagation and reintroduction techniques for rare snail species (e.g., Magnificent Rams-horn, Greenfield Rams-horn) (Lysne et al 2008).
- Investigate species considered a host or vector for pathogens or parasites, their prevalence, and pathways for infection of White-tailed Deer and other ungulate species. Studies may include collection and testing of deer and elk fecal samples, brain tissue, or vertebral canal tissue (Slomke et al. 1995).

Management Practices. Management practices that reduce habitat impacts and work synergistically with other conservation actions are needed to enhance the resilience of this taxon. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

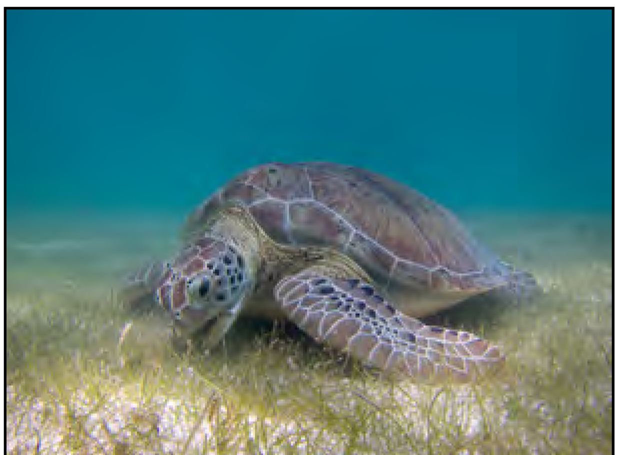
Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it increases ecosystem resilience.

3.10 Marine Species

3.10.1 Introduction

The management and protection of migratory, pelagic, or other marine species fall under a host of jurisdictions in North Carolina depending on the location of the species at a given point in time. Similarly, there is inter-jurisdictional responsibility for management of coastal, estuarine and marine habitats that are critical to marine species survival. This presents a constant challenge to resource managers because coordinated efforts among multiple agencies are necessary to manage the fish and wildlife resources of the state effectively. Four agencies have jurisdiction and authority over particular estuarine and marine (aquatic) species in the state:

- National Oceanic and Atmospheric Administration (NOAA) Fisheries
- US Fish and Wildlife Service (USFWS)
- NC Division of Marine Fisheries (NCDMF)
- NC Wildlife Resources Commission (NCWRC), when the species are in inland waters.



Green Sea Turtle (P. Lindgren WikiMedia) https://commons.wikimedia.org/wiki/User:P.Lindgren#/media/File:Green_Sea_Turtle_grazing_seagrass.jpg. Used under license CC BY-NC-SA 2.5

Marine and pelagic species were not directly prioritized during the Taxa Team evaluation process primarily for reasons of jurisdictional limitations and lack of information. However, marine species and habitats are a critical resource for North Carolina, and the management and conservation of those resources are high priorities. The information provided in this section was developed by reviewing existing information sources on marine and pelagic species and habitats and through review and input by partner organizations that are directly responsible for managing these resources. Pelagic bird species are addressed as a separate topic in Section 3.11.

Table 3.29 lists marine or estuarine species known to occur currently or historically in North Carolina coastal waters that are SGCN priority species. Note that sea turtle species were included in the Taxa Team evaluation of reptiles because they use terrestrial habitats (beaches) for nesting; therefore, sea turtles are also included in the reptile SGCN list (see Section 3.8) .

3.10.2 Federal Regulations

Under the Marine Mammal Protection Act (MMPA), all marine mammals are protected from take in US waters and by US citizens on the high seas, and marine mammals and marine mammal products are prohibited from importation into the United States. The NOAA Fisheries is responsible for the management, conservation, and protection of living marine resources within the US Exclusive Economic Zone (3 to 200 miles offshore), including sea turtles, marine and anadromous fish, plants and invertebrates, cetaceans, and

Table 3.29 SGCN marine species

Taxon	Scientific Name	Common Name	Federal/ State Status*
FISH	*Acipenser brevirostrum*	Shortnose Sturgeon	E/E
	Acipenser oxyrinchus	Atlantic Sturgeon	E/E
	Pristis pectinata	Smalltooth Sawfish	E/E
MAMMAL	*Balaenoptera physalus*	Fin Whale	E/E
	Eubalaena glacialis	Northern Right Whale	E/E
	Megaptera novaeangliae	Humpback Whale	E/E
	Physeter catodon [microcephalus]	Sperm Whale	E/E
	Trichechus manatus	West Indian Manatee	E/E
REPTILE	*Caretta caretta*	Loggerhead Sea Turtle	T/T
	Chelonia mydas	Green Sea Turtle	**T/T
	Dermochelys coriacea	Leatherback Sea Turtle	E/E
	Eretmochelys imbricata imbricata	Hawksbill Sea Turtle	E/E
	Lepidochelys kempii	Kemp's Ridley Sea Turtle	E/E
	Malaclemys terrapin	Diamondback Terrapin	SC

* See Table 3.2 for abbreviations.

** The juvenile foraging population of Green Sea Turtles found in the inshore waters of North Carolina comprises a mix of turtles from threatened and endangered populations, representing turtles from nesting populations in Florida that are designated as endangered and individuals from the Caribbean that are designated as threatened.

pinnipeds. The NOAA Fisheries jurisdiction also extends into state waters for protected marine species. Central to that mission are the objectives to protect ocean, coast, and Great Lakes resources, to recover protected species, and to rebuild and maintain sustainable fisheries.

The NOAA Fisheries Office of Protected Resources (OPR) is charged with the implementation of the Endangered Species Act (ESA) of 1973 for marine and anadromous species. The OPR develops, implements, and administers programs for the protection, conservation, and recovery of species protected under the ESA. This office also develops and implements policies, procedures, and regulations for permits to take (harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect) listed species according to the ESA. The NOAA Fisheries has developed and is responsible for implementation of recovery plans for threatened and endangered marine species. Recovery plans are available for several species from this web page: http://www.nmfs.noaa.gov/pr/conservation. In addition to these plans, marine mammal stock assessment reports for all Atlantic species are available from the following web page: http://www.nmfs.noaa.gov/pr/sars/species.htm.

Smalltooth Sawfish (David Iliff, WikiMedia Commons) https://en.wikipedia.org/wiki/Sawshark#/media/File:Pristis_pectinata_-_Georgia_Aquarium_Jan_2006.jpg. Used under license CC BY-SA 2.5

The Highly Migratory Species Division of NOAA Fisheries manages Atlantic highly migratory species (HMS), including tunas, sharks, swordfish, and billfish, and implements the Fishery Management Plans (FMPs) for Atlantic tunas, swordfish, and sharks. Management of HMS requires international cooperation, and rebuilding programs must reflect traditional participation in the fisheries by US fishermen, relative to foreign fleets. Along with the Magnuson–Stevens Act, US fisheries management must be consistent with the requirements of other laws, including the Atlantic Tunas Convention Act, Marine Mammal Protection Act, the Endangered Species Act, the Migratory Bird Treaty Act, and several other federal laws.

3.10.3 State Regulations

North Carolina is a member of the Atlantic States Marine Fisheries Commission (ASMFC). The ASMFC represents the 15 Atlantic coast states as a deliberative body, coordinating the conservation and management of shared nearshore (within state waters) fishery resources (marine, shell, and anadromous species) for sustainable use. The ASMFC promotes interstate fisheries management, law enforcement, research and statistics, fisheries, science, and habitat conservation.

The NC Division of Marine Fisheries (NCDMF) is responsible for the stewardship of the state's marine and estuarine fisheries resources. NCDMF jurisdiction encompasses all coastal waters and extends to three miles offshore. The agency actively participates in federal and regional management of migratory species by providing technical guidance, assisting with coastwide or regional fishery management issues, and working cooperatively with other state and federal agencies.

3.10.4 Conservation Concerns

NOAA Fisheries grants at-risk marine mammal species a variety of protection levels under the ESA and the MMPA. Among these are endangered status, threatened status, and depleted status. Under the MMPA, a species is designated as depleted when it falls below its optimum sustainable population. Once a species has been designated as depleted, a conservation plan is developed to guide research and management actions to restore the health of the species.

Some federally protected species, such as sea turtles, receive significant attention when nesting on our beaches, but the majority of their lives are spent at sea. There is great need to continue cooperative efforts among regulatory and management agencies to expand our understanding of and protection for those species.

Designation as a Federal Species of Concern (FSC) carries no legal protection status under ESA. Only those species that are being actively considered a Candidate species for listing are protected under the ESA. Similar levels of federal and state listings such as MMPA Depleted or the state Significantly Rare (SR) designation indicate conservation concern for marine species (NCNHP).

Musick et al. (2000) identified marine, estuarine, and diadromous fish stocks at risk of extinction in North America. While the North Carolina coast is not an identified "hotspot" for species at risk, our coastal waters fall within the potential range of 17 species listed in the publication, 7 of which do not carry any listing status.

Table 3.30 provides a list of marine species for which there are other listing status designations and those which are considered "at risk" species whose current or historical range includes North Carolina coastal or offshore waters.

Some of the species discussed above may also be found in estuarine or inland waters (e.g., Diamondback Terrapin, West Indian Manatee, anadromous fish) or on North Carolina beaches (e.g., sea turtles). Others not directly mentioned above may also use marine or estuarine environments (e.g., beach-nesting birds). For those typically marine species that are also associated with coastal estuaries and beaches or that travel into inland waters, we

Table 3.30 Other status designations and at-risk marine species of conservation concern

Scientific Name	Common Name	Federal Status*	Risk Category: Factor(s)**
Carcharhinus obscurus	Dusky Shark	FSC	V: L
Carcharhinus signatus	Night Shark	FSC	—
Carcharodon carcharias	White Shark	FMP	CD: L
Cetorhinus maximus	Basking Shark	FMP	CD: L
Dermatolepis inermis	Marbled Grouper	—	V: R, L
Epinephelus drummondhayi	Speckled Hind	FSC	E: L
Epinephelus itajara	Goliath Grouper	FSC	—
Epinephelus flavolimbatus	Yellowedge Grouper	—	E: L
Epinephelus nigritus	Warsaw Grouper	FSC	E: L
Epinephelus niveatus	Snowy Grouper	—	V: L
Epinephelus striatus	Nassau Grouper	FSC	—
Mycteroperca bonaci	Black Grouper	—	V: L
Mycteroperca microlepis	Gag	—	V: L
Mycteroperca phenax	Scamp	—	V: L
Odontaspis taurus	Sand Tiger Shark	FSC	V: L
Raja laevis	Barndoor Skate	FSC	V: L
Rhincodon typus	Whale Shark	FMP	CD: R, L
Tursiops truncatus	Western North Atlantic Coastal Bottlenose Dolphin	MMPA — Depleted	—

* See Table 3.2 for FSC definition; other abbreviations described above.

** Risk Category:

CD—Conservation Dependent: reduced but stabilized or recovering under a continuing conservation plan.

E—Endangered: high risk of extinction in the wild in the immediate future.

V—Vulnerable: special concern; not endangered or threatened severely, but at possible risk of falling into one of those categories in the near future.

** Risk Factor(s):

L—Life history limitations

R—Rarity

V—Vulnerable habitat

have addressed appropriate conservation needs within those particular habitat types (see Chapter 4 Habitats).

3.10.5 Knowledge Gaps

Surveys, monitoring, and research of estuarine and marine species is difficult, making the collection of data, the synthesis of information, and the protection of those species that much more challenging. There have been no recent systematic accounts of species rarity or distribution for marine or estuarine fish species in the state (LeGrand et al. 2004).

The NOAA Fisheries OPR establishes cooperative agreements with states regarding listed species management and protection and identifies endangered species research needs to collect appropriate information for management decisions. For example, NOAA Fisheries has a cooperative agreement with NCWRC regarding sea turtle nesting and strandings on North Carolina beaches.

3.10.6 Management Needs

The FMPs developed by regional Fishery Management Councils (FMCs) for species commercially and recreationally harvested are implemented by NOAA Fisheries Regional Offices. North Carolina is a member of two fishery management councils: the Mid-Atlantic Fishery Management Council (MAFMC) and the South Atlantic Fishery Management Council (SAFMC).

- The MAFMC is responsible for management of fisheries in federal waters that occur predominantly off the mid-Atlantic coast from North Carolina to New York.
- The SAFMC is responsible for the conservation and management of fish stocks within the federal 200-mile limit of the Atlantic off the coasts of North Carolina, South Carolina, Georgia, and Florida (east coast only to Key West).

Table 3.31 lists the species for which the regional FMCs have developed management plans.

The FMPs for NC marine resources can be found online at the MAFMC website (www.mafmc.org/) and the SAFMC website (safmc.net/). The SAFMC resource library provides FMPs for species managed by the Councils, including coastal migratory pelagics (mackerels), bluefish, flounder, and shrimp, as well as marine habitats.

The NCDMF is also responsible for preparing interstate FMPs for adoption by the NCMFC for all commercially and recreationally significant species or fisheries that comprise state marine or estuarine resources. The goal of these plans is to ensure long-term viability of these fisheries. State FMPs have been developed for Blue Crab, Hard Clam, Oyster , Red Drum, Southern Flounder, Striped Bass, and Striped Mullet.

The NCDMF Habitat Protection Section is responsible for the development of the Coastal Habitat Protection Plan (CHPP) (Street et al. 2004) to conserve and protect important marine fisheries habitat (see Chapter 4 for more information on estuarine habitats).

Table 3.31 Species and regional FMP development and implementation responsibility

Mid-Atlantic FMPs	South Atlantic FMPs	
Species (Common Name)	Groups	Species (Common Name)
Summer Flounder	Coastal Migratory Pelagics (3 spp.)	Golden Crab
Scup	Dolphin and Wahoo (2 spp.)	Wreckfish
Black Sea Bass	Shrimp (5 spp.)	Hogfish
Atlantic Mackerel	Sea Basses and Groupers (20 spp.)	Atlantic Spadefish
Longfin Squid	Snappers (14 spp.)	Spiny Lobster
Illex Squid	Porgies (7 spp.)	Sargassum
Butterfish	Grunts (5 spp.)	
Ocean Quahog	Jacks (5 spp.)	
Atlantic Surfclams	Tilefishes (3 spp.)	
Bluefish	Triggerfishes (2 spp.)	
Golden Tilefish	Coral, Coral Reefs and Live/Hard Bottom Habitats	
Spiny Dogfish		
Monkfish		

MAFMPs and Amendments: http://www.mafmc.org/fishery-management-plans
SAFMPs and Amendments: http://safmc.net/resource-library/fishery-management-plans-amendments

3.10.7 Threats and Problems

The successful conservation of marine species will require the mitigation of threats both within NC borders and beyond. Thus, interstate and international partnerships and cooperation are critical components of marine species conservation. Descriptions of the threats listed below were taken from various marine species recovery plans. Recovery plans can be accessed at http://www.nmfs.noaa.gov/pr/PR3/recovery.html.

3.10.7.1 Nesting Threats

These onshore threats primarily impact beach-nesting sea turtles and birds.

- *Beach erosion*—Erosion can result in partial or total loss of suitable nesting habitat. Coastal development and associated activities have accelerated erosion rates and interruption of natural shoreline migration.

- *Shoreline modifications*—Fortifications put in place as a result of shoreline development (including sand fences, sea walls, rip rap, groins, jetties) can accelerate beach erosion rates and reduce available nesting habitat; improperly placed drift fences can impede nesting attempts and/or trap hatchlings or nesting female sea turtles.

- *Beach nourishment*—If nourishment occurs during nesting season, direct impacts can include burial of nests and nest disturbance. Dissimilar sand sources can impact site selection, digging behavior, incubation, and hatchling success. Beach nourishment can also result in significant compaction or concretion of the beach.

- *Artificial lighting*—Lighting associated with beachfront development (residences, street lights, vehicles) can severely impact emerging hatchlings by causing disorientation, which drastically increases fatalities. Artificial lighting can attract hatchlings, causing them to move in the opposite direction of the water, which then exposes them to predators, entrapment in vegetation, and/or vehicle strikes. Adult nesting sea turtles may abort nesting attempts at greater frequencies near lighted areas.

- *Beach cleaning*—Mechanical raking (using heavy machinery) can compact or destroy nests. Disposal of debris near the dune line can cover incubating clutches, entrap emergent hatchlings, and/or alter nest temperatures.

- *Increased human presence*—Disturbance to nesting sea turtles is the most critical threat caused by human presence on beaches. Night-time human activity can cause female turtles to abort nesting attempts.

- *Recreational beach equipment (including vehicular driving)*—Beach chairs, tents, and other recreational equipment can directly impact nests (covering or disturbing incubating nests) or indirectly cause disturbance such that female turtles abort nesting attempts. Vehicle use on beaches has similar effects to heavy machinery used in beach-cleaning efforts (compact or destroy nests, entrap nestlings); vehicle lighting can disorient hatchlings and adults alike.

- *Military exercises*—Training activities on coastal shorelines have the potential to disrupt nesting behavior and increase non-nesting emergences of nesting females, run over nesting females and emerging hatchlings, and destroy nests.

- *Exotic dune and beach vegetation*—Nonnative vegetation can out-compete native vegetation such as sea oats and dune grass. Often less stabilizing, nonnative vegetation can lead to erosion and degradation of nesting habitat.

- *Nest depredation*—Predation by ghost crabs, raccoons, foxes, or fire ants (among others) is a significant threat to eggs and hatchlings (both sea turtle and shorebirds). Disorientation of emergent hatchlings by artificial lighting increases their chances of being depredated by one of these animals.

- *Poaching*—Illegal harvest of eggs (primarily sea turtle) from nests is unlikely but does occur.

3.10.7.2 Marine Threats

These threats are water related and may impact sea turtles, fish species, and marine mammals.

- *Vessel interactions (including collisions)*—Propeller and collision injuries are a significant threat, especially to marine mammals and sea turtles. These types of injuries are reported at higher frequencies in areas that have heavy boat and vessel traffic.

- *Oil and gas exploration*—Oil spills have been shown to impact respiration, blood chemistry, and salt-gland function in sea turtles. Spills in the vicinity of nesting beaches can place nesting adults, eggs, and hatchlings at significant risk. Oil deposits on the ocean floor can reduce food sources for all marine species and result in ingestion of tar balls. In addition to suffering effects from spills, sea turtles and other marine species can be negatively impacted by seismic surveys, operational discharge containing heavy metals, explosive platform removal (mentioned below), platform lighting, and noise from drill ships and production activities.

- *Dredging*—Dredging can result in direct destruction or degradation of habitat and/or incidental take of marine species. Channelization of inshore and nearshore habitats can result in the disposal of dredge material on beaches and shallow habitats, impacting nesting success or foraging grounds.

- *Pollution*—Pesticides, polychlorinated biphenyls (PCBs), and heavy metals have been detected in marine species, though levels that result in adverse effects are difficult to quantify.

- *Fisheries*—Bycatch of marine organisms occurs in a number of different fisheries, including trawl, purse seine, hook and line, gill net, pound net, long-line, and trap fisheries. These interactions often lead to serious injury or death.

- *Power plant entrainment*—Saltwater cooling intake systems at coastal power plants have been reported to entrap marine species.

- *Underwater explosions*—Use of underwater explosives to remove abandoned oil platforms, for military activities, or for oil exploration can result in injury or death to marine species in the vicinity of the explosion.

- *Entanglement*—Marine species can become entangled in a variety of materials other than active fishing gear, including steel or monofilament line, synthetic or natural rope, or discarded plastic material, often resulting in injuries which can lead to weakened individuals who are more susceptible to death by other factors, or to direct mortalities.

- *Ingestion of marine debris*—Marine species may ingest a variety of potentially harmful debris materials, including plastic bags, balloons, styrofoam, and tar balls. Effects of debris ingestion can include obstructions of the gut, absorption of toxic byproducts, and reduced absorption of nutrients.

- *Poaching*—Illegal harvest of marine species has declined considerably since the development and enforcement of protection regulation; however, arrests are still made for illegal capture and possession of marine species.

- *Noise*—The impacts of noise from shipping, industrial, or military activities on the communication, behavior, and distribution of whales and other marine species remains unknown, but is suspected to be significant.

3.10.8 Additional Information

Recovery plans are available, or are in development, for the following federally listed species that can inhabit North Carolina coastal or offshore waters and can be accessed online (http://www.nmfs.noaa.gov/pr/recovery/plans.htm):

- Green Sea Turtle
- Leatherback Sea Turtle
- Loggerhead Sea Turtle
- Kemp's Ridley Sea Turtle
- Hawksbill Sea Turtle
- Shortnose Sturgeon
- Right Whale
- Humpback Whale
- Fin/Sei Whale (*draft*)
- Sperm Whale (*in development*)

Take reduction teams (TRTs) have been formed and convened with the purpose of developing take reduction plans to assist in the recovery or to prevent the depletion of strategic marine mammal stocks that interact with various commercial fisheries. A strategic stock is one which is listed as endangered or threatened under the ESA, is declining and likely to be listed as threatened under the ESA, is listed as depleted under the MMPA, or has direct human-caused mortality exceeding the stock's Potential Biological Removal level (see Glossary). These TRTs consist of a balance of representatives from the fishing industry, fishery management councils, state and federal resource management agencies, the scientific community, and conservation organizations. To date, six TRTs have been established and four represent Atlantic coast resources:

- Atlantic Large Whale Take Reduction Team
- Atlantic Offshore Cetacean Take Reduction Team
- Mid-Atlantic Harbor Porpoise Take Reduction Team
- Western North Atlantic Coastal Bottlenose Dolphin Take Reduction Team

More information on the TRTs and the take reduction plans developed for marine mammal stocks can be found online at the following web page: http://www.nmfs.noaa.gov/pr/interactions/trt/.

Marine mammal stock assessment reports for all Atlantic species can be found online at http://www.nmfs.noaa.gov/prot_res/PR2/Stock_Assessment_Program/individual_sars.html.

Additional FMPs are available for highly migratory Atlantic tuna, swordfish, and shark species and can be found online at http://www.nmfs.noaa.gov/sfa/hms/documents/fmp/tss_fmp/index.html.

3.10.9 Recommendations

In general, protection and restoration of natural community composition and function and protection of surrounding natural areas under current conditions are the best ways to ensure suitable habitats are available for marine species. Measures that protect a large and diverse pool of populations are the best ways to ensure that species are able to survive future stresses and adapt to changing climate conditions. The following recommendations apply broadly to all efforts toward marine species conservation.

Surveys. Distribution and status surveys should focus on SGCN (see Table 3.29) and other priority species believed to be declining or dependent on at-risk or sensitive communities. Specifically, efforts to develop more precise population estimates for all marine taxa are needed.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to waters of the state. Studies include identification of population trends, as well as assessment of conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of the life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration for priority species. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Conduct genetics research to further understand stock structure and breeding population contributions in North Carolina and beyond, especially for Bottlenose Dolphin, Pilot Whale, and Loggerhead and Green sea turtles.
- Examine pollution effects on coastal and estuarine species.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital.

- Support the implementation of FMPs to manage and protect marine species.
- Implement public education and other efforts to reduce discarded “ghost” fishing gear to reduce marine species entanglement; potential development of a fishing line recycling program (potential to model from Florida’s existing monofilament recycling program).
- Improve communications and coordination with other NOAA offices, state and federal marine resource agencies, and universities to combat common threats and develop efficient and effective conservation strategies for all marine species and their habitats.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable.

This improves chances of achieving conservation goals, improves efficiency, and prevents duplication of effort.

- Continue and expand cooperation between NOAA Fisheries and the appropriate state agencies to facilitate marine species management, protection, and research, especially for listed species.
- Support and assist in the attainment of the goals, objectives, strategies, and performance measures set forth in the NOAA Fisheries Strategic Plan (NOAA 2003).
- Support the recommendations put forth in the CHPP (Street et al. 2004) to promote fisheries habitat protection in North Carolina and to facilitate the necessary policy decisions.
- Coordinate between NOAA Fisheries and NCDMF to evaluate interactions between marine mammals, sea turtles, and fishing gear and develop gear modifications where needed.
- Continue cooperation with fisheries resource managers, commercial fishermen, and regulatory agencies to reduce bycatch and unintentional take of protected marine resources (e.g., explore diamondback terrapin bycatch in crab pots).

3.11 Pelagic Seabirds

3.11.1 Introduction

Pelagic seabirds are those species that spend long periods away from land and obtain all or most of their food from the sea while flying, swimming, or diving (Nettleship 1977, 1991) and come to land only to breed. In general, these species are seen primarily away from the sight of land, and thus are typically seen only from boats and ships when in North Carolina waters. Since 1991, the Black-capped, Herald, and Fea's petrels have been recorded annually and photographed on numerous occasions off North Carolina (Brinkley 2012).

The Gulf Stream, a warmwater current that runs roughly parallel to the NC coast, is a critical region for pelagic birds in North Carolina between the months of May and October (especially that segment offshore from Oregon Inlet to south of Cape Hatteras) due to the interplay with the southbound Labrador Current, which creates an upwelling of nutrient-rich waters. Key pelagic species within this Gulf Stream region include the Black-capped Petrel and other tubenoses (family Procellariidae). Cold inshore waters are a critical zone during winter. Key pelagic species associated with this region include Northern Gannet and alcids (family Alcidae).

Bermuda Petrels nest on four small islets that provide less than 3.5 acres breeding habitat in the western North Atlantic Ocean. These nesting sites are highly erodible limestone and prone to being overwashed during storms. While these pelagic birds are endemic to Bermuda, they are known to occur off North Carolina's coast. Several other pelagic species have been reported to occur off the NC coast primarily as they travel between breeding grounds and wintering habitats, and thus are not considered to be "resident" in our waters during either the warmer months or during the winter. Transient species include most jaegers and the Roseate Tern.

Black-capped Petrel (Patrick Coin, WikiMedia) https://en.wikipedia.org/wiki/Blackcapped_petrel#/media/File:Pterodroma_hasitataPCCA20070623-3608B.jpg. Used under license CC BY-SA 2.5

Several pelagic species have been identified as species of concern by the Northwestern Atlantic Marine Bird Conservation Cooperative and ranked by level of concern based on regional, continental, and responsibility concerns (as of 2014). Responsibility was based on the proportion of population occurring in the Northwestern Atlantic region (Maine to Florida). Two species, Roseate Tern and Black-capped Petrel, are federally listed for protection under the federal Endangered Species Act (ESA).

The data are insufficient to determine the conservation needs of pelagic species in North Carolina, therefore they are considered a knowledge gap priority. A list of pelagic seabird species considered a conservation priority in the Southeast (as identified by various bird conservation efforts) and the level of concern as a Northwestern Atlantic region species of concern is provided in Table 3.32.

3.11.2 Conservation Concerns

Two of the species in Table 3.32 are listed by the International Union for Conservation of Nature (IUCN) as endangered (Bermuda Petrel, Black-capped Petrel). A taxon is listed by IUCN as endangered when the best available evidence indicates that it meets any of the evaluation criteria and is therefore considered to be facing a very high risk of extinction in the wild. IUCN evaluation criteria can be found online at http://www.iucnredlist.org/technical-documents/red-list-documents.

Table 3.32 Pelagic seabirds of conservation concern

Family	Scientific Name	Common Name	Level of Concern
Alcidae	*Alca torda*	Razorbill	High
	Alle alle	Dovekie	—
Hydrobatidae	*Oceanites oceanicus*	Wilson's Storm-petrel	—
	Oceanodroma castro	Band-rumped Storm-petrel	High
	Oceanodroma leucorhoa	Leach's Storm-petrel	High
Laridae	*Onychoprion anaethetus*	Bridled Tern	Low
	Onychoprion fuscatus	Sooty Tern	Low
	Sterna dougallii	Roseate Tern (Threatened)	High
Phaethontidae	*Phaethon lepturus*	White-tailed Tropicbird	Low
Procellariidae	*Calonectris diomedea*	Cory's Shearwater	Medium
	Pterodroma arminjoniana	Herald (Trindade) Petrel	—
	Pterodroma cahow	Bermuda Petrel	High
	Pterodroma feae	Fea's Petrel	—
	Pterodroma hasitata	Black-capped Petrel (Endangered)	High
	Puffinus gravis	Great Shearwater	Medium
	Puffinus griseus	Sooty Shearwater	—
	Puffinus lherminieri	Audubon's Shearwater	High
	Puffinus puffinus	Manx Shearwater	Medium
Scolopacidae	*Phalaropus fulicarius*	Red Phalarope	Medium
Stercorariidae	*Stercorarius longicaudus*	Long-tailed Jaeger	—
	Stercorarius parasiticus	Parasitic Jaeger	—
	Stercorarius pomarinus	Pomarine Jaeger	—
Sulidae	*Morus bassanus*	Northern Gannet	High

The SAMBI Pelagic Bird Conservation Plan (SAMBI 2004) and the Southeastern Waterbird Conservation Plan (Hunter et al. 2006) are key resources that identify conservation and management actions for pelagic bird species in the southeastern United States. These plans identify information on ecology and status, priority species, species suites, and habitat requirements, population issues, habitat issues, implementation recommendations and opportunities, conservation strategies, inventory and monitoring needs, research needs, education and outreach needs, and potential partners. Key information taken from those reports is summarized below. The PIF bird conservation plan for the South Atlantic Coastal Plain (Hunter et al. 2001b) also presents similar information.

Where appropriate, the recommendations put forth in the SAMBI Plan should be incorporated into pelagic bird conservation efforts in North Carolina by all partner agencies and organizations. Key needs are detailed for Black-capped and Bermuda Petrels, most of which are in the Caribbean (Bermuda, Hispaniola, Lesser Antilles). It should be noted that some of the SAMBI Plan recommendations are not necessarily attainable in North

Carolina, but are included below to highlight the need for cooperation and coordination among states and countries to effect change.

The impact that conservation efforts in North Carolina can have on pelagic seabirds is less direct, especially since most of the species do not breed in the state (except the occasional Sooty Tern). Key breeding areas for pelagic species include the Arctic region, the north Atlantic, the West Indies/Caribbean, and other portions of the south Atlantic. Still, all efforts to promote activities that aid in research, management, and conservation of pelagic seabird species should be pursued whenever possible in North Carolina.

Pomarine Jaeger (Patrick Coin, WikiMedia)
https://www.flickr.com/photos/pcoin/633585761/

Table 3.33 provides a list of potential partners and partnerships for pelagic bird conservation.

3.11.3 Knowledge Gaps

There is strong evidence that seabird bycatch rates vary by fishing fleet and by area (Yeh et al. 2013). In a summary of studies done in the Atlantic Ocean from 1987 to 2006, reported bycatch rates varied from 0.07 birds per thousand hooks in Canadian fisheries in 2001 to 4.7 per thousand hooks for the fisheries of Uruguay in 1993/1994 (Tuck et al. 2011). A lack of observer data from most member countries constrained the International Commission for the Conservation of Atlantic Tunas (ICCAT) Subcommittee on Ecosystems estimate of the annual seabird bycatch for the entire ICCAT area (e.g., Atlantic Ocean) (ICCAT 2010a; Yeh et al. 2013). The United States is a member of ICCAT and actively participates and supports the protocols and research recommendations developed by the organization.

The ICCAT Standing Committee on Research and Statistics (SCRS) reviewed ecological risk assessments of the impact of ICCAT fisheries on sea turtles and seabird bycatch mitigation measures and recently developed a list of research needs. The recommendations for research topics include a need to review whether ICCAT mitigation measures reflect best practices; to develop indicators that can be used to evaluate the efficiency of mitigation

Table 3.33 Potential partners and partnerships for pelagic bird conservation

State Agencies	Federal Agencies	Conservation Organizations
NC Museum of Natural Sciences	National Marine Fisheries Service, National Oceanic and Atmospheric Administration (NOAA)	Partners in Flight
NC Wildlife Resources Commission	South Atlantic Migratory Bird Initiative (SAMBI) partners	The Waterbird Conservation Council
NC Division of Marine Fisheries	US Fish and Wildlife Service, Region 4 Seabird Working Group; Eastern North Carolina-Southeastern Virginia Strategic Habitat Conservation Team (includes NPS and USGS in addition to USFWS)	Waterbird Monitoring Partnership—Patuxent Wildlife Research Center
Other state fish and wildlife agencies	International Association of Fish and Wildlife Agencies (Shorebird and Waterbird Working Group)	Circumpolar Seabird Working Group
	South Atlantic Fisheries Management Council	Waterbird Society
	Bermuda Ministry of the Environment	Society of Caribbean Ornithology
		National Audubon Society and state Audubon chapters
		American Bird Conservancy
		South Atlantic Landscape Conservation Cooperative
		Bermuda Audubon Society

measures; and to review the estimation methodologies and compile indirect bycatch mortality estimates for sea turtles (ICCAT 2014).

3.11.4 Management Needs

Management of pelagic birds in the United States falls under the jurisdiction of the USFWS. To address concerns about negative interactions with marine fisheries, the NOAA Fisheries Unit (hereafter NOAA Fisheries) works with the USFWS, regional fisheries management councils and coastal states through the Interagency Seabird Working Group. As a part of this Working Group's effort, in 2001 NOAA Fisheries (also National Marine Fisheries Service, NMFS) began implementing the National Plan of Action for Reducing the Incidental Catch of Seabirds in Longline Fisheries (NMFS 2001). In that same year, an Executive Order established that every federal agency whose actions are likely to impact migratory bird populations negatively must enter into a Memorandum of Understanding with the USFWS (Murphy 2004).

Two specific issues relevant to North Carolina include bird bycatch in gillnets (especially for Red-throated Loon, Common Loon, and Northern Gannet) (Hunter 2004b) and pelagic longline bycatch (especially for Black-capped Petrel, Bermuda Petrel, and Audubon's Shearwater) (Hunter 2004a).

Northern Gannet (Brian Patteson)

3.11.5 Threats and Problems

The major issues facing pelagic seabirds in offshore and nearshore waters are conflicts with fisheries, oil and hazardous materials, and debris ingestion and entanglement. Major habitat issues for all species include loss and degradation of habitat. The Southeastern Waterbird Conservation Plan (Hunter et al. 2006) notes pelagic species are vulnerable to conflicts with off-shore fishing gear, colliding with lights on boats and structures during inclement weather, and possibly high mercury contamination in forage (especially fish). Information about threats that require management action is provided in the following paragraphs and in Chapter 5 (Threats).

Fishing Gear. Marine fisheries exact a significant toll on ocean-feeding birds through bycatch—the incidental catching and killing of seabirds. The distribution of many pelagic seabirds overlaps with marine fishing operations making seabird bycatch from longline, demersal longline, trawl, and other pelagic fisheries an important threat (Baker et al. 2007; Watkins et al. 2008; Anderson et al. 2011; Yeh et al 2013). The distribution of many seabird species overlaps with pelagic longline fisheries for tuna, tuna-like species, and sharks (Yeh et al. 2013). The ICCAT reports that fleets from at least 36 countries operating in the Atlantic Ocean were responsible for deploying an average 315 million hooks annually from 2004 to 2008 (ICCAT 2010a; Yeh et al. 2013). ICCAT identified 41 seabird populations of 28 species as being at serious risk from ICCAT longline fisheries (ICCAT 2008). These included one critically endangered, seven endangered, and nine vulnerable species as listed by the IUCN (see IUCN Red List, www.redlist.org).

Longlines, gillnets, and other fishing gear can prove fatal (Forsell 1999). In North Carolina, the Red-throated Loon may be the most heavily impacted by gillnets. Excessive bycatch of forage fish as well as fisheries using the same prey used by waterbirds can reduce the birds' food supplies. Trawls that affect the sea bottom alter the habitat on which the prey of seabirds and coastal waterbirds depend.

Seabirds ingest materials and debris as a natural consequence of foraging. Ingesting plastics and other artificial flotsam can be detrimental. Additionally, seabirds are caught in discarded and/or abandoned fishing line, nets, and other waste.

Black Skimmer (Melissa McGaw, NCWRC)

Oil and Wind Energy. Oil is a major environmental threat to pelagic species, especially along major shipping transportation corridors. Oil may be released during platform construction, offshore drilling, and shipping and spillage. Waterbirds are commonly injured by oil spills, chronic oil discharge in bilge water, and release of hazardous materials. Additionally, lights on drilling structures may disorient, attract, or confuse some pelagic birds, resulting in injury or death. Energy exploration and development off the coast of North Carolina, either for oil extraction or wind, is an emerging hazard that potentially threatens numerous marine and pelagic species, including seabirds.

Habitat Loss. Conflicts with fisheries, oil and hazardous material issues, and offshore pollution contribute to the degradation of foraging habitat for many pelagic species, particularly in shipping channels and areas heavily used by the marine fisheries industry. Mass harvest of Sargassum would affect forage prey base for pelagic species. Harvest or overharvest of Atlantic Menhaden, Atlantic Herring, and other managed prey populations may affect the forage prey base for pelagic seabirds. Seabirds congregate throughout the year, and in non-nesting seasons they congregate at roosts and loafing areas. These sites require both protection and management to maintain their value to seabirds.

3.11.6 Additional Information

In 1999, the United Nations Food and Agriculture Organization (FAO) developed the International Plan of Action for reducing seabird bycatch in longline fisheries (FAO 1999) that called on longline nations to assess their impact and implement mitigation regulations where necessary. Since the development of that plan, best-practice guidelines have been developed to facilitate creation of national plans of action by individual countries and to provide a framework from which to implement those plans at the level of regional fisheries management organizations (FAO 2008; Yeh et al. 2013).

The Agreement on the Conservation of Albatrosses and Petrels (ACAP) was established in 2001 to achieve and maintain favorable conservation status for albatrosses and petrels through research, monitoring, reduction of incidental mortality in fisheries, eradication of nonnative species at breeding sites, reduction of disturbance and habitat loss, and reduction of pollution (Species assessments 2015). Thirteen countries (known as Parties to the Agreement) have joined the ACAP. The United States is not currently a party to the agreement. While none of the species listed in Table 3.32 are covered by this agreement, recommendations on bycatch mitigation, conservation guidelines, management plans, and data resources may provide information that can be applied to species of regional concern.

3.11.7 Recommendations

Measures that protect a large and diverse pool of seabird populations are the best ways to ensure that species are able to survive future stresses and adapt to changing climate conditions.

Surveys. General surveys are needed to complete primary distributional status for all priority species (see Table 3.32). Conduct pelagic bird surveys in areas outside of the Oregon Inlet to Hatteras Inlet region, both in the cold water zone north of Oregon Inlet and the warm waters (including the Gulf Stream) south of Hatteras Inlet.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to waters of the state. Studies include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Initiate species-specific monitoring for White-tailed Tropicbird, Audubon's Shearwater, and Roseate Tern.
- Monitor mortality and morbidity of seabirds wherever it occurs.
- Identify and monitor important foraging, migrating, and wintering seabird areas.
- Increase monitoring of seabird bycatch (also see above, related policy needs).
- Obtain seasonal population estimates, distribution, and abundance information for seabirds in the southeastern US Continental Shelf.
- Increase monitoring and reporting of stranded seabirds.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of the histories and status help determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Examine the role of commercial fisheries in seabird mortality.
- Determine population level effects of oil and hazardous materials on seabirds.
- Assess mercury loads in seabirds.
- Identify key marine habitats.
- Examine value of Sargassum to seabirds.
- Examine effects of Sargassum harvest to seabird habitat and populations.
- Along South Atlantic coast beaches, research into the rates of and reasons for wintering common loon mortality should help evaluate the risks to seabird populations in this area.
- Establish whether foraging Black-capped Petrels within the Gulf Stream (especially off of Cape Hatteras, North Carolina) are the same as birds concurrently breeding in Haiti (Hunter 2004b).
- Nonpersistent lines, nets, and traps should be developed.
- Methods should be improved for tracing lost or abandoned fishing gear back to owners.
- Review whether ICCAT mitigation measures reflect best practices (ICCAT 2014).
- Develop indicators that can be used to evaluate the efficiency of mitigation measures (ICCAT 2014).
- Review the estimation methodologies and compile indirect bycatch mortality estimates for sea birds (ICCAT 2014).

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital.

- The policy of elimination of waterbird bycatch in fisheries should be embraced by all fisheries management entities (in North Carolina, appropriate agencies include the NCWRC, NCDMF, NOAA Fisheries, the USFWS, and the ASMFC).
- Minimize oil effects on seabirds through increased enforcement of shipping activities, safe operational procedures, spill clean-up, and rehabilitation of oiled birds.
- Strictly enforce the prohibition of debris, line, and net dumping, especially gillnets and longlines.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Habitat conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Develop partnerships between seabird conservation efforts and fishery industries and sport anglers.
- Address impacts to seabirds from offshore and inshore fisheries in all future fishery plans.
- Consider specifying forage fish allocations of species used by seabirds as prey, within appropriate FMPs.
- Follow the recommendations for education and outreach measures put forth in the North American Waterbird Conservation Plan (Kushlan et al. 2002).
- Follow through on all South Atlantic–Caribbean seabird connections as outlined in the Atlas of Breeding Seabirds of the West Indies to set regional priorities for all the West Indies.

3.12 Insects

3.12.1 Introduction

Insects and other arthropods are the most diverse group of any organisms, plant or animal. The NC General Statutes define insects, for the most part belonging to the taxonomic class Insecta, as any of the numerous small invertebrate animals generally having the body more or less obviously segmented, comprising six-legged, usually winged forms as adults (e.g., beetles, bugs, bees, flies), and other allied classes of arthropods whose members are wingless and usually have more than six legs (e.g., spiders, mites, ticks, centipedes, and sowbugs) (see GS 106-65).

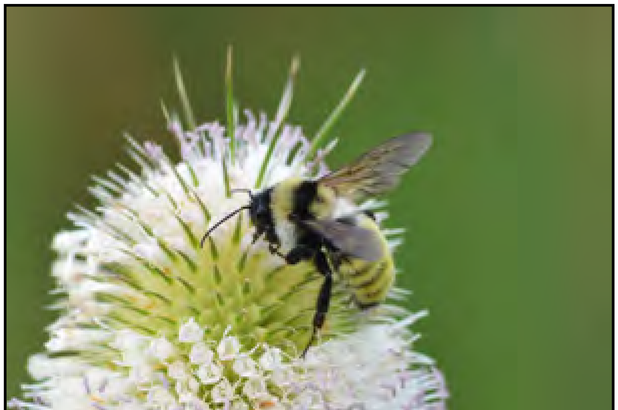
The United States has the greatest diversity of freshwater insects in the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), which are commonly referred to as EPTs (Abell et al. 2000; Silk and Ciruna 2006). A review of occurrence data recorded in the NCNHP database indicates there are well over 2,000 species of Lepidoptera (butterflies, moths)—the best-studied order of insects in North Carolina—known to occur in the state (LeGrand et al. 2014). Equally large, if not larger, numbers can be expected for several other insect orders. Beetles (order Coleoptera) in particular are believed to outnumber all other taxonomic groups in terms of the number of species.

Monarch butterfly (Randy Robertson)
https://www.flickr.com/photos/randysonofrobert/1436168760/
Used under license CC BY 2.0

The ecological significance of insects is great. They play a key role in ecological processes such as primary consumption, decomposition, and pollination. The majority of our plant species included on the state or federal endangered and threatened lists are dependent on insects for pollination. In some cases, specific species of insect pollinators may do most of the work and their loss may contribute to the endangerment of the plant. The Rough-leaf Loosestrife (*Lysimachia asperulifolia)* may be one such example in North Carolina (Franklin 2001). The current low levels of seed set may indicate that a major, specialized pollinator has been lost.

Insects are a primary food source for many vertebrate species groups. Game species that are largely or partly dependent on insects for food include Wild Turkey, Northern Bobwhite, Ruffed Grouse, and even Black Bear (Landers et al. 1979). Endangered species that rely primarily on insects include the Red-cockaded Woodpecker, Virginia Big-eared Bat, Gray Bat, and Indiana Bat. Insects can also present considerable pest management challenges, especially introduced exotics such as the Gypsy Moth and Hemlock Woolly Adelgid (Hanula and Franzred 1995). Conversely, the use of insects as biological controls may offer the best chance of combating these exotics.

The NCWRC does not have jurisdiction over most of these taxa, and there is a scarcity of biologists focused on these groups. Knowledge levels and data availability for insects, terrestrial gastropods, and arachnids are among the lowest of any animal group in the state. However, these taxa are an integral part of the ecosystems they share with other invertebrate and vertebrate species, as well as being vital for agriculture.



Golden Northern Bumble Bee (Andrew C, flickr) https://flic.kr/p/oCHe34.

Federally listed insect species are protected under the provisions of the Endangered Species Act, and in North Carolina, the USFWS is the lead agency for conservation of these species. Only two state agencies are actively involved in conducting insect surveys and using this information for conservation.

- The NC Division of Water Resources (NCDWR, formerly Division of Water Quality) Biological Assessment Branch conducts aquatic invertebrate sampling as part of widespread monitoring of biological integrity in NC waters. The Biological Assessment Branch uses stream insects (caddisflies, mayflies, stoneflies, beetles) for monitoring water quality and conducts stream surveys across the state on a regular basis. Staff does not attempt to determine the conservation concern for any of these species, nor does staff seek protection for insects per se. However, at least some stream reaches identified as High Quality Waters or Outstanding Resource Waters through this process receive a significant amount of protection.

- The NCNHP is the only state agency involved in directly determining the conservation status of individual insect species and other invertebrates and using this information to help guide ecosystem conservation. The NCNHP itself conducts surveys for a few selected groups including moths, butterflies, grasshoppers, and dragonflies (the results of several of these surveys are available as NCNHP reports). NCNHP also collaborates with the NCDWR Biological Assessment Branch in using survey data to identify rare species of aquatic insects. NCNHP works in partnership with USFWS to conduct status surveys on several species of rare insects (e.g., NCNHP conducted surveys on the St. Francis' Satyr that led to its being listed as endangered).

The NC Department of Agriculture and Consumer Services (NCDACS) has authority and jurisdiction over those insect species deemed to be a pest for plant and forest trees. Otherwise, insects and other noncrustacean arthropods are not protected by state law, nor are other groups of invertebrates except for mollusks and crustaceans. Yet several insect species are among the most endangered of NC species, primarily due to the loss of particular types of habitats and wide use of pesticides, herbicides, and other biological control agents.

There is also national support via the Farm Bill for pollinator conservation, but little baseline data are available for the diversity of native bees and other pollinators important for crop pollination in the state. NatureServe and the Xerces Society track some bees in the genus *Bombus* and related cleptoparasitic species but otherwise there is little information available on a national level.

Recognizing that insects fall outside the bounds of the taxa prioritization process used by the Taxa Teams (and described in the White Paper, Appendix F), we have used recommendations from species experts and reviewed NCNHP occurrence data to identify conservation priorities for these groups. We have incorporated species and habitat priorities and conservation recommendations for these groups into the Plan where possible.

Table 3.34 lists SGCN priority insect species which are completely terrestrial and that occur currently or historically in North Carolina.

Nearly half of all aquatic insects considered to be true flies (order Diptera) are almost exclusively restricted to freshwater by an aquatic larval stage, as are mayflies, stoneflies, caddisflies, dragonflies, and Dobson Flies (order Megaloptera) (Suter and Cormier 2014). Inland freshwaters cover a very small percentage of the Earth's surface but they provide habitat to almost 100,000 insect species from at least 12 orders that have one or more life stages in freshwater.

Often the aquatic larval stage lasts significantly longer than the terrestrial adult life stage. Aquatic insects spend one or more stages of their life cycles in the water, with the majority living in water as eggs and larvae before maturing into adults and moving to terrestrial habitats. Their ecological roles as primary consumers, detritivores, predators, and pollinators have an important influence on both terrestrial and aquatic communities and they can serve as bioindicators of natural community health (Suter and Cormier 2014).

Aquatic insects are a primary food resource for many fish and crayfish species. As they emerge from aquatic larva to adult insects and disperse to surrounding areas they become an important prey resource for bats and birds that forage in riparian areas. Table 3.35 lists insect SGCN, by taxonomic order, that have both an aquatic life stage and a terrestrial stage. The 2005 WAP did not identify insect SGCN.

The 2005 WAP provided a very good overview of general conservation issues involving insects and other invertebrates developed by Hall (1999a) in his inventory of Lepidoptera of the Albemarle–Pamlico region of North Carolina. Much of the material covering arthropods and other insects provided in the 2005 WAP is still relevant.

Table 3.34 Terrestrial insect SGCN

Order	Scientific Name	Common Name	Federal/ State Status*
Arachnida	*Microhexura montivaga*	Spruce–fir Moss Spider	E/—
Coleoptera	*Nicrophorus americanus*	American Burying Beetle	E/SR
Hymenoptera	*Bombus affinis*	Rusty-patched Bumble Bee	—
	Bombus fervidus	Golden Northern Bumble Bee	—
	Bombus fraternus	Southern Plains Bumble Bee	—
	Bombus pensylvanicus	American Bumble Bee	—
	Bombus terricola	Yellowbanded Bumble Bee	—
	Bombus vagans	Half Black Bumble Bee	—
	Bombus variabilis	Variable Cuckoo Bumble Bee	—
Lepidoptera	*Agrotis carolina*	Carolina Agrotis	FSC/—
	Atryton earogosarogos	Eastern Arogos Skipper	FSC/—
	Atryton opsis sp. 1	Crystal Skipper	FSC/—
	Catocala grisatra	Grisatra Underwing Moth	—
	Danaus plexippus	Monarch	—
	Euphyes berryi	Berry’s Skipper	—
	Euphyes dukesi	Dukes’ Skipper	—
	Hemipachnobia monochromatea	Sundew Cutworm Moth	—
	Hemipachnobia subporphyrea	Venus Flytrap Cutworm Moth	FSC/—
	Lemmeria digitalis	Fingered Lemmeria Moth	—
	Meropleon diversicolor sullivani	Sullivan’s Meropleon	—
	Neonympha mitchellii francisci	St. Francis’ Satyr	E/—
	Papaipema eryngii	Rattlesnake-master Borer Moth	C/—
	Phyciodes batesii maconensis	Appalachian Tawny Crescent	FSC/—
	Poanes aaroni aaroni	Aaron’s Skipper	—
	Problema bulenta	Rare Skipper	FSC/—
	Pyrgus wyandot	Appalachian Grizzled Skipper	FSC/—
	Spartiniphaga carterae	a moth	—
Orthoptera	*Stethophyma celatum*	Broad-winged Sedge Grasshopper	—/SR

* See Table 3.2 for abbreviations.

Except where other references are noted, the following information is largely based on Hall’s work, including collaborations with others (1999a, 1999b, 2003, 2004; Hall and Schweitzer 1993; Hall and Schafale 1999; Hall and Sullivan 2000, 2004; Hall et al. 1999a, 1999b, 1999c; LeGrand et al. 2004).

3.12.2 Conservation Concerns

Invertebrates often have highly specific habitat requirements, much more so than is typical for vertebrates. Many insects, for example, have larvae that feed only on a particular host plant. Habitat requirements for these species include those for host plants as well as

Table 3.35 Aquatic insect SGCN

Order	Scientific Name	Common Name	Federal/ State Status*
Odonata	*Ophiogomphus edumudo*	Edmund's Snaketail	FSC/SR
	Progomphus bellei	Belle's Sandragon	FSC/SR
Orthoptera	*Melanoplus decorus*	Decorated Spur-throat Melanoplus	—/SR
Ephemeroptera	*Baetisca becki*	a mayfly	—/SR
	Baetisca obesa	a mayfly	—/SR
	Baetopus trishae	a mayfly	—/SR
	Barbaetis benfieldi	Benfield's Bearded Small Minnow Mayfly	—/SR
	Homoeoneuria cahabensis	Cahaba Sand-filtering Mayfly	—/SR
	Serratella spiculosa	Spiculose Serratellan Mayfly	—
	Tortopus puella	a mayfly	—/SR
Plecoptera	*Megaleuctra williamsae*	Williams' Rare Winter Stonefly	FSC/SR
	Zapada chila	Smokies Forestfly	—/SR
Tricoptera	*Ceraclea cancellata*	a longhorned caddisfly	—/SR
	Diplectrona metaqui	a diplectronan caddisfly	—/SR
	Manophylax altus	Mount Mitchell Caddisfly	—/SR
	Rhyacophila vibox	a rhyacophilan caddisfly	—

* See Table 3.2 for abbreviations.

habitats for the adult insects. In addition to those considered critically imperiled, many species identified for conservation concern are known from only a single population in the state; are associated with rare plants or unique natural communities; are endemic or known only to occur in North Carolina; have highly disjunct populations separated from the rest of their range; or the best known populations occur in the state.

In North Carolina, there are two invertebrate species listed as federally endangered under the ESA: St. Francis' Satyr butterfly and Spruce–fir Moss Spider. One species has been listed as a candidate for listing status, Rattlesnake-master Borer Moth, which indicates the USFWS has enough information to warrant proposing them for listing but is precluded from doing so by higher listing priorities. The American Burying Beetle is also listed as endangered under the ESA, but it is believed to have been extirpated from the state.

Data from the website www.DiscoverLife.org indicate that there are more than 3,600 bee species in six taxonomic families in North Carolina. There are numerous species that are of high conservation concern because they have experienced alarming population declines, especially within the past 20 years. In some cases, local extirpations may explain their absence from parts of their native range. For example, if the long-term declining trend for relative abundance of the Southern Plains Bumble Bee continues, this species could potentially go extinct before the end of this century (Hatfield et al. 2012).

In 2013, a petition was submitted to request that the Rusty-patched Bumble Bee be listed as an Endangered Species under the ESA. Another species, the Variable Cuckoo Bumble Bee is considered to be critically endangered because the population has declined by more than 80% overall based on historic records, while more current survey data show declines in relative abundance of more than 99% during the past decade (Hatfield et al. 2012). Declines are at least in part due to pathogen infection, habitat alterations and conversion, declines in habitat quality, and exposure to certain types of insecticides and other environmental chemicals.

The St. Francis' Satyr butterfly is only known from Cumberland and Hoke counties in the Sandhills ecoregion. The larval host of the St. Francis' Satyr is sedges (*Carex* spp.) (Murdock 1996). This butterfly is known to inhabit wide, wet meadows dominated by sedges and other wetland graminoid species. These wetlands are often acidic and ephemeral boggy areas that are relicts of beaver activity. These sites must be continually maintained to prevent woody vegetation from becoming established.

The USFWS has determined the Rattlesnake-master Borer Moth warrants protection under the ESA, but there are no current plans to propose listing because there are other species considered a higher priority for listing (USFWS 2013). This moth species occurs in 16 populations in five states, including North Carolina. Its only food source is a prairie habitat plant, the Rattlesnake-master (*Eryngium yuccifolium*).

Spruce–fir Moss Spider occurs in well-drained moss and liverwort mats growing on rocks in well-shaded areas of spruce–fir forests in the Appalachian mountains of North Carolina and Tennessee. As published in the Federal Register (USFWS 2001) the USFWS designated primary elements found in the Pisgah National Forest in North Carolina and portions of the Cherokee National Forest in North Carolina and Tennessee as critical habitat for this species. Within these areas the primary elements considered as critical habitat include the Fraser Fir or fir-dominated spruce–fir forests at and above 5,400 feet elevations. It also includes moderately thick and sheltered mats of humid (not wet) moss and liverwort

Spruce–fir Moss Spider (USFWS) https://upload.wikimedia.org/wikipedia/commons/thumb/3/39/Spruce_Fir_Moss_Spider.jpg/200px-Spruce_Fir_Moss_Spider.jpg. Used under license CC BY 2.0

growing on rocks that have a thin layer of soil or humus between the moss and the rock found under the spruce and fir trees.

Status surveys conducted on three species resulted in NCNHP recommendations that Eastern Arogos Skipper be listed as threatened (Hall et al. 1999a) and that an undescribed species of dusted skipper (*Atrytonopsis* sp. 1) be listed as endangered after its taxonomic status has been resolved (Hall 2003). Results from a status survey for the Venus Flytrap Cutworm Moth indicate that this species be recommended for listing as endangered (Hall and Sullivan 2000, 2004).

At least three other species are believed to have been extirpated from the state: Regal Fritillary, Eastern Arogos Skipper, and Southern Dusted Skipper. Repeated surveys for these species have failed to detect their presence at sites where they were formerly known to occur. Several other insect species are also known only from historic records but no real surveys have been made.

The NCNHP tracks several invertebrate species groups and Table 3.36 summarizes the number of rare insect and arachnid species being tracked (LeGrand et al. 2004, 2014). A complete list of all species tracked by the NCNHP is published in the report "List of the Rare Animal Species of North Carolina" (LeGrand et al. 2014). Tracked species include those listed as endangered, threatened, special concern, and significantly rare. The arachnid list is selective of cave and other montane species and is not intended to be a complete list of the rare arachnids in the state.

Table 3.36 Summary of invertebrate species tracked by NCNHP

	State Status		Federal Status
Group	No. of species tracked (2005 WAP)	No. of species tracked (NCNHP 2014)	No. of species tracked (Listing Status)
Arachnids	11	13	1 (E)
Mayflies	16	18	0
Stoneflies	7	9	0
Caddisflies	14	20	0
Dragonflies and damselflies	37	40	0
Flies	1	0	0
Moths	70	107	1 (C)
Butterflies	38	37	1 (E)
Grasshoppers and katydids	15	25	0
Beetles	5	6	1 (E) extirpated in NC
True bugs	1	1	0

3.12.3 Knowledge Gaps

Conservation of insects in North Carolina requires more surveys, research, and monitoring of species, as well as management, restoration, and protection of habitat. Our understanding of this group of species (other than butterflies) is far lower than almost any other animal group in the state. There are few biologists in the state focused on the type of surveys, research, and monitoring activities needed to understand these groups. They are an integral part of the ecosystems they share with other species and it is important to take advantage of any opportunities to expand our knowledge and understanding when possible.

There are a large number of species that are still too poorly known to estimate their conservation significance. The NCNHP has undertaken a series of insect inventories in the Coastal Plain ecoregion of North Carolina to bring understanding of the distribution, abundance, and habitat affinities for at least a few important groups of invertebrates. These surveys have uncovered not only species never before documented in North Carolina, but even species completely new to science (e.g., *Apameini*, New Genus 4, Species 1) (Hall 1999a, b).

3.12.4 Management Needs

Preserves can be regarded as islands of habitat to some degree. They are often chosen for conservation as something special in areas where the rest of the landscape has been significantly altered. All too frequently, preserves contain the only remnants of native ecosystems for miles around. While these preserves are intended to remain "natural," active management is often needed to accomplish this goal, although management, almost by definition, involves some form of artificial disturbance. This disturbance may replace a natural form, such as wildfires, or it may be entirely new, such as spraying an entire preserve with a pesticide to control an exotic pest such as the Gypsy Moth (Hall 1999a, b).

Insect populations often undergo extreme fluctuations in numbers, resulting from vagaries in weather or cyclical changes in abundance of their predators or parasites. They are much more prone to local extirpation than either vertebrates or plants. As discussed below, they often survive only where there are enough well-dispersed habitat patches to support a metapopulation.

Despite their vulnerability to local extirpation, some species can survive in long-lasting, relict populations, as long as natural ecosystem processes are continuous through time. For example, a population of the Brown Elfin found on the summit of Occoneechee Mountain, a State Natural Area along the Eno River, may have existed there since the end of the Ice Age approximately 10,000 years ago, just as have several rare plants with similar montane or boreal distributions. No other populations of this species are known within 50 miles.

Their presence on this monadnock landscape is indicative not only of the high quality of the habitats that currently exist, but of the continuity of those habitats and the ecological processes maintaining them throughout that immense span of time. This ability to maintain relict populations is shared with many rare plant species but is less typical for vertebrates.

For these reasons, the presence of healthy populations of rare or habitat-specialist species of insects and other invertebrates is invariably an indication of a high degree of native ecosystem integrity. Where high-quality natural areas exist and have maintained their quality through time, a significant diversity of insects and other invertebrates—containing both rare species and a high proportion of habitat specialists—should be expected.

Although some species of invertebrates, like some plants, can maintain small relict populations over large spans of time, most invertebrates require a distribution of habitats spread out over an entire landscape. This is especially the case for species prone to local extirpation and that depend on a metapopulation structure for survival within a region.

- A metapopulation is composed of a number of subpopulations, each of which may be relatively unstable, some increasing in a given year, others declining to the point of extirpation. As long as movement is possible between the sub-populations, declining populations can be “rescued” by immigration from increasing populations elsewhere within the metapopulation.
- A metapopulation can therefore be much more stable than its parts, at least as long as not all subpopulations are affected by the same set of events.
- Metapopulations are most stable when they are spread over a significant area of the landscape.

Conservation biologists are just beginning to realize how important metapopulations are for animals in general (for vertebrate examples, see McCullough 1996). Due to the greater fluctuations their subpopulations experience within a given year or season, invertebrates are often dependent on metapopulation structures. This is especially true of species associated with ecosystems maintained by frequent disturbances, such as fire, storms, or floods. While vertebrates (and many plants) often have escape mechanisms for coping with unpredictable ecological disruptions, invertebrates typically do not. The only way many insects species survive in habitats maintained by frequent fire, for instance, is through recolonization of recently burned areas from unburned patches of habitat (Hall and Schweitzer 1993).

While recognizing that insects and other invertebrates may never be studied as fully as other species groups by preserve managers, Hall (1999a) makes the point that some attention must be given toward their proper management if an ecosystem-based approach is the desired outcome. He presents five “rule-of-thumb” generalizations that may be a first-step toward more comprehensive management of natural areas and ecological preserves in North Carolina.

Insects and other invertebrates may respond to certain management practices very differently than plants or vertebrates; gauging the success of management by the effects on those species may miss significant damage being done inadvertently to insects and other nontarget species. This is particularly true for prescribed burning. The NCNHP has developed a set of guidelines for conducting burns in ways that minimize impacts to rare insect populations (Hall and Schwietzer 1993; Hall 1999a).

If ecosystem-level conservation planning is to succeed, managers must include invertebrates in site management considerations (Hall 1999a). The following passages, which were included in the 2005 WAP and remain appropriate, are excerpted from Hall (1999a).

> **Rule of Thumb 1.**
> Management actions that significantly alter some aspect of an ecosystem are likely to have major effects on insects and other invertebrates. The responses of these species to the management actions may be very different than those of plants or vertebrates, the usual intended beneficiaries of the action. In the worst case, a large number of the unknown but important “cogs and wheels” of the ecosystem may be lost as a result of the action. Keeping this in mind, additional rules of thumb will be described below that can help reduce the likelihood of a dire outcome.
>
> Nature preserves, including most state parks, are usually established where high-quality examples of native ecosystems exist, as indicated by vegetative communities or the presence of rare species of plants or vertebrates. Although few preserves have yet been created specifically with insects or other invertebrates in mind, areas of high-quality native habitats usually contain significant faunas of invertebrates as well. There are, in fact, several reasons why invertebrates frequently are among the rarest species in a given preserve.
>
> **Rule of Thumb 2.**
> The larger landscape is important in the conservation of insects and other invertebrates. When natural landscapes are replaced with a mosaic of small patches of native habitats in a matrix of lands converted to human uses (habitat fragmentation) all species are affected. Fragmentation reduces the overall amount of available habitat, involving outright losses as well as more subtle reductions due to edge effects. The most severe effects, however, may be on species critically dependent on metapopulations structures.
>
> By definition, habitat fragmentation is a process that increases the distances between suitable habitat patches and therefore increases the difficulties or outright danger to

individuals dispersing from one habitat block to another. Since the very existence of a metapopulation depends on dispersal between suitable patches of habitat, any factor that reduces the changes of successful dispersal may doom the whole metapopulation to eventual extirpation, not just individual subpopulations as normally occurs within intact landscapes. Habitat specialists, particularly those dependent on naturally rare types of habitat or on disturbance-maintained habitats, are at greatest risk.

Rule of Thumb 3.
Insects and other invertebrates should be considered at particular risk from fragmentation of native habitats. Even though invertebrate populations can be particularly high within a given subpopulation during a given season, this should not be taken as a sign that, as small species, they only need a limited amount of space to maintain themselves. Their long-term survival within a region may depend on as much landscape as is required to support a population (or metapopulation) of Black Bears, Red-cockaded Woodpeckers, or other species of vertebrates.

Several insects are believed to have become critically endangered through loss of metapopulation structure, even though habitats within portions of the range of the metapopulations still appear to be high in quality. Examples in the Coastal Plain include the Arogos Skipper, St. Francis' Satyr, and Venus Flytrap Cutworm Moth.

Rule of Thumb 4.
Wherever possible, management activities should be restricted to only a portion of a given habitat type. Other areas of the same habitat should be set aside as refuge areas (although potentially subject to treatment at a later time).

Rule of Thumb 5.
In cases where a management action affects an entire preserve, as in treatment for gypsy moths, decisions about the scope, intensity, and alternative treatments should be based according to the proximity of refuge areas beyond the boundary of the preserve. Where other, untreated blocks of habitat are located close by, a wider range of management options can be considered. Even in the worst case, where species are extirpated from the preserve, recolonization from outside can still be expected. Where external refuges are located far away, however, management decisions should be based on the worst possible case: irrecoverable losses of species from the preserve.

3.12.5 Threats and Problems

The greatest threat to insects comes from habitat loss. Thus conservation efforts aimed at protecting native ecosystems offers the best hope for the majority of endangered insect species. Even on lands that have been protected to maintain their natural features, management practices need to take the specific requirements of insects into account.

Population growth and subsequent development, especially habitat degradation, fragmentation and destruction, result in impacts to terrestrial and aquatic systems that can affect all insect species. In addition, nontarget impacts of pesticides (insecticides and herbicides) are harming invertebrate (macro and soil dwelling) and vertebrate populations (Larson et al. 2013; Hopwood et al. 2013; Pleasants and Oberhauser 2013; Gibbons et al. 2015).

Introduced pathogens from the commercial bumble bee industry are suspected as potential contributors to significant bumble bee declines throughout North America (Cameron et al. 2011; Colla et al. 2006; Otterstatter and Thomson 2008; Murray et al. 2013). Declines in bumble bee species may be associated with the introduction of pathogens imported on a species of native bumble bee reared in Europe and reintroduced for pollination of crops in the United States (primarily for blueberry, cranberry, and greenhouse tomato production) (Cameron et al. 2011). Introduction of a beetle to control invasive thistle populations is decimating native thistle populations (Blitzer et al. 2012).

Some species—particularly butterflies—are sought after by collectors, and overcollection can be a threat in some situations. A giant skipper species, *Megathymus cofaqui*, may have been extirpated from the state due to overcollection. Insect collecting is not regulated under state law, although permits are required in some cases for collecting on public lands (e.g., state parks, game lands, national forests).

3.12.6 Additional Information

Given the strategic (not operational) nature of this document, we have not identified population objectives for each and every species mentioned herein. In the 2005 document, we noted that we were unable to assess specific population objectives for the majority of our fish and wildlife species because of data limitations and knowledge gaps. However, conservation and management objectives may have been developed through cooperative efforts of specific conservation partnerships. Recovery plans for species on the federal threatened and endangered species list also identify population and management objectives related to species recovery thresholds. Relevant conservation plans listed below provide information and recommendations for conservation and management actions.

- “Recovery plan for St. Francis’ Satyr” (Murdock 1996). Available on the internet http://ecos.fws.gov/docs/recovery_plans/1996/960423.pdf.
- “Recovery plan for Spruce–fir Moss Spider” (Harp and Fridell 1998). Available on the internet http://ecos.fws.gov/docs/recovery_plans/1998/980911b.pdf.
- Butterflies of North America (Lotts and Naberhaus 2014). Northern Prairie Wildlife Research Center website: www.butterfliesandmoths.org. This site provides state-by-state

accounts of butterfly species, including information on habitat, range, conservation, management need, global rank, and references.

- Conserving Bumble Bees. Guidelines for Creating and Managing Habitat for America's Declining Pollinators (Hatfield et al. 2012). Available from the Xerces Society web page http://www.xerces.org/wp-content/uploads/2012/06/conserving_bb.pdf.

3.12.7 Recommendations

In general, protection and restoration of natural community composition and function and protection of surrounding natural areas under current conditions are the best ways to ensure suitable habitats are available for insect species. Measures that protect a large and diverse pool of populations are the best way to ensure that species are able to survive future stresses and adapt to changing climate conditions.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities. Surveys are needed for all "insect" species.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Avoid using systemic pesticides such as neonicotinoids (Hatfield et al. 2012).

- When possible, encourage use of species-specific insecticides to minimize nontarget impacts (Lee-Mader et al. 2014). Nontarget impacts, particularly to rare species, also need to be carefully assessed any time pesticides (or biological control agents) are applied to natural areas.

- Key natural areas must be protected during large-scale applications of insecticides with broad nontarget impacts. This is especially important in areas where native habitats are restricted in distribution (e.g., maritime and longleaf pine forests) (Hall et al. 1999a).
- Moths and other night-flying insects are particularly impacted by outdoor lighting and where possible, low-voltage, shielded fixtures should be used. Lighting of any kind should be avoided around habitats likely to support rare nocturnal insects (Hall 1999a).
- Native flowering plants are beneficial to bumble bees by providing nectar and pollen sources. Perennial plants with purple, blue, or yellow flowers may be preferred (Hatfield et al. 2012).
- When applying management treatments (fire, mowing, herbicides) to habitats, leave one or more large patches untreated to serve as refugia. When burning areas with bumble bee nests, consider burning no more than one-third of the land area each year and burning specific areas once every three to six years (Hatfield et al. 2012).
- Do not purchase commercial bumble bees for use outside of the native range of the species. Only use commercial bumble bees in greenhouses. Do not use them for open-field crops. (Hatfield et al. 2012).

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

References

Abell RA, Olsen DM, Dinerstein E, Hurley PT, Diggs, JT, Eichbaum, W, Walters S, Wettengel W, Allnutt T, Loucks CJ, et al. 2000. Freshwater ecoregions of North America: a conservation assessment. Washington (DC): Island Press. 319 p.

Abell R, Thieme ML, Revenga C, Bryer M, Kottelat M, Bogutskaya N, Coad B, Mandrak N, Balderas SC, Bussing W, et al. 2008. Freshwater ecoregions of the world: a new map of biogeographic units for freshwater biodiversity conservation. BioSci. 58(5):403–414.

Adams WF, editor. 1990. A report on the conservation status of North Carolina's freshwater and terrestrial molluscan fauna. The Scientific Council on Freshwater and Terrestrial Mollusks. 246 p.

Adams M, Miller D, Muths E, Corn P, Grant E, Bailey I, Fellers G, Fisher R, Sadinski W, Waddle H, et al. 2013. Trends in amphibian occupancy in the United States. PLoS ONE. [accessed 2015 August];8(5):e64347. doi:10.1371/journal.pone.0064347.

Allendorf FW, Lundquist LL. 2003. Introduction: population biology, evolution, and control of invasive species. Conserv Biol. 17:24–30.

AmphibiaWeb. 2015. AmphibiaWeb Taxonomy Version 2.0. Information on amphibian biology and conservation [web application]. Berkeley (CA); [accessed 2015 August] http://amphibiaweb.org/taxonomy/index.html.

Amyot JP, Downing JA. 1991. Endo- and epibenthic distribution of the unionid mollusk *Elliptio complanata*. J N Am Benthol Soc. 10(3):280–285.

Amyot JP, Downing JA. 1997. Seasonal variation in vertical and horizontal movement of the freshwater bivalve *Elliptio complanata* (Mollusca: Unionidae). Freshw Biol. 37:345–354.

[AMJV] Appalachian Mountains Joint Venture. N.d. Enhancing cerulean warbler habitat in the Appalachians: a guide for foresters fact sheet [internet]. [accessed 2015 August] http://amjv.org/documents/Cerulean_FS_Foresters_Version_Final_(1).pdf. 2 p.

Anderson ORJ, Small CJ, Croxall JP, Dunn EK, Sullivan BJ, Yates O, Black A. 2011. Global seabird bycatch in longline fisheries. Endanger Species Res. 14:91–106.

Anderson RC, Prestwood AK. 1981. Lungworms. In: Davidson WR, Hayes FA, Nettles VF, Kellog FE, editors. Diseases and parasites of white-tailed deer. Tallahassee (FL): Tall Timbers Research Station. p. 266–317.

Arida E, Bull CM. 2008. Optimising the design of artificial refuges for the Australian skink, Egerniastokesii. Appl Herpetol. 5:161–172.

[ARMI] Amphibian Research and Monitoring Initiative [website]. [updated 2015 July 13]. http://armi.usgs.gov.

Arponen A. 2012. Prioritizing species for conservation planning. Biodivers Conserv. 21:875–893.

Ashton MJ, Layzer JB. 2010. Summer microhabitat use by adult and young-of-year snail darters (*Percina tanasi*) in two rivers. Ecol Freshw Fish. 19:609–617.

Augspurger T, Keller AE, Black MC, Cope WG, Dwyer FJ. 2003. Water quality guidance for protection of freshwater mussels (Unionidae) from ammonia exposure. Environ Toxicol Chem. 22(11):2569–2575.

Bailey MA, Holmes JN, Buhlmann KA, Mitchell JC. 2006. Habitat management guidelines for amphibians and reptiles of the southeastern United States. Technical Publication HMG-2. Montgomery (AL): Partners in Amphibian and Reptile Conservation; [accessed 2013 May]. 88 p. http://separc.files.wordpress.com/2013/04/se-hmg.pdf.

Baker GB, Double MC, Gales R, Tuck GN, Abbott CL, Ryan PG, Petersen SL, Robertson CJR, Alderman R. 2007. A global assessment of the impact of fisheries-related mortality on shy and white-capped albatrosses: conservation implications. Biol Conserv. 137:319–333.

Beane JC, Graham SP, Thorp TJ, Pusser LT. 2014. Natural history of the Southern Hognose Snake (*Heterodon simus*) in North Carolina, USA. Copeia. 2014(1):168–175.

Belanger SE. 1991. The effect of dissolved oxygen, sediment, and sewage treatment plant discharges upon growth, survival and density of Asiatic clams. Hydrobiol. 218:113–126.

Benoit LK, Askins RA. 2002. Relationship between habitat area and the distribution of tidal marsh birds. Wilson Bull. 114(3):314–323.

Blaustein AR, Walls SC, Bancroft BA, Lawler JJ, Searle CL, Gervasi SS. 2010. Direct and indirect effects of climate change on amphibian populations. Divers 2:281–313.

Blazer VS, Iwanowicz LR, Starliper CE, Iwanowicz DD, Barbash P, Hedrick JD, Reeser SJ, Mullican JE, Zaugg SD, Burkhardt MR, et al. 2010. Mortality of centrarchid fishes in the Potomac drainage: survey results and overview of potential contributing factors. J Aquat Anim Health. 22:190–218.

Blitzer EJ, Dormann CF, Holzschuh A, Klein AM, Rand TA, Tscharntke T. 2012. Spillover of functionally important organisms between managed and natural habitats. Agric, Ecosyst Environ. 146:34–43.

Bogan AE. 1993. Freshwater bivalve extinctions (Mollusca: Unionoida): a search for causes. Am Zool. 33(6):599–609.

Bogan AE. 1996. Decline and decimation: the extirpation of the unionid bivalves in North America. J Shellfish Res. 15:484.

Bogan AE, Smith JM, Raley ME. 2011. The Lilliput (*Toxolasma parvum*) (Mollusca: Bivalvia: Unionidae) introduced into North Carolina. J N C Acad Sci. 127(2):192–193.

Bogner HE, Baldassarre GA. 2002. The effectiveness of call–response surveys for detecting least bitterns. J Wildl Manage. 66(4):976–984.

Bosch J, Rincon PA. 2008. Chytridiomycosis-mediated expansion of bufobufo in a montane area of central Spain: an indirect effect of the disease. Divers Distrib. 14(4):637–643.

Boschung HT, Mayden RL. 2004. Fishes of Alabama. Washington (DC): Smithsonian Press. 736 p.

Bourne GR. 1993. Differential snail-size predation by snail kites and limpkins. Oikos. 68:217–223.

Brewer SK, Orth DJ. 2015. Smallmouth Bass *Micropterus dolomieu Lacepède*, 1802. Am Fish Soc Symp. 82:9–26.

Brim-Box J, Williams JD. 2000. Unionid mollusks of the Apalachicola Basin in Alabama, Florida, and Georgia. Bull Ala Mus Nat Hist. 21:1–143.

Bringolf RB, Heltsley RM, Newton TJ, Eads CB, Fraley SJ, Shea D, Cope WG. 2010. Environmental occurrence and reproductive effects of the pharmaceutical fluoxetine in native freshwater mussels. Environ Toxicol Chem. 29(6):1311–1318.

Brinkley ES. 2012. Bermuda Petrel (*Pterodroma cahow*). In Schulenbger TS, editor. Neotropical birds online. Ithaca (NY): Cornell Lab of Ornithology; [accessed 2015 July]. http://neotropical.birds.cornell.edu/portal/species/overview?p_p_spp=700756.

Bouchet P, Rocroi JP. 2005. Classification and nomenclator of gastropod families (Vol. 47, No. 1/2). Institute of Malacology. Hackenheim (Germany): Conch Books. 397 p.

Brown KM. 2001. Gastropoda. In: Thorp JH, Covich AP, editors. Ecology and classification of North American freshwater invertebrates. 2nd ed. San Diego (CA): Academic Press. p. 297–330.

Brown KM, Alexander JE, Thorp JH. 1998. Differences in the ecology and distribution of lotic pulmonate and prosobranch gastropods. Am Malacol Bull. 14(2):91–101.

Brown KM, Devries GH. 2000. Habitat certainty and the structure of freshwater snail guilds. Paper presented at the 33rd Annual American Institute of Biological Sciences Meeting, University Park (PA).

Brown KM, Lydeard CE. 2010. Mollusca: Gastropoda. In: Thorpe JH, Covich AP, editors. Ecology and classification of freshwater invertebrates of North America. 3rd ed. Boston (MA): Academic Press. p. 277–307.

Brown SC, Schulte S, Harrington B, Winn B, Bart J, Howe M. 2005. Population size and winter distribution of eastern American Oystercatchers. J Wildl Manag. 69(4):1538–1545.

Brusca RC, Brusca GJ. 1990. Invertebrates. Sunderland (MA): Sinauer Associates. 922 p.

Bucci JP. 2007. Assessment of the feeding ecology of native and non-native freshwater bivalves in a North Carolina river basin [dissertation]. [Raleigh (NC)]: NC State University. [accessed 2015 August]. http://repository.lib.ncsu.edu/ir/bitstream/1840.16/3244/1/etd.pdf. 237 p.

Buehler DA, Giocomo JJ, Jones J, Hamel PB, Rogers CM, Beachy TA, Varble DW, Nicholson CP, Roth KL, Barg J, et al. 2008. Cerulean Warbler reproduction, survival, and models of population decline. J Wildl Manag. 72:646–653.

Burch JB. 1962. How to know the eastern land snails; pictured-keys for determining the land snails of the United States occurring east of the Rocky Mountain divide. Dubuque (IA): WC Brown Co. 214 pp.

Burch JB. 1989. North American freshwater snails. Hamburg (MI): Malacological Publications. 365 p.

Burke JS, Rohde FC. 2015. Diadromous fish stocks of America's southeastern Atlantic coast. NOAA Technical Memorandum NOS NCCOS 198. [accessed 2015 July]. http://www2.coastalscience.noaa.gov/publications/detail.aspx?resource=GNbbbGhbsftgS9zE5HJOkBD4P2FDXI4iDogDgOeUJRQ=. 55 p.

Butcher GS, Niven DK. 2007. Combining data from the Christmas Bird Count and the Breeding Bird Survey to determine the continental status and trends of North America birds. Ivyland (PA): National Audubon Society.

Butler RS. 2002. Imperiled fishes of the southern Appalachian ecosystem, with emphasis on the nonfederally listed fauna. Asheville (NC): US Fish and Wildlife Service. 46 p.

Cagle FR. 1952. The status of turtles *Graptemys pulchra* Baur and *Graptemys barbouri* Carr and Marchand, with notes on their natural history. Copeia. 1952:223–234.

Cameron SA, Lozier JD, Strange JP, Koch JB, Cordes N, Solter LF, Griswold TL. 2011. Patterns of widespread decline in North American bumble bees. Proc Natl Acad Sci. [accessed 2015 August];108(2):662–667. http://www.pnas.org/content/108/2/662.full.pdf.

[CFRP] Cape Fear River Partnership. 2013. Cape Fear River Basin action plan for migratory fish. NOAA Habitat Conservation, Habitat Protection. [accessed 2015 August]. 81 p. http://www.habitat.noaa.gov/protection/capefear/index.html.

[CBC] Carolina Bird Club. 2014. Official list of the birds of North Carolina [website]. [accessed 2015 August]. http://www.carolinabirdclub.org/brc/checklist_of_North_Carolina_birds.html.

Chambers PA, Hanson JM, Burke JM, Prepas EE. 1990. The impacts of the crayfish *Orconectes virilis* on aquatic macrophytes. Freshw Biol. 24: 81–91.

Chesser RT, Banks RC, Cicero C, Dunn JL, Kratter AW, Lovette IJ, Navarro-Sigüenza AG, Rasmussen PC, Remsen Jr. JV, Rising JD, et al. 2014. Fifty-fifth supplement to the American Ornithologists' Union *Check-list of North American Birds*. Auk. 131(4):CSi–CSxv.

Cohen JB, Karpanty SM, Fraser JD, Truitt BR. 2010. The effect of benthic prey abundance and size on Red Knot (*Calidriscanutus*) distribution at an alternative migratory stopover site on the US Atlantic Coast. J Ornithol. 151:355–364.

Colla SR, Otterstatter MC, Gegear RJ, Thomson JD. 2006. Plight of the bumble bee: pathogen spillover from commercial to wild populations. Biol Conserv. 129:461–467.

Congressional Record. 2011. Proceedings and Debates of the 112thCongress, First Session. Vol. 157, No. 169. Washington, DC. [accessed 2015 August] http://www.gpo.gov/fdsys/pkg/CREC-2011-11-07/pdf/CREC-2011-11-07-pt1-PgH7401-7.pdf.

Conway CJ, Sulzman C, Raulston BE. 2004. Factors affecting detection probability of California black rails. J Wildl Manag. 68(2):360–370.

Conway CJ. 2011. Standardized North American marsh bird monitoring protocol. Waterbirds. [accessed 2015 September];34(3):319–356. http://www.bioone.org/doi/pdf/10.1675/063.034.0307.

Cooper JE. 1998. A new species of crayfish of the genus *Procambarus*, subgenus *Ortmannicus* (Decapoda: Cambaridae), from the Waccamaw River basin, North and South Carolina. Proc Biol Soc Wash. 111(1):81–91.

Cooper JE. 2000a. *Cambarus* (*Cambarus*) *davidi*, a new species of crayfish (Decapoda: Cambaridae) from North Carolina. Proc Biol Soc Wash. 113(2):431–442.

Cooper JE. 2000b. A new species of crayfish of the genus *Cambarus*, subgenus *Cambarus* (Decapoda: Cambaridae) from the Broad River Basin of North Carolina. J Elisa Mitchell Sci Soc. 116(1):1–12.

Cooper JE. 2006a. A new species of crayfish of the genus *Cambarus Erichson*, 1846 (Decapoda: Cambaridae) from the eastern Blue Ridge foothills and western Piedmont Plateau of North Carolina. Proc Biol Soc Wash. 119(1):67–80.

Cooper JE. 2006b. A new species of crayfish of the genus *Cambarus Erichson*, 1846, subgenus *Puncticambarus Hobbs*, 1969 (Decapoda: Cambaridae), from the Hiwassee River Basin of North Carolina. Proc Biol Soc Wash. 119(1):81–90.

Cooper JE. 2007. *Corbicula fluminea* (Asian clam) in the Roanoke River, North Carolina: a stressed population? Southeast Nat. 6(3):413–434.

Cooper JE. 2010. Annotated checklist of the crayfishes of North Carolina, and correlations of distributions with hydrologic units and physiographic provinces. J N C Acad Sci. 126(3):69–76.

Cooper JE. 2011. Redescription and distribution of the crayfish, *Procambarus* (*Ortmannicus*) *pearsei* (Creaser, 1934) (Decapoda: Cambaridae), with notes on its biology. Proc Biol Soc Wash. 124(1):9–22.

Cooper JE, Cooper DG. 2003. A new crayfish of the genus *Cambarus Erichson*, 1846 (Decapoda: Cambaridae) from the Cape Fear River basin in the Sandhills of North Carolina. Proc Biol Soc Wash. 116(4):920–932.

Cooper JE, Cooper MR. 1995. A new species of crayfish of the genus *Orconectes*, subgenus *Procericambarus* (Decapoda: Cambaridae) endemic to the Neuse and Tar-Pamlico River Basins, North Carolina. Brimleyana. 23:65–87.

Cooper JE, Russ WR. 2013. Four crayfishes (Decapoda: Cambaridae) new to the North Carolina fauna, with notes on other species in the state. J N C Acad Sci. 129(2):53–57.

Cooper JE, Schofield KA. 2002. *Cambarus* (*Jugicambarus*) *tuckasegee*, a new species of crayfish (Decapoda: Cambaridae) from the Little Tennessee River basin, North Carolina. Proc Biol Soc Wash. 115(2):371–381.

Cooper TR. 2007. King rail conservation plan and status assessment, version 1.0. Fort Snelling (MN): US Fish and Wildlife Service.

Covich AP, Palmer MA, Crowl TA. 1999. The role of benthic invertebrate species in freshwater ecosystems. BioSci. [accessed 2015 August];49(2):119-127. http://bioscience.oxfordjournals.org/content/49/2/119.full.pdf+html.

Crandall K, Buhay J. 2008. Global diversity of crayfish (Astacidae, Cambaridae, and Parastacidae: Decapoda). Hydrobiol. 595:295–301.

Davidson EW, Snyder J, Lightner D, Ruthg G, Lucas J, Gilley J. 2010. Exploration of potential microbial control agents for the invasive crayfish, *Orconectes virilis*. Biocontrol Sci Technol. 20:3, 297–310.

Davis MB, Simons TR, Groom MJ, Weaver JL, Cordes JR. 2001. The breeding status of the American Oystercatcher on the east coast of North America and breeding success in North Carolina. Waterbirds. 24(2):195–202.

Delany S, Nagy S, Davidson N. 2010. State of the world's waterbirds 2010. Ede (Netherlands): Wetlands International. 24 p.

Delany S, Scott S. 2002. Waterbird population estimates. 3rd ed. Wageningen (Netherlands): Wetlands International.

Demarest D. n.d. Southern Piedmont, executive summary [web page]. Partners in Flight; [accessed 2015 August]. http://www.partnersinflight.org/bcps/pl_11sum.htm.

DeRose-Wilson A, Fraser JD, Karpanty SM, Catlin DH. 2013. Nest-site selection and demography of Wilson's Plovers on a North Carolina barrier island. J Field Ornithol. 84(4):329–344.

De Steven D, Toner MM. 2004. Vegetation of upper coastal plain depression wetlands: environmental templates and wetland dynamics within a landscape framework. Wetl. 24:23–42.

Diaz S, Fargione J, Chapin III FS, Tilman D. 2006. Biodiversity loss threatens human well-being. PLoS Biol. [accessed 2015];4(8):1300–1305. doi:10.1371/journal.pbio.0040277.

Dourson DC. 2013. Land snails of the Great Smoky Mountains National Park and Southern Appalachians Tennessee and North Carolina. Bakersville (NC): Goatslug Publications. 336 p.

Dunn EH, Francis CM, Blancher PJ, Drennan SR, Howe MA, Lepage D, Robbins CS, Rosenberg KV, Sauer JR, Smith KG. 2005. Enhancing the scientific value of the Christmas Bird Count. Auk. 122(1):338–346.

Eckblad JW, Lehtinen SF. 1991. Decline in fingernail clam populations (Family Sphaeriidae) from backwater lakes of the Upper Mississippi River. J Freshw Ecol. 6:353–362.

Eggleston JR, Kehn TM, Wood Jr. GH. 1999. Anthracite. In Schultz GH, editor. The geology of Pennsylvania. Special Publication 1. Pittsburgh (PA): Pennsylvania Geological Survey and Pittsburgh Geological Society. Pp. 458–469.

Erwin RM. 1989. Responses to human intruders by birds nesting in colonies: experimental results and management guidelines. Colon Waterbirds. 12(1):104–108.

Erwin RM. 2005. Management, monitoring and protection protocols for colonially nesting waterbirds at Cape Hatteras National Seashore, North Carolina. Final report to National Park Service. Laurel (MD): USGS Patuxent Wildlife Research Center. 29 p.

Etnier DA. 1997. Jeopardized southeastern freshwater fishes: a search for causes. In: Benz GW, Collins DE, editors. Aquatic fauna in peril: the southeastern perspective. Decatur (GA): Southeast Aquatic Research. p. 88–104.

Evans LH, Edgerton BF. 2002. Pathogens, parasites and commensals. In: Holdich DM, editor. Biology of freshwater crayfish. Malden (MA): Wiley-Blackwell Science. 512 p.

[FAO] Food and Agriculture Organization. 1999. International Plan of Action for reducing incidental catch of seabirds in longline fisheries. Rome (Italy): Food and Agricultural Organization of the United Nations.

[FAO] Food and Agriculture Organization. 2008. Report of the expert consultation on Best Practice Technical Guidelines for IPOA/NPOA–Seabirds. FAO Fisheries and Aquaculture Report 880. Bergen (Norway): Food and Agricultural Organization of the United Nations.

Feinberg JA, Newman CE, Watkins-Colwell GJ, Schlesinger MD, Zarate B, Burger J. 2014. Cryptic diversity in metropolis: confirmation of a new leopard frog species (Anura: Ranidae) from New York City and surrounding Atlantic coast regions. PLoS ONE. [accessed 2015 July];9(10): e108213. doi:10.1371/journal.pone.0108213.

FitzGerald DM, Fenster MS, Argow BA, Buynevich IV. 2008. Coastal impacts due to sea-level rise. Annu Rev Earth Planet Sci. 36:601–647.

Flebbe PA, Holcomb J, Harrison J, Swift Jr. LW. 1996b. Evaluation of the assessment In: The southern Appalachian assessment aquatics technical report, Report 2 of 5. Atlanta (GA): US Department of Agriculture, Forest Service, Southern Region. p. 133–140.

Flebbe PA, Herrig JA. 2000. Patterns of aquatic species imperilment in the southern Appalachians: an evaluation of regional databases. Environ Manag. 25(6):681–694.

Fleming WJ, Augspurger TP, Alderman JA. 1995. Freshwater mussel die-off attributed to anticholinesterase poisoning. Environ Toxicol Chem. 14(5):877–879.

Ford WM, Evans AM, Odom RH, Rodrigue JL, Kelly CA, Abaid N, Diggins CA, Newcomb D. 2015. Predictive habitat models derived from nest-box occupancy for the endangered Carolina Northern Flying Squirrel in the southern Appalachians. Endanger Species Res. [accessed 2015 August];27:131–140. http://www.fs.fed.us/nrs/pubs/jrnl/2015/nrs_2015_Ford_001.pdf.

Ford WM, Kelly CA, Rodrigue JL, Odom RH, Newcomb D, Gilley LM, Diggins CA. 2014. Late winter and early spring home range and habitat use of the endangered Carolina Northern Flying Squirrel in western North Carolina. Endanger Species Res. 23:73–82.

Forsell DJ. 1999. Mortality of migratory waterbirds in Mid-Atlantic coastal anchored gillnets during March and April 1998. Annapolis (MD): US Fish and Wildlife Service. 29 p.

Fournie J, Chetail M. 1984. Calcium dynamics in land gastropods. Am Zool. 24(4):857–870.

Fox JE. 2005. Non-traditional targets of endocrine disrupting chemicals: The roots of hormone signaling. Integr Comp Biol. 45:179–188.

Franklin MA. 2001. Factors affecting seed production in natural populations of *Lysimachia asperulifolia poir.* (Primulaceae), a rare, self-incompatible plant species [thesis]. [Raleigh (NC)]: NC State University, Department of Botany.

Frost DR, Grant T, Faivovich J, Bain RH, Haas A, Haddad CFB, De Sa RO, Channing A, Wilkinson M, Donnellan SC, et al. 2006. The amphibian tree of life. Bulletin Number 297. New York (NY): American Museum of Natural History. 370 p.

Gangloff MM, Siefferman L, Seesock W, Webber EC. 2009. Influence of urban tributaries on freshwater mussel populations in a biologically diverse piedmont (USA) stream. Hydrobiol. 636:191–201.

Garroway CJ, Bowman J, Cascaden TJ, Holloway GL, Mahan CG, Malcolm JR, Steele MA, Turner G, Wilson PJ. 2010. Climate change induced hybridization in flying squirrels. Glob Change Biol. 16:113–121.

Garvon JM, Bird J. 2005. Attraction of the land snail *Anguispira alternate* to fresh feces of white-tailed deer: implications in the transmission of *Parelaphostrongylus tenuis*. Can J Zool. 83:358–362.

Gascon CJ, Collins P, Moore RD, Church DR, McKay JE, Mendelson III JR (editors). 2007. Amphibian conservation action plan. Gland (Switzerland): IUCN/SSC Amphibian Specialist Group; [accessed 2015 August]. 68 p. http://memphiszoo2013.sitewrench.com/assets/1478/acap.pdf.

Gibbons JW, Scott DE, Ryan TJ, Buhlmann KA, Tuberville TD, Metts BS, Greene JL, Mills T, Leiden Y, Poppy S, et al. 2000. The global decline of reptiles, déjà vu amphibians. BioSci 50:653–666.

Gibbons D, Morrissey C, Mineau P. 2015. A review of the direct and indirect effects of neonicotinoids and fipronil on vertebrate wildlife. Environ Sci Pollut Res. [accessed 2015 August];22:103–118. doi:10.1007/s11356-014-3180-5.

Gibbs JP, Melvin SM. 1997. Power to detect trends in waterbird abundance with call-response surveys. J Wildl Manag. 61(4):1262–1267.

Gilley LM. 2013. Discovery and characterization of high-frequency calls in North American Flying Squirrels (*Glaucomys sabrinus* and *G.volans*): implications for ecology, behavior, and conservation [dissertation]. [Auburn (AL)]: Auburn University.

Gillies RR, Brim-Box J, Symanzik J, Rodemaker EJ. 2003. Effects of urbanization on the aquatic fauna of the Line Creek watershed, Atlanta – a satellite perspective. Remote Sens Environ. 86(3):411–422.

Gillis PL. 2011. Assessing the toxicity of sodium chloride to the glochidia of freshwater mussels: implications for salinization of surface waters. Environ Pollut. 159(6):1702–1708.

[GWWG] Golden-winged Warbler Working Group. 2013. Best management practices for Golden-winged warbler habitats in the Appalachian Region: a guide for land managers and landowners. Golden-winged Warbler Working Group; [accessed 2015 August]. http://www.allaboutbirds.org/bbimages/clo/pdf/GWWA-APPLRegionalGuide_130808_lo-res.pdf.

Goudreau SE, Neves RJ, Sheehan RJ. 1993. Effects of wastewater treatment plan effluents on freshwater mollusks in the upper Clinch River, Virginia, USA. Hydrobiol. 252:211–230.

Greenwood KS, Thorp JH. 2001. Aspects of ecology and conservation of sympatric, prosobranch snails in a large river. Hydrobiologia 455(1-3):229-236.

Haag WR. 2012. North American freshwater mussels. Cambridge (England): Cambridge University Press. 505 p.

Haag WR, Williams JD. 2014. Biodiversity on the brink: an assessment of conservation strategies for North American freshwater mussels. Hydrobiol. 735:45–60.

Hall RO, Vanderloop MC, Dybdahl MF. 2003. Exotic snails dominate nitrogen and carbon cycling in a highly productive stream. Front Ecol Environ. 1:407–411.

Hall SP. 1999a. Inventory of lepidoptera of the Albemarle-Pamlico peninsular region of North Carolina, including Pettigrew, Goose Creek, and Jockey's Ridge State Parks and Nag's Head Woods Ecological Preserve. Raleigh (NC): NC Natural Heritage Program.

Hall SP. 1999b. Inventory of the moths and butterflies of the lower Roanoke River floodplain. Raleigh (NC): NC Natural Heritage Program.

Hall SP. 2003. Status survey for *Atrytonopsis* new species 1 in North Carolina. Raleigh (NC): US Fish and Wildlife Service, Raleigh Field Office.

Hall SP. 2004. Assessment of terrestrial habitat quality and landscape integrity in the Albemarle-Pamlico Estuarine Study Area, using a Habitat/Indicator-Group analysis. Raleigh (NC): NC Natural Heritage Program.

Hall SP, Baker WH, Gatrelle RR, Minno MC, Schweitzer DF, Sullivan JB, Calhoun JV, Minno M, Slotten JR. 1999a. A rangewide status survey of the eastern Arogos skipper *Atrytonea arogos* (Lepidoptera: Hesperiidae). Asheville (NC): US Fish and Wildlife Service, Region 6 Endangered Species Field Office.

Hall SP, Schafale MP. 1999. Conservation assessment of the Southeast Coastal Plain of North Carolina, using site-oriented and landscape-oriented analyses. Raleigh (NC): NC Natural Heritage Program.

Hall SP, Schweitzer DF. 1993. A survey of the moths, butterflies, and grasshoppers of four Nature Conservancy preserves in southeastern North Carolina. Durham (NC): The Nature Conservancy.

Hall SP, Sullivan JB. 2000. A rangewide status survey of the Venus flytrap moth *Hemipachnobia subporphyrea* (Lepidoptera: Noctuidae). Asheville (NC): US Fish and Wildlife Service, Region 6 Endangered Species Field Office.

Hall SP, Sullivan JB. 2004. Status survey for *Hemipachnobia subporphyrea*, based on larval presence and feeding sign. Raleigh (NC): US Fish and Wildlife Service, Raleigh Field Office.

Hall SP, Sullivan JB, Schweitzer DF. 1999b. Assessment of risk to non-target macro-moths after *Bacillus thuringiensis* var. *kurstaki* application to Asian gypsy moth in the Cape Fear region of North Carolina. Morgantown (WV): US Forest Service, Forest Health Technology Enterprise Team.

Hall SP, Sullivan JB, Schweitzer DF. 1999c. Eradication of the Asian-strain of the gypsy moth from the Cape Fear Region of North Carolina: assessment of risk to nontarget macro-lepidoptera. Morgantown (WV): US Forest Service, Forest Health Technology Enterprise Team.

Hamburg SP, Yanai RD, Arthur MA, Blum JD, Siccama TG. 2003. Biotic control of calcium cycling in northern hardwood forests: acid rain and aging forests. Ecosyst. 6:399–406.

Hanson JM, Chambers PA, Prepas EE. 1990. Selective foraging by the crayfish *Orconectes virilis* and its impact on macroinvertebrates. Freshw Biol. 24:69–80.

Hanula JL, Franzred KE. 1995. Arthropod prey of nestling red-cockaded Woodpeckers in the upper Coastal Plain of South Carolina. Wilson Bull. [accessed 2015 August];107(3):485–495. https://sora.unm.edu/sites/default/files/journals/wilson/v107n03/p0485-p0495.pdf.

Harp J, Fridell JA. 1998. Recovery plan for Spruce–fir Moss Spider. Atlanta (GA): US Fish and Wildlife Service, Southeast Region; [accessed 2015 July]. http://ecos.fws.gov/docs/recovery_plans/1998/980911b.pdf.

Hatfield R, Jepsen S, Mader E, Hoffman Black S, Shepherd M. 2012. Conserving bumble bees: guidelines for creating and managing habitat for America's declining pollinators. Portland (OR): The Xerces Society for Invertebrate Conservation; [accessed 2015 July]. http://www.xerces.org/wp-content/uploads/2012/06/conserving_bb.pdf.

Hawkins CP, Furnish JK. 1987. Are snails important competitors in stream ecosystems? Oikos. 49:209–220.

Haynes JM, Stewart TW, Cook GE. 1999. Benthic macroinvertebrate communities in southwestern Lake Ontario following invasion of *Dreissena*: continuing change. Internat Assoc Great Lakes Res, J Great Lakes Res. [accessed 2015 August];25(4):828–838. http://www.reabic.net/publ/Haynes_et%20al_1999_Dreissena.pdf.

Hazelton PD, Cope WG, Mosher S, Pandolfo TJ, Belden JB, Barnhart MC, Bringolf RB. 2013. Fluoxetine alters adult freshwater mussel behavior and larval metamorphosis. Sci Total Environ. 445-446:94–100.

Hazelton PD, Cope WG, Pandolfo TJ, Mosher S, Strynar MJ, Barnhart MC, Bringolf RB. 2012. Partial life-cycle and acute toxicity of perfluoroalkyl acids to freshwater mussels. Environ Toxicol Chem. 31(7):1611-1620.

Herman DW. 2003. Status of the bog turtle, *Clemmys muhlenbergii* Schoepff, in the southern United States. Final Report to the US Fish and Wildlife Service on the 1996-2002 Status Survey Conducted Under Grant Agreement #14480004-96-9126. US Fish and Wildlife Service. 93 p.

Hickman Jr. CP, Roberts LS, Larson A. 2000. Animal diversity. 2nd ed. Boston (MA): McGraw-Hill. 429 p.

Hickman CP, Roberts LS, Larson A. 2003. Animal diversity. 3rd ed. New York (NY): McGraw-Hill. 447 p.

Hill EF, Fleming WJ. 1982. Anticholinesterase poisoning of birds, field monitoring and diagnosis of acute poisoning. Environ Toxicol Chem. 1:27–38.

Hobbs Jr. HH. 1942. The crayfishes of Florida. Biological Science Series no. 3. Gainesville (FL): University of Florida Publications.

Hobbs Jr. HH. 1981. The crayfishes of Georgia. Smithsonian Contributions to Zoology no. 318. Washington (DC): Smithsonian Institution Press.

Holdich DM, editor. 2002. Biology of freshwater crayfish. Ames (IA): Iowa State University Press. 702 p.

Hopwood J, Black SH, Vaughn M, Lee-Mader E. 2013. Beyond the birds and the bees. Portland (OR): The Xerces Society for Invertebrate Conservation. 25 p.

Howe MA, Geissler PH, Harrington BA. 1989. Population trends of North American shorebirds based on the International Shorebird Survey. Biol Conserv. 49(3):185–199.

Hunter C, Katz R, Pashley D, Ford B. 1999. Partners in Flight Bird Conservation Plan for the Southern Blue Ridge (Physiographic Area 23). Version 1.0. Atlanta (GA): American Bird Conservancy and USFWS; [accessed 2015 August]. 101 p. http://www.partnersinflight.org/bcps/plan/pl_23_10.pdf.

Hunter WC. 2004a. Proposed state lists of priority bird species for FWS Southeast Region States, Commonwealth of Puerto Rico, and U.S. Virgin Islands. Atlanta (GA): US Fish & Wildlife Service.

Hunter WC. 2004b. Southeast U.S. waterbird conservation priorities. Atlanta (GA): US Fish and Wildlife Service.

Hunter WC, Buehler DA, Canterbury RA, Confer JL, Hamel PB. 2001a. Conservation of disturbance-dependent birds in eastern North America. Wildl Soc Bull. 29(2):440–455.

Hunter WC, Collazo J, Noffsinger B, Winn B, Allen D, Harrington B, Epstein M, Saliva J. 2005. Southeastern Coastal Plains Caribbean Regional Shorebird Plan. Version 1.0. Atlanta (GA): US Fish and Wildlife Service; [accessed 2015 August]. 51 p. http://www.acjv.org/documents/shorebird_plan_se_car.pdf.

Hunter WC, Golder W, Melvin S, Wheeler J. 2006. Southeast United States regional waterbird conservation plan. Atlanta (GA): US Fish and Wildlife Service Atlanta; Wilmington (NC): North Carolina Audubon Society; [accessed 2015 August]. http://www.waterbirdconservation.org/pdfs/regional/seusplanfinal906.pdf.

Hunter WC, Peoples L, Collazo J. 2001b. Partners in Flight bird conservation plan for the South Atlantic Coastal Plain. The Plains (VA): American Bird Conservancy.

Iguchi T, Katsu Y. 2008. Commonality in signaling of endocrine disruption from snail to human. BioSci. 58(11):1061–1067.

[ICCAT] International Commission for the Conservation of Atlantic Tunas. 2008. Report of the 2007 inter-sessional meeting of the sub-committee on ecosystems. Collect Vol Sci Pap ICCAT. [accessed 2015 August];62(6):1671–1720. http://www.iccat.int/Documents/CVSP/CV062_2008/no_6/CV062061671.pdf.

[ICCAT] International Commission for the Conservation of Atlantic Tunas. 2010a. Report of the Standing Committee on Research and Statistics (SCRS). Madrid (Spain): International Commission for the Conservation of Atlantic Tunas; [accessed 2015 August]. http://www.iccat.int/Documents/BienRep/REP_EN_08-09_II_2.pdf.

[ICCAT] International Commission for the Conservation of Atlantic Tunas. 2014. Report of the Standing Committee on Research and Statistics (SCRS). Madrid (Spain): International Commission for the Conservation of Tunas; [accessed 2015 August]. http://www.iccat.int/Documents/BienRep/REP_EN_12-13_II_2.pdf.

Important Bird Areas of the US [webpage]. 2013. National Audubon Society; [accessed 2014 Nov]. http://www.audubon.org/bird/iba.

[IUCN] International Union for Conservation of Nature. 2014. The IUCN red list of threatened species [website]. Version 2014.2. [accessed 2015 July] http://www.iucnredlist.org.

Jarvis JD. 2011. Water quality in the Upper Little Tennessee River and its potential effects on the Appalachian Elktoe mussel (*Alasmidonta raveneliana*) [thesis]. [Cullowhee (NC)]: Western Carolina University, Department of Geosciences and Natural Resources.

Jelks HL, Walsh SJ, Burkhead NM, Contreras-Balderas S, Diaz-Pardo E, Hendrickson DA, Lyons J, Mandrak NE, McCornick F, Nelson JS, et al. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fish. 33(8):372–407.

Johnson D. 2001. Habitat fragmentation effects on birds in grasslands and wetlands: a critique of our knowledge. Great Plains Res: J Nat Soc Sci. 11:211–231.

Johnson PD. 2009. Freshwater snail biodiversity and conservation. Sustaining America's aquatic biodiversity. Publication 420-530. Cohutta (GA): Virginia Cooperative Extension. 7 p.

Johnson PD, Bogan AE, Brown KM, Burkhead NM, Cordeiro JR, Garner JT, Hartfield PD, Lepitzki DAW, Mackie GL, Pip E, et al. 2013. Conservation status of freshwater gastropods of Canada and the United States. Fish. [accessed 2015 August];38(6):247–282. http://fisheries.org/docs/fisheries_magazine_archive/fisheries_3806.pdf.

Johnson PD, Brown KM. 1997. The role of current and light in explaining the habitat distribution of the lotic snail Elimia semicarinata (Say). J N Am Benthol Soc. 16(3):545–561.

Jones JW, Hallerman EM, Neves RJ. 2006. Genetic management guidelines for captive propagation of freshwater mussels (Unionoidea). J Shellfish Res. 25(2):527–535.

Kalisz PJ, Powell JE. 2003. Effect of calcareous road dust on land snails (Gastropoda: Pulmonata) and millipedes (Diplopoda) in acid forest soils of the Daniel Boone National Forest of Kentucky, USA. For Ecol Manag. 186(1):177–183.

Karriker KS. 1993. Effects of intensive silviculture on breeding and wintering birds in North Carolina pocosins [thesis]. [Raleigh (NC)]: NC State University.

Kaushal SS, Likens GE, Jaworski NA, Pace ML, Sides AM, Seekell D, Belt KT, Secor DT, Wingate RL. 2010. Rising stream and river temperatures in the United States. Front Ecol Environ. 8:461–466.

Kelly CA, Diggins CA, Lawrence AJ. 2013. Crossing structures reconnect federally endangered flying squirrel populations divided for 20 years by road barrier. Wildl Soc Bull. 37(2):375–379.

Kerans BL, Dybdahl MF, Gangloff MM, Jannot JE. 2005. *Potamopyrgus antipodarum*: distribution, density, and effects on native macroinvertebrate assemblages in the Greater Yellowstone Ecosystem. J N Am Benthol Soc. 24:123–138.

Killeen TJ, Douglas M, Consiglio T, Jørgensen PM, Mejia J. 2007. Dry spots and wet spots in the Andean hotspot. J Biogeogr. 34:1357–1373.

King TL, Eackles MS, Gjetvaj B, Hoe WR. 1999. Intraspecific phylogeography of *Lasmigona subviridis* (Bivalvia: Unionidae): conservation implications of range discontinuity. Mol Ecol. 8:S65–S78.

Klein C, Wilson K, Watts M, Stein J, Berry S, Carwardine J, Smith MS, Mackey B, Possingham H. 2009. Incorporating ecological and evolutionary processes into continental-scale conservation planning. Ecol Appl. 19:206–217.

Kolpin DW, Furlong ET, Meyer MT, Thurman EM, Zaugg SD, Barber LB, Buxton HT. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999-2000: a national reconnaissance. Environ Sci Technol. 36:1202–1211.

Kopachena JG, Crist CJ. 2000. Macro-habitat features associated with painted and indigo buntings in northeast Texas. Wilson Bull. 112(1):108–114.

Kreisel KJ, Stein SJ. Bird use of burned and unburned coniferous forests during winter. Wilson Bull. 111(2):243–250.

Krementz DG, Christie JS. 2000. Clearcut stand size and scrub-successional bird assemblages. Auk. 117(4):913–924.

Kushlan JA, Steinkamp MJ, Parsons KC, Capp J, Cruz MA, Coulter M, Davidson I, Dickson L, Edelson N, Elliot R, et al. 2002. The North American waterbird conservation plan, Version 1. Washington (DC): Waterbird Conservation for the Americas; [accessed 2015 August]. http://www.waterbirdconservation.org/nawcp.html.

Lacki MJ, Bayless ML. 2014. A conservation strategy for Rafinesque's Big-eared Bat (*Corynorhinus rafinesquii*) and Southeastern Myotis (*Myotis austroriparius*). Austin (TX): Bat Conservation International ; [accessed 2015 August]. http://www.batcon.org/pdfs/ConservationPlanforCORAandMYAU_2014.pdf.

Landers JL, Hamilton RJ, Johnson AS, Marchinton RL. 1979. Foods and habitat of black bears in southeastern North Carolina. J Wildl Manage. 43(1):143–153.

Lankester MW, Anderson RC. 1968. Gastropods as intermediate hosts of *Pneumostrongylus tenuis* doughtery of white-tailed deer. Can J Zool. 46:373–383.

Lannoo MJ (editor). 2005. Amphibian declines: The conservation status of United States species. University of California Press. Berkeley and Los Angeles (CA). 1115 pp.

Larson JL, Redmond CT, Potter DA. 2013. Assessing insecticide hazard to bumble bees foraging on flowering weeds in treated lawns. PLoS ONE. [accessed 2015 August];8(6): e66375. doi:10.1371/journal.pone.0066375.

Lawler JJ, Shafer SL, Bancroft BA, Blaustein AR. 2009. Projected climate impacts for the amphibians of the Western Hemisphere. Conserv Biol. 24:38–50.

Layzer JB, Scott EM. 2006. Restoration and colonization of freshwater mussels and fish in a southeastern United States tailwater. River Res Appl. 22:476–491.

Lee-Mader E, Hopwood J, Morandin L, Vaughan M, Black SH. 2014. Farming with Native Beneficial Insects: Ecological Pest Control Solutions. North Adams (MA): The Xerces Society Guide, Storey Publishing. 272 p.

Leff LG, Burch JL, McArthur JV. 1990. Spatial distribution, seston removal, and potential competitive interactions of the bivalves *Corbicula fluminea* and *Elliptio complanata*, in a coastal plain stream. Freshw Biol. 24:409–416.

Legare ML, Eddleman WR, Buckley PA, Kelly C. 1999. The effectiveness of tape playback in estimating black rail density. J Wildl Manag. 63(1):116–125.

LeGrand HE, Howard Jr. TE. 2013. The mammals of North Carolina: first approximation. Raleigh (NC): NC Natural Heritage Program; [accessed 2015 August]. http://www.dpr.ncparks.gov/mammals/pdf/nc_mammal_apx_1.pdf.

LeGrand HE, McRae SE, Hall SP, Finnegan JT. 2004. Natural Heritage Program list of the rare animal species of North Carolina. Raleigh (NC): NC Natural Heritage Program.

LeGrand HE, Ratcliffe JA, Finnegan JT. 2014. Natural Heritage Program list of the rare animal species of North Carolina. Raleigh (NC): NC Natural Heritage Program, Office of Land and Water Stewardship; [accessed 2015 August]. http://portal.ncdenr.org/c/document_library/get_file?uuid=537d88dd-5168-4374-aaba-a159785bbfbe&groupId=61587.

Leidy RA and Moyle PB. 1998. Conservation status of the world's fish fauna: an overview. In: Fiedler Pl, Kareiva PM, editors. Conservation biology: for the coming decade. 2nd ed. New York (NY): Chapman and Hall. 576 p.

Lettink M, Cree A. 2007. Relative use of three types of artificial retreats by terrestrial lizards in grazed coastal shrubland, New Zealand. Appl Herpetol. 4:227–243.

Leung B, Lodge DM, Finnoff D, Shogren JF, Lewis MA, Lamberti G. 2002. An ounce of prevention or a pound of cure: bioeconomic risk analysis of invasive species. Proc Royal Soc Lond B. 269:2407–2413.

Lieb DA, Bouchard RW, Carline RF, Nuttall TR, Wallace JR, Burkholder CL. 2011. Conservation and management of crayfishes: lessons from Pennsylvania. Fish. 36(10):489–507.

Linstone HA, Turoff M, editors. 2002. The Delphi Method: techniques and applications. Reading (MA): Addison-Wesley; [accessed 2015 July]. 618 p. http://is.njit.edu/pubs/delphibook/delphibook.pdf.

Lodge D, Taylor C, Holdich D, Skurdal J. 2000a. Nonindigenous crayfishes threaten North American freshwater biodiversity: lessons from Europe. Fish. 25:7–20.

Lodge DM, Taylor CA, Holdich DM, Skurdal J. 2000b. Reducing impacts of exotic crayfish introductions: new policies needed. Fish. 25:21–33.

Long JM, Nibbelink NP, McAbee KT, and Stahli JW. 2012. Assessment of freshwater fish assemblages and their habitats in the National Park Service system of the southeastern United States. Fish. 37(5):212–225.

Loss SR, Will T, Marra PP. 2013. The impact of free-ranging domestic cats on wildlife of the United States. Nat Commun. [accessed 2013 Jan 30];4(1396). http://www.nature.com/doifinder/10.1038/ncomms2380.

Lotts K, Naberhaus T, coordinators. 2015. Butterflies and moths of North America [website]. [accessed 2015 August]. http://www.butterfliesandmoths.org.

Lowe S, Browne M, Boudjelas S, De Poorter M. 2000. 100 of the world's worst invasive alien species a selection from the global invasive species database. The Invasive Species Specialist Group (ISSG), Species Survival Commission of the World Conservation Union (IUCN); [accessed 2015 September]. http://calendar.k-state.edu/withlab/consbiol/IUCN_invaders.pdf.

Lydeard C,Mayden RL. 1995. A diverse and endangered aquatic ecosystem of the southeast United States. Conserv Biol. 9:800–805.

Lydeard C, Cowie RH, Ponder WF, Bogan AE, Bouchet P, Clark SA, Cummings KS, Frest TJ, Gargominy O, Herbert DG, et al. 2004. The global decline of nonmarine mollusks. BioSci. 54(4):321–330.

Lysne SJ, Perez KE, Brown KM, Minton RL, Sides JD. 2008. A review of freshwater gastropod conservation: challenges and opportunities. J N Am Benthol Soc. 27(2):463–470.

Mace GM, Purvis A. 2008. Evolutionary biology and practical conservation: bridging a widening gap. Mol Ecol. 17(1):9–19.

Mallin MA. 2010. Potential environmental problems from building the proposed North Carolina International Terminal: preliminary report. Wilmington (NC): University of North Carolina Wilmington, Center for Marine Science; [accessed 2015 August]. 31 p. http://savethecape.org/STC/images/stories/PDFs/UNCW80910.pdf.

Maxwell JR, Edwards CJ, Jensen ME, Paustian SJ, Parrott H, Hill DM. 1995. A hierarchical framework of aquatic ecological units in North America (Nearctic Zone). General Technical Report NC-176. St. Paul (MN): Forest Service, North Central Forest Experiment Station. 78 p.

Mayasich J, Grandmaison D, Phillips C. 2003. Eastern hellbender status assessment report. NRRI/TR-2003/09. Duluth (MN): Natural Resources Research Institute; [accessed 2015 August]. 43 p. http://www.fws.gov/midwest/es/soc/amphibians/eahe-sa.pdf.

McCullough DR. 1996. Metapopulations and wildlife conservation. 2nd ed. Washington (DC): Island Press. 439 p.

Meyers JM. 2005. Management, monitoring, and protection protocols for American Oystercatchers at Cape Hatteras National Seashore, North Carolina. Laurel (MD): National Park Service. 24 p.

Mohseni O, Erickson TR, Stefan HG. 1999. Sensitivity of stream temperatures in the United States to air temperatures projected under a global warming scenario. Water Resour Res. 35:3723–3733.

Moore MJ, DiStefano RJ, Larson ER. 2013. An assessment of life-history studies for USA and Canadian crayfishes: identifying biases and knowledge gaps to improve conservation and management. Freshw Sci. 32(4):1276–1287.

Morris JT, Sundareshwar PV, Nietch CT, Kjerfve B, Cahoon DR. 2002. Responses of coastal wetlands to rising sea level. Ecol. 83(10):2869–2877.

Mottesi G, Savacool M. 1997. Jones Lake State Park aquatic inventory. Alderman J, editor. Raleigh (NC): NC Wildlife Resources Commission.

Mulvey M, Lydeard C, Pyer DL, Hicks KM, Brim-Box J, Williams JD, Butler RS. 1997. Conservation genetics of North American freshwater mussels Amblema and Megalonaias. Conserv Biol. 11(4):868–878.

Murdock NA. 1996. Recovery plan for St. Francis' satyr. Atlanta (GA): US Fish and Wildlife Service, Southeast Region; [accessed 2015 August]. http://ecos.fws.gov/docs/recovery_plans/1996/960423.pdf.

Murray TE, Coffey MF, Kehoe E, Horgan FG. 2013. Pathogen prevalence in commercially reared bumble bees and evidence of spillover in conspecific populations. Biol Conserv. 159:269–276.

Murphy M. 2004. Seabirds. Charleston (SC): South Atlantic Fishery Management Council.

Musick JA, Harbin MM, Berkeley SA, Burgess GH, Eklund AM, Findley L, Gilmore RG, Golden JT, Ha DS, Huntsman GR, et al. 2000. Marine, estuarine, anadromous fish stocks at risk of extinction in North America (exclusive of pacific salmonids). Fish. 25:6–30.

Myers N, Knoll A. 2001. The biotic crisis and the future of evolution. Proc Natl Acad Sci U S Am. 98:5389–5392.

Myers P, Espinosa R, Parr CS, Jones T, Hammond GS, Dewey TA. 2014. The Animal Diversity Web (internet). Ann Arbor (MI): University of Michigan; [accessed 2015 August]. http://animaldiversity.org.

[NAAMP] North American Amphibian Monitoring Program [webpage]. Washington (DC): US Geological Survey; [accessed 2015 July]. https://www.pwrc.usgs.gov/naamp/index.cfm.

[NABCI] North American Bird Conservation Initiative, US Committee. 2000. The North American bird conservation initiative in the United States: a vision of American bird conservation. Arlington (VA): US NABCI Committee; [accessed 2015 September]. http://www.pwrc.usgs.gov/pif/nabci/NABCIfndtn.pdf.

[NABCI] North American Bird Conservation Initiative, US Committee. 2009. The state of the birds: United States of America. Washington (DC): US Department of Interior. 36 p.

[NABCI] North American Bird Conservation Initiative, US Committee. 2014. The State of the Birds Report 2014 [webpage]. Washington (DC): US Department of Interior; [accessed 2015 September]. http://www.stateofthebirds.org.

[NAWMP] North American Waterfowl Management Plan. 1998. Expanding the vision: 1998 update. Arlington (VA): US Fish and Wildlife Services; [accessed 2015 August]. 43 p. http://www.iwjv.org/sites/default/files/nawmp_1998_plan.pdf.

[NAWMP] North American Waterfowl Management Plan. 2004a. Strategic guidance. Arlington (VA): US Fish and Wildlife Service, Division of Bird Habitat Conservation; [accessed 2015 August]. 36 p. http://www.iwjv.org/sites/default/files/nawmp_2004_plan_0.pdf.

[NAWMP] North American Waterfowl Management Plan. 2004b. Implementation framework. Arlington (VA): US Fish and Wildlife Service, Division of Bird Habitat Conservation; [accessed 2015 August]. 120 p. http://www.iwjv.org/sites/default/files/nawmp_implementationframework.pdf.

[NCAC] NC Administrative Code. N.d. 15A Subchapter 2B – Surface water and wetland standards: Section .0100 – Procedures for assignment of water quality standards. [accessed 2015 July]. http://ncrules.state.nc.us/ncac/title%2015a%20-%20environment%20and%20natural%20resources/chapter%2002%20-%20environmental%20management/subchapter%20b/subchapter%20b%20rules.pdf.

[NCANSMP] NC Aquatic Nuisance Species Management Plan. 2015. Draft, prepared by the NC Aquatic Nuisance Species Management Plan Committee.

[NCGS] NC General Statute. N.d.a. Chapter 113, Subchapter IV. Conservation of Marine and Estuarine and Wildlife Resources, General Definitions. [accessed 2015 July]. http://www.ncga.state.nc.us/enactedlegislation/statutes/html/byarticle/chapter_113/article_12.html.

[NCGS] NC General Statute. N.d.b. Chapter 113, Article 20. Miscellaneous regulatory provisions. [accessed 2015 Jun 4]. http://www.ncga.state.nc.us/EnactedLegislation/Statutes/PDF/ByArticle/Chapter_113/Article_20.pdf.

[NCGS] NC General Statute. N.d.c. Chapter 113, Article 21. Licenses and permits issued by the Wildlife Resources Commission. [accessed 2015 Jun 4]. http://www.ncga.state.nc.us/EnactedLegislation/Statutes/PDF/ByArticle/Chapter_113/Article_21.pdf.

[NCGS] NC General Statute. N.d.d. Chapter 113, Article 22. Regulation of wildlife. [accessed 2015 Jun 4]. http://www.ncga.state.nc.us/EnactedLegislation/Statutes/PDF/ByArticle/Chapter_113/Article_22.pdf.

[NCGS] NC General Statute. N.d.e. Chapter 113, Article 25. Endangered and threatened wildlife and wildlife species of special concern. [accessed 2015 Jun 4]. http://www.ncga.state.nc.us/EnactedLegislation/Statutes/PDF/ByArticle/Chapter_113/Article_25.pdf.

[NCGS] NC General Statute. N.d.f. Chapter 143, Article 24. Wildlife Resources Commission. [accessed 2015 Jun 4]. http://www.ncga.state.nc.us/EnactedLegislation/Statutes/PDF/ByArticle/Chapter_143/Article_24.pdf.

[NCHS] NC Herpetological Society [website]. c. 2015. NC Herpetological Society; [accessed 2015 July]. http://ncherps.org.

[NCMNS] NC Museum of Natural Sciences. N.d. Invertebrates collection [web page]. [accessed 2015 August]. http://www.naturalsciences.org/research/invertebrates-collection.

[NCPARC] NC Partners in Amphibian and Reptile Conservation [webpage]. c. 2014. Partners in Amphibian and Reptile Conservation; [accessed 2015 July]. http://www.ncparc.org.

[NCWRC] NC Wildlife Resources Commission. 2002. Guidance memorandum to address and mitigate secondary and cumulative impacts to aquatic and terrestrial wildlife resources and water quality. Raleigh, NC; [accessed 2015 July]. 25 p. http://www.ncwildlife.org/Portals/0/Conserving/documents/2002_GuidanceMemorandumforSecondaryandCumulativeImpacts.pdf.

[NCWRC] NC Wildlife Resources Commission. 2012. Conservation recommendations for priority terrestrial wildlife species and habitats in North Carolina. Raleigh (NC): NC Wildlife Resources Commission; [accessed 2015 July]. 96 p. http://www.ncwildlife.org/Portals/0/Conserving/documents/ConservingTerrestrialHabitatsandSpecies.pdf.

[NCWRC and USFWS] NC Wildlife Resources Commission, US Fish and Wildlife Service. 2013. North Carolina's white-nose syndrome surveillance and response plan. Raleigh (NC); [accessed 2015 July]. 37 p. http://www.ncwildlife.org/Portals/0/Conserving/documents/WildlifeDiversity/NCWNS_Surveillance%20ResponsePlan.pdf.

Nekola JC. 1999. Paleorefugia and neorefugia: the influence of colonization history on community pattern and process. Ecol. 80(8):2459–2473.

Nekola JC, Smith TA. 1999. Terrestrial gastropod richness patterns in Wisconsin carbonate cliff communities. Malacol. 41:253–269.

Nettleship DN. 1977. Seabird resources of eastern Canada: status, problems and prospects. In: Mosquin T, Suchal C, editors. Canada's threatened species and habitats. Special Publication Number 6. Ottawa (Canada): Canadian Nature Federation. p. 96–108.

Nettleship DN. 1991. Seabird management and future research. Colon Waterbirds. 14(2):77–215.

Neves RJ. 1993. A state-of-the-unionids address. In Cummings KW, Buchanan AC, Koch LM, editors. Conservation and management of freshwater mussels. Rock Island (IL): Upper Mississippi River Conservation Committee. p. 1–10.

Neves RJ, Angermeier PL. 1990. Habitat alteration and its effects on native fishes in the upper Tennessee River system, east-central USA. J Fish Biol. 37:45–52.

Neves RJ, Bogan AE, Williams JD, Ahlstedt SA, Hartfield PW. 1997. Status of the aquatic mollusks in the southeastern United States: a downward spiral of diversity. In Benz GW, Collins DE, editors. Aquatic fauna in peril: the southeastern perspective. Decatur (GA): Southeast Aquatic Research Institute. p. 43–86.

Neves RJ, Odum MC. 1989. Muskrat predation on endangered freshwater mussels in Virginia. J Wildl Manage. 53:934–941.

Long JM, Nibbelink NP, McAbee KT, Stahli JW. 2012. Assessment of freshwater fish assemblages and their habitats in the National Park Service system of the southeastern United States. Fish. [accessed 2015 August];37(5):212–225. http://www.tandfonline.com/doi/abs/10.1080/03632415.2012.676835.

[NMFS] National Marine Fisheries Service. 2001. United States national plan of action for reducing the incidental catch of seabirds in longline fisheries. Washington (DC): US Department of Commerce.

[NMFS] National Marine Fisheries Service. 2011. Listing endangered and threatened wildlife and plants; 90-day finding on a petition to list alewife and blueback herring as threatened under the endangered species act. Fed Regist. [accessed 2015 August];76(212):67652–67656. www.federalregister.gov/articles/2011/11/02/2011-28430/listing-endangered-and-threatened-wildlife-and-plants-90-day-finding-on-a-petition-to-list-alewife.

[NMFS] National Marine Fisheries Service. 2012. River herring climate change workshop report. Gloucester (MA): National Marine Fisheries Service, Northeast Regional Office; [accessed 2015 August]. www.greateratlantic.fisheries.noaa.gov/prot_res/CandidateSpeciesProgram/sswpdocs/RIVER%20HERRING%20CLIMATE%20CHANGE%20WORKSHOP%20REPORT_122712.pdf.

[NOAA] National Oceanic Atmospheric Administration. 1975. Table 364: Coastline and shoreline of the United States by state. The national atlas of the United States, coastline and shoreline. [accessed 2015 August]. http://www.census.gov/compendia/statab/2012/tables/12s0364.pdf.

Nystrom P. 2002. Ecology. In: Holdich DM, editor. Biology of freshwater crayfish. Oxford (England): Blackwell Science. p. 192–235.

Organ J, Mahoney S. 2007. The future of public trust. The legal status of the public trust doctrine. Wildl Prof. [accessed 2015 July];Summer. http://training.fws.gov/courses/csp/csp3112/resources/Related_References/Overview_of_Public_Trust_Doctrine.pdf.

Otterstatter MC, Thomson JD. 2008. Does pathogen spillover from commercially reared bumble bees threaten wild pollinators? PLoS ONE. [accessed 2015 August];3(7):e2771. doi:10.1371/journal.pone.0002771.

Perez KE, Minton RL. 2008. Practical applications for systematics and taxonomy in North American freshwater gastropod conservation. J N Am Benthol Soc. 27(2):471–483.

Pflieger WL. 1996. The crayfishes of Missouri. Jefferson City (MO): Missouri Department of Conservation. 152 p.

Piephoff T, Camburn K, Davis R, LeGrand HE, Pippen J, Pratt D, Shultz S, Swick N, Tove M. 2013. Official list of the birds of North Carolina [webpage]. NC Bird Records Committee; [accessed 2015 Mar 31]. http://www.carolinabirdclub.org/brc/checklist_of_North_Carolina_birds.html.

Pleasants JM, Oberhauser KS. 2012. Milkweed loss in agricultural fields because of herbicide use: effect on the monarch butterfly population. R Entomol Soc: Insect Conserv Divers. [accessed 2015 August]. doi:10.1111/j.1752-4598.2012.00196.x.

Rabeni CF. 1992. Trophic linkage between stream Centrarchids and their crayfish prey. Can J Fish Aquat Sci. 49:1714–1721.

Rabeni CF, Smale MA. 1995. Effects of siltation on stream fishes and the potential mitigating role of the buffering riparian zone. Hydrobiol. 303(1-3):211–219.

Ray KL. 2011. Factors affecting Wilson's Plover (*Charadrius wilsonia*) demography and habitat use at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina [thesis]. [Blacksburg (VA)]: Virginia Polytechnic Institute and State University.

Reeves B, Pfaffko M. 2013. Conserving the Eastern Hellbender in Tennessee. Endanger Species Bull. [accessed 2015 September]. http://www.teaming.com/sites/default/files/Conserving%20the%20Eastern%20Hellbender%20in%20Tennessee_0.pdf.

Reilly E, Clayton D, Nauman R, Olson D, Welsh H, Devlin B. 2009. Spatial model of optimal habitat for the Siskiyou Mountains salamander (*Plethodonstormi*) north of the Siskiyou crest. In: Olson DH, Clayton DR, Reilly EC, Nauman RS, Devlin B, Welsh Jr. HH, editors. Conservation of the Siskiyou Mountains Salamander (*Plethodonstormi*). Northwest Fauna. 6: 1–73. p. 23–25

Reynolds J, Souty-Grosset C. 2012. Management of freshwater biodiversity: Crayfish as bioindicators. Cambridge (England): Cambridge University Press. 384 p.

Ricciardi A, Palmer ME, Yan ND. 2011. Should biological invasions be managed as natural disasters? BioSci. 61(4):312–317.

Rich TD, Beardmore CJ, Berlanga H, Blancher PJ, Bradstreet MSW, Butcher GS, Demarest DW, Dunn EH, Hunter WC, Iñigo-Elias EE, et al. 2004. Partners in Flight North American landbird conservation plan. Ithaca (NY): Cornell Lab of Ornithology; [updated 2005 March; accessed 2015 August]. http://www.partnersinflight.org/cont_plan/.

Richards DC. 2004. Competition between the threatened Bliss Rapids snail, *Taylorconcha serpenticola* (Hershler et al.) and the invasive, aquatic snail *Potamopyrgus antipodarum* (Gray) [dissertation]. [Bozeman (MT)]: Montana State University. [accessed 2015 August]. 177 p. http://scholarworks.montana.edu/xmlui/bitstream/handle/1/2129/RichardsD1204.pdf?sequence=1.

Richman NI, Bohm M, Adams SB, Alvarez F, Bergey EA, Bunn JJS, Burnham Q, Cordeiro J, Coughran J, Crandall KA, et al. 2015. Multiple drivers of decline in the global status of freshwater crayfish (Decapoda: Astacidea). Philos Trans B. [accessed 2015 August];370(1662). doi:10.1098/rstb.2014.0060.

Ricketts TH, Dinerstein E, Olson DM, Loucks C. 1999. Who's where in North America? Patterns of species richness and the utility of indicator taxa for conservation. BioSci. 49(5):369–381.

Ripley J, Iwanowicz L, Blazer V, Foran C. 2008. Utilization of protein expression profiles as indicators of environmental impairment of Smallmouth Bass (*Micropterus dolomieu*) from the Shenandoah River, Virginia, USA. Environ Toxicol Chem. 27:1756–1767.

Rittenhouse TAG, Harper EB, Rehard LE, Semlitsch RD. 2008. The role of microhabitats in the desiccation and survival of amphibians in recently harvested oak-hickory forest. Copeia. 4:807–814.

Roe KJ, Lydeard C. 1998. Molecular systematics of the freshwater mussel genus *Potamilus* (Bivalvia: Unionidae). Malacol. 39(1-2):195–205.

Russ WT, Fraley SJ. 2014. Status update for six rare crayfishes (Decapoda: Cambaridae) in western North Carolina. J N C Acad Sci. 130(2):25–39.

Sabine JB, Meyers JM, Moore CT, Schweitzer SH. 2008. Effects of human activity on behavior of breeding American Oystercatchers, Cumberland Island National Seashore, Georgia, USA. Waterbirds. 31(1):70–82.

[SAMAB] Southern Appalachian Man and the Biosphere. 1996a. Southern Appalachian assessment report, summary report. [accessed 2015 August]. 164 p. http://www.samab.org/site/wp-content/uploads/2011/06/SAA_summary_report.pdf.

[SAMAB] Southern Appalachian Man and the Biosphere. 1996b. Southern Appalachian Assessment Report, Aquatic Resources Technical Report. [accessed 2015 August]. 146 p. http://www.samab.org/site/wp-content/uploads/2011/06/SAA-Aquatics-report.pdf.

[SAMBI] South Atlantic Migratory Bird Initiative. 2004. South Atlantic Migratory Bird Initiative Pelagic Conservation Plan [draft]. Charleston (SC): US Fish and Wildlife Service. 10 p.

Sauer JR, Link WA, Fallon JE, Pardieck KL, Ziolkowski Jr. DJ. 2013. The North American Breeding Bird Survey 1966–2011: summary analysis and species accounts. N Am Fauna. [accessed 2015 August];79:1–32. doi:10.3996/nafa.79.0001.

Schuster GA. 1997. Resource management of freshwater crustaceans in the southeastern United States. In: Benz GW, Collins ED, editors. Aquatic fauna in peril: the southeastern perspective. Decatur (GA): Southeast Aquatic Research Institute. p. 269–282.

Schwalb AN, Pusch MT. 2007. Horizontal and vertical movements of unionid mussels in a lowland river. J N Am Benthol Soc. 26(2):261–271.

Serb JM. 2006. Discovery of genetically distinct sympatric lineages in the freshwater mussel *Cyprogenia aberti* (Bivalvia: Unionidae). J Mollus Stud. 72(4):425–434.

Shannon L, Biggins RG, Hylton RE. 1993. Freshwater mussels in peril: perspectives of the US Fish and Wildlife Service. In: Cummings KS, Buchanan AC, Koch LM, editors. Conservation and management of freshwater mussels. Rock Island (IL): Upper Mississippi River Conservation Committee. p. 66–68.

Shields MA, Parnell JF. 1990. Marsh nesting by American oystercatchers in North Carolina. J Field Ornithol. 61(4):431–433.

Shochat E, Lerman SB, Anderies JM, Warren PS, Faeth SH, Nilon CH. 2010. Invasion, competition, and biodiversity loss in urban ecosystems. BioSci. 60(3):199–208.

Shoo LP, Storlie C. Williams YM, Williams SE. 2010. Potential for mountaintop boulder fields to buffer species against extreme heat stress under climate change. Int J Biometeorol. 54:475–478.

Shoo LP, Olson DH, McMenamin SK, Murray KA, VanSluys M, Donnelly MA, Stratford D, Terhivuo J, Merino-Viteri A, Herbert SM, et al. 2011. Engineering a future for amphibians under climate change. J Appl Ecol. [accessed 2015 August];48: 487–492. doi: 10.1111/j.1365-2664.2010.01942.x.

Silk N, Ciruna K, editors. 2006. A practitioner's guide to freshwater biodiversity conservation. Washington (DC): Island Press. 408 p.

Simmons JW, Fraley SJ. 2010. Distribution, status, and life-history observations of crayfishes in western North Carolina. Southeast Nat. [accessed 2015 July];9(3):79–126. doi:10.1656/058.009.s316.

Skeldon MA, Vadeboncoeur MA, Hamburg SP, Blum JD. 2007. Terrestrial gastropod responses to an ecosystem-level calcium manipulation in a northern hardwood forest. Can J Zool. [accessed 2015 August];85(9):994–1007. http://scholars.unh.edu/cgi/viewcontent.cgi?article=1017&context=ersc.

Slomke AM, Lankester MW, Peterson WJ. 1995. Infrapopulation dynamics of *Parelaphostrongylus tenuis* in white-tailed deer. J Wildl Dis. 31(2):125–135.

Smallwood JA, Causey MF, Mossop DH, Klucsarits JR, Robertson B, Robertson S, Mason J, Maurer MJ, Melvin RJ, Dawson RD, et al. 2009. Why are American kestrel (*Falco sparverius*) populations declining in North America? Evidence from nest box programs. J Raptor Res. 43(4):274–282.

Snyder NFR, Derrickson SR, Beissinger SR, Wiley WJ, Smith TB, Toone WD, Miller B. 1996. Limitations of captive breeding in endangered species recovery. Conserv Biol. [accessed 2015 August];10:338–348. https://www.cnr.berkeley.edu/beislab/BeissingerLab/publications/Snyder_etal_ConsBio_1996.pdf.

Somers AB, Bridle KA, Herman DW, Nelson AB. 2000. The restoration and management of small wetlands of the mountains and piedmont in the southeast: a manual emphasizing endangered and threatened species habitat with a focus on bog turtles. A joint publication of the Watershed Science and Wetland Science Institutes of the US Department of Agriculture, Natural Resources Conservation Service, The University of North Carolina at Greensboro, and Pilot View Resource Conservation and Development, Inc. [accessed 2015 August]. 152 p. http://libres.uncg.edu/ir/uncg/f/A_Somers_Restoration_2000_intro-toc.pdf.

Somers AB, Mansfield-Jones J, Braswell J. 2007. In stream, streamside, and under stream bank movements of a bog turtle, *Glyptemys muhlenbergii*. Chelonian Conserv Biol. 6(2):286–288.

Somers AB, Matthews CE. 2006. The box turtle connection: a passageway into the natural world. Greensboro (NC); [accessed 2015 August]. 127 p. http://www.uncg.edu/~absomers/BoxTurtleBook.pdf.

Species assessments [webpage]. c. 2015. Tasmania (Australia): Agreement on the Conservation of Albatrosses and Petrels; [accessed 2015 August]. http://www.acap.aq/en/acap-species.

Statzner B, Peltret O, Tomanova S. 2003. Crayfish as geomorphic agents and ecosystem engineers: effect of a biomass gradient on baseflow and flood-induced transport of gravel and sand in experimental streams. Freshw Biol. 48:147–163.

Steffy LY, Kilham SS. 2006. Effects of urbanization and land use on fish communities in the Valley Creek watershed, Chester County, Pennsylvania. Urban Ecosyst. 9:119–133.

Stein BA. 2002. States of the Union: ranking America's biodiversity. Arlington (VA): NatureServe.

Stenroth P, Nystrom P. 2003. Exotic crayfish in a brown water stream: effects on juvenile trout, invertebrates and algae. Freshw Biol. 48:466–475.

Storfer A. 2003. Amphibian declines: future directions. Divers Distrib. [accessed 2015 August];9:151–163. http://public.wsu.edu/~storfer/pdfs/Storfer_2003.pdf.

Street MW, Deaton AS, Chappell WS, Mooreside PD. 2004. Coastal habitat protection plan. Morehead City (NC): NC Division of Marine Fisheries.

Sturbois A, Ponsero A, Desroy N, Le Mao P, Fournier J. 2015. Exploitation of intertidal feeding resources by the red knot *Calidris canutus* under megatidal conditions (Bay of Saint-Brieuc, France). J Sea Res. 96:23–30.

Suski JG, Salice CJ, Patiño R. 2012. Species- specific and transgenerational responses to increasing salinity in sympatric freshwater gastropods. Environ Toxicol Chem 31(11):2517–2524.

Suter II GW, Cormier SM. 2014. Why care about aquatic insects: uses, benefits, and services. Integr Environ Assess Manag. 11(2):188–194.

Taillie PJ, Marcus JF, Carpenter JP, Anderson SK. In review. The current distribution and habitat associations of Bachman's Sparrow (*Peuecea aestivalis*) in North Carolina, USA. Chat.

Taillie PJ, Peterson MN, Moorman CE. 2015. The relative importance of multi-scale factors in the distribution of Bachman's Sparrow and the implications for ecosystem conservation. Condor. 117(2):137–146.

Taylor CA, Schuster GA, Cooper JE, DiStefano RJ, Eversole AG, Hamr P, Hobbs III HH, Robison HW, Skelton CE, Thomas RF. 2007. A reassessment of the conservation status of crayfishes of the United States and Canada after 10+ years of increased awareness. Fish. [accessed 2015 July];32(8):372–389. doi:10.1577/1548-8446(2007)32[372:AROTCS]2.0.CO;2.

Taylor CA, Schuster GA. 2004.The crayfishes of Kentucky. Special Publication no. 28. Champaign (IL): Illinois Natural History Survey. 219 p.

Taylor CA, Warren Jr. ML, Fitzpatrick Jr. JE, Hobbs III HH, Jezerinac RE, Pflieger WL, Robison HW. 1996. Conservation status of crayfishes of the United States and Canada. Fish. 21(4):25–38.

Thoma RF. 2012. The life history and conservation status of the Grandfather Mountain crayfish (*Cambarus* [*Cambarus*] *eeseeohensis*) in North Carolina. MBI Technical Report MCI/2012-X-X. Columbus (OH): Center for Applied Bioassessment & Biocriteria, Midwest Biodiversity Institute. 14 p.

Trani MK, Ford WM, Chapman BR, editors. 2007. The land manager's guide to mammals of the South. Durham (NC): The Nature Conservancy, Southeastern Region; [accessed 2015 July]. http://www.nrs.fs.fed.us/pubs/jrnl/2007/nrs_2007_trani-lndmgr-full_009.pdf.

Tuck GN, Phillips RA, Small C, Thomson RB, Klaer NL, Taylor F, Wanless RM, Arrizabalaga H. 2011. An assessment of seabird–fishery interactions in the Atlantic Ocean. ICES J. Mar. Sci. 68:1628–1637.

[UCB] University of California at Berkeley. 2010. The common law and civil law traditions [web page]. Berkeley (CA): The Robbins Collection, School of Law (Boalt Hall); [accessed 2015 September] https://www.law.berkeley.edu/library/robbins/CommonLawCivilLawTraditions.html.

USFWS National Digital Library [website]. c2011–2015. US Fish and Wildlife Service; [accessed 2015 August]. http://digitalmedia.fws.gov/cdm/.

[USFWS] US Fish and Wildlife Service. 1990. Appalachian northern flying squirrels (*Glaucomys sabrinus fuscus* and *Glaucomys sabrinus coloratus*) recovery plan. Annapolis (MD): US Fish and Wildlife Service; [accessed 2015 July]. http://ecos.fws.gov/docs/recovery_plan/900924c.pdf.

[USFWS] US Fish and Wildlife Service. 1996. Piping plover (*Charadrius melodus*) Atlantic Coast population revised recovery plan. Hadley (VA): US Fish and Wildlife Service.

[USFWS] US Fish and Wildlife Service. 2000. Policy regarding controlled propagation of species listed under the Endangered Species Act. Fed Regist. [accessed 2015 August];65:56916–56922. https://www.fws.gov/endangered/laws-policies/policy-controlled-propagation.html.

[USFWS] US Fish and Wildlife Service. 2001. Fish and Wildlife Service designates critical habitat for endangered spruce-fir moss spider [Internet]. [accessed 2015 August]. http://www.fws.gov/southeast/news/2001/r01-044.html.

[USFWS] US Fish and Wildlife Service. 2011a. Abundance and productivity estimates – 2010 update: Atlantic Coast piping plover population. Sudbury (MA): US Fish and Wildlife Service. 4 p.

[USFWS] US Fish and Wildlife Service. 2011b. Endangered and threatened wildlife and plants; 90-day finding on a petition to list the American eel as threatened. Fed Regist. [accessed 2015 August];76(189):60431-60444. http://www.gpo.gov/fdsys/pkg/FR-2011-09-29/pdf/FR-2011-09-29.pdf.

[USFWS] US Fish and Wildlife Service. 2013. US Fish and Wildlife Service finds listing warranted but precluded for rattlesnake-master borer moth [Internet]. [accessed 2015 August]. http://www.fws.gov/midwest/news/669.html.

[USFWS] US Fish and Wildlife Service. 2014. Endangered and threatened wildlife and plants; threatened species status of the rufa red knot. 50 CFR Part 17. Fed Regist. 79(238):73706–73748.

[USFWS] US Fish and Wildlife Service. 2015. Red Wolf recovery program, history of the Red Wolf recovery program [web page]. USFWS Southeast Region [last updated 2015 July 13; accessed 2015 August]. http://www.fws.gov/redwolf/redwolfrecovery.html.

Vaughn CC, Hakenkamp CC. 2001. The functional role of burrowing bivalves in freshwater ecosystems. Freshw Biol. 46:1431–1446.

Vaughn CC, Taylor CM. 1999. Impoundments and the decline of freshwater mussels: a case study of an extinction gradient. Conserv Biol (13):912–920.

Vogt RC. 1981. Food partitioning in three sympatric species of map turtle, genus *Graptemys* (Testudinata, Emydidae). Am Midl Nat. 105:102–111.

Walrut BP. 2004. Domestication and absolute ownership of fish in the English common law. J Fish Biol. 65:325.

Wang G, Ma P, Zhang Q, Lewis J, Lacey M, Furukawa Y, O'Reilly SE, Meaux S, McLachlan J, Zhang S. 2012. Endocrine disrupting chemicals in New Orleans surface waters and Mississippi Sound sediments. J Environ Monit. 14:1353–1364.

Wang N, Ingersoll CG, Ivey CD, Hardesty DK, May TW, Augspurger T, Roberts AD, van Genderen E, Barnhart MC. 2010. Sensitivity of early life stages of freshwater mussels (Unionidae) to acute and chronic toxicity of lead, cadmium, and zinc in water. Environ Toxicol Chem. 29(9):2053–2063.

Warren ML, Angermeier PL, Burr BM, Haag WR. 1997. Decline of a diverse fish fauna: patterns of imperilment and protection in the southeastern United States: In Benz GW, Collins DE, editors. Aquatic fauna in peril: the southeastern perspective. Decatur (GA): Southeast Aquatic Research Institute. p. 105–164.

Watkins BP, Petersen SL, Ryan PG. 2008. Interactions between seabirds and deep-water hake trawl gear: an assessment of impacts in South African waters. Anim Conserv. 11:247–254.

Watson C, Malloy K. 2006. The South Atlantic Migratory Bird Initiative implementation plan: an integrated approach to conservation of all birds across all habitats. Atlanta (GA): US Fish and Wildlife Service; [accessed 2015 August]. 99 p. http://www.acjv.org/documents/SAMBI_Plan3.2.pdf.

Watts BD, Paxton BJ. 2014. Status and distribution of colonial waterbirds in coastal Virginia: 2013 breeding season. Williamsburg (VA): Center for Conservative Biology, College of William and Mary/Virginia Commonwealth University. 23 p.

Watters GT, O'Dee SH, Chordas III S. 2001. Patterns of vertical migration in freshwater mussels (Bivalvia: Unionoida). Ecol. 16(4):541–550.

Weigl PD. 2007. The Northern Flying Squirrel (*Glaucomy sabrinus*): a conservation challenge. J Mammal. 88(4):897–907.

Welch SM. 2006. Multi-scale habitat associations of three primary burrowing crayfish [dissertation]. [Clemson (SC)]: Clemson University. 112 p.

Welch SM, Eversole AG. 2006. The occurrence of primary burrowing crayfish in terrestrial habitat. Biol Conserv. 130:458–464.

Williams JD, Warren Jr. ML, Cummings KS, Harris JL, Neves RL. 1993. Conservation status of freshwater mussels of the United States and Canada. Fish. 18:6–22.

Willson JD, Dorcas ME. 2003. Effects of habitat disturbance on stream salamanders: implications for buffer zones and watershed management. Conserv Biol. 17(3):763–771.

Wilson DM, Naimo TJ, Wiener JG, Anderson RV, Sandheinrich MB, Sparks RE. 1995. Declining populations of the fingernail clam *Musculium transversum* in the upper Mississippi River. Hydrobiol. (34):209–220.

Wilson EO. 2005. Systematics and the future of biology. Proc Natl Acad Sci U S Am. 102:6520–6521.

Wilson MD, Watts BD. 1999. Response of brown-headed nuthatches to thinning of pine plantations. Wilson Bull. 111(1):56–60.

Wilson MD, Watts BD. 2000. Breeding bird communities in pine plantations on the coastal plain of North Carolina. Chat. 64(1):1–14.

Wilson RC, Henson T. 1993. History of cooperative management of North Carolina's colony-nesting waterbirds. Proc Annu Conf Southeast Assoc Fish Wildl Agencies. 47:328–332.

Wilson WAS. 2008. Bioaccumulation of trace elements by bivalves in the Altamaha River system [dissertation]. [Athens (GA)]: University of Georgia.

Winn B, Brown S, Spiegel C, Reynolds D, Johnston S. 2013. Atlantic Flyway shorebird conservation business strategy. Manomet (MA): Manomet Center for Conservation Sciences. 27 p.

Withrow JR, Smith EL, Koch FH, Yemshanov D. 2015. Managing outbreaks of invasive species – a new method to prioritize preemptive quarantine efforts across large geographic regions. J Env Manag. 150:367–377.

Wood PB, Sheehan J, Keyser P, Buehler D, Larkin J, Rodewald A, Stoleson S, Wigley TB, Mizel J, Boves T, et al. 2013. Management guidelines for enhancing Cerulean Warbler breeding habitat in Appalachian hardwood forests. The Plains (VA): American Bird Conservancy; [accessed 2015 August]. http://woodlandstewards.osu.edu/sites/woodlands/files/d6/files/pubfiles/Cerulean%20Management%20Guide.pdf. 28 p.

Yeh YM, Huang HW, Dietrich KS, Melvin E. 2013. Estimates of seabird incidental catch by pelagic longline fisheries in the South Atlantic Ocean. Anim Conserv. 16:141–152.

Habitats

4

Required Element 2

Descriptions of locations and relative condition of key habitats and community types essential to conservation of species identified as conservation priorities.

4.1 Introduction

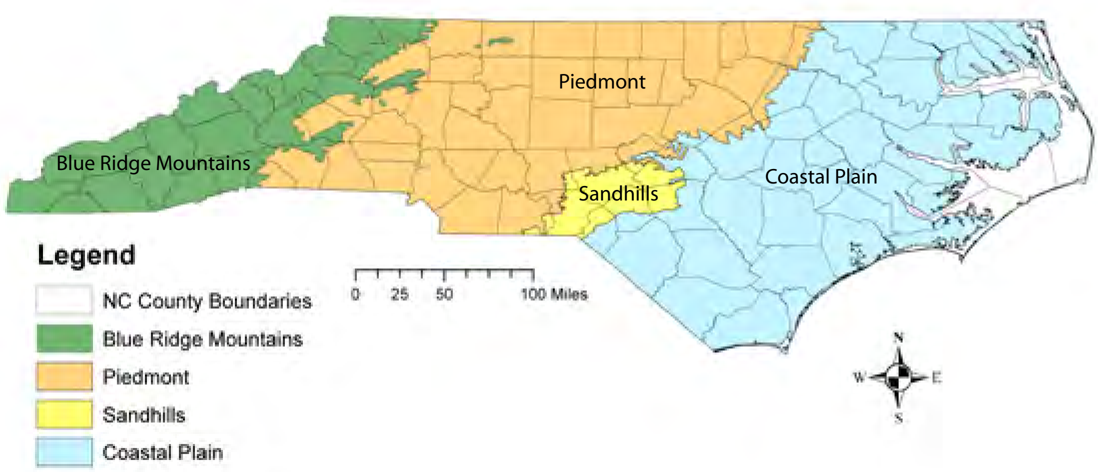
There are many factors that influence where a species occurs in the landscape, its distribution and abundance, and its rate of reproductive success and survival (Hall et al. 1997; Winger 1981; Turner 1989). A landscape composed of multiple natural community types is more likely to contain the necessary resources to provide habitat for a species (Stewart et al. 2010; Morrison et al. 2012). Landscape composition varies across the state with elevation, moisture and temperature gradients, and soil textures having a significant influence on natural community structure. The concept of habitat is based on the availability of the appropriate combination of food, cover, and water resources, climatic conditions, and other environmental conditions (e.g., competitors, predators, connectivity) that supports the ability of a species to survive and reproduce (Hall et al. 1997; Morrison et al. 2012).

An important concept in wildlife–habitat relationships is that they are specific to the organism, are temporally and spatially scale-dependent, and are influenced by each organism in the system (Hall et al. 1997; Wiens 1989). Some habitats that can form when vegetation is dormant and rainfall is high, such as ephemeral pools and wetlands, are distributed seasonally due to climatic and environmental conditions. In other cases, a habitat may be distributed based on periodic natural disturbances, such as wildfire or flooding. Given the complexities of natural communities and the variability of the organisms associated with them, we use local and regional landscape-scale approaches more often than species-specific approaches to accomplish conservation. Therefore, habitats are considered to be the sum of all the resources a species needs to survive and persist (Hall et al. 1997).

Whether they are aquatic or terrestrial systems, natural communities and the habitats they provide are highly interconnected and influence one another. As an aid to understanding this complexity and to provide a landscape framework for conservation planning, it is helpful to represent broadly the distribution of important natural communities by using widely accepted ecoregional units. Ecoregions are often defined based on landscape settings and patterns that are influenced by climate, soils, land surface form, and potential natural vegetation (Omernik 1987), and can be useful for organizing, interpreting, and reporting information about land-use dynamics (Gallant et al. 2004). Though North Carolina generally is considered to consist of three physiographic provinces—Mountains, Piedmont, and Coastal Plain—we have used four ecoregion boundaries described by Bailey (1995, 1998, 2009) and Omernik and Griffith (2008) as a framework for the wetland and terrestrial community descriptions found in this document. Figure 4.1 provides a map of the four ecoregions used in this Plan to organize information.

- **Southern Blue Ridge Mountains (Mountains)**. The Mountain ecoregion includes all portions of the Southern Appalachian mountain physiographic province that are west of the Blue Ridge Escarpment. As shown in Figure 4.1, there are several foothill ranges (the Brushy, Sauratown, and South mountains) located within the Piedmont province that are part of the Mountain ecoregion. North Carolina has the highest elevations of any state east of the Mississippi River, with Mount Mitchell being the highest peak at 6,684 feet (above mean sea level) (SCO 2014). This ecoregion covers about 17% of the state and is predominantly forested with small patches of agricultural and developed lands found mainly in the broad valleys.

FIGURE 4.1 North Carolina Ecoregions (Bailey 2009)



- **Piedmont**. The Piedmont ecoregion includes areas east of the foot of the Blue Ridge Escarpment and west of the fall line, excluding the Brushy, Sauratown, and South mountain ranges. The fall line is a major break in geologic structure between the Piedmont and the Coastal Plain which results in differences in ecosystem patterns and the variety of relief and roughness (Bailey 2009). This ecoregion covers about 40% of the state, is centrally located between the Mountains and Coastal Plain, and generally contains the most urban areas with the highest population densities. A variety of underlying hard rock formations influence the landform, with gently rolling hills to the rather steep hills of the Uwharrie Mountain Range (Montgomery, Randolph, and Stanly counties) and the Kings Mountain Range (Cleveland and Gaston counties) (SCO 2014). Elevations range from about 1,500 feet in the foothills to about 200 feet at the fall line (SCO 2014). Because water resources are often seasonally limited, several reservoirs have been built to provide drinking water to rapidly developing urban and suburban centers that are replacing agriculture and forest lands (Gallant et al. 2004).

- **Sandhills**. The North Carolina Sandhills are the southwestern portion of the Coastal Plain physiographic province. The Sandhills ecoregion is distinguished by its distinctive geomorphology and vegetation and covers about 3% of the state. It is generally located between the south-central and southeastern part of the state, encompassing portions of Anson, Cumberland, Harnett, Hoke, Lee, Moore, Richmond, Scotland, and Montgomery counties. The name derives from the predominantly sandy soils formed of Cretaceous-age marine sands and, in some places, clays that are capped by Tertiary-age sands deposited over Piedmont metamorphic rocks. The landscape has rolling hills and nutrient-poor soils. The Sandhills represents a former coastline and is well known for having many rare plants (Omernik and Griffith 2008).

- **Mid-Atlantic Coastal Plain (Coastal Plain).** This ecoregion includes areas east of the fall line (excluding the Sandhills) and the tidal coast (ocean, sounds, barrier islands, and mainland brackish and salt marshes). The Coastal Plain covers about 40% of the state (Land et al. 2004). It may be divided roughly into two sections: the tidewater area (lower Coastal Plain), which is largely flat and swampy, and the interior portion (upper Coastal Plain), which is made up of gently sloping elevations and is better drained than other regions. The average elevation is from about 200 feet at the fall line (or western boundary separation from the Piedmont), sloping to an elevation of generally 50 feet or less over most of the mainland landscape, with barrier islands being close to sea level (SCO 2014).

4.1.1 Natural Community Descriptions

This Chapter provides descriptions for important aquatic, wetland, and terrestrial natural communities found in North Carolina and updates material provided in Chapter 5 of the original Plan (NCWRC 2005). The community descriptions incorporate a subset of the climate change vulnerability assessments conducted by the NC Natural Heritage Program (NCNHP) with other resource agencies in 2010.

Section 4.2 provides descriptions for 12 aquatic community types. Their characteristics have been incorporated into the descriptions of the 17 river basins described by the NC Department of Environment and Natural Resources, Division of Water Resources. Table 4.1 provides a list of the aquatic community descriptions provided in this Chapter and the ecoregions where they occur. The stream and river system classifications are based on a framework developed by the Southeast Aquatic Resources Partnership (Olivero-Sheldon and Anderson 2013) and system descriptions are delineated based on size of the drainage area (DA). Table 4.2 provides a list of the 17 river basins and identifies which ecoregions of the state they cross.

Recommendations for conservation and management actions, specific to each of the 12 aquatic natural community types and the 17 river basins described in this section, are provided at the end of each description. Appendix H provides a crosswalk between the aquatic priority species introduced in Chapter 3 and the aquatic habitats and river basins where they are found in North Carolina.

Section 4.3 provides descriptions for the four ecoregions as well as for 11 wetland and 17 terrestrial communities. Table 4.3 provides a list of the terrestrial community types (in alphabetical order) described in this Chapter and the ecoregions where they occur. The community types are based on descriptions developed by the NCNHP (Schafale 2012).

Table 4.1 Aquatic communities and ecoregion associations

Community Descriptions	Mountains	Piedmont	Sandhills	Coastal Plain
Coldwater Systems (<20°C)	X	X		
Coolwater Systems (>20°C, <25°C)	X	X		
Warmwater Systems (>25°C)	X	X	X	X
Headwaters/Small Creek Communities (<40 sq.mi. DA)	X	X	X	X
Large Creeks/Small River Communities (40–200 sq.mi. DA)	X	X	X	X
Medium River Communities (200–3,800 sq.mi. DA)	X	X	X	X
Large River Communities (>3,800 sq.mi. DA)				X
Stream Swamp Systems				X
Natural Lakes				X
Reservoirs & Impoundments	X	X	X	X
Groundwater, Springs, Subterranean Water	X	X	X	X
Estuarine Aquatic Communities				X

Table 4.2 North Carolina river basins and ecoregion associations (click on link for a river basin map)

River Basin	Mountains	Piedmont	Sandhills	Coastal Plain
Broad	X	X		
Catawba	X	X		
Cape Fear		X	X	X
Chowan				X
French Broad	X			
Hiwassee	X			
Little Tennessee	X			
Lumber			X	X
Neuse		X		X
New	X			
Pasquotank				X
Roanoke	X	X		X
Savannah	X			
Tar–Pamlico		X		X
Watauga	X			
White Oak				X
Yadkin–Pee Dee	X	X	X	

Appendix H associates the terrestrial Species of Greatest Conservation Need (SGCN) introduced in Chapter 3 and the terrestrial habitats and ecoregions they use in North Carolina. The information in this Section updates material found in Chapter 5 of the original Plan (NCWRC 2005).

Section 4.4 provides additional information about conservation concerns for coastal and marine environments managed by the NC Division of Marine Fisheries (NCDMF) and the National Oceanic and Atmospheric Administration (NOAA) Fisheries, including the estuarine aquatic communities described in Section 4.2. Conservation measures developed by these agencies as well as by the Albemarle–Pamlico National Estuary Partnership (APNEP) are included, and directions to additional information about these measures are provided in this section. This information updates material found in Chapter 5C of the original Plan (NCWRC 2005).

4.1.2 Natural Community Priorities

The North Carolina Wildlife Resource Commission's (NCWRC) land acquisition objectives include consideration for protecting important aquatic and terrestrial habitats. Other objectives include expanding and connecting game lands and land conservation

Table 4.3 Natural community types and ecoregion associations

Community Types	Mountains	Piedmont	Sandhills	Coastal Plain
WETLAND COMMUNITIES				
Bogs & Fens	X			
Estuarine Wetland Communities				X
Floodplains—Blackwater Systems			X	X
Floodplains—Brownwater Systems				X
Floodplains—Inland Systems	X	X	X	
Freshwater Tidal Wetlands				X
Nonalluvial Mineral Wetlands			X	X
Pocosins			X	X
Upland Pools & Depressions	X	X	X	X
Upland Seepages & Spray Cliffs	X	X	X	X
Wet Pine Savannas			X	X
UPLAND COMMUNITIES				
Caves & Mines	X	X		X
Cove Forests	X			
Dry Coniferous Woodlands (includes Loblolly & Slash Pine Timberlands)	X	X	X	X
Dry Longleaf Pine Communities		X	X	X
Grass & Heath Balds	X	X		
High-elevation Cliffs & Rock Outcrops	X			
Low Elevation Flatrocks, Cliffs, & Rock Outcrops	X	X		X
Mafic Glades & Barrens	X			
Maritime Forests				X
Maritime Grasslands				X
Mesic Forests		X	X	X
Oak & Mixed Hardwood/Pine Forests		X	X	X
Montane Oak Forests	X			
Northern Hardwood Forests	X			
Sand, Shell, & Wrack Shorelines				X
Spruce–fir Forests	X			
Successional Communities (Herbaceous, Shrub, and Woody)	X	X	X	X

areas; providing the public with opportunities for hunting, fishing, wildlife observation, and other recreation activities; protecting wildlife migration corridors and providing connectivity between priority habitats. These and other objectives are outlined in the Commission's Phase I Land Acquisition Investigation Form used to evaluate potential land acquisition sites.

Many of the state's natural community types cover large areas and are well represented, while others cover less area and may be more at risk from loss of biodiversity when considering local and regional threats (i.e., land use change, development). Given the richness of their biodiversity, the ecosystem services they support, and the benefits they provide to wildlife (including SGCN and other priority species), certain natural community types are of higher priority for land conservation action because they are more imperiled (NCWRC 2012). These priority habitats are identified in Table 4.4.

The NC Division of Coastal Management (NCDCM) manages the Coastal and Estuarine Land Conservation Program (CELCP), which is a federal funding program that helps protect important coastal and estuarine lands (NCDCM 2007, 2011). In North Carolina, the CELCP Plan identifies coastal and estuarine areas in the 20 coastal counties that have significant conservation, recreation, ecological, historical, or aesthetic values, or that are threatened by conversion from their natural or recreational state to other uses. Priority is given to

Table 4.4 Priority natural community types and their ecoregion associations

Ecoregion	Community Type
Statewide	All wetlands
	Riparian and floodplain communities
	Early successional communities
	Rock outcrops
	Streams and rivers
	Caves and mines
Mountains	Bogs and fens
	Spruce–fir forests
	High-elevation habitats
Piedmont	Large unfragmented tracts near existing conservation holdings
	Managed early successional landscapes
Sandhills	Large unfragmented tracts near existing conservation holdings
	Managed early successional landscapes
Coastal Plain	Sand, shell, and wrack shoreline (beaches)
	Maritime grasslands and dunes
	Maritime forests
	Coastal peatlands (pocosins)
	Estuarine islands*
	Inlet spits*

* Community descriptions for estuarine islands and inlet spits are not provided in this document; however, the estuarine islands and inlet spits are found along the state's coast and are created by natural sand deposition and by placement of dredged (spoil) materials (NCWRC 2012). These habitats are important for numerous colonial waterbirds, wading birds, and beach-nesting shorebird species, including many that are listed as SGCN and priority species.

lands that can be effectively managed and protected and that have significant ecological value. The most recent update of the CELCP Plan (NCDCM 2011) identifies wetlands, coastal forests, working lands (agriculture and forestry), waterfront lands (barrier islands, riparian lands), island ecosystems (including beach and dune systems), floodplains and riparian zones, wildlife preserves and game lands, trails and greenways, cultural and historic sites, and marl outcrops as priority areas for conservation.

4.1.3 Species and Habitat Associations

This chapter focuses on aquatic, wetland, and terrestrial communities that provide important habitat for SGCN and other priority species as outlined in Required Element 2. The natural community descriptions discuss problems affecting the habitats and species associated with each community. Recommended priority conservation actions identify surveys, monitoring, research, management practices, and partnerships and cooperative efforts that benefit SGCN and their habitats and address provisions of the Eight Required Elements.

The habitats presented in this document represent the major habitat types in the state. Each description provides information about the wildlife associated with that habitat and highlights the threats, needs, and conservation priorities of that particular habitat. Appendix H contains a list by taxonomic group for priority species associated with each habitat discussed in this chapter. Some habitat associations reflect use as secondary or transitional for a species and are used as corridors or connections when they need to move from their primary habitat to another location.

The usefulness of the habitat association table will depend on the species. For some, the associations can be loosely defined or opportunistic. For others, the relationship is tight or obligate. The Peregrine Falcon, which usually nests on high-elevation rock outcrops but has been known to nest on top of urban highrise buildings, provides an example of an opportunistic habitat association. Other examples include colonial nesting shorebirds that typically use shell middens or flats between sand dunes for nesting, but have also used gravel roof tops of buildings adjacent to the shoreline. Some bats require specific types of maternity roosts (e.g., tree cavities) and hibernacula (e.g., caves), which is a tight habitat association. However, their use of stream and river corridors or open riparian areas for foraging can be considered a loosely defined habitat association because the community structure will vary by location, depending on vegetation, DA, hydrology, and other landscape factors.

4.2 Aquatic Communities

The various geology, physiography, and climate attributes of North Carolina contribute to the wide diversity of aquatic resources found across the state's ecoregions (Abell et al. 2000; Smock et al. 2005). North Carolina's natural aquatic communities provide a variety of potential habitats that are influenced by numerous conditions such as landscape position, gradient, width, depth, temperature, velocity, substrate or bed material, chemistry, and land cover (Winger 1981). The aquatic communities can be thought of as a mosaic of temporal and spatial conditions spread across the continuous reach of the system (Vannote et al. 1980).

While aquatic systems represent a small percentage of the landscape, they are living systems that represent some of the most endangered ecosystems in the state because they are subject to an increasing number of persistent threats that include resource withdrawals, pollution, invasive species, barriers, the effects of climate variability, and impacts to the surrounding terrestrial communities (MEA 2005; Revenga et al. 2005; Abell et al. 2000, 2008).

There are many subject areas in science and biology where classification systems have been developed and accepted for standard practice, and are commonly used as descriptions and for locating, storing, and exchanging data. While there is not one globally agreed upon classification system applied to describing aquatic communities or hydrologic systems, there are several definitions and classification schemes in wide use. For example, watersheds (also called basins or catchments) (Thorp 2002; Wagener et al. 2007) are commonly described and delineated to include all of the land draining into a particular surface water system such as a stream, river, or lake (Abell et al. 2000).

A watershed can represent an unlimited number of spatial scales such as the area that drains to a single headwater stream or a larger area that encompasses several streams that share a hydrologic connection. The largest watersheds delineated in North Carolina represent all of the land draining into one of the 17 major river systems in the state which are identified in Table 4.1.2 and described in Section 4.5 of this chapter.

Inland freshwaters are a type of aquatic natural community generally categorized as being either lotic or lentic systems. Lotic systems are running waters such as rivers and streams (Alexander and Fairbridge 1999; Abell et al. 2000; Thorp and Covich 2001) and there are various methods used to classify them based on pattern, geomorphological conditions, or by groups using shared characteristics (Rosgen 1994). An early method categorizes streams based on connectivity patterns with other flowing systems, and classifies streams into a dendritic hierarchical order where the smallest unit is a first order stream (Strahler 1957).

Lentic systems are standing waters such as lakes, reservoirs, ponds, swamps, and marshes. Schindler and Scheuerell (2002) note that lakes are complex ecosystems with distinct habitats that are influenced by physical parameters (e.g., depth, substrates), thermal influences (e.g., air and water temperatures, discharges), and water chemistry (e.g., oxygen, nutrients, pollution) and how these influences are stratified throughout the water body (vertical dimensions). Benthic habitats within standing waters are associated with the physical structure and substrates of the lake bottom (Eschmeyer 1936; Christensen et al. 1996b; Covich et al. 1999; Schindler and Scheuerell 2002). Riparian or littoral habitats occur at the transition between terrestrial communities and the aquatic system (Schindler and Scheuerell 2002).

Another method organizes streams into hydrologic units representing a drainage network comprised of a stream and all of its tributaries (Benke and Cushing 2005; Wagener et al. 2007; Sawicz et al. 2011). These drainage networks are referred to as drainage areas (DAs) and the characteristics of each unit are influenced directly by the attributes within the boundaries that define the basin (Huang et al. 2007; Sawicz et al. 2011).

Estuarine systems are another type of aquatic natural community that is formed at the link between land, freshwaters, and the ocean, and may be referred to as estuarine, brackish, or transitional waters (Levin et al. 2001; Tagliapietra et al. 2009). Estuarine systems are semi-enclosed coastal waters that are tidally influenced, have a connection with seawater, and contain brackish waters that result when seawater is measurably diluted with fresh water from land drainage (Cameron and Pritchard 1963; Pritchard 1967; Cowardin et al. 1979; Tagliapietra et al. 2009). Brackish waters result from the mingling of freshwaters and marine saltwaters and in most cases will have a low salinity gradient (measured as parts per thousand), but can range from mixohaline (0.5–30 ppt) to euhaline (30–40 ppt) to hyperhaline (>40 ppt) depending on proximity to ocean saltwaters and fluvial, tidal, and climatic conditions that drive saltwater (i.e., salt wedge) upstream into freshwaters (Cowardin et al. 1979; Emery and Myers 1996; Neuendorf et al. 2005; Tagliapietra et al. 2009).

Water quality is not the only variable that will influence species richness and relative abundance in aquatic communities. The presence of variable habitat types (pools, riffles, and runs in streams); the difference in water velocities, depths, and temperatures; and the types and combinations of substrate courseness and material (e.g., sand, gravel, aquatic vegetation, woody debris) (Hrodey et al. 2009) have an influence on which species make up the community. Moderate to high-quality in-stream habitats will have a substrate of various sized rocks with low embeddedness; woody debris such as sticks, leafpacks, snags; undercut banks with root mats; frequent distribution of pools and riffles of varying depths and widths; and stable banks with good tree canopy and a medium to wide riparian zone with few (if any) breaks (NCDWQ 2011c). Poor in-stream habitats will have primarily sand substrates, an absence of riffles; narrow and sparsely vegetated riparian zones with breaks; and deeply entrenched channels with unstable, vertical, and sparsely vegetated banks (NCDWQ 2011c). Species diversity is potentially greatest in large streams and medium-sized rivers, especially in riffle and run habitats.

Common names are used throughout this document for all species discussions except those animals for which there is taxonomic uncertainty; in those few instances the scientific name is used to identify the species. Appendix E provides a list of common and scientific species names for invasive and nonnative species. Appendix G provides common and scientific names for SGCN and priority species.

4.2.1 Problems Affecting Aquatic Communities

There are numerous threats that can affect a broad range of aquatic natural systems and some of the most common and widely occurring are described in this section. The natural community descriptions provided in this Chapter provide information about the problems that affect specific community types. Additional information about threats likely to impact wildlife and habitats is provided in Chapter 5.

Wastewater Discharges. Point source discharges from industrial or municipal effluent can be a source of contamination to aquatic systems. These potential sources of water pollution are subject to the National Pollutant Discharge Elimination System (NPDES) permit requirements designed to address numerous types of pollutants associated with specific industry types and subject to US Environmental Protection Agency (EPA) regulation. For example, effluents associated with sewage treatment can affect the pH of receiving waters and be a source of suspended solids, biological oxygen demand, ammonia, phosphates, and chlorine. Suspended solids in discharges can increase turbidity that reduces light penetration, absorbs metals and organic materials in the water column, and concentrates them into sediment when they settle on the bottom substrate. High levels of total dissolved solids in the discharges can add salts to receiving waters. Acidic or alkaline wastes can change the pH of receiving waters and affect the solubility of dissolved chemicals and adsorption of certain metals, which can result in toxicity and lethal water conditions for aquatic organisms (McDaniel 1993). Emerging contaminants in wastewater effluent such as pharmaceuticals, endocrine-distrupting compounds (EDCs), cosmetics, and other personal care products have become a source of concern for adverse health impacts to aquatic life (see "Pollution" below).

Thermal Discharges. Discharge waters with temperatures that are a few degrees different from receiving waters can cause changes to the metabolic activity, behavior, and physiological conditions of aquatic species. Growth rates are impacted by increased temperatures, and life history synchrony (reproduction or emergence) might be affected where there are thermal discharges (McDaniel 1993).

Petroleum Spills. Waterborne spills of petroleum products such as oil and grease can impact receiving waters by interfering with gaseous exchange and coating substrates with sludge and smothering organisms. Oil and grease can coat respiratory structures of fish and aquatic invertebrates and oxygen depletion in the water column can change community composition and structure (McDaniel 1993).

Pathogens and Microorganisms. These types of contaminants are primarily a concern to human health through water-based recreation activities and water-supply usage streams. Significant concerns include, but are not limited to, salmonellosis, shigellosis, enteropathogenic *E.coli*, enterovirus, and parasitic protozoa and worms. Many of these organisms are harbored in warm-blooded animals and are shed through animal wastes or fecal contamination of meats during food production processes. Freshwater fish can also harbor organisms that are consumed by humans. Other sources of these contaminants are sewage wastes, stormwater runoff, and concentrated animal operations (McDaniel 1993).

Nutrient Loads. Phosphorus and nitrogen are the nutrients most often associated with enrichment problems in aquatic ecosystems. Nutrient enrichment causes eutrophication that will cause changes to aquatic ecosystem structure and function (Smith et al. 1999, 2006). Eutrophication increases the frequency and intensity of algal blooms, especially cyanobacteria (blue-green algae) in freshwater lakes and harmful phytoplankton (e.g., dinoflagellates) blooms (referred to as red tides) in coastal areas (Smith et al. 2006; Downing et al. 2001; Huisman et al. 2005; Anderson 1994).

Dams. Impoundments create direct impacts through alteration of flow patterns and loss of in-stream habitats; changes in sediment transport and channel structure; impediments to genetic flow through restriction of fish movement; and thermal stratification and low dissolved oxygen (DO) content. They also can cause thermal or nutrient discharges from storage water (Yeager 1993). Hydropower dams, as a subset, contribute to unnatural flow regimes and hypolimnetic releases that cause a cool or warmwater assemblage to be replaced by a cold or coolwater one. Dams on rivers with anadromous fish block historical spawning grounds that can result in reduced populations due to lack of good spawning habitat and altered fish assemblage in rivers and streams above impoundment.

Withdrawals. Water withdrawals are commonly made for use in industrial processes, irrigation for crops, livestock watering, and drinking water resources. The physical characteristics of streams and rivers are altered when waters are impounded to form reservoirs. Physical changes caused by withdrawals taken from rivers and streams that reduce water levels include changes to the channel dimensions, water velocities, substrate composition, and water temperature. Withdrawals can permanently reduce availability of local water resources when there is no return of any of the withdrawn water to the local hydrologic cycle. Withdrawals can also result in lowered water tables and secondary impacts to nearby riparian wetlands and littoral habitats (Zale et al. 1993).

Land Use Impacts. Converting land use from natural forest to agriculture or silviculture production and residential and commercial development continues to threaten stream integrity because of the loss of riparian buffers and related increases in sediment, bank erosion, and stormwater runoff containing sediment and other potentially toxic materials. Erosion and the resultant sedimentation are the largest sources of nonpoint source pollution in this system. Livestock access to streams contributes heavily to bank erosion, sedimentation, and nutrient input. Timber harvests and poorly constructed and maintained timber roads are additional sources of erosion if proper controls are not used and maintained.

An increase in impervious surfaces due to roads, parking lots, homes, and businesses increases the amount and speed of runoff being delivered into aquatic systems. Decreased groundwater recharge between storms due to impervious surfaces leads to a decrease in stream base flows. Runoff from urban areas often contains higher concentrations of nutrients (such as nitrogen and phosphorus), sediment, metals, hydrocarbons, and microbes.

Exotic and Invasive Species. Exotic species invasion is a concern, with the Asian Clam, and Rusty and Virile crayfish having been collected in both cool and coldwater streams. Asian Clam populations have increased significantly in recent years and are extremely abundant in certain large rivers such as the Little Tennessee River. These may have negative effects on native species, such as competition for space and resources. With increases in water temperature, some invasive species may move into these coldwater habitats.

Invasive plants in the riparian area (such as Japanese Knotweed) can have negative impacts on stream systems by creating a monoculture with poor nutrient inputs, reducing bank stability, and allowing too much sunlight to infiltrate, resulting in warmer stream temperatures. Other invasive species, such as the exotic pest Hemlock Wooly Adelgid, may be a significant factor in coldwater stream communities because of the important role that hemlock plays in these riparian areas. If hemlocks are removed from the system, nutrient inputs and temperature regimes may be disrupted, which would in turn disrupt aquatic organism life cycles and cues.

Clearing and Snagging. Clearing removes standing trees and riparian vegetation from streambanks and snagging removes woody debris (logjams, snags, mid-channel bars) from within streams. These measures are often taken to lower stream discharge volume and improve drainage, especially in urban areas. Direct effects are the physical alteration of the habitat while indirect effects include changes in fluvial processes (Cobb and Kaufman 1993).

Riparian vegetation is critical to the overall stream and streambank stability and moderation of water temperatures. Lack of riparian vegetation or inadequate forested buffer widths can cause streambank erosion and sedimentation. In addition to stabilizing streambanks, riparian vegetation serves as nutrient input to the stream community, filters pollutants, and helps regulate stream temperature by providing shade. Lack of sufficient vegetation cover contributes to rising water temperatures, especially where water depths are shallow enough that the entire water column is subject to solar heating.

Climate Variability. Research conducted by Eaton and Sheller (1996) and Mohseni et al. (2003) assessed the effects of climate warming on 57 species of fishes in streams across the United States. Depending on minimum temperature tolerance assumptions, species requiring coolwater habitats could experience a 12%–15% decrease in available habitat (DeWan et al. 2010). When the connectivity between streams and rivers within drainage basins provides adequate dispersal corridors, species at the southern extent of their geographical distribution may shift their distributions northward into cooler habitats (Allan et al. 2005). Where adequate dispersal corridors are limited or restricted, access to or availability of cooler water habitats may limit the range of those species subject to narrow temperature tolerance (DeWan et al. 2010).

Increased air temperatures may lead to increased water temperatures and potentially lower DO levels; however, increased air temperature may have varying effects on coolwater systems due to factors such as the degree of groundwater influence, amount of shading by riparian vegetation, and watershed aspect. Hot spells can have the same effect as overall increased air temperatures but on a much more acute scale. Problems such as increased evaporation and therefore, lower amounts of flowing water, will vary depending on factors such as groundwater influence.

Chronically warmer water temperatures and lower DO levels may increase stress on organisms. The increased water temperature alone can cause a decline in DO and any decline in DO can lead to fish kills, whether as a direct result of increased water temperature or as a secondary effect of algal blooms. Thermal stratification will likely not be an issue when aquatic systems are relatively shallow; however, the large river systems of the Piedmont and Coastal Plain ecoregions and deep water reservoirs could experience stratification, algal blooms, and potential fish kills related to higher than normal water temperatures (DeWan et al. 2010; Band and Salvesen 2009).

Drought. Severe and prolonged droughts may decrease stream flow, decrease groundwater recharge, and increase evaporation. Lower water levels during dry times will increase stress to the system. Connectivity to contributing waters within the system will be restricted or eliminated by low and no-flow conditions. Changes in flow regime will likely result in changes in the overall stream morphology and transport of sediment that leads to altered habitat composition. The balance between surface flow and groundwater recharge may be altered. Decreases in overall summer precipitation may cause reduced water flows, which can further contribute to warmer water temperatures and water quality stressors (DeWan et al. 2010; Karl et al. 2009; Band and Salvesen 2009; Holman et al. 2010).

Pollution. Decreased stream flows can allow an accumulation of sediment and chemical inputs from stormwater runoff and effluent discharge because there is less frequent flushing in the system. Recent studies have shown that endocrine-disrupting chemicals (EDCs) in treated wastewater can inhibit reproduction and cause feminization of mussels, fish, and some amphibians (Hayes et al. 2006; Elrod et al. 2003a, 2003b; Huang et al. 2003a, 2003b). Although little is known about the effects of EDCs, additional studies are being conducted to document the levels of EDCs in discharges, and measures are being identified to reduce or eliminate EDCs from wastewater prior to discharge, should those discharge studies show increases in EDC levels (Conn et al. 2006; Kim et al. 2007; Kasprzyk-Hordern et al. 2008; Joss et al. 2006; Kolpin et al. 2002; Nowotny et al. 2007).

Phenology Changes. There is a life history link between freshwater mussels and fish, and the mechanisms or effects of phenological disruptions are unknown at this time. Freshwater mussel larvae (glochidia) are dependent on a host fish for transformation into juveniles. Temperature cues play a large role in the release of glochidia from female mussels and also in the movement and migrations of fish. Therefore, predicted changing temperatures could cause phenological disruptions affecting the reproductive capacity of freshwater mussels. As water temperatures increase, freshwater mussels inhabiting cool water systems could experience a shift in their range, moving into previously coldwater systems as their host fish move upstream.

Storms. Increased storm intensity can lead to flooding and therefore increased stormwater runoff and erosion. With increased stormwater runoff, there is an increase in loading of sediments, nutrients, and contaminants into streams and potential negative effects on biota, such as fish kills. With a change in the intensity and variability of rainfall, there are potential changes to stream flow patterns, channel hydrodynamics, and the volume of groundwater (Band and Salvesen 2009; Holman et al. 2010; Bakke 2008). An increase in the number of tropical events can lead to flash flooding, which causes many of the abovementioned responses. Effects such as increased sediments and contaminants into aquatic systems, in addition to major disruption to channel design and hydrodynamics, potentially upset the physical, chemical, and biological structure of streams (Band and Salvesen 2009).

Heavy rainfall events have been documented in the western mountains of the state (Keim 1997) and have contributed to soil erosion, sedimentation, and stream dynamics (DeWan et al. 2010). An increase in the number of tropical events can lead to flash flooding, which causes many of the abovementioned responses and landslides, which are of particular concern in mountainous, high-elevation areas. Landslides lead to increased sediments and contaminants in aquatic systems, in addition to major disruption to channel design and hydrodynamics, potentially upsetting the physical, chemical, and biological structure of streams (Band and Salvesen 2009).

4.2.2 Recommendations

The recommendations provided in this Section are appropriate for implementation in all aquatic natural communities. In addition to these recommendations, priorities that should be implemented in the communities described in Sections 4.2.3 through 4.2.14 are specific to those systems. Actions specific to the river basins that contain these types of aquatic communities are provided in Section 4.5 of this chapter.

Surveys. Distributional and status surveys are needed for aquatic snails, crayfish, mussels, and fish (in order of general need).

- Conduct stream surveys adjacent to areas poised for development (edge of urban expansion) to establish baseline populations and identify problems before development expands.
- Work cooperatively with partners to collect occurrence and abundance data on macro-benthic species.
- Conduct surveys to detect presence and collect life-history and abundance data for freshwater snails and crayfishes, as there is limited information available on these species.

Monitoring. Monitoring of aquatic taxa is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These monitoring efforts will inform future decisions on how to manage aquatic species. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Monitor aquatic taxa to assess species and ecosystem health and to gauge resiliency of organisms to a changing climate.
- Develop long-term monitoring strategies to document population trends, from which conservation strategies can be specifically designed to target those species which are experiencing declines.
- Monitor population trends to determine if species are adapting to changing habitats and apply what is learned to future management decisions (Bakke 2008).
- Monitor aquatic nonnative invasive species, analyze population trends, and assess their effect on native priority species populations.

- Use survey efforts to develop long-term monitoring strategies that will document population trends and provided a basis to design conservation strategies that target priority species.

- Monitor the effect of base flow impacts on priority species and correlate results with climate conditions.

- Develop climate change monitoring protocols or methods to monitor baseflow where priority species occur outside projects related to regulated water use (Federal Energy Regulatory Commission [FERC] licensing).

- Monitor agriculture and forestry best management practices (BMPs) to determine if they are meeting stormwater runoff control requirements.

- Ensure that bridge and culvert designs allow for stream movement and aquatic organism passage. Design standards may need alteration to accommodate environmental changes and increased floodwaters (Transportation Research Board 2008).

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behaviors, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of priority species to specific threats and studies and should provide recommendations for mitigation and restoration. Aquatic species propagation is an area of current and ongoing research. Developing techniques for propagation of aquatic species is critical for preserving those species and their genetic stock, particularly those that are rare, at high risk of extinction or extirpation, and difficult to propagate in a laboratory setting.

- Expand hatchery facilities and efforts of the Conservation Aquatics Center at NCWRC Marion Hatchery to support aquatic species propagation programs and release juveniles as part of a reintroduction and augmentation program.

- Conduct genetic research to resolve taxonomic issues for aquatic species.

- Statewide, assess stream habitats and the effect of perched and undersized pipes and culverts that are a barrier to fish passage.

- Conduct studies to improve our understanding of habitat trends and key habitat associations for priority species.

- Investigate relationships between macrobenthic and aquatic priority species assemblages.

- Utilize environmental DNA (eDNA) and other emerging genetic techniques to better understand aquatic species.
- Use propagation techniques to grow new populations of priority and declining aquatic populations.
- Examine stream temperature and associated microclimatic responses to a range of shading variables from riparian vegetation.
- Work with partners and support development of regulations for control of aquatic nuisance species.
- Study the extent and impact of exotic species introductions, as well as effective control measures for the most problematic exotics.
- Gain information regarding the specific microhabitat needs of priority species to develop long term conservation strategies.
- Conduct research to determine the best way to use a habitat guild approach in developing habitat suitability criteria in a stream system. This research will have benefits for studies melding hydrodynamic models to habitat needs for fish assemblages and the best approach to including rare species into habitat guilds (Persinger et al. 2011).
- Assess guild structures and their associated criteria in other rivers and test the transferability of guilds between river systems (Persinger et al. 2011).

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Expand hatchery facilities to increase capacity for propagation of priority and nongame species.
- Ensure that management of riverine habitats promotes the natural evolution and movement of woody and rocky structures and natural processes like bank dynamics, channel meanders, and flood regimes.
- Implement and support use of agriculture and forestry Best Management Practices (BMPs) to control stormwater runoff. Structures such as bioretention cells (i.e., rain gardens), cisterns, permeable pavement, runnels, vegetated swales, and filter strips can be used in various ways as stormwater BMPs.

- Support fencing livestock out of streams as a measure to protect riparian vegetation, maintain bank stability, and reduce nutrient inputs to the aquatic system.

- Reduce impervious surfaces as one measure to control runoff and erosion. Research has shown that impervious levels of 8%–12% represent a threshold where small changes in urganization can cause major changes in stream condition (Wang et al. 2001). There are also many BMPs that may be alternatives to reduce runoff. Encourage use of pervious paving materials where feasible.

- Initiate a drought management program that modifies discharge permits when base flow conditions decrease and the 7Q10 is lowered.

- Augment in-stream habitat to enhance its structural complexity to increase fish community abundance, biomass, and diversity (Hrodey and Sutton 2008).

- Preserve or restore riparian vegetation to maintain stable streambanks and dissipate water runoff energy, which allows for sediment deposition.

- In managed rivers, restore stream flows that promote controlled overbank flows and hydrological connectivity between the river and the floodplain.

- Update flood maps as required by changes in flood patterns (frequency and duration) and flooded lands to ensure protection of life and property (Band and Salvesen 2009).

- Protect potential migration corridors and preserve connectivity that allows for species and ecosystem migration.

Partnerships and Cooperative Efforts. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable.

- Work with partners and support development of regulations for control of aquatic nuisance species.

- Undertake immediate and continuing efforts to limit water quality deterioration from point sources of pollution as well as nonpoint sources. In general, the most critical conservation actions necessary to sustain populations of riverine habitat species involve protection of water quality and aquatic habitats.

- Protect floodplains and riparian wetlands from development or land uses that interfere with flood control or floodwater attenuation. Changes in flood patterns (frequency and duration) and flooded lands may periodically require updating flood maps to ensure protection of life and property (Band and Salvesen, 2009).

- Preserve forests and open space, farm land, rural landscapes, and park lands. Manage open lands and plant trees and vegetation in urban areas to aid in carbon sequestration.
- Plant riparian areas with vegetation with a broad elevational range within a particular watershed and with broad hydrologic tolerance to promote resiliency from climate change.
- Use easements and value taxation, and fee simple purchase for land conservation or preservation.
- Promote efforts to control stormwater management and point source pollution.
- Land use planning and zoning laws are needed to guide development, land clearing activities, and hydrology alterations within floodplains. Planning such as this may for example route highways and other corridors that cross floodplains as closely as possible to existing corridors to avoid fragmenting an extensive corridor of forest.

4.2.3 Coldwater Streams

4.2.3.1 Ecosystem Description

Coldwater habitats can be found in different sized streams in the Mountain and Piedmont ecoregions and in springs or groundwater-fed systems found in all ecoregions of the state. Often the streams are headwaters, but the upper portions of some small and medium river systems can have coldwater habitats, particularly if they are influenced by cooling water discharges from hydropower facilities or effluent discharges from industrial processes.

The coldwater designation is based upon two general principles: temperature regime and fish community structure. When used to classify coldwater streams, the temperature regimes of summer water temperatures typically do not exceed 20 degrees Celsius (°C) [68 degrees Fahrenheit (°F)]. This is a suggested temperature that will usually support a coldwater fish community structure that includes salmonid species (e.g., trout species) (USACE 2003). For migrating salmonids in the Pacific northwest, the EPA recommends a 7-day average daily maximum water temperature of 20°C (EPA 2012a). McCullough et al. (2009) suggest 22°C–23°C as a threshold for juvenile salmonid species. A review of research literature seems to indicate the need for availability of a temperature gradient appropriate to support differing size, age, and possibly sex of the species.

Whether the seasonal and daily variation of water temperature is natural or induced, the temperature will influence the distribution of aquatic species in this aquatic system (Caissie

2006). Coldwater streams generally have a fish species composition that includes: Brook, Brown, and Rainbow trout, Mottled Sculpin, Longnose and Blacknose Dace, and Central Stoneroller. This list of species is not inclusive and is provided as general guidance on community structure.

Table 4.5. lists the type of aquatic natural communities that may provide coldwater habitats and the ecoregion where they likely occur. Descriptions of these natural communities can be found in Sections 4.2.4 through 4.2.13 of this chapter.

The 2005 WAP (see Chapter 5) included riverine aquatic communities, which can include coldwater stream habitats, as a priority natural community type (NCWRC 2005).

Table 4.5 Aquatic natural communities containing coldwater habitats

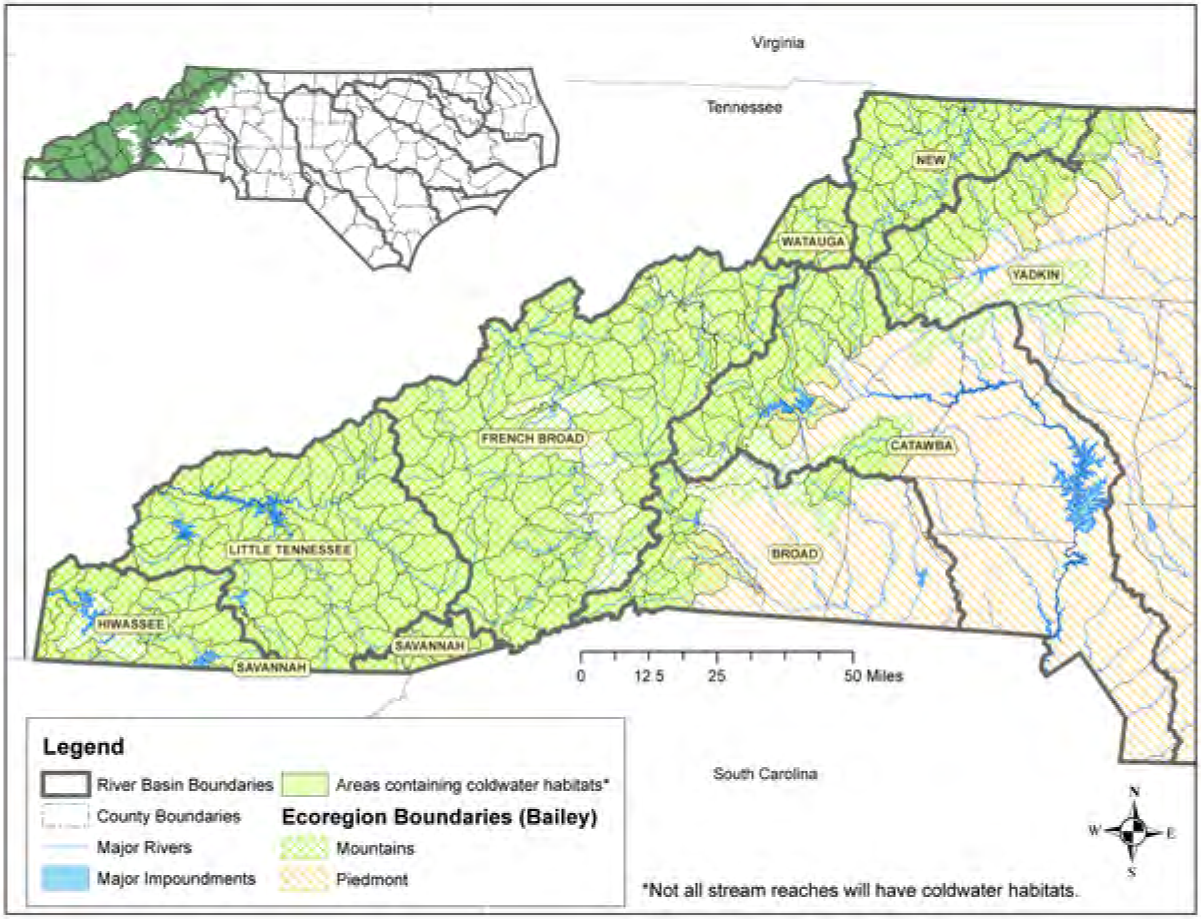
Stream Size	Ecoregions
Headwaters/Small Creeks (< 40 sq.mi. DA)	Mountain, Piedmont
Large Creeks/Small Rivers (40–200 sq.mi. DA)	Mountain, Piedmont
Medium Rivers (200–3,800 sq.mi. DA)	Mountain, Piedmont
Reservoirs & Impoundments	Mountain
Springs/Groundwater/Cave Waters	Statewide

4.2.3.2 Location of Habitat

Coldwater aquatic communities can be found in the Broad, Catawba, French Broad, Hiwassee, Little Tennessee, New, Savannah, Watauga, and upper Yadkin river basins. A review of US Geological Survey (USGS) real-time stream gauge data for water temperatures shows that Cataloochee Creek (near Cataloochee, NC), Mills River (near Mills River, NC), Pigeon River (near Canton, NC), Yadkin River (near Patterson, NC), and Catawba River (near Pleasant Gardens, NC) historically have persistent cold waters during the summer (USGS 2014a). Examples of other locations where coldwater habitats occur in at least a portion of the stream, and where brook trout and other coldwater fish species have been detected during field surveys, include Big Laurel Creek, Brasstown Creek, Cane River, Cove Creek, Mitchell River, Nolichucky River, and the Nantahala River. These locations represent only a few of the coldwater habitats found in the state.

Figure 4.2 indicates the approximate location where coldwater habitats occur within the river basins of western North Carolina. The presence or absence of riparian buffers, discharge into the waters, or other local landscape conditions will influence water temperatures and aquatic communities. It is important to understand that not all of the streams, rivers, and impoundments that occur within the shaded area of Figure 4.2 provide coldwater habitats or have trout or other coldwater species present in the community.

Figure 4.2 Location of coldwater habitats



4.2.3.3 Problems Affecting Habitats

Water Quality. As with coolwater streams, erosion and the resultant sedimentation are the largest sources of nonpoint source pollution in most aquatic systems. Sources of erosion include disturbance from development activities and agriculture. Residential development, particularly in steep slope areas, is of particular concern because of increased erosion. Livestock access to streams contributes heavily to bank erosion, sedimentation, and nutrient input. Timber harvests and poorly constructed and maintained timber roads are additional sources of erosion if proper controls are not used and maintained.

Many of the water quality and water quantity impacts resulting from climate change are analogous to impacts from economic development and population growth in North Carolina. Climate change is predicted to decrease rainfall and therefore, limit water supply, while growth and development have been increasing and continue to increase water supply demands. Historical stream flow patterns are projected to be altered due to climate change impacts; however, these are already being altered due to rapid urbanization.

An increase in impervious surfaces due to roads, parking lots, homes, and businesses increases the amount and speed of runoff being delivered into aquatic systems. Runoff from urban areas often contains higher concentrations of nutrients (such as nitrogen and phosphorus), sediment, metals, hydrocarbons, and microbes. Decreased groundwater recharge between storms due to impervious surfaces leads to a decrease in stream base flows.

Invasive Species. Introduction of nonnative species creates competitive pressure on native populations. Yellowfin Shiner is native to the Savannah River Basin but has been introduced to the Little Tennessee River Basin, and their range could expand into other coldwater systems with warming water temperatures.

Climate Impacts. Lower water levels during dry times will increase stress to the system. Connectivity to contributing waters within the system will be restricted or eliminated by low- and no-flow conditions. Changes in flow regime will likely result in changes in the overall stream morphology and transport of sediment.

An increase in frequency and intensity of storms due to climate change will have a similar impact on stream systems by increasing pollutant loading. Increased storm intensity that causes flooding can lead to increased stormwater runoff and erosion. With increased stormwater runoff, there is an increase in loading of sediments, nutrients, and contaminants into streams and potential negative effects on biota, such as fish kills. With a change in intensity and variability of rainfall, there are potential changes to stream flow patterns, channel hydrodynamics, and the volume of groundwater (Band and Salvesen 2009; Holman et al. 2010; Bakke 2009).

4.2.3.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While climate change is not the most severe threat to coldwater systems, a combination of synergistic effects with development and lack of forested riparian corridors could stress these systems to the point where several species are unable to persist.

Table 4.6 provides the results of a vulnerability assessment completed by the NCNHP (2010) for coldwater systems that compare climate change impacts in order of importance with other types of potential threats.

Table 4.6 Comparison of climate change with other threats to coldwater systems

Threat	Rank Order	Comments
Development	1	Direct, secondary, and cumulative effects from development. Residential development, particularly in steep slope areas, is of particular concern because of increased erosion.
Lack of Riparian Vegetation	1	Lack of riparian vegetation or inadequate width of forested buffers can cause streambank erosion and sedimentation. Vegetation also provides shading that reduces water temperature and is a source of detritus that is a food resource for macrobenthic species.
Pollution	2	Point and nonpoint sources—runoff and EDCs—are threats. Recent studies have shown that EDCs in treated wastewater can inhibit reproduction and cause feminization of mussels and fish. Christmas tree farms use high amounts of herbicides and pesticides that may persist in soil for long periods of time or run off into streams.
Cattle in Streams	2	Livestock access to streams contributes heavily to bank erosion, sedimentation, and nutrient input.
Climate Change	3	Coldwater systems may shrink in habitat and extent, making small streams more vulnerable to water temperature increases because of their low thermal capacity (Caissie 2006).
Water Withdrawals	4	Water withdrawals can be problematic, particularly in streams with already low 7Q10 flows, because they may reduce available habitat for aquatic species. Irrigation withdrawals pose a threat to flow regime.
Conversion to Agriculture/ Silviculture	4	Conversion of land, both from forest to agriculture or silviculture, as well as from development projects, continues to threaten stream integrity, resulting in increased sediment, bank erosion, and stormwater runoff containing sediment and other potentially toxic materials. Timber harvests with improper erosion controls and poorly constructed and maintained timber roads can cause erosion.
Impoundment/ Dams	4	Effects are both direct and indirect, including loss of habitat, shifts in food web, and change in species composition. Numerous watersheds in the Mountains no longer contain trout assemblages likely due to a proliferation of ponds that not only block fish movements, but also cause decreased stream flows and increased water temperatures.
Invasive Species	5	Invasive plants in the riparian area can have negative impacts on stream systems by creating a monoculture (e.g., Japanese Knotweed) with poor nutrient inputs, reducing bank stability, and allowing too much sunlight to infiltrate, resulting in warmer stream temperatures. The Asian Clam or Rusty Crayfish may compete for space and resources, although specific interactions are largely unknown.

4.2.3.5 Impacts to Wildlife

Appendix G provides a list of species identified by the Taxa Teams as priority species because of knowledge gap, management concerns, or management needs. Appendix H provides a list of SGCN associated with coldwater habitats.

Coldwater stream communities contain several rare species that are at risk of extirpation or extinction because they are vulnerable to warming water temperatures and other water quality changes. Several SGCN and priority species have very limited distributions or, if widely dispersed, have small populations (e.g., Eastern Spiny Softshell Turtle, Loggerhead Musk Turtle, Junaluska and Longtail Salamanders). Isolation or habitat fragmentation could affect life cycle or prey components for a variety of species.

Trout populations in North Carolina are already at the southern end of their range and the native brook trout should be a species considered vulnerable to extinction in this ecosystem group. They typically occupy the upper reaches of mountain headwater streams and few populations have the ability to migrate to colder waters. Typically trout are unable to survive in waters where temperatures rise above 20°C–24°C during summer. Because of the already limited range of trout in North Carolina, it is unlikely these fish will be able to seek refuge from warming water temperatures. It should be noted that Weaver (2010) examined the effects of trout stocking on native nongame fishes and found no significant differences in fish density, species richness, species diversity, or fish microhabitat use associated with short-term effects of trout stocking.

Freshwater mussels rarely overlap habitat with trout; however, with changes to the temperature regimes in these systems, trout may be extirpated and freshwater mussels could expand or shift habitats. As water temperatures increase, freshwater mussels inhabiting coolwater systems could move into coldwater systems as their host fish move upstream.

These habitats are also important for a variety of mammals that are semi-aquatic and/or that have an aquatic food base (e.g., Water Shrews, Muskrats, Beavers, River Otters, and certain bats). Selected bird species rely upon aquatic habitats including rivers and streams to provide habitat or a food base. These include various waterfowl, wading birds, and certain songbirds like the Louisiana Waterthrush.

4.2.3.6 Recommendations

Because coldwater systems occur primarily at higher elevations within Mountain ecoregion watersheds (usually as headwater streams) it is important to preserve their connectivity throughout the watershed. As water temperatures change and become warmer at lower elevations, many species that require colder temperature streams may not be able to migrate if there are barriers to movement. Barriers can include Beaver dams and man-made structures such as pipes, culverts, and dams. Section 4.2.2 provides recommendations appropriate for all aquatic communities, statewide. Actions specific to the river basins that contain coldwater streams are provided in Section 4.5 of this chapter.

Surveys. Distributional and status surveys are needed for aquatic snails, crayfish, mussels, and fish (in order of general need).

- Conduct baseline surveys to determine current distributions for the several SGCN associated with stream habitats in western North Carolina that are known in only a few localities, and/or are considered rare or declining (e.g., Water Shrew, Hellbender, Junaluska and Longtail Salamanders, Mudpuppy, Eastern Spiny Softshell, and Loggerhead Musk Turtles).

- Gather better information about the status and distribution of more common species associated with stream habitats (e.g., Shovel-nosed and Three-lined Salamanders).

- Investigate population status of native Brook Trout.

Monitoring. Monitoring of aquatic taxa is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These monitoring efforts will inform future decisions on how to manage aquatic species. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

Research. Research topics that facilitate appropriate conservation actions includes habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of priority species to specific threats and studies and should provide recommendations for mitigation and restoration. Aquatic species propagation is an area of current and ongoing research. Developing techniques for propagation of aquatic species is critical for preserving those species and their genetic stock, particularly those that are rare, at high risk of extinction or extirpation, and difficult to propagate in a laboratory setting.

- Determine specific flow regimes necessary to support microhabitat for particular species (e.g., Junaluska Salamander).

- Determine the effect that Beaver ponds have on downstream movement of toxins and sediment.

- Gather better information regarding the inputs and influence of groundwater sources to accurately predict the influence of climate change on coldwater systems.

- Conduct genetic research to resolve taxonomic issues for aquatic species, such as the 'Acuminate Crayfish' complex (*Cambarus* sp. C) and a Lake Waccamaw *Lampsilis* mussel complex.

- Study the combined effect of land use changes and climatic effects on long-term stream temperature trends as they relate to native brook trout protection, restoration, and management.

- Investigate thermal tolerance for brook trout and other native species.

- Examine stream temperature and associated microclimatic responses to a range of shading variables from riparian vegetation.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Increase the effective connectivity (i.e., gene flow) between headwater brook trout populations through removal of artificial barriers and promote habitat connectivity.

Partnerships and Cooperative Efforts. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable.

- Plant riparian areas with native vegetation with a broad elevational range within a particular watershed and with broad hydrologic tolerance to promote resilience from climate change.

4.2.4 Coolwater Streams

4.2.4.1 Ecosystem Description

Coolwater streams are found in small and large river systems in the Mountain ecoregion. Many have impoundments and reservoirs (see Section 4.2.13 Reservoirs & Impoundments for additional information). Many of the coolwater streams and rivers originate in high-elevation areas in the upper portion of watersheds as cold waters but transition to coolwater with a decrease in elevation or gradient and the addition of tributary waters.

The coolwater designation is based upon two general principles: temperature regime and fish community structure. Temperature regime can also be used to help classify coolwater streams where summer temperatures are predominantly warmer than 20°C (68°F) but typically do not exceed 25°C (76°F). This is a suggested temperature that will typically support the fish community structure (USACE 2003). Coolwater streams generally have a fish species composition that includes: Smallmouth Bass, Rock Bass, Walleye, Muskellunge, Creek Chub, River Chub, Bluehead Chub, Whitetail Shiner, White Sucker, Tennessee Shiner, Mirror Shiner, Warpaint Shiner, Northern Hog Sucker, Fantail Darter, Greenside Darter, and Greenfin Darter. This list is not inclusive and provides general guidance on aquatic community structure.

Riverine aquatic communities, which are identified in the 2005 WAP as a priority aquatic habitat, are a component of this habitat type (see Chapter 5) (NCWRC 2005). Bogs and associated wetlands and floodplain forests are two WAP priority habitats that also may be associated with coolwater stream communities; they provide habitat for wildlife that use adjacent terrestrial habitats.

4.2.4.2 Location of Habitat

Coolwater aquatic communities can be found in the upper Yadkin, Hiwassee, Little Tennessee, Savannah, French Broad, Watauga, New, Catawba, and Broad River basins. A review of US Geological Survey (USGS) real-time stream gauge data for water temperatures shows that Cheoah River (near Tapoco, NC), Hyco River (near McGehees Mill, NC), Wolf Island Creek (near Reidsville, NC), Candy Creek (near Monticello, NC), and Deep Creek (near Moriah, NC) historically have cool waters during the summer (USGS 2014a). Other examples include the Valley River, Hiwassee River (below Mission Lake Dam), Little Tennessee River, Pigeon River (below the confluence of the East and West Forks Pigeon River), French Broad River (below Nicholson Creek and Davidson River), Nolichucky River, New River, and Johns River. The 2005 WAP includes riverine aquatic communities, which contain coolwater streams, as a priority habitat (see Chapter 5) (NCWRC 2005).

4.2.4.3 Problems Affecting Habitats

Water Quality. As with coldwater streams, erosion and the resultant sedimentation are the largest sources of nonpoint source pollution in this system. Sources of erosion include disturbance from development activities and agriculture. Residential development, particularly in steep-slope areas, is of particular concern because of increased erosion. Livestock access to streams contributes heavily to bank erosion, sedimentation, and nutrient input. Timber harvests and poorly constructed and maintained timber roads are additional sources of erosion if proper controls are not used and maintained.

Many of the water quality and water quantity impacts resulting from climate change are analogous to impacts from economic development and population growth in North Carolina. Climate change is predicted to decrease rainfall and therefore limit water supply; however, growth and development have increased and continue to increase water supply demands. Historical stream flow patterns are projected to be altered due to climate change impacts, but these are already being altered due to rapid urbanization.

An increase in impervious surfaces due to roads, parking lots, homes, and businesses, increases the amount and speed of runoff being delivered into aquatic systems. Decreased groundwater recharge between storms due to impervious surfaces leads to a decrease in stream base flows. Runoff from urban areas often contains higher concentrations of nutrients (such as nitrogen and phosphorus), sediment, metals, hydrocarbons, and microbes.

Coolwater systems may be more likely to experience a change in species composition as aquatic species shift their range or distribution, and sensitive species decline or are extirpated by changes in water quality and temperature. Aquatic species are particularly sensitive to temperature cues and warming waters could cause species in coolwater habitats to attempt moving upstream into previously cold waters if there is suitable habitat. Some mussel species, for example, are limited in distribution because of coldwater influences. Alternatively, species could become extirpated because they are unable to move before their current locations persistently become warmwaters.

Invasive Species. Introduction of nonnative species creates competitive pressure on native populations. Yellowfin Shiner, native to the Savannah River Basin, has been introduced to the Little Tennessee River Basin. Their range could expand into other coldwater systems with warming water temperatures. Changes in stream conditions could increase competition with fish species, particularly the federally threatened Spotfin Chub.

Climate Impacts. Research conducted by Eaton and Sheller (1996) and Mohseni et al. (2003) assessed the effects of climate warming on 57 species of fishes in streams across the US. Depending on minimum temperature tolerance assumptions, species requiring coolwater habitats could experience a 12%–15% decrease in available habitat (DeWan et al. 2010). When the connectivity between streams and rivers within drainage basins provide adequate dispersal corridors, species at the southern extent of their geographical distribution may shift their distributions northward into cooler habitats (Allan et al. 2005). Where adequate dispersal corridors are limited or restricted, access to or availability of cooler water habitats may limit the range of those species subject to narrow temperature tolerance (DeWan et al. 2010).

4.2.4.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. Aquatic systems have been under threat from a variety of perturbations in the past and many of those continue today. Conversion of land (both from forest to agriculture or silviculture, as well as from development projects), continues to threaten stream integrity resulting in increased sediment, bank erosion, and stormwater runoff containing sediment and other potentially toxic materials. Considering current conditions in these systems, climate change is likely to have a synergistic effect with other threats that are of more immediate concern. Table 4.7 provides a review of

Table 4.7 Comparison of climate change with other threatsto coolwater systems

Threat	Rank Order	Comments
Development	1	Residential development, especially in steep slope areas, is of particular concern because of increased erosion. Most coolwater streams are larger streams and rivers and many have wider valleys where land use is more susceptible to being developed than on steeper-sloped headwater streams. Row crops, agricultural grazing, and urban/suburban development are common. Increased presence of impervious surfaces due to roads, parking lots, homes, and businesses increases the amount and speed of runoff being delivered into aquatic systems.
Sediment and Erosion	1	Stormwater runoff will amplify the loading of nutrients, sediment, and contaminants into streams, rivers, and reservoirs, which may alter overall channel design; have a negative effect on biota due to habitat changes, increased turbidity, and chemical exposure; and affect drinking water quality (Band and Salvesen 2009).
Pollution	1	Runoff from urban areas often contains higher concentrations of nutrients (such as nitrogen and phosphorus), sediment, metals, hydrocarbons, and microbes. An increase in frequency and intensity of storms due to climate change will have a similar impact on stream systems by increasing pollutant loading. Point and nonpoint sources—runoff and EDCs—are also threats.
Cattle in Streams	1	Livestock access to streams contributes heavily to bank erosion, sedimentation, and nutrient input.
Lack of Riparian Vegetation	1	Riparian vegetation serves as nutrient input to the stream community and helps regulate stream temperature by providing shade. Lack of riparian vegetation or inadequate width of forested buffer can cause streambank erosion and sedimentation.
Conversion to Agriculture/ Silviculture	2	Loss of forest cover can cause increased erosion and sedimentation and negatively impact aquatic systems. Poorly constructed and maintained timber roads are another source of erosion.
Water Withdrawals	2	Irrigation and water supply withdrawals pose a threat to flow regime. Water withdrawals can be problematic, particularly in streams with already low 7Q10 flows, because they may reduce available habitat for aquatic species. Decreased groundwater recharge between storms due to impervious surfaces leads to a decrease in stream baseflow.
Flood Regime Alteration	2	Many rivers that were once free-flowing are now flooded by reservoirs, severely fragmenting habitat and often isolating populations of species above and below the impoundment. Floodplains and wetlands are natural features designed for flood control through attenuation and dissipation of floodwaters. Development and other impacts can reduce this service.
Climate Change	3	Climate change is predicted to decrease rainfall and therefore, limit water supply. Effects will likely compound with other threats to increase the severity of several threats to aquatic systems.
Invasive Species	4	Invasive plants in the riparian area can have negative impacts on stream systems by creating a monoculture (such as Japanese Knotweed) with poor nutrient inputs, reducing bank stability, and allowing too much sunlight to infiltrate, resulting in warmer stream temperatures. Invasive aquatic species, like the Asian Clam or Rusty Crayfish, may have negative effects on native species, such as competition for space and resources.

expected climate change impacts in order of importance in comparison with other types of threats.

4.2.4.5 Impacts to Wildlife

Appendix G includes a list of SGCN and other species for which there are knowledge gaps and management concern priorities. Appendix H identifies SGCN that use coolwater streams.

The temperature tolerance range of aquatic species can be specific and the availability of cool waters that do not exceed tolerances can be a limiting factor in determining where species can find appropriate habitat, especially as average water temperatures experience warming trends (DeWan et al. 2010). Appalachian Elktoe is a mussel species that requires cool, clean, well-oxygenated waters, but appropriate aquatic habitat in its range is generally fragmented. Habitat fragmentation can disrupt life-cycle relationships of SGCN priority mussel species and their host fish because the mussels are unable to move into coolwaters as warming trends occur. But their host-fish species are more mobile and may move into new coolwater ranges (Opdam and Wascher 2004; DeWan et al. 2010).

Coolwater riverine habitats are important for a number of reptiles and amphibians, including certain turtles, frogs, and salamanders that utilize aquatic habitats during part or all of their life cycle. These habitats are also important for a variety of mammals that are semi-aquatic and/or have an aquatic food base (e.g., Water Shrews, Muskrats, Beavers, River Otters, and certain bats). Selected bird species (such as various waterfowl, wading birds, and certain songbirds like the Louisiana Waterthrush) also rely upon aquatic habitats to provide habitat or a food base.

4.2.4.6 Recommendations

It is important to preserve the connectivity of cool water systems because they provide a link to coldwater systems that will become refugia as water temperature gradients change and previously cool waters become persistently warmer. As water temperatures change, many species may not be able to migrate into cooler streams if there are barriers to movement or habitats are fragmented so that coolwater habitats are interspersed amongst warmer water habitats. Section 4.2.2 provides recommendations appropriate for all aquatic communities, statewide. Actions specific to the river basins that contain coolwater streams are provided in Section 4.5.

Surveys. Distributional and status surveys are needed for aquatic snails, crayfish, mussels, and fish (in order of general need).

- Conduct stream surveys adjacent to areas poised for development (edge of urban expansion) to establish baseline populations and identify problems before development expands.

Monitoring. Monitoring of aquatic taxa is critical to assessing species and ecosystem health, and gauging the resilience of organisms to a changing climate. These monitoring efforts will inform future decisions on how to manage aquatic species. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of priority species to specific threats, and studies should provide recommendations for mitigation and restoration. Aquatic species propagation is an area of current and ongoing research. Developing techniques for propagation of aquatic species is critical for preserving those species and their genetic stock, particularly those that are rare, at high risk of extinction or extirpation, and difficult to propagate in a laboratory setting.

- Examine stream temperature and associated microclimatic responses to a range of shading variables from riparian vegetation.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Reduce impervious surfaces as one measure to control runoff and erosion. Research has shown that impervious levels of 8%–12% represent a region where small changes in urbanization can cause major changes in stream condition (Wang et al. 2001). There are also many BMPs that may be alternatives to reduce runoff.

Partnerships and Cooperative Efforts. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable.

- Promote efforts to control stormwater management point source pollution.

- Land use planning and zoning laws are needed to guide development, land clearing activities, and hydrology alterations within floodplains. Planning such as this may for example route highways and other corridors that cross floodplains as closely as possible to existing corridors to avoid fragmenting an extensive corridor of forest.

4.2.5 Warmwater Streams

4.2.5.1 Ecosystem Description

Warmwater streams are found throughout the state. Cold and coolwater streams and rivers that originate in the upper portion of watersheds in the Mountains, transition to warm waters with a decrease in elevation and as tributary waters combine to form larger systems. The warmwater designation is based upon two general principles: temperature regime and fish community composition. Temperature regime can be used to help classify warmwater streams where summer temperatures are predominantly warmer than 25°C (77°F). This is based on suggested temperatures that define cold and coolwaters (USACE 2003). Warmwater streams can have a wide variety of fish species composition depending on landscape location, surrounding land use, elevation, substrate, depth, temperature gradients, and water quality. Examples of warmwater fish species in North Carolina include Blacknose Dace, Creek Chub, Green Sunfish, Largemouth Bass, and White Sucker.

Riverine aquatic communities, which include warmwater aquatic systems, are described in the 2005 WAP as a priority aquatic habitat (see Chapter 5) (NCWRC 2005).

4.2.5.2 Location of Habitat

Warmwater aquatic communities make up the majority of aquatic communities and can be found in all ecoregions of the state. Lower reaches of some river systems that originate in the Mountains will transition to warmwater communities with declining elevations and as warmwater tributaries contribute to the flow. Examples include the lower reaches of rivers in the Piedmont ecoregion such as the Broad River and Catawba River.

4.2.5.3 Problems Affecting Habitats

Dams. Impacts to aquatic species occur when habitats are modified and movement between habitats is blocked (Lessard and Hayes 2003). Dams change the overall physical, chemical, and biological structure of streams by modifying stream flows and changing lotic systems to lentic systems; influencing the export of water, sediment, and nutrients to downstream systems; altering water temperatures and thermal regimes; and disconnecting streams from their floodplains and riparian communities (Wang et al. 2011). The results of a study by Wang et al. (2011) indicate that both downstream and upstream dams influence fish assemblages in nonimpounded stream segments; however, the study found the cumulative effects of other environmental factors such as stream size, adjacent land uses, water quality, and stream flow and thermal regimes may have a more significant influence on fish occurrence and abundance.

Thermal Stratification and Algal Blooms. Thermal stratification is rare in warmwater streams due to the mixing effect of flows and lack of sufficient depth. During periods of low water flow and little wind, deeper pools within a river may become stratified with little or no vertical mixing. Under these conditions DO levels in the deeper water may be depressed and become unsuitable for many aquatic organisms. Algal blooms in the surface water can exacerbate DO depletion and result in local degradation of water quality. Such conditions are temporary and are readily alleviated by increased water flow or increased wind velocity.

In Coastal Plain streams, stratification may occur due to saltwater intrusion occurring as a subsurface density flow. The denser saltwater does not mix with the less dense fresh water and as a result the water column becomes stratified. Oxygen depletion as well as toxic bacterial and algal blooms can be associated with this type of event, often leading to significant mortalities within the aquatic community.

Invasive Species. Warmwater streams provide pathways for invasion by nonnative species. In the absence of obstructions such as dams, culverts, waterfalls, etc., invasive species can travel long distances within a system and establish viable populations within the main stem river as well as tributaries. Once in a river system, invasive species are difficult, if not impossible, to eradicate or even control.

Water Quality. Warmwater streams typically occur at lower altitudes with a relatively moderate topography. Thus the adjacent land is more likely to be used for purposes such as residential development industry, commerce, and agriculture. All of these are sources for discharges of various chemicals into the river, which can moderately or substantially affect biological communities. The moderate temperature regime of these waters often accelerates biological activity promoted by inputs of organic compounds resulting in degraded water quality.

Sedimentation is particularly problematic in warmwater streams. Development of riparian and adjacent areas can accelerate erosion and relatively low stream gradients can promote the deposition of eroded sediment within the stream channels. Sedimentation can decrease the depth, increase water temperatures, and decrease the biological productivity of affected waters.

Rivers flowing through or near urban and suburban areas may receive products from sewage treatment plants, such as incompletely processed pharmaceuticals, that can affect the production of hormones in aquatic fauna.

4.2.5.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. Aquatic systems have been under threat from a variety of perturbations in the past and many of those continue today. Conversion of land, both from forest to agriculture or silviculture, as well as from development projects, continues to threaten stream integrity resulting in increased sediment, bank erosion, and stormwater runoff containing sediment and other potentially toxic materials. Considering current conditions in these systems, climate change is likely to have a synergistic effect with other threats that are of more immediate concern.

A comparison of climate-related impacts to other threats is not included in this description because the NCNHP vulnerability assessments completed in 2010 did not include warmwater systems as a community type. However, development, sediment and erosion, and pollution are primary concerns, and results similar to the comparison for coolwater systems are expected (see Table 4.7 in Section 4.2.4).

4.2.5.5 Impacts to Wildlife

Appendix G includes a list of species for which there are knowledge gap and management concern priorities. Appendix H includes SGCN that use warmwater streams.

Fish can regulate their metabolism by changing location or congregating in response to thermal stratification that can occur seasonally or in response to artificial thermal effluent (e.g., power plant discharge) (Reynolds and Casterline 1979; Peterson and Rabeni 1996). The temperature tolerance range of aquatic species can be specific and the availability of warm waters that do not exceed tolerances can be a limiting factor in determining where species can find appropriate habitat, especially as average water temperatures experience warming trends (DeWan et al. 2010). Even though they may not normally congregate during the winter, fish may do so if warmer water is available instead of the traditionally colder water. This will result in increased vulnerability to predation and exposure to disease (Peterson and Rabeni 1996).

Many large warmwater rivers in the Piedmont and Coastal Plain ecoregions have hydropower dams that regulate daily flow. These fluctuations can result in streambed and bank instability, scouring, erosion, and turbidity and can discourage riparian vegetation and streambed vegetation and algal growth (Walburg et al. 1983; Cushman 1985; Peterson and Rabeni 1996). These impacts may contribute to a reduction in macroinvertebrate prey and loss of emergent and submerged vegetation, which will affect fish productivity (Peterson and Rabeni 1996). The loss of vegetated and edge of channel habitats that serve as nursery areas for young fish can impact age classes, and species that have low reproduction rates may experience loss of entire years of reproductive potential (Peterson and Rabeni 1996).

Warmwater habitats are important for a number of reptiles and amphibians including certain turtles, frogs, and salamanders that utilize aquatic habitats during part or all of their life cycle. These habitats are also important for a variety of mammals that are semi-aquatic and/or that have an aquatic food base (e.g., Water Shrews, Muskrats, Beavers, River Otters, and certain bats). Selected bird species also rely upon aquatic habitats including rivers and streams to provide habitat or a food base; these include various waterfowl, wading birds, and certain songbirds.

4.2.5.6 Recommendations

It is important to preserve the connectivity of warmwater systems because they provide a link to cool and coldwater systems that will become refugia as water temperature gradients change and previously cool waters become persistently warmer. As water temperatures change, many species may not be able to migrate into waters with appropriate temperatures if there are barriers to movement or habitats are fragmented so that warmwater habitats are interspersed amongst habitats that do not meet thermal requirements. Section 4.2.2 provides recommendations appropriate for all aquatic communities, statewide. Actions specific to the river basins that contain warmwater streams are provided in Section 4.5.

Surveys. Distributional and status surveys are needed for aquatic snails, crayfish, mussels, and fish (in order of general need).

- Conduct surveys to detect presence and collect life history and abundance data for freshwater snails and crayfish, as there is limited information available on these species.

Monitoring. Monitoring of aquatic taxa is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web. Research must also be conducted to determine vulnerability of priority species to specific threats, and studies should provide recommendations for mitigation and restoration. Aquatic species propagation is an area of current and ongoing research. Developing techniques for propagation of aquatic species is critical for preserving those species and their genetic stock, particularly those that are rare, at high risk of extinction or extirpation, and difficult to propagate in a laboratory setting.

- Gain a broad community-level perspective to simplify the in-stream flow assessments associated with hydropower projects. Research is needed to develop habitat suitability criteria to aid in the assessments (Lobb and Orth 1991).

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

Partnerships and Cooperative Efforts. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable.

4.2.6 Groundwater, Springs, and Subterranean Water Systems

4.2.6.1 Ecosystem Description

Groundwater is present throughout North Carolina at varying depths below the land surface. The traditional definition for groundwater is subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated (Freeze and Cherry 1979). For this aquatic community description, we use the term "groundwater" to represent all subsurface waters generically, including saturated soils and underground streams. These systems may interact with or transition to other types of habitats (e.g., streams, lakes, wetlands) (Winter et al. 1998) which are described as separate natural communities in other sections of this chapter.

Groundwater is subsurface water stored in a zone of soil saturation and occurs beneath the water table (Freeze and Cherry 1979; Fetter 2001) and differs from surface waters because of the absence of light and the fact that organic matter and oxygen are imported from the surface (Hahn 2009). Groundwater recharge is the process where water infiltrated from the surface is added to the saturated zone; the top of the saturation zone is referred to as the water table (Domenico and Schwartz 1998; Campbell and Coes 2010). Groundwater forms a water table that can lie at the ground's surface and contribute to the baseflow of a stream or it can be situated underground at varying depths, existing as subsurface flow. Some groundwater discharge is an interstitial habitat that is hydrologically linked to and contributes baseflow to wetlands, ponds, or lakes (Culver et al. 2012). Groundwater intersects with streams where the water table is at or slightly above the streambed (Gordon et al. 1992; Peterson and Rabeni 1996).

Springs are points of focused groundwater discharged at a small point on the land surface (van der Kamp 1995; McGinley 2013). They are generally stable in terms of water quality, temperature and flow (Fleury 2009). Springs can also form at the spots where karst waters emerge from the local underground drainage system and develop on the surface or in caves (Fleury 2009). They are made up of groundwater that has infiltrated at different times, from different places, and potentially under different conditions than currently exist (van der Kamp 1995). In contrast, seeps discharge to a larger area than a spring (McGinley 2013). Seepage springs are a diffuse discharge of gravity-fed water where the land surface is wet compared to surrounding areas, but there is no observable flow (Culver et al. 2012).

Subterranean water develops in permeable layers of soil, sand, and rock. A subterranean system that carries groundwater in sufficient quantity to provide usable water supplies is called an aquifer (Hynes 1983; Barnes-Svarney and Svarney 2004; Kokkonen et al. 2011). Coastal Plain groundwater is found primarily in porous sand and limestone (carbonate rock), and is regionally classified as being shallow unconfined (surficial) aquifers or deeper confined aquifers (Smith and Chapman 2005; USGS 2012a; Denver et al. 2014). All aquifers have an impermeable layer beneath them that stops the groundwater from infiltrating further. When the layers above it are permeable, it is an unconfined aquifer and when the permeable layer occurs between two impermeable layers, it is a confined aquifer (Domenico and Schwartz 1998; McGinley 2013). Precipitation in aquifer outcrop areas is a major source of recharge to aquifers under predevelopment and present-day conditions (Aucott 1996).

Many of the Coastal Plain aquifers are karst systems that have formed over geologic time scales through the dissolution of carbonate bedrock, resulting in the formation of the caves, sinkholes, springs, and subterranean streams that are typical features of a karst system (Fleury 2009; USGS 2012a). Aquifers in the central Coastal Plain area are formed from unconsolidated deposits of sand, silt, clay, and limestone (Heath and Spruill 2003). Aquifers in the Piedmont and Mountain ecoregions are found in Triassic Basin rocks that are covered by regolith (soil, saprolite, alluvium, and colluvium) (USGS 2012a). Karst systems and other subterranean resources should be considered non-renewable once they have been depleted or degraded, because they are formed by specific processes that occur over long geologic time periods (Gunn et al. 2000).

4.2.6.2 Location of Habitat

Since aquifers are geological features that are often used for drinking water, supply mapping information is generally available. Such principal aquifers include the Lower Cape Fear, Upper Cape Fear, Black Creek, Pee Dee, Castle Hayne, Yorktown, Surficial, and Bedrock aquifers. Minor aquifers in the State include the Lower Cretaceous, Beaufort, and Pungo River (NCDWR 2010b; USGS 2012a). Potentiometric surface maps for several Coastal Plain ecoregion aquifers are available from the NC Division of Water Resources (2015i). Springs are generally associated with stream systems, especially headwater streams, and other surface water bodies such as farm ponds.

4.2.6.3 Problems Affecting Habitats

One of the most important issues concerning groundwater systems is the increasing demand for water supplies due to growth and urbanization (Land et al. 2004). Groundwater extraction to meet this demand is often at unsustainable rates (Fleury 2009) and results in declining water levels, saltwater encroachment (in Coastal Plain systems), dewatering, and land subsidence (e.g., sink holes) (Land et al. 2004; Fleury 2009). Groundwater pressure can drop when there is rapid and excessive drawdown of an aquifer and the pore space holding the groundwater shrinks. This leads to compaction of the aquifer at depth (Fleury 2009). Voids can form in the soils and porous rock that once held water, which causes subsidence and collapse of the land surface (Patton and DeHan 1998; Fleury 2009).

According to the USGS, groundwater withdrawals from the Castle Hayne aquifer have caused land subsidence measuring as large as 7 inches, and has been documented (during the 33-year period from 1935–68) in the central Coastal Plain of North Carolina. Overall water-level declines are estimated to be as much as 20 feet near pumping centers (McSwain et al. 2014; USGS 2014b).

Mining operations can remove notable features from the landscape and alter the hydraulic gradients that contribute to groundwater systems. Quarrying often reduces spring discharge, causing drawdown of the water table, sinkholes, and the destruction of caves. Tailing ponds associated with mining operations may leak or collapse, and can become a source of toxic chemicals in local water supplies.

Because of their permeable rock structure and presence of sink holes, karst systems are especially vulnerable to pollution, water withdrawals, and changes in land use (Bakalowicz 2005; Calo and Parise 2009; Brinkmann and Parise 2012). Agricultural activities can degrade the quality of groundwater quality through the usage of fertilizers and pesticides and storage or disposal of livestock or poultry wastes on land (Freeze and Cherry 1979). Contamination from nitrate-based fertilizers used on agricultural lands can wash into groundwater that is a source of residential drinking-water wells (Fleury 2009).

Dripwater flows are critical both to cave biota and to the microclimates of the caves themselves, and if those flows carry surface-level contaminants, the entire cave environment can be affected (Fleury 2009). Human use of caves can alter the physical structure of the caves themselves, change the water chemistry or hydrology within the cave, or destroy cave structures and cave-dwelling organisms (Fleury 2009).

Another concern is the advance of the saltwater front from coastal waters into freshwater systems, commonly referred to as saltwater encroachment. For example, New Bern's freshwater wells have experienced saltwater encroachment since the late 1960s. A Cove City drinking-water well field was about 5 miles west of where the front was previously located and the start of withdrawals there in 1968 is believed to have resulted in a reversal of the saltwater zone hydraulic gradient. Since then the front has been advancing and represents what is essentially a permanent decrease in subterranean freshwater storage capacity (Heath and Spruill 2003; USGS 2012b).

4.2.6.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats helps define short- and long-term conservation actions and recommendations. While climate change is not the most severe threat to this natural resource, a combination of synergistic effects with other threats could stress these systems to the point of depletion. A comparison to other threats has not been conducted for this natural community type.

4.2.6.5 Impacts to Wildlife

The unique characteristics of species associated with groundwater, springs, and subterranean water are referred to as troglomorphy: reduced or absent eyes and pigment and elongated, thin appendages (Culver and Pipan 2009; Culver et al. 2012). These obligate subterranean-dwelling aquatic species are considered stygobionts (Barr and Holsinger 1985; Culver et al. 2012). Obligate cave-dwelling animals are considered to be troglobites and include turbellarians, gastropods, millipedes, arachnids, pseudoscorpions, isopods, amphipods, beetles, fishes, and salamanders (Barr and Holsinger 1985).

There has been little research in North Carolina, but research conducted by Kenk (1935, 1972, 1977a, 1977b) and Culver with others (1969, 1971, 2004, 2006, 2008, 2009, 2010) that focused on subterranean systems in Washington, DC, Maryland, and Virginia provided information that may assist in understanding what type of subterranean species are present in North Carolina. According to Culver et al. (2012), two tidewater amphipods (*Stygobromus araeus* and *S.indentatus*) occur frequently enough to have permanent populations in some seepage springs and hypotelminorheic habitats (small isolated aquifers underlain by clay). One of the amphipods (*S. indentatus*) was included in a petition filed by the Center for Biological Diversity, requesting that the USFWS list the species for protection under the ESA. The petition lists the species as occurring in North Carolina. Culver et al. (2012) indicate the tidewater amphipod was found in a shallow well in Nash County, North Carolina.

4.2.6.6 Recommendations

Groundwater is a valuable resource often used for industry, commerce, agriculture, and most importantly, drinking water (Webbers 1995). Contaminants in the recharge zone can be transported in waters contributing to springs, wells (including drinking waters), and surface waters that provide aquatic habitats. All groundwaters need to be protected because contamination can cause water quality problems not only in these sysetms, but also to other waters connected to them and ultimately create long-term negative impacts to aquatic species. Section 4.2.2 provides recommendations appropriate for all aquatic communities, statewide.

Surveys. Distributional and status surveys are necessary for species that utilize these waters, especially for invertebrates.

Monitoring. Monitoring ecosystem health helps develop an understanding about its resilience to a changing climate. Monitoring efforts inform future decisions on how to manage and safe-guard the system. Long-term monitoring is needed to identify trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability to specific threats, such as fracking and groundwater extraction. Recommendations for mitigation and restoration of degraded systems should be included.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

Partnerships and Cooperative Efforts. Conservation programs, incentives, partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. This includes protective measures that utilize existing regulatory frameworks to protect habitats and species. When insufficient measures of protection exist, new regulations should be developed.

4.2.7 Headwater Streams/Small Creeks

4.2.7.1 Ecosystem Description

The headwater stream and small creek community includes intermittent and first and second order streams and make up the largest proportion of drainage reaches in the landscape (Leopold et al. 1964; Meyer et al. 2007; Gothe et al. 2014). The majority of land area in North Carolina (approximately 80%– 85%) drains to headwater streams (Gregory 2009) and constitutes at least 80% of the nation's stream network (Meyer et al. 2003). Headwater streams are very important elements in the stream and river networks in terms of influencing water quality and quantity.

A stream classification system using DA as a break for size classes, similar to those described in the Northeast Aquatic Habitat Classification System and the National Fish Habitat Framework, has been applied to this aquatic community description. The hierarchical classification system shown in Table 4.2.1 defines headwater streams as having a DA of 40 square miles or less (Olivero and Anderson 2008; Olivero-Sheldon and Anderson 2013).

Stream size affects the aquatic biological assemblages within a stream reach (Vannote et al. 1980; Higgins et al. 2005; Olivero-Sheldon and Anderson 2013). Species diversity tends to be lower in headwater systems when base flow conditions are highly variable. Overall, species richness is typically lower than in small river systems and is often comprised of the most common generalist species; mussels are often absent from headwater streams. In these aquatic communities, the coarse organic matter from riparian vegetation provides the energy resources for what is often a consumer community dominated by shredding insects (Olivero-Sheldon and Anderson 2013). Benthic macroinvertebrates are a very important component of the community, and aquatic insect species richness can be very high even in headwaters in agricultural and urban landscapes (Moore and Palmer 2005; Meyer et al. 2007).

Headwater streams in the Mountain ecoregion are influenced by location on the landscape. Persistent water temperatures will determine whether they are considered coolwater systems or coldwater systems. Headwater streams found in other areas of the state are more likely to be considered warm water systems. Warmwater systems are those that have water temperatures that are persistently greater than 25°C (77°F). Water temperature contributes significantly to the species assemblages that occur in aquatic environments.

4.2.7.2 Location of Habitat

These systems can be found statewide but are more prevalent in the Mountain and Piedmont ecoregions. Headwater systems may be associated with small wetland systems and some originate at natural spring heads. Many streams in this community type are unnamed tributaries; however, examples include Morgan Creek, Parkers Creek, Little Creek, and White Oak Creek. The 2005 WAP described riverine aquatic communities, which would include headwater streams, as a priority habitat (see Chapter 5) (NCWRC 2005).

4.2.7.3 Problems Affecting Habitats

In North Carolina, headwater systems are vulnerable to impacts because they often occur in agricultural and urbanized environments and are less likely to be protected by regulatory requirements such as avoidance and minimization measures and conservation of riparian buffers. The North Carolina Ecosystem Response to Climate Change: NC Department of Environment and Natural Resources (NCDENR) Assessment of Effects and Adaptation Measures (NCNHP 2010) Report for Headwater Systems provides more information about the expected impacts of climate change and other threats to this community type.

Land Use. Headwater streams are primarily located on private lands and are more likely to be threatened by changes in land use practices. Land use change that results in greater areas of impervious surface can increase stormwater runoff of nutrients, sediment, and contaminants. The increased loads could affect water quality and habitat for aquatic species (Band and Salvesen 2009). Headwater systems in agricultural areas where BMPs, such as no-till farming, are used and where riparian buffers are maintained were found to have high macroinvertebrate richness compared to headwaters in urban areas (Moore and Palmer 2005). Small impoundments used for irrigation or as an amenity (e.g., swimming, fishing) are often located in headwater streams and may not be subject to dam safety rules that carry minimum flow requirements. Lack of minimum flows will exacerbate the effects of drought and where water levels become shallow the resulting high water temperature will kill aquatic species.

Riparian vegetation is critical to the overall stream and streambank stability. Lack of riparian vegetation or inadequate width of forested buffer can cause streambank erosion and sedimentation. In addition to stabilizing streambanks, riparian vegetation serves as a food and nutrient input to the stream community and helps regulate stream temperature by providing shade.

Water Quality. Headwater streams often make up as much as 85% of the total stream length within a drainage network and contribute both water, woody debris, and nutrients collected from adjacent landscapes downstream to larger streams (Peterson et al. 2001). Studies have shown that headwater streams retain and transform as much as 50% or more of the nitrogen inputs from their watershed, often within short distances and over short time periods (Peterson et al. 2001). Despite their small size, headwater streams serve an important function in regulating nitrogen uptake and processing that protects water quality. Small drainages, and especially headwater systems, are sensitive to local conditions such as nutrient loads in runoff (Peterson et al. 2001; Meyer et al. 2007). When nutrient loads are high, headwater streams can lose their capacity to retain and transform nitrogen locally, thereby allowing greater nutrient loads to flow into downstream waters where they contribute to water degradation and eutrophication (Peterson et al. 2001).

Erosion and the resultant sedimentation are the largest sources of nonpoint source pollution in most aquatic systems. Sources of erosion include disturbance from development activities and agriculture. Residential development can increase erosion during the construction process, but can also be a secondary cause of increased impervious surfaces in the watershed. Livestock access to streams contributes heavily to bank erosion, sedimentation, and nutrient input. Timber harvests and poorly constructed and maintained timber roads are additional sources of erosion if proper controls are not used and maintained.

Recent studies have shown that EDCs in treated wastewater can inhibit reproduction and cause feminization of mussels and fish. Although little is known about the effects of EDCs, additional studies are being conducted to document the levels of EDCs in discharges, and measures are being identified to reduce or eliminate EDCs from wastewater prior to discharge, should those discharge studies show increases in EDC levels (Conn et al. 2006; Kim et al. 2007; Kasprzyk-Hordern et al. 2008; Joss et al. 2006; Kolpin et al. 2002; Nowotny et al. 2007).

Aquatic species could experience shifts in their range or distribution and sensitive species may experience decline or extirpation due to changes in water quality and habitat. Piedmont headwater streams are already vulnerable to drought conditions with low DO or partial or complete drying of streams; climate-change induced drought will only increase this vulnerability. Aquatic species could become extirpated or may move further downstream into higher order streams. Therefore, these systems may experience a change in species composition.

Invasive Species. Invasive plants in the riparian area often have negative impacts on stream systems often times, by creating a monoculture with poor nutrient inputs, reducing bank stability and allowing too much sunlight to infiltrate, resulting in warmer stream temperatures. Invasive aquatic species, like the Asian Clam, may have negative effects on native species through competition for space and resources.

Climate Impacts. Many of the water quality and water quantity impacts resulting from climate change are analogous to impacts from economic development and population growth in North Carolina. Climate change is predicted to decrease rainfall and thereby limit water supply while growth and development have increased and continue to increase water supply demands. Historical stream flow patterns are projected to be altered due to climate change impacts; yet these patterns are already being altered due to rapid urbanization. An increase in impervious surfaces due to the proliferation of roads, parking lots, homes, and businesses increases the amount and speed of runoff being delivered into aquatic systems.

Increased air temperatures may lead to increased water temperatures and potentially lower DO levels because headwater streams tend to be small systems. Higher air and water temperatures can lead to increased evaporation, which results in less flowing water available for aquatic species. Hot spells can have the same effect as overall increased air temperatures but on a much more acute scale. These stream systems are vitally important to the overall health of the downstream watershed, yet are likely to experience potentially severe physical, chemical, and biological changes with temperature and DO alteration (DeWan et al. 2010; Karl et al. 2009; Band and Salvesen 2009).

Potential increased air temperatures and resulting increased water temperatures can lead to algal blooms in aquatic systems that diminish stream oxygen availability. The increased water temperature alone can cause a decline in DO and any decline in DO can lead to fish kills, whether as a direct result of increased water temperature or as a secondary effect of algal blooms. These effects are highly likely, in addition to complete drying of streams during drought conditions, in Piedmont headwaters streams (DeWan et al. 2010; Band and Salvesen 2009).

Potential changes in precipitation will contribute to severe and prolonged droughts resulting in decreased stream flow, decreased groundwater recharge, and increased evaporation. Reduced water flows will further contribute to warmer water temperatures and further stress water quality. Headwater streams could dry up, potentially leading to aquatic species extirpation (DeWan et al. 2010; Karl et al. 2009; Band and Salvesen 2009; Holman et al. 2010). During droughts, recharge of groundwater will decline as the temperature and spacing between rainfall events increase. Responding by increasing groundwater pumping will further stress or deplete aquifers and place increasing strain on surface water resources. Increased water withdrawals for agriculture could further stress surface water resources and available aquatic habitat.

Additionally, decreased groundwater recharge between storms due to impervious surfaces leads to a decrease in stream base flows. Runoff from urban areas often contains higher concentrations of nutrients (such as nitrogen and phosphorus), sediment, metals, hydrocarbons, and microbes. An increase in frequency and intensity of storms due to climate change will have a similar impact on stream systems by increasing pollutant loading. Therefore, challenges to water quality and water quantity as related to climate change are similar to those being confronted to accommodate growth and development. Adaptation strategies for water resource management could limit negative effects of both climate change and continuing development (Band and Salvesen 2009).

Storms. Increased storm intensity can lead to periodic flooding and therefore, increased stormwater runoff and increased erosion. With increased stormwater runoff there is an increase in loading of sediments, nutrients, and contaminants into streams and potential negative effects on biota. With a change in intensity and variability of rainfall, there are potential changes to stream flow patterns and channel hydrodynamics (Band and Salvesen 2009; Holman et al. 2010; Bakke 2008). An increase in the number of tropical events can lead to flash flooding, which causes many of the above-mentioned responses. Effects such as increased sediments and contaminants into aquatic systems, in addition to major disruption to channel design and hydrodynamics, potentially upset the physical, chemical, and biological structure of streams (Band and Salvesen 2009).

Because of potential changes in storm frequency and intensity, it is likely that channel hydrodynamics will be altered. Associated with channel hydrodynamics are changes in flow regime, sediment transport, and overall channel design. Changes may occur in aquatic species' habitats, and how or if these species adapt to changing habitats will require close monitoring to observe trends and help inform future management decisions (Bakke 2008).

4.2.7.4 Climate Change Compared to Other Threats

These stream systems are vitally important to the overall health of the downstream watershed, yet are likely to experience potentially severe physical, chemical, and biological changes with temperature and DO alteration (DeWan et al. 2010; Karl et al. 2009; Band and Salvesen 2009). Table 4.8 provides a review of expected climate change impacts in order of importance in comparison with other types of threats.

4.2.7.5 Impacts to Wildlife

Appendix G includes a list of SGCN and priority species for which there are knowledge gap and management concern priorities. Appendix H identifies SGCN that use Headwater Streams.

Headwater systems offer a range of habitats that can support an abundance and diversity of species, depending on water depth and seasonality of flows, hydrologic regime, temperature, water chemistry, substrate types, and connectivity to downstream systems (Meyer et al. 2007). Biodiversity will be influenced by the presence of species unique to headwater systems and whether connectivity within the DA allows species that seasonally use headwaters for particular life history stages (e.g., spawning, nursery areas) to move upstream from larger streams (Meyer et al. 2007). Headwater systems, especially those associated with springs and seeps, are likely to have a high diversity of insects, especially those genera with an aquatic life history cycle. Research conducted at Coweeta Hydrologic Laboratory in western North Carolina collected at least 51 families and 145 genera of aquatic insects in eight headwater streams during three decades of sampling (Meyer et al. 2007).

Climate change effects, especially drought and higher temperatures, will likely have a significant impact on headwater stream communities, possibly creating a shift where several perennial streams will become intermittent or ephemeral systems. This potential shift will result in the loss of aquatic species diversity. Aquatic species could experience shifts in their range or distribution and sensitive species may experience decline or extirpation due to changes in water quality and habitat. Headwater streams could dry up, potentially leading to aquatic species extirpation (DeWan et al. 2010; Karl et al. 2009; Band and Salvesen 2009; Holman et al. 2010).

Table 4.8 Comparison of climate change with other threats to headwater streams/small creeks

Threat	Rank Order	Comments
Development	1	An increase in impervious surfaces due to roads, parking lots, homes, and businesses, increases the amount and speed of runoff being delivered into aquatic systems, and decreased groundwater recharge between storms leads to a decrease in stream baseflow. Runoff from urban areas often contains higher concentrations of nutrients (such as nitrogen and phosphorus), sediment, metals, hydrocarbons, and microbes.
Erosion and Sedimentation	1	Streams in the Triassic Basin are particularly susceptible to erosion and are likely at greatest risk from erosion given proximity to many urban and suburban development centers. Erosion and the resultant sedimentation are the largest sources of nonpoint source pollution in most aquatic systems.
Climate Change	2	Headwater streams may shrink in habitat or extent.
Lack of Riparian Vegetation	2	Lack of riparian vegetation or inadequate width of forested buffer can cause streambank erosion and sedimentation. In addition to stabilizing streambanks, riparian vegetation serves as a food/nutrient input to the stream community and helps regulate stream temperature by providing shade.
Logging/Exploitation	2	While bank vegetation is usually undisturbed, logging is a major threat to streams if proper erosion controls are not used and maintained. Poorly constructed and maintained timber roads also contribute to erosion.
Flood Regime Alteration	3	High and low flow extremes pose a threat.
Invasive Species	4	Invasive plants in the riparian area often have negative impacts on stream systems by creating a monoculture with poor nutrient inputs, reducing bank stability, and allowing too much sunlight to infiltrate, causing warmer stream temperatures. Invasive aquatic species, like the Asian Clam, may have negative effects on native species, such as when competing for space and resources.
Cattle in Streams	4	Livestock access to streams contributes heavily to bank erosion, sedimentation, and nutrient input.
Pollution	5	The majority of headwater streams are on lands in private ownership, making them at risk from land use practices that may increase stormwater runoff of nutrients, sediment, and contaminants. Endocrine-disrupting chemicals in treated wastewater can inhibit reproduction and cause feminization of mussels and fish (Conn et al. 2006; Kim et al. 2007; Kasprzyk-Hordern et al. 2008; Joss et al. 2006; Kolpin et al. 2002; Nowotny et al. 2007). Runoff from impervious surfaces carries lawn pesticides, road oil, and other pollutants from developed areas into surface waters.

Potential increased air temperatures and resulting increased water temperatures can lead to algal blooms in aquatic systems, which diminish stream oxygen availability. The increased water temperature alone can cause a decline in DO and any decline in DO can lead to fish kills, whether as a direct result of increased water temperature or as a secondary effect of algal blooms.

Maintaining water quality is important for the species that rely upon headwater streams for habitat as well as for those species which rely indirectly on the system as provision of habitat for their prey. Wetlands associated with headwater streams are important as breeding sites for amphibian species and can also be important breeding habitat for crayfishes. Concentrated stormwater flows can strip salamander eggs from river banks and vegetation, reducing reproductive success.

Riparian areas serve as thermal refugia because they provide stream shading and have higher water content than upland areas. Animals with thermoregulatory limitations have refugia which will become increasingly important with anticipated increases in air temperatures. Drought and loss of vegetated cover will reduce available refugia for these species.

Riparian areas associated with headwater streams provide habitat for terrestrial wildlife species and are a linkage between aquatic and terrestrial systems which serve as corridors for movement of terrestrial wildlife species (Seavy et al. 2009; NCWRC 2002; Wenger 1999). Some birds may use headwater stream communities and associated small wetlands for nesting and feeding areas.

4.2.7.6 Recommendations

Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience, such as: protecting watersheds for clean water, flood attenuation, and decreased erosion and sedimentation; providing ecological corridors for species movement throughout the landscape in response to changing habitats; preserving existing habitats to help prevent forced migration (Band and Salvesen 2009). Section 4.2.2 provides recommendations appropriate for all aquatic communities, statewide. Actions specific to the state's river basins are provided in Section 4.5.

Surveys. Distributional and status surveys are needed for aquatic snails, crayfish, mussels, and fish (in order of general need).Identify the location of headwater systems and associated small wetland communities in the Piedmont.

- Initiate distribution surveys for all amphibian species associated with headwater communities, but especially the Mole Salamander, Eastern Tiger Salamander, Dwarf Salamander, and Four-toed Salamander.

- Gather better information about the status and distribution of more common species associated with Piedmont headwater and associated wetland habitats (e.g., Three-lined Salamander, Common Ribbonsnake).

Monitoring. Monitoring of aquatic taxa is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These monitoring efforts will inform future decisions on how to manage aquatic species. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Determine population trends and persistence of small wetland breeding amphibian populations, particularly the Mole Salamander, Eastern Tiger Salamander, Dwarf Salamander, and Four-toed Salamander.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of priority species to specific threats, and studies should provide recommendations for mitigation and restoration. Aquatic species propagation is an area of current and ongoing research. Developing techniques for propagation of aquatic species is critical for preserving those species and their genetic stock, particularly those that are rare, at high risk of extinction or extirpation, and difficult to propagate in a laboratory setting.

- Study the efficacy and practicality of "toad tunnels" and other wildlife crossings that allow passage under roadways and help maintain connectivity between headwater community (including associated wetlands) metapopulations.
- Determine minimum upland buffers required to sustain at-risk amphibian populations.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Use stormwater management techniques that strive to restore or maintain the pre-development hydrograph.

Partnerships and Cooperative Efforts. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable.

4.2.8 Large Creeks/Small Rivers

4.2.8.1 Ecosystem Description

Small river communities represent the next stream order above headwater streams and typically consist of third- and fourth-order perennial large creeks or streams and small river systems. They may have fragmented habitats due to mill dams and other similar structures, but are generally too small to contain major operational hydroelectric dams. Species richness increases significantly in these systems and larger and more diverse fish and mussel assemblage are found as compared to the headwater stream community.

4.2.8.2 Location of Habitat

Small river communities can be found statewide. Those located in the Mountain ecoregion may contain coolwater or coldwater systems depending on where they occur in the landscape. Those found in other areas of the state are warmwater systems, where water temperatures are persistently greater than 25°C (77°F).

Examples of this community type include the Little River, Eno River, Swift Creek, Uwharrie River, Deep River, Upper Tar River, and Dan River. The 2005 WAP described Piedmont riverine aquatic communities and adjacent terrestrial small wetland communities and floodplain forests which are components of this community, as priority habitats (see Chapter 5) (NCWRC 2005).

4.2.8.3 Problems Affecting Habitats

Land Use. Aquatic systems in North Carolina have been threatened by a variety of perturbations in the past, and many of those same threats continue today. Converting land uses from natural forest to agriculture or silviculture production and residential and commercial development continues to threaten stream integrity because of related increases in sediment, bank erosion, and stormwater runoff containing sediment and other potentially toxic materials.

Riparian vegetation is critical to the overall stream and streambank stability and moderation of water temperatures. Lack of riparian vegetation or inadequate width of forested buffer can cause streambank erosion and sedimentation. In addition to stabilizing streambanks, riparian vegetation serves as nutrient input to the stream community and helps regulate stream temperature by providing shade. Lack of sufficient vegetation cover contributes to rising water temperatures, especially where water depths are shallow enough that the entire water column is subject to solar heating.

There are few contiguous blocks of protected habitats in the Piedmont ecoregion so small river systems are threatened by land use practices that may increase stormwater runoff of nutrients, sediment, and contaminants. The increased loads could affect water quality and habitat for aquatic species, as well as drinking water supplies for municipalities (Band and Salvesen 2009).

Many rivers that were once free-flowing are now flooded by reservoirs, severely fragmenting habitat and often isolating populations of species above and below the impoundment. Indirect effects to the unimpounded portions of the system include disruption of natural thermal and hydrologic regimes and a reduction in downstream flows. These impacts will have a negative influence on aquatic habitat and will reduce base flow available for drinking water for downstream municipalities. Drought conditions over the past several years have required many municipalities to evaluate their water supply and capacity to meet demand. Residential and commercial growth in urban areas generates new demands for water supplies. An increase in the number of proposed reservoirs is a potential consequence of reduced water supply and increased demand.

Water Quality. Erosion and the resultant sedimentation are the largest sources of nonpoint source pollution in most aquatic systems. Sources of erosion include disturbance from development activities and agriculture land uses. Residential development can increase erosion during the construction process and is a source of increased impervious surfaces in the watershed which can also increase erosion. The Piedmont ecoregion is highly developed and most watersheds have high percentages of impervious surfaces that contribute to increased runoff, stream and bank erosion, pollution inputs, and increased flashiness of streams and rivers. Livestock access to streams contributes heavily to bank erosion, sedimentation, and nutrient input. Timber harvests and poorly constructed and maintained timber roads are additional sources of erosion if proper controls are not used and maintained.

Potential increased air temperatures and therefore increased water temperatures can lead to algal blooms in aquatic systems which diminishes stream oxygen availability. The increased water temperature alone can cause a decline in DO and any decline in DO can lead to fish kills, whether as a direct result of increased water temperature or as a secondary effect of algal blooms (DeWan et al. 2010; Band and Salvesen 2009).

Many of the water quality and water quantity impacts resulting from climate change are analogous to impacts from economic development and population growth in North Carolina. Climate change is predicted to decrease rainfall and therefore, limit water supply. Growth and development, however, have been increasing and will continue to increase water supply demands. Historical stream flow patterns—already being altered due to rapid urbanization—are projected to be further altered due to climate change impacts.

An increase in impervious surfaces due to roads, parking lots, homes, and businesses increases the amount and speed of runoff being delivered into aquatic systems. Decreased groundwater recharge between storms due to impervious surfaces leads to a decrease in stream base flows. Runoff from urban areas often contains higher concentrations of nutrients (such as nitrogen and phosphorus), sediment, metals, hydrocarbons, and microbes.

Invasive Species. The introduction of any invasive species is cause for concern, and the prevalence of warmer water temperatures may increase the likelihood of the invasion of additional exotic species, once thought to be non-threatening because the winters were too cold for their survival. While exotic species invasion is a concern, there is insufficient research to understand the effects to this community. The Asian Clam is found in aquatic systems throughout the state but its effects on native mussels are largely unknown. Flathead Catfish are a concern because of direct predation on native species. Nutria are considered a serious pest species in the United States because they eat a variety of wetland and agricultural plants and their burrowing damages streambanks, impoundments, and drainage systems.

Invasive plants in the riparian area can have negative impacts on stream systems by creating a monoculture (such as Japanese Knotweed) with poor nutrient inputs that reduces bank stability and allows too much sunlight and therefore, creates warmer stream temperatures. Exotic insect pests may be a significant factor in small river communities because they negatively impact native vegetation, thereby allowing nonnative species to flourish.

Climate Impacts. Potential changes in precipitation have numerous and varied effects. Severe and prolonged droughts may decrease stream flow, decrease groundwater recharge, and increase evaporation, resulting in impacts to streams of this theme. A decrease in overall summer precipitation will likely cause reduced water flows, which will contribute to warmer water temperatures and further stress water quality. This is particularly important in the context of seasonal droughts because during low-flow periods, nutrients may become concentrated and flush out of systems more slowly (DeWan et al. 2010; Karl et al. 2009; Band and Salvesen 2009; Holman et al. 2010).

Increased air temperatures may lead to increased water temperatures and potentially lower DO levels. Higher air and water temperatures can also lead to increased evaporation, which results in less flowing water available for aquatic species. Hot spells can have the same effect as overall increased air temperatures but on a much more acute scale. Algal blooms are possible in these systems and can exacerbate DO problems, particularly when flows are low (DeWan et al. 2010; Karl et al. 2009; Band and Salvesen 2009; Holman et al. 2010).

An increase in frequency and intensity of storms due to climate change will have a similar impact on stream systems by increasing pollutant loading. Increased storm intensity that causes flooding can lead to increased stormwater runoff and erosion. With increased stormwater runoff, there is an increase in loading of sediments, nutrients and contaminants into streams and potential negative effects on biota, such as fish kills. With a change in intensity and variability of rainfall, there are potential changes to streamflow patterns, channel hydrodynamics, and the volume of groundwater (Band and Salvesen 2009; Holman et al. 2010; Bakke 2008).

An increase in the number of tropical events can lead to flash flooding, which causes many of the abovementioned responses, and landslides, which are of particular concern in mountainous, high-elevation areas. Landslides lead to increased sediments and contaminants into aquatic systems, in addition to major disruption to channel design and hydrodynamics, potentially upsetting the physical, chemical, and biological structure of streams (Band and Salvesen 2009).

Because of potential changes in storm frequency and intensity, it is likely that channel hydrodynamics will be altered. Associated with channel hydrodynamics are changes in flow regime, sediment transport, and overall channel design. The current pattern of riffles, runs, and pools may be altered, creating changes in aquatic species' habitats. Increased storm intensity may cause increased erosion with large amounts of sediment that move downstream, which can then deposit into pools or bury riffles. Additionally, storms may cause the felling of riparian trees, particularly in areas with narrow riparian areas. Increased woody debris in these streams will also change channel hydrodynamics as well as available habitat. Determining how or if species adapt to changing habitats will require close monitoring to observe trends and to help inform future management decisions (Bakke 2008).

4.2.8.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While climate change is not the most severe threat to large creeks and small rivers, a combination of the synergistic effects that come with development and lack of riparian corridors could stress these systems to the point where several species are unable to persist (see Table 4.9).

4.2.8.5 Impacts to Wildlife

Appendix G includes a list of SGCN and other priority species for which there are knowledge gap and management concern priorities. Appendix H identifies SGCN that use large creeks or small rivers.

Table 4.9 Comparison of climate change with other threats to large creeks/small rivers

Threat	Rank Order	Comments
Development	1	Development causes direct, secondary, and cumulative effects. Residential development can increase erosion during the construction process and as a secondary result of increased impervious surfaces in the watershed. Growth and development increase water supply demands, and streamflow patterns are being altered due to rapid urbanization. An increase in impervious surfaces due to roads, parking lots, homes, and businesses also increases the amount and speed of runoff being delivered into aquatic systems. Decreased groundwater recharge between storms due to impervious surfaces contributes to reductions in stream baseflow.
Pollution	2	Erosion and the resultant sedimentation are the largest sources of nonpoint source pollution in most aquatic systems. Runoff from urban areas often contains higher concentrations of nutrients (such as nitrogen and phosphorus), sediment, metals, hydrocarbons, and microbes. Point and nonpoint sources—runoff and EDCs—are also threats.
Water Withdrawals	2	Irrigation and water supply withdrawals pose a threat to flow regime.
Flood Regime Alteration	2	High and low flow extremes pose a threat.
Livestock	3	Livestock access to streams contributes heavily to bank erosion, sedimentation, and nutrient input.
Logging/ Exploitation	3	Clearing of riparian areas is problematic. Timber harvesting can increaseerosion if proper controls are not used and maintained, in addition to damage caused by poorly constructed and maintained timber roads.
Lack of Riparian Vegetation	3	Loss of riparian vegetation contributes to streambank erosion and sedimentation. Riparian vegetation serves as a food/nutrient input to the stream community and helps regulate stream temperature by providing shade.
Climate Change	4	Climate change-related challenges to water quality and quantity are similar to those being caused bygrowth and development. Climate change effects will likely amplify other threats and increase their severity in aquatic systems.
Conversion to Agriculture/ Silviculture	4	Loss of forest cover can increase erosion and sedimentation, as well as negatively impact aquatic systems.
Invasive Species	5	Invasive plants in the riparian area can have negative impacts on stream systems by creating a monoculture with poor nutrient inputs that reduces bank stability, thereby allowing too much sunlight and warmer stream temperatures. Invasive aquatic species, like the Asian Clam, may have negative effects on native species due to competition for space and resources. Specific interactions are unknown.
Impoundments	6	Water supply needs could increase number of impoundments and their disruptions to flow regime and aquatic habitat.

Small river communities provide a number of important habitats, life cycles, or prey components to a vast assemblage of terrestrial, semi-aquatic, and aquatic wildlife. Wetlands associated with riverine systems can be important breeding sites for some amphibian and crayfish species. Birds may use riverine and adjacent terrestrial communities for nesting and feeding areas.

Because of the link between freshwater mussels and fish, phenological disruptions are a possibility, but exact mechanisms or effects for many species are still uncertain at this time. Freshwater mussel larvae (glochidia) are dependent on a host fish for transformation into juveniles. Host fish species are known for some mussel species, yet unknown for others. Temperature cues play a large role in the release of glochidia from female mussels and also in the movement and migrations of fish. Therefore, with changing temperatures predicted with climate change, there could be phenological disruptions affecting the reproductive capacity of freshwater mussels.

Aquatic species could experience shifts in their range or distribution and sensitive species may experience decline or extirpation due to changes in water quality and habitat. Recent studies have shown that EDCs in treated wastewater can inhibit reproduction and cause feminization of mussels and fish. Aquatic species are particularly sensitive to temperature cues and recent research has shown that many species of freshwater mussels may already be living at the upper thermal tolerances of their early life stages (glochidia and juveniles) (Pandolfo et al. 2010). Extreme temperature events could be especially harmful. These systems may experience a change in species composition due to various changes in habitat and water quality.

4.2.8.6 Recommendations

Considering current conditions in large streams and small rivers, climate change is likely to have a synergistic effect with other threats that are of more immediate concern, such as the development and lack of/removal of riparian vegetation. Piedmont small river system communities will probably persist but species assemblages will likely change. Very few specific climate change-related impacts have been identified, and the rare species and their habitats are expected to persist. Section 4.2.2 provides recommendations appropriate for all aquatic communities, statewide. Actions specific to the state's river basins are provided in Section 4.5.

Surveys. Distributional and status surveys are needed for aquatic snails, crayfish, mussels, and fish (in order of general need).

- Determine the distribution and abundance of aquatic species, especially the Gulf Coast Spiny Softshell, Striped Mud Turtle, and Eastern Mudsnake.
- Gather better information about the status and distribution of common species associated with riverine habitats (e.g., Three-lined Salamander, Common Ribbonsnake).

- Expand research, survey, and monitoring efforts beyond collecting presence–absence data, to look at long-term trends across species groups, habitats, and the effects of management actions.

Monitoring. Monitoring of aquatic taxa is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage aquatic species. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of priority species to specific threats and studies to provide recommendations for mitigation and restoration. Aquatic species propagation is an area of current and ongoing research. Developing techniques for propagation of aquatic species is critical for preserving those species and their genetic stock, particularly those that are rare, at high risk of extinction or extirpation, and difficult to propagate in a laboratory setting.

- Conduct studies to document the levels of EDCs in wastewater discharges and identify measures that will reduce or eliminate EDCs from wastewater prior to discharge.

- Determine the impacts of "snagging" (removing woody debris after storms) on wildlife populations.

- Conduct research to investigate Nutria population densities, population growth rates, dispersal range, and extent of property damage from burrowing and herbivory.

- Determine the effect Beaver ponds have on downstream movement of pollutants (toxins and sediments).

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Seek opportunities to restore canebreak communities through controlled burning or other management strategies.

- Maintain large trees around reservoirs for potential eagle nests, and maintain forest cover in the tailrace below dams for eagle foraging.

- Participate in mutual planning with adjacent states for regional species concerns, because some priority species are likely to expand their range due to climate change impacts.

- Plant riparian areas with vegetation with a broad elevational range within a particular watershed. Also plant vegetation with broad hydrologic tolerance to promote resilience from climate change.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change and promote ecosystem resilience overall.

4.2.9 Medium River Communities

4.2.9.1 Ecosystem Description

Medium river communities drain watersheds 200 to 3,800 square miles in size and have coolwater systems (Section 4.2.4) where they drain Mountain ecoregion watersheds and warmwater systems (Section 4.2.5) everywhere else in the state. The Nature Conservancy notes that medium rivers have an average bankfull width of 115 feet (Anderson et al. 2014). The aquatic communities will have a higher proportion of warmwater species relative to coolwater species (Aquatic Habitat Guides n.d.).

Riverine aquatic communities, which include warmwater aquatic systems, are identified in the 2005 NC Wildlife Action Plan (WAP) as a priority aquatic habitat (see Chapter 5) (NCWRC 2005).

4.2.9.2 Location of Habitat

Medium river communities are found statewide in all ecoregions. Examples include Fishing Creek, Contentnea Creek, portions of Deep and Dan rivers, and the Smith, Mayo, Haw, Black, Broad, Nolichucky, Little Tennessee, and Tuckasegee rivers.

The 2005 WAP described riverine aquatic communities as a priority habitat (see Chapter 5) (NCWRC 2005). Adjacent terrestrial systems that may be hydrologically connected to medium river communities include floodplain forests, tidal swamp forests, and various wetland communities. These terrestrial systems provide habitat for species that also rely upon rivers for habitat (e.g., American Beaver, River Otter, various insects), as well as those species which rely indirectly upon the habitat by virtue of provision of habitat for their prey (NCWRC 2005).

4.2.9.3 Problems Affecting Habitats

Medium river communities in North Carolina have been threatened by a variety of perturbations in the past, similar to threats to small and large rivers, and many of those same threats continue today.

Land Use. Converting land uses from natural forest to agriculture or silviculture production and residential and commercial development continues to threaten stream integrity. Deforestation and increased impervious surfaces cause increases in sedimentation, bank erosion, and stormwater runoff containing sediment and other pollutants. Erosion and the resultant sedimentation are the largest sources of nonpoint source pollution in most aquatic systems. The increased loads could affect water quality and habitat for aquatic species, as well as drinking water supplies for municipalities (Band and Salvesen 2009). Sources of erosion include disturbance from development activities and agriculture.

Residential development can increase erosion during the construction process, but also as a secondary result of increased impervious surfaces in the watershed. Most watersheds in the Piedmont are already highly developed and development pressure is likely to increase in the Coastal Plain, which will lead to an increase in impervious surfaces, increasing runoff, stream and bank erosion, pollution inputs and increased flashiness of rivers. An increase in impervious surfaces due to roads, parking lots, homes, and businesses increases the amount and speed of runoff being delivered into aquatic systems. Decreased groundwater recharge between storms due to impervious surfaces leads to a decrease in stream base flows.

Riparian vegetation is critical to overall stream and streambank stability and moderation of water temperatures. Lack of riparian vegetation or inadequate width of forested buffers can cause streambank erosion and sedimentation. In addition to stabilizing streambanks, riparian vegetation contributes nutrients to the stream community, provides large woody debris that increases habitat complexity, and helps regulate stream temperature by providing shade. Lack of sufficient vegetation cover contributes to rising water temperatures, especially where water depths are shallow enough that the entire water column is subject to solar heating.

Impoundment. Dam construction on medium rivers has altered hydrology and morphology. Many rivers that were once free-flowing are now dammed, severely fragmenting habitat and often isolating populations of aquatic species above and below the impoundments. Indirect effects to portions of the system downstream of dams include disruption of natural hydrologic and thermal regimes. Increases in water surface area of impoundments and the resulting increases in evaporation rates, in addition to water withdrawals, reduces the amount of water available downstream. Low DO levels can also impair waters downstream of dams.

Water Quality. Changes in land use patterns within a watershed cause changes in water quality; land use alterations closer to stream channels typically have more impact. Runoff from urban areas often contains higher concentrations of nutrients (such as nitrogen and phosphorus), sediment, metals, hydrocarbons, and microbes. Allowing livestock access to rivers can contribute to bank erosion, sedimentation, and nutrient input. Timber harvest and poorly constructed and maintained timber roads are additional sources of erosion if proper controls are not used and maintained.

Climate change has the potential to increase air temperatures; therefore increased water temperatures can lead to algal blooms which reduce stream oxygen availability. The increased water temperature alone can cause a decline in DO and DO declines can lead to fish kills, whether as a direct result of increased water temperature or as a secondary effect of algal blooms (DeWan et al. 2010; Band and Salvesen 2009).

Invasive Species. Medium river communities in our state contain invasive species in addition to the native flora and fauna. These invasive species impact native species through competition, predation, and hybridization. They can also alter habitat and transmit diseases. The introduction of any invasive species is cause for concern, and the prevalence of warmer water temperatures in the future may increase the likelihood of the invasion of additional exotic species, once thought to be nonthreatening because the winters were too cold for their survival.

Invasive aquatic animal species, such as Asian Clams, Mystery Snails, Red Swamp Crawfish, and Nutria may have negative effects on native species through competition for space and resources and as disease vectors. The Asian Clam is an exotic species found in aquatic systems throughout the state; its effects on native mussels are largely unknown. Flathead Catfish are a concern because of direct predation on native species. Nutria are considered a serious pest species in the United States because they eat a variety of wetland and agricultural plants and their burrowing damages streambanks, impoundments, and drainage systems.

Invasive plants in the riparian area can have negative impacts on stream systems by creating a monoculture (such as Japanese Knotweed) with poor nutrient inputs that reduces bank stability and shading and therefore, creates warmer stream temperatures. Alligator Weed creates floating mats that disrupt DO levels. Invasive aquatic plants such as Asian Dayflower, Hydrilla, Water Hyacinth, and Giant Salvinia could pose more of a threat to these systems with a warmer climate. Exotic insect pests may be a significant factor in river communities because they negatively impact native vegetation, thereby altering habitats or allowing nonnative species to flourish.

Climate Impacts. Climate change is likely to have a synergistic effect with other, more impending threats to medium river systems, such as development and lack of/removal of riparian vegetation. Aquatic systems have been under threat from a variety of perturbations in the past and many of those continue today. Many of the water quality and water quantity impacts resulting from climate change are analogous to impacts from economic development and population growth in North Carolina. Climate change is predicted to alter seasonal precipitation patterns that can limit water supply. Growth and development, however, have been increasing and will continue to increase water supply demands. Historical stream flow patterns—already being altered due to rapid urbanization—are projected to be further altered due to climate change impacts.

Potential changes in precipitation may have numerous and varied effects. Severe and prolonged droughts may decrease stream flow, decrease groundwater recharge, and increase evaporation, resulting in impacts to medium rivers. A decrease in overall summer precipitation will likely cause reduced water flows, which will contribute to warmer water temperatures and further stress water quality. This is particularly important in the context of seasonal droughts because during low-flow periods, nutrients may become concentrated and flush out of systems more slowly (DeWan et al. 2010; Karl et al. 2009; Band and Salvesen 2009; Holman et al. 2010).

Increased air temperatures may lead to increased water temperatures and potentially lower DO levels. Higher air and water temperatures can also lead to increased evaporation, which results in less flowing water available for aquatic species. Hot spells can have the same effect as overall increased air temperatures but on a much more acute scale. Algal blooms are possible in these systems and can exacerbate DO problems, particularly when flows are low (DeWan et al. 2010; Karl et al. 2009; Band and Salvesen 2009; Holman et al. 2010).

An increase in frequency and intensity of storms due to climate change will have a similar impact on stream systems by increasing pollutant loading. Increased storm intensity that causes flooding can lead to increased stormwater runoff and erosion. With increased stormwater runoff, there is an increase in loading of sediments, nutrients, and contaminants into streams and potential negative effects on biota, such as fish kills. With a change in intensity and variability of rainfall, there are potential changes to streamflow patterns, channel hydrodynamics, and the volume of groundwater (Band and Salvesen 2009; Holman et al. 2010; Bakke 2008).

Drought conditions over the past several years have required many municipalities to evaluate their water supply and capacity to meet demand. Residential and commercial growth in urban areas generates new demands for water supplies. An increase in the number of proposed reservoirs and surface water withdrawals is a potential consequence of reduced water supply and increased demand.

Because of potential changes in storm frequency and intensity, it is likely that channel hydrodynamics will be altered. Associated with channel hydrodynamics are changes in flow regime, sediment transport, and overall channel design. The current pattern of riffles, runs, and pools may be altered, creating changes in aquatic species' habitats. Increased storm intensity may cause increased erosion with large amounts of sediment that move downstream, which can then deposit into pools or bury riffles. Additionally, storms may cause the felling of riparian trees, particularly in areas with narrow riparian areas. Increased woody debris in these streams will also change channel hydrodynamics as well as available habitat. Determining how or if species adapt to changing habitats will require close monitoring to observe trends and to help inform future management decisions (Bakke 2008).

4.2.9.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. In the past, aquatic systems have been under threat from a variety of perturbations and many of those continue today. Conversion of land, both from forest to agriculture or silviculture, as well as from development projects, continues to threaten stream integrity resulting in increased sediment, bank erosion, and stormwater runoff containing sediment and other potentially toxic materials. Considering current conditions in these systems, climate change is likely to have a synergistic effect with other threats that are of more immediate concern. Table 4.10 provides a review of expected climate change impacts in order of importance in comparison with other types of threats.

4.2.9.5 Impacts to Wildlife

Appendix G includes a list of SGCN and other priority species for which there are knowledge gap and management concern priorities. Appendix H identifies SGCN that use medium river communities.

The temperature tolerance range of aquatic species can be specific and the availability of warm waters that do not exceed tolerances can be a limiting factor for where species can find appropriate habitat, especially as average water temperatures experience warming trends (DeWan et al. 2010). Warmwater habitats are important for a number of reptiles and amphibians including certain turtles, frogs, and salamanders that utilize aquatic habitats during part or all of their life cycle. These habitats are also important for a variety of mammals that are semi-aquatic and/or that have an aquatic food base (e.g., Water Shrews, Muskrats, Beavers, River Otters, and certain bats). Selected bird species, such as various waterfowl, wading birds, and certain songbirds, also rely upon aquatic habitats (including rivers and streams) to provide habitat or a food base.

Table 4.10 Comparison of climate change with other threats to medium river communities

Threat	Rank Order	Comments
Development	1	Residential development, particularly in steep slope areas, is of particular concern because of increased erosion. Most coolwater streams are larger streams and rivers and many have wider valleys where land use is more susceptible to being developed than on steeper sloped headwater streams. Row crops, agricultural grazing, and urban/suburban development are common. Increased impervious surfaces due to roads, parking lots, homes, and businesses increase the amount and speed of runoff being delivered into aquatic systems.
Sediment and Erosion	1	Stormwater runoff will amplify the loading of nutrients, sediment, and contaminants into streams, rivers, and reservoirs, which may alter overall channel design, have a negative effect on biota due to habitat changes, increased turbidity, and chemical exposure, and affect drinking water quality (Band and Salvesen 2009).
Pollution	1	Runoff from urban areas often contains higher concentrations of nutrients (such as nitrogen and phosphorus), sediment, metals, hydrocarbons, and microbes. An increase in frequency and intensity of storms due to climate change will have a similar impact on stream systems by increasing pollutant loading. Point and nonpoint sources—runoff and EDCs—are also threats.
Cattle in Streams	1	Livestock access to streams contributes heavily to bank erosion, sedimentation, and nutrient input.
Lack of Riparian Vegetation	1	Riparian vegetation serves as nutrient input to the stream community and helps regulate stream temperature by providing shade. Lack of riparian vegetation or inadequate width of forested buffer can cause streambank erosion and sedimentation.
Conversion to Agriculture/ Silviculture	2	Loss of forest cover can cause increased erosion and sedimentation and negatively impact aquatic systems. Poorly constructed and maintained timber roads are another source of erosion.
Water Withdrawals	2	Irrigation and water supply withdrawals pose a threat to flow regime. Water withdrawals can be problematic, particularly in streams with already low 7Q10 flows, because they may reduce available habitat for aquatic species. Decreased groundwater recharge between storms due to impervious surfaces leads to a decrease in stream baseflow.
Flood Regime Alteration	2	Many rivers that were once free-flowing are now flooded by reservoirs, severely fragmenting habitat and often isolating populations of species above and below the impoundment. Floodplains and wetlands are natural features designed for flood control through attenuation and dissipation of floodwaters. Development and other impacts can reduce this service.
Climate Change	3	Climate change is predicted to decrease rainfall and therefore limit water supply. Effects will likely compound with other threats to increase the severity of several threats to aquatic systems.
Invasive Species	4	Invasive plants in the riparian area can have negative impacts on stream systems by creating a monoculture (such as Japanese Knotweed) with poor nutrient inputs, reducing bank stability, and allowing too much sunlight and therefore warmer stream temperatures. Invasive aquatic species, like the Asian Clam or Rusty Crayfish, may have negative effects on native species, such as competition for space and resources.

4.2.9.6 Recommendations

It is important to preserve the connectivity of warmwater systems because they provide a link to cool and coldwater systems that will become refugia as water temperature gradients change and previously cool waters become persistently warmer. As water temperatures change, many species may not be able to migrate into waters with appropriate temperatures if there are barriers to movement or habitats are fragmented so that warmwater habitats are interspersed amongst habitats that do not meet thermal requirements. Section 4.2.2 provides recommendations appropriate for all aquatic communities, statewide. Actions specific to the state's river basins are provided in Section 4.5.

Surveys. Distributional and status surveys are needed for aquatic snails, crayfish, mussels, and fish (in order of general need).

Monitoring. Monitoring of aquatic taxa is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of priority species to specific threats and studies should provide recommendations for mitigation and restoration. Aquatic species propagation is an area of current and ongoing research. Developing techniques for propagation of aquatic species is critical for preserving those species and their genetic stock, particularly those that are rare, at high risk of extinction or extirpation, and difficult to propagate in a laboratory setting.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable.

4.2.10 Large River Communities

4.2.10.1 Ecosystem Description

Large river communities occur statewide and are the largest and highest order rivers in the Piedmont and Coastal Plain ecoregions. Many originate in the Piedmont and are some of the most fragmented aquatic systems because they are the site of major hydroelectric projects. After passing over the fall line that divides the Piedmont and Coastal Plain ecoregions they transition into more typical Coastal Plain rivers with sandy substrates and wider floodplains. Large river communities are warmwater systems, where summer water temperatures are persistently greater than 25°C (77°F).

4.2.10.2 Location of Habitat

Certain reaches of the Hiwassee, French Broad, and Little Tennessee rivers can be categorized as having large river communities. Examples in the Piedmont ecoregion include the Yadkin—Pee Dee River (downstream of the confluence of the South Yadkin and Yadkin rivers), Catawba River (downstream of Lake James), and the Neuse, Tar, Cape Fear, and Roanoke rivers above the Fall Line that divides the eastern Piedmont from the western Coastal Plain. Examples of large river communities in the Coastal Plain ecoregion are found in the Cape Fear, Chowan, Lumber, Neuse, Pasquotank, Roanoke, Tar–Pamlico, and White Oak River basins.

The 2005 WAP described the riverine aquatic communities as a priority habitat (see Chapter 5) (NCWRC 2005). Adjacent terrestrial systems that may be hydrologically connected to this riverine community include floodplain forests, tidal swamp forests, and wetland communities. These communities provide habitat for species that rely upon rivers and streams for habitat, as well as those species which rely indirectly upon the habitat by virtue of provision of habitat for their prey.

4.2.10.3 Problems Affecting Habitats

Land Use. Aquatic systems in North Carolina have been threatened by a variety of perturbations in the past and many of those same threats continue today. Converting land uses from natural forest to agriculture or silviculture production and residential and commercial development continues to threaten stream integrity because of related increases in sediment, bank erosion, and stormwater runoff containing sediment and other potentially toxic materials.

Riparian vegetation is critical to the overall stream and streambank stability and moderation of water temperatures. Lack of riparian vegetation or inadequate width of forested buffer can cause streambank erosion and sedimentation. In addition to stabilizing streambanks, riparian vegetation serves as nutrient input to the stream community and helps regulate stream temperature by providing shade. Lack of sufficient vegetation cover contributes to rising water temperatures, especially where water depths are shallow enough that the entire water column is subject to solar heating.

Erosion and the resultant sedimentation are the largest sources of nonpoint source pollution in most aquatic systems. Sources of erosion include disturbance from development activities and agriculture. Residential development can increase erosion during the construction process, but also as a secondary result of increased impervious surfaces in the watershed. Development pressure is likely to increase in the Coastal Plain, which will lead to a proliferation in impervious surfaces, increasing runoff, stream and bank erosion, and pollution inputs. Most watersheds in the Piedmont are already highly developed and have high percentages of impervious surfaces, leading to increased runoff, stream and bank erosion, pollution inputs, and increased flashiness of streams and rivers.

Impoundment. Dam construction has altered flows and river hydrology and morphology. Dams along the Yadkin, Pee Dee, and Catawba Rivers are subject to coldwater releases and peaking flow regulation through licenses issued by the Federal Energy Regulatory Commission. Many rivers in the Piedmont that were once free-flowing are now flooded by reservoirs, severely fragmenting habitat and often isolating populations of species above and below the impoundment. Indirect effects to the unimpounded portions of the system include disruption of natural thermal and hydrologic regimes and a reduction in downstream flows. These impacts will have a negative influence on aquatic habitat as well as reducing the base flow available for drinking water for downstream municipalities.

Water Quality. Increased stormwater runoff will amplify the loading of nutrients, sediment, and contaminants into streams, rivers, and reservoirs. The increased loads could affect water quality and habitat for aquatic species, as well as drinking water for municipalities. Stormwater controls and retrofits will become increasingly important (Band and Salvesen 2010).

Storms. Because of potential changes in storm frequency and intensity, it is likely that channel hydrodynamics will be altered. Changes in flow regime, sediment transport, and overall channel design are associated with channel hydrodynamics. The current pattern of riffles, runs, and pools may be altered, creating changes in aquatic species' habitats. In these large rivers, gravel and sand bars may be displaced and formed in other locations and reservoirs may experience increased sediment deposits. How or if species adapt to changing habitats will require close monitoring to observe trends and help inform future management decisions (Bakke 2008).

Invasive Species. The introduction of any invasive species is cause for concern and the prevalence of warmer water temperatures may increase the likelihood of exotic species becoming established that were previously thought to be non-threatening because the winters were too cold for survival.

Invasive plants in the riparian area can have negative impacts on stream systems by creating a monoculture with poor nutrient inputs, reducing bank stability, and reducing shading (warmer stream temperatures). Alligator Weed creates floating mats that disrupt DO levels. Asian Dayflower, Hydrilla, Water Hyacinth, and Giant Salvinia could pose more of a threat to these systems with a warmer climate.

Invasive aquatic animal species, such as Asian Clams, Mystery Snails, Red Swamp Crayfish, and Nutria may have negative effects on native species through competition for space and resources and as a disease vector. The Asian Clam is an exotic species found in aquatic systems throughout the state. However, its effects on native mussels are largely unknown. Mystery Snails have been collected in reservoirs on the Catawba and Yadkin–Pee Dee Rivers and in the Pee Dee River proper, between Tillery and Blewett Falls Reservoirs. These large snails feed primarily on algae and diatoms and have been known to clog water intake screens in other parts of the United States, but effects on native mollusks are largely unknown. They have the potential to serve as vectors for the transmission of parasites and diseases. Flathead Catfish are a concern because of direct predation on native species.

Climate Impacts. Very few specific climate change-related impacts have been identified, and the rare species and their habitats are expected to persist. Climate change is likely to have a synergistic effect with other, more immediate concerns in these systems, such as development and lack of/removal of riparian vegetation. Aquatic systems have been under threat from a variety of perturbations in the past and many of those continue today.

Sea level rise is likely to impact the lower reaches of large Coastal Plain rivers because inundation is predicted to varying degrees. The combined increase of inland flooding due to higher precipitation events with elevated sea levels will exacerbate coastal inundation. Saltwater intrusion into currently freshwater streams will shift the transition from freshwater to brackish water further upstream. As the chemical composition of currently freshwater systems changes, associated freshwater wetlands could be converted to salt marshes as saltwater moves further upstream into these rivers (Band and Salvesen 2009; Holman et al. 2010; Bakke 2008; Burkett et al. 2000). Changes in salinity and tidal influence will likely change the overall species composition in these systems.

Drought conditions over the past several years have required many municipalities to evaluate their water supply and capacity to meet demand. Residential and commercial growth in urban areas generates new demands for water supplies. An increase in the number of proposed reservoirs is a potential consequence of reduced water supply and increased demand.

Potential increased air temperatures will influence water temperatures and can lead to algal blooms in aquatic systems, which in turn diminishes stream oxygen availability. The increased water temperature alone can cause a decline in DO and any decline in DO can lead to fish kills, whether as a direct result of increased water temperature or as a secondary effect of algal blooms. This phenomenon may be increasingly expressed within reservoirs on large Piedmont rivers (DeWan et al. 2010; Band and Salvesen 2009).

4.2.10.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. Sea level rise already impacts large rivers at their terminus along the Atlantic coast. Other climate change impacts may not be as severe a threat, but a combination of synergistic effects with other existing conditions could stress these systems to the point where several species are unable to persist. Table 4.11 provides a review of expected climate change impacts in order of importance in comparison with other types of threats.

4.2.10.5 Impacts to Wildlife

Appendix G includes a list of SGCN and other priority species for which there are knowledge gap and management concern priorities. Appendix H identifies SGCN that use large river communities.

Weather extremes (such as drought, floods, tropical depressions, hurricanes) that are expected to be amplified by climate change can have profound effects on fishery production in large Coastal Plain rivers.

Chronically warmer temperatures and lower DO levels will increase stress on aquatic organisms and disrupt trophic relationships. Aquatic species could experience shifts in their range or distribution and sensitive species may experience decline or extirpation due to changes in water quality and habitat.

Aquatic species are particularly sensitive to temperature cues and recent research has shown that many species of freshwater mussels may already be living at the upper thermal tolerances of their early life stages (glochidia and juveniles) (Pandolfo et al. 2010). Because of the link between freshwater mussels and fish, phenological disruptions are a possibility, but exact mechanisms or effects are not well understood. Freshwater mussel larvae (glochidia) are dependent on a host fish for transformation into juveniles. Host fish species are known for some mussel species, yet unknown for others. Temperature cues play a large role in the release of glochidia from female mussels and also in the movement and migrations of fish.

Table 4.11 Comparison of climate change with other threats to large river communities

Threat	Rank Order	Comments
Development	1	Direct, secondary, and cumulative effects from development include increased sediment, bank erosion, and stormwater runoff containing sediment and other potentially toxic materials.
Flood Regime Alteration	2	Alterations such as reduced flooding and impervious surfaces that increase flashy flow in combination with changes in precipitation will have a big effect on these systems. Alteration of hydrology due to dam creation and wetland draining are also affecting this habitat type.
Pollution	2	Runoff from urban areas often contains higher concentrations of nutrients (such as nitrogen and phosphorus), sediment, metals, hydrocarbons, and microbes. Erosion and the resultant sedimentation are the largest sources of nonpoint source pollution in most aquatic systems. Increased stormwater runoff will amplify the loading of nutrients, sediment and contaminants. The increased loads could affect water quality and habitat for aquatic species, as well as drinking water for municipalities. Point and nonpoint sources—runoff and EDCs—are also threats. Confined animal operations and animal waste lagoon discharges are a potential source of contamination if not properly managed and maintained. In particular, nutrient loads have the potential to greatly increase with the construction of new poultry processing facilities on the coast.
Climate Change	3	Sea level rise, drought, increased storm activity, and higher temperatures are threats to large Coastal Plain rivers.
Water Withdrawals	3	Irrigation, water supply, and energy development withdrawals pose threats to flow regime. Streamflow is likely to be reduced during droughts, and recharge of groundwater will decline as the temperature and spacing between rainfall events increase. Increased demands for drinking water supply will further stress or deplete aquifers and place increasing strain on surface water resources. Increasing evaporation and plant water loss rates alter the balance of runoff and groundwater recharge which is likely to lead to saltwater intrusion into shallow aquifers. Water withdrawals can be problematic, particularly in streams with already low 7Q10 flows, because they may reduce available habitat for aquatic species.
Lack of Riparian Vegetation	3	Loss of riparian vegetation causes numerous problems which are outlined throughout this Plan.Of particular concern is the loss of shading and a source of detritus for food webs, the increased potential for runoff of sediments into stream channels, and increased potential for bank erosion.
Energy Development	4	Hydropower impoundments could become more prevalent as population growth exerts higher demands for energy resources. Impoundments contribute to fragmentation and loss of important stream habitats (e.g., riffles, runs).
Invasive Species	4	Invasive plants in the riparian area can have negative impacts on stream systems by creating a monoculture with poor nutrient inputs, reducing bank stability, and reduced shading (warmer stream temperatures). Alligator weed creates floating mats that disrupt DO levels. Asian Dayflower, Hydrilla, Water Hyacinth, and Giant Salvinia could pose more of a threat to these systems with a warm climate. Invasive aquatic animal species, such as the Asian Clam, Red Swamp Crayfish, and Nutria may have negative effects on native species, such as competition for space and resources.

Therefore, with changing temperatures predicted with climate change, there could be phenological disruptions affecting the reproductive capacity of freshwater mussels.

Riverine habitats are especially important to herpetofauna that utilize aquatic habitats during part or all of their life cycle. Most of the listed priority amphibian and reptile species associated with riverine habitat have limited distributions, unknown distributions, or widely dispersed but small populations. Isolation or fragmentation of particular habitat stretches occupied by those species could have significant long-term effects upon the sustainability of those populations.

Increased storm intensity can lead to flooding and therefore, increased stormwater runoff and increased erosion. With increased stormwater runoff, there is an increase in loading of sediments, nutrients and contaminants into streams and potential negative effects on biota. Long-duration flooding has had impacts on ground-nesting bird species. Severe flooding can also interfere with successful transport of larval anadromous fishes hatched during the spring to downstream nursery areas. Abnormally high spring flows have been shown to coincide with reduced summer abundance of young-of-year striped bass in the Roanoke River (Hassler et al. 1981; Manooch and Rulifson 1989).

As a salt wedge moves upstream into the lowest Coastal Plain reaches, it is likely that existing freshwater fauna may be replaced with more estuarine water species. If salinity levels increase gradually, there could be adaptation by some freshwater species to this change. Additionally, freshwater species could migrate upstream to escape the increased salinity if suitable habitat and water quality parameters are available in smaller systems and connectivity between streams is available. Range shifts can be expected to increase competition for resources.

Red Swamp Crawfish is prevalent in the Coastal Plain and although effects on native crayfish are not fully understood, it is likely that competition for resources will occur. Herbivory and burrowing damage from Nutria are concerns because they eat a variety of wetland and agricultural plants and their burrowing damages streambanks, impoundments, and drainage systems. Nutria have expanded their range from the Coastal Plain into the central Piedmont. Nutria may be a vector for diseases (e.g., tuberculosis and septicemia) or parasites (e.g., *Giardia, Fasciola*, Liver Flukes, and nematodes), with fecal contamination in water the likely pathway (Carr 2010).

4.2.10.6 Recommendations

Large river communities provide a number of important habitats, life cycle, or prey components to a vast assemblage of terrestrial, semi-aquatic, and aquatic wildlife. The lower reaches of Coastal Plain larger rivers are more vulnerable to the effects of climate change, especially rising sea levels and saltwater intrusion, which will likely change the overall species composition in these systems. Important actions to promote resilience are to protect and maintain floodplains and riparian vegetation. Piedmont large river systems are likely to be impacted by continued development and the water quality issues associated with runoff and withdrawals. Section 4.2.2 provides recommendations appropriate for all aquatic communities, statewide. Actions specific to the state's river basins are provided in Section 4.5.

Surveys. Distributional and status surveys are needed for aquatic snails, crayfish, mussels, and fish (in order of general need).

- Carry out surveys todocument the distribution, relative abundance, and status of many wildlife species associated with riverine habitats. Priorities for conducting surveys need to focus on species believed to be declining, at risk, or mainly dependent on riverine communities.

- Conduct additional surveys for species for which current distribution information is already available or for species that are considered common (NCWRC 2005).

Monitoring. Monitoring of aquatic taxa is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage aquatic species. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Develop or enhance long-term monitoring for amphibians and reptiles (Taylor and Jones 2002). There is also a decided lack of long-term monitoring information on most bat species (Ellis et al. 2002).

- Continue existing programs and expand monitoring of anoxic and hypoxic water conditions, particularly during spring anadromous fish spawning, summer droughts, and before and after tropical storms.

- Install new and maintain existing USGS flow/water quality monitoring stations to collect real-time discharge and DO data.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferencesreproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of priority species to specific threats and studies should provide recommendations for mitigation and restoration. Aquatic species propagation is an area of current and ongoing research. Developing techniques for propagation of aquatic species is critical for preserving those species and their genetic stock, particularly those that are rare, at high risk of extinction or extirpation and difficult to propagate in a laboratory setting.

- Conduct studies to determine how large riverine habitats and the species that occupy the habitat recover or change after major flooding events from hurricanes.
- Investigate the effects of large scale snagging (removal of downed trees) within the rivers after hurricanes.
- Conduct research to investigate population densities, population growth rates, dispersal range, and extent of property damage from Nutria burrowing and herbivory.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Make efforts toretain old growth floodplain forest (e.g., for Chimney Swifts, bats, and herpetofauna).
- Manage flow regimes in Coastal Plain rivers as much as possible to mirror the pre-dam hydrograph.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Increase buffer widths to mitigate impacts from pollution into river systems and to maintain habitat at the edge of these aquatic communities that will provide cover and foraging areas for many wildlife species using riverine habitat.
- Pursue land acquisition and easements through cooperation with land trusts in an effort to increase the width of riparian buffers and create larger patches of connected habitat.

4.2.11 Stream Swamp Systems

4.2.11.1 Ecosystem Description

Small stream swamp communities are found in the lower Coastal Plain ecoregion and represent aquatic habitats of small to medium streams, larger swamp systems, and artificial ditches that are not included in the large river community description. Floodwaters generally drain slower in these systems, thereby increasing the duration and extent of interface between the aquatic habitat and adjacent land as compared to floodplain communities that are found in other ecoregions. Substrate in these systems is typically sand or organic matter and many waters have high quantities of tannins. Although ditches are artificial habitats, they are included in this theme because they frequently have hydrologic connection to natural streams and over time the aquatic communities resemble these natural systems.

4.2.11.2 Location of Habitat

Examples of this community type include Town Creek, Great Coharie Creek, and Juniper Creek in the Coastal Plain. Priority habitats identified in the 2005 WAP that are similar to this community include the Mid-Atlantic Coastal Plain Riverine Aquatic Communities and Tidal Swamp Forest and Wetlands (see Chapter 5) (NCWRC 2005).

4.2.11.3 Problems Affecting Habitats

Land Use. Aquatic systems in North Carolina have been threatened by a variety of perturbations in the past and many of those same threats continue today. For example, ditches used to drain stream swamp communities will alter local hydrology, eliminate aquatic habitats, and alter terrestrial communities that depend on hydrologic input from the swamp, and can be a conduit for saltwater intrusion, depending on landscape position. Converting land uses from natural forest to agriculture or silviculture production and residential and commercial development continues to threaten stream integrity. The threat comes from related increases in sediment, bank erosion, and stormwater runoff containing sediment and other potentially toxic materials. Floodplains and wetlands associated with stream swamp communities are natural features designed for flood control and dissipating floodwaters. Floodplain development interferes with this natural capacity and worsens downstream flooding, scour, and erosion.

Riparian vegetation is critical to the overall stream and streambank stability and moderation of water temperatures. Riparian areas include land adjacent to water bodies (e.g., floodplains) and are critical to the overall stream and streambank stability. In addition to erosion control, riparian areas allow for sediment and pollutant deposition (by dissipating energy from runoff and allowing for filtration); infiltration of water runoff to allow for groundwater recharge; regulation of stream temperature by providing shade; attenuation of storm flows (flood control); carbon sequestration by mature woody vegetation; and increased stream habitat complexity by contributing woody debris. They also provide habitat for terrestrial wildlife species and serve as corridors for movement of terrestrial wildlife species (Seavy et al. 2009; NCWRC 2002; Wenger 1999).

Lack of sufficient vegetation or inadequate width of forested buffer contributes to rising water temperatures, especially where water depths are shallow enough that the entire water column is subject to solar heating. In addition to stabilizing streambanks, riparian vegetation serves as a food/nutrient input to the stream community and helps regulate stream temperature by providing shade.

Water Quality. Erosion and the resultant sedimentation are the largest sources of non-point source pollution in most aquatic systems. Development activities and agriculture can be the most significant sources of erosion and sediment. Timber harvests and poorly constructed and maintained timber roads are additional sources of erosion if proper controls are not used and maintained. Increased stormwater runoff will amplify the loading of nutrients, sediment, and contaminants into streams, rivers, and reservoirs. The increased loads could affect water quality and habitat for aquatic species, as well as drinking water for municipalities. Stormwater controls and retrofits will become increasingly important (Band and Salvesen 2009).

Algal blooms are possible in these systems and can exacerbate DO problems, particularly when flows are low. Increased water temperature, resuspension of bottom sediment during storms, and increased nutrient content of freshwater and coastal waters can increase pathogen replication, persistence, survival, and transmission (DeWan et al. 2010; Karl et al. 2009; Band and Salvesen 2009; Holman et al. 2010).

Confined animal operations are common in the Coastal Plain ecoregion and may have significant impacts on water resources. Livestock access to streams contributes heavily to bank erosion, sedimentation, and nutrient input. Animal waste lagoon discharges are a potential source of contamination if not properly managed and maintained.

Invasive Species. The introduction of any invasive species is cause for concern and the prevalence of warmer water temperatures may increase the the presence of exotic species that were previously thought to be non-threatening because the winters were too cold for survival. The Asian Clam is found in aquatic systems throughout the state; however, its effects on native mussels are largely unknown. Red Swamp Crawfish are prevalent in the Coastal Plain and although effects on native crayfish are not fully understood, it is likely that competition for resources such as food and space are potential impacts. Flathead Catfish are a concern because of direct predation on native species.

Climate Impacts. Increased air temperatures may lead to increased water temperatures and potentially lower DO levels. Stream swamp communities experience periodic temperature increases and DO decreases that may be exacerbated by changing climate conditions. Higher air and water temperatures can also lead to increased evaporation, which results in less flowing water available for aquatic species to use. Hot spells can have the same effect as overall increased air temperatures but on a much more acute scale.

According to DeWan et al. (2010), hydrologic regimes in the Coastal Plain are likely to be much more sensitive to changes in precipitation than to changes in temperature. Potential changes in the amounts and timing of precipitation have numerous and varied effects. Decreases in overall summer precipitation will likely cause reduced water flows, which will further contribute to warmer water temperatures and stress water quality. This is particularly important in the context of seasonal droughts, because nutrients may become concentrated and flush out of systems more slowly during low flow periods. Severe and prolonged droughts may decrease streamflow, decrease groundwater recharge, and increase evaporation, resulting in impacts to streams of this theme. Additionally, upstream headwaters and other small streams contributing flow to stream swamp communities could dry up, posing potential impacts to aquatic species and downstream flow regimes (DeWan et al. 2010; Karl et al. 2009; Holman et al. 2010).

Increased storm intensity can lead to flooding and increased stormwater runoff and erosion. With increased stormwater runoff there is also an increase in sediments, nutrients, and contaminants loading into streams and potential negative effects on biota. The increased loads could affect water quality and habitat for aquatic species, as well as drinking water for municipalities. Stormwater controls and retrofits will become increasingly important (Band and Salvesen 2009). With a change in intensity and variability of rainfall, there are potential changes to stream flow patterns, channel hydrodynamics, lake levels, and the volume of groundwater from aquifers (Band and Salvesen 2009; Holman et al. 2010; Bakke 2008).

Channel hydrodynamics include flow regime, sediment transport, and overall channel design and can be altered by changes in storm frequency and intensity. Some streams in this aquatic system have a pattern of riffles, runs, and pools, and will exhibit overall changes to the quantity and quality of these habitats. Other streams and swamps have relatively slack water and comparatively few riffles and runs and they may exhibit a shifting of sand bars. Storms may cause the felling of riparian trees, particularly in areas with narrow riparian areas. Increased woody debris in these streams will alter channel hydrodynamics as well as available habitat.

An increase in the number of tropical events can lead to flash flooding, which causes many of the above-mentioned responses. Effects such as increased sediments and contaminants into aquatic systems, in addition to major disruption to channel design and hydrodynamics, potentially upset the physical, chemical, and biological structure of streams. Tropical events may also exacerbate problems associated with saltwater intrusion (Band and Salvesen 2009).

Sea level rise is likely to impact stream swamp communities, as the combined increase of inland flooding due to higher precipitation events coupled with elevated sea levels will exacerbate coastal inundation. Additionally, saltwater intrusion into freshwater streams is a possibility as sea level rises. The chemical composition of freshwater systems could change and freshwater wetlands and swamps could be converted to salt marshes (Band and Salvesen 2009; Holman et al. 2010; Bakke 2008; Burkett et al. 2000).

4.2.11.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While climate change is not the most severe threat to stream swamp communities, a combination of synergistic effects with development and lack of riparian corridors could stress these systems to the point where several species are unable to persist. Many of the threats that affect other stream communities discussed in this Chapter will also impact stream swamp systems and the comments provided should be considered valid for this aquatic community. Table 4.12 provides a review of expected climate change impacts in order of importance in comparison with other types of threats.

4.2.11.5 Impacts to Wildlife

Appendix G includes a list of SGCN and other priority species for which there are knowledge gap and management concern priorities. Appendix H identifies SGCN that use stream swamp systems.

Rapid changes in water temperature will have direct impacts on the physiology and metabolic rates of freshwater biota (Allan et al. 2005), which are dominated by cold-blooded organisms with no physiological ability to regulate their body temperature. Aquatic species are particularly sensitive to temperature cues and recent research has shown that many species of freshwater mussels may already be living at the upper thermal tolerances of their early life stages (glochidia and juveniles) (Pandolfo et al. 2010). Eaton et al. (1995) reported maximum temperature tolerance estimates for 30 species of freshwater fishes occurring in the United States. Temperature tolerance ranges are species-specific, and the availability of cooler waters may become limiting to some species in their current range in a warmer climate.

Table 4.12 Comparison of climate change with other threats to stream swamp systems

Threat	Rank Order	Comments
Development	1	Direct, secondary, and cumulative effects from development include increased sediment, bank erosion, and stormwater runoff containing sediment and other potentially toxic materials.
Groundwater Depletion	2	During droughts, water levels will decline as temperature increases and rainfall events decrease. Any increase to pumping or water withdrawals can cause depletion and low DO due to low-flow conditions.
Logging/ Exploitation	2	While bank vegetation is usually undisturbed, logging is a major threat to streams in the Coastal Plain. Loss of forest cover can cause increased erosion and sedimentation and negatively impact aquatic systems.
Water Withdrawals	2	Irrigation, water supply, and energy development withdrawals pose a threat to flow regime.
Climate Change	2	Sea level rise, as a result of climate change, is a major threat to Coastal Plain rivers.
Pollution	3	Point and nonpoint sources—runoff and EDCs—are threats. Erosion and the resultant sedimentation are the largest sources of nonpoint source pollution in most all aquatic systems. Runoff from urban areas often contains higher concentrations of nutrients, such as nitrogen and phosphorus, sediment, metals, hydrocarbons, and microbes.
Lack of Riparian Vegetation	3	Loss of riparian vegetation contributes to stream bank erosion and sedimentation. Riparian vegetation serves as a food/nutrient input to the stream community and helps regulate stream temperature by providing shade.
Livestock	4	Livestock access to streams contributes heavily to bank destabilization and erosion, sedimentation, and nutrient input.
Invasive Species	4	Invasive plants and animals are potential problems, although specific interactions are unknown.

Aquatic species could experience shifts in their range or distribution and sensitive species may experience decline or extirpation due to changes in water quality and habitat. The ability of freshwater organisms to move to new locations is constrained by the connectivity of streams and rivers within drainage basins and by the connectivity between suitable habitat types within an aquatic system.

Saltwater intrusion is expected to impact large rivers initially, and the extent to which saltwater will reach small streams and swamps is yet to be determined. However, if these smaller systems experience saltwater intrusion, existing freshwater fauna may be replaced with more brackish water species and, if salinity levels increase gradually, there could be adaptation by some freshwater species to this change. Additionally, if these systems remain freshwater, but large rivers at confluences with these smaller systems are brackish water, it could lower genetic diversity and available habitat for species that moved between large and small river systems in the Coastal Plain. Also, there may be a change in the number of freshwater streams and swamps in this community type as some may become brackish or saltwater systems.

Because of the link between freshwater mussels and fish, phenological disruptions are a possibility, but exact mechanisms or effects are not understood. Freshwater mussel larvae (glochidia) are dependent on a host fish for transformation into juveniles. Host fish species are known for some mussel species, but unknown for others. Temperature cues play a large role in the release of glochidia from female mussels and also in the movement and migrations of fish. With changing temperatures predicted with climate change there could be phenological disruptions affecting the reproductive capacity of freshwater mussels.

Recent studies have shown that EDCs in treated wastewater can inhibit reproduction and cause feminization of mussels and fish. Although little is known about the effects of EDCs, additional studies are being conducted to document the levels of EDCs in discharges. Measures are being identified to reduce or eliminate EDCs from wastewater prior to discharge should those discharge studies show increases in EDC levels (Conn et al. 2006; Kim et al. 2007; Kasprzyk-Hordern et al. 2008; Joss et al. 2006; Kolpin et al. 2002; Nowotny et al. 2007).

While this community represents riverine aquatic habitats, there are terrestrial species that utilize this resource. Several priority bird species are threatened by rising sea levels through habitat conversion from saltwater intrusion; loss of nesting, foraging, or cover habitats from inundation; and impacts that reduce prey species found in this habitat. For example, the Little Blue Heron and Wood Stork prefer freshwater pools, inland swamp, or mudflats and usually nest further inland (LeGrand et al. 2012). Inundation and saltwater intrusion will reduce habitat quality and availability and potentially displace birds when currently occupied habitats are converted to brackish systems.

Most of the listed priority amphibian and reptile species associated with riverine aquatic habitats have limited distributions, or little is known about their distribution, or they are widely dispersed but have small populations. Isolation or fragmentation of particular habitat stretches occupied by those species could have significant long-term effects upon the sustainability of those populations in North Carolina.

Temperature may have significant effects on developmental pathways or behaviors influencing reproduction and survival. For example, sex determination in hard-shell turtles is largely temperature dependent (Bull 1980, Bull et al. 1982). Rising temperatures can also affect metabolic and growth rates in insects and other ectotherms (Dukes et al. 2009; Sheridan and Bickford 2011), resulting in faster development and shorter lifecycles in some cases. Increased winter temperatures and frost-free days may also affect overwinter survival of some insects and pathogens (Dukes et al. 2009), resulting in increased population sizes that contribute to outbreaks.

4.2.11.6 Recommendations

Monitoring of aquatic taxa is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These monitoring efforts will inform future decisions on how to manage aquatic species. In addition to monitoring, there are several research questions that need to be answered about certain species or taxa of aquatic organisms. Section 4.2.2 provides recommendations appropriate for all aquatic communities, statewide. Actions specific to the river basins that contain stream swamp communities are provided in Section 4.5.

Surveys. Distributional and status surveys are needed for aquatic snails, crayfish, mussels, and fish (in order of general need).

- Determine the components of foraging bat communities along rivers.
- Establish species-specific surveys to improve our knowledge of the status and distribution of the Least Bittern, American Bittern, Yellow Rail, and Black Rail at all times of the year (Conway et al. 2004).

Monitoring. Monitoring of aquatic taxa is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These monitoring efforts will inform future decisions on how to manage aquatic species. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Monitor water quality below large agricultural farms (including livestock and poultry operations).
- Establish mist net stations for passerine birds in this habitat type at all times of the year.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of priority species to specific threats and studies should provide recommendations for mitigation and restoration. Aquatic species propagation is an area of current and ongoing research. Developing techniques for the propagation of aquatic species is critical for preserving them and their genetic stock. This is especially true for those that are rare, at high risk of extinction or extirpation, and difficult to propagate in a laboratory setting.

- Verify the genetic makeup of the Sandhills Salamander, which has yet to be formally described.

- Examine the extent and impact of exotic species introductions; conduct research on effective control measures for the most problematic exotics.
- Conduct research on fire management in marsh habitats to determine optimal frequency, timing, and firing techniques (e.g., flanking fire, back fire) to benefit priority birds.
- Conduct a systematics study to differentiate between the two subspecies of Least Shrew.
- Examine habitat use and conduct nesting habitat research on the Black Rail and then on other marshbirds using telemetry (Bogner and Baldassarre 2002).
- Investigate the past, current, and potential future impact of Nutria.
- Investigate the effect of Beaver ponds on downstream movement of pollutants (toxins and sediment).

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- The best benefit for Coastal Plain riverine aquatic communities would be to maintain and enhance riparian buffers.
- Determine the impacts of snagging (removing woody debris after storms) on wildlife populations.
- Explore techniques for restoration of tidal swamp forest and wetlands.
- Explore the biological controls recommended for some aquatic plants species, as they can be a problem, particularly in impounded waters and in slower moving waters.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the greatest extent possible to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

4.2.12 Natural Lakes

4.2.12.1 Ecosystem Description

Natural lakes include Carolina bays and depressions in peatlands that may have been created by deep peat burns or some other cause. Most are oval in shape, but a few are elongate and appear to be simply wide places along creeks. This ecosystem group also includes the deeper water systems that lack vegetation as well as the vegetated natural shoreline communities.

Most have tannin-stained water and are fairly low in productivity. Algae, primarily green algae or diatoms, are the primary plants, although a variety of aquatic vascular plants can be present. Fish numbers and diversity are low to very low. A variety of insects and other invertebrate animals spend some or all of their life cycle in the water.

The natural lake shoreline community type includes areas of emergent aquatic plants along lake margins and in wetland areas affected by changes in the lake's hydrology. It is a heterogeneous type with much variation. Most shorelines are marshy, dominated by emergent plants such as Maidencane. A few examples are well-developed swamp forests, dominated by Sweetgum, cypress, or a mixture of trees. The forested shorelines of several lakes are important nesting sites for colonial waterbirds such as herons.

While most lakes are naturally very acidic, Lake Waccamaw has limestone outcrops on the lake shore that give the water a neutral pH and high calcium content. A much higher diversity of animals is present, including many more fish species and a diverse mollusk fauna. Seven species of mussels, snails, and fish are endemic to this one lake, or to the lake and the upper Waccamaw river system.

4.2.12.2 Location of Habitat

Natural lakes are found only in the Coastal Plain ecoregion. There are 22 natural lakes and examples of systems that provide important wildlife habitat include Lake Mattamuskeet (Hyde County), Lake Ellis Simon (Craven County), and Lake Waccamaw (Columbus County). The 2005 WAP describes natural lakes in the Coastal Plain ecoregion as a priority habitat (see Chapter 5) (NCWRC 2005).

4.2.12.3 Problems Affecting Habitats

Development and loss of associated riparian habitats are primary concerns. Shorelines are often trampled and shoreline erosion and mowing is a concern in many areas. Point and nonpoint source pollution sources from residential areas and other sources (e.g., water craft engines) are prevalent, and nonpoint source pollution from agriculture and logging is possible, potentially leading to algal blooms and low DO events. Disturbance by boats and personal watercraft creates wakes and associated noise pollution that disturb water birds and water fowl.

High water levels can create shoreline damage (e.g., erosion, flooding) while prolonged low water levels may contribute to water quality issues and impact delivery of lake ecosystem services (Foulds 1977; Wildman et al. 2011; Crase et al. 2008; Molinos et al. 2015). Surface waters, including natural lakes, often receive wastes, sediments, and pollutants from runoff because of their position in the landscape (Dudgeon et al. 2006). Changes in hydrology and water chemistry affect water quality.

Water levels may be low during droughts and periods of high temperatures and lakes may become stratified with little or no vertical mixing within the water column. Under these conditions DO levels in deeper waters may be depressed and become unsuitable for many aquatic organisms. Algal blooms in the surface water can exacerbate DO depletion and result in local degradation of water quality. Such conditions are temporary and are usually alleviated by increased water flow or increased wind velocity.

Water level fluctuations may also lead to changes in patterns of boundary mixing (i.e., the process of enhanced mixing near the lateral boundaries of a lake which affects sediment resuspension and vertical nutrient fluxes), induced mainly in stratified lakes by internal wave activity at the depth of the thermocline. Progressively declining water levels would be expected to lower the thermocline and therefore displace boundary mixing (Zohary and Ostrovsky 2011; Molinos et al. 2015). Persistance of these issues can exacerbate water quality problems by contributing to long-term eutrophication in natural lakes (Hambright et al. 2004; Molinos et al. 2015).

4.2.12.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While climate change is not the most severe threat, synergistic effects combined with other existing conditions could stress these systems to the point where several species are unable to persist.

The most important effect of climate change for lakes is likely to be the occurrence of more extreme rainfall events and more frequent droughts. Table 4.13 compares climate change with other existing threats.

Table 4.13 Comparison of climate change with other threats to natural lakes

Threat	Rank Order	Comments
Pollution	1	Point and nonpoint source pollution from residential areas and other sources (e.g., 2-stroke watercraft engines) are prevalent, and nonpoint source pollution from agriculture and logging is possible for several sites. This pollution leads to algal blooms and low DO events (NCWRC 2005).
Development	1	Development destroys or disturbs shoreline vegetation,often extending well into the lake because of docks and boat activity associated with them. Shoreline construction creates impermeable surfaces that alter runoff into the lake, often involves artificial drainage or fill that further alters water flow, and is a source of pollution by nutrients, pathogens, and toxic chemicals. Most of these problems continue after construction, so past development remains an ongoing stress.
Invasive Species	2	Invasive species are the greatest threat for some lakes. Phragmites invasion is already a problem and could increase. Herbivory and burrowing damage from Nutria are concerns because they eat a variety of wetland and agricultural plants and their burrowing damages streambanks, impoundments, and drainage systems.
Impoundments	3	If long-term average rainfall does not change, average lake levels will probably remain around the same, though increased evaporation might lower them to some degree. Many lakes already have water control structures at their outlets, and have water levels that are partly artificially manipulated. Artificial control of lake levels by dams, ditches, or water control structures could affect overall water elevations.
Logging/ Exploitation	4	Nonpoint source pollution from agriculture and logging is possible for several sites and can lead to algal blooms and low DO events (NCWRC 2005).
Climate Change—Sea Level Rise	4	Several lakes, including Milltail Lake, Whipping Creek Lake, Swan Creek Lake, and Hidden Lake, lie near sea level and are connected to the sounds by creeks. Several of the more unique lakes of the central Pamlimarle Peninsula are connected to the sounds by canals, increasing the risk of damage to them. The small lakes in Dare and Tyrrell County will almost certainly be lost because of rising sea level. The large lakes of the Pamlimarle Peninsula, such as Lake Mattamuskeet and Lake Phelps, lie at the highest elevations in the area, but may be affected if sea level rise is greater than the mid-level scenario.
Climate Change	4	Climate change will potentially have a direct influence on availability of thermal habitats in aquatic environments, which in turn can become a constraint to feeding habitat access and subsequent consequences on species growth (DeWan et al. 2010).

4.2.12.5 Impacts to Wildlife

Appendix G includes a list of SGCN and other priority species for which there are knowledge gap and management concern priorities. Appendix H identifies SGCN that use natural lake systems.

In particular, natural lakes and immediately adjacent cover (especially the smaller ponds) provide habitat for wading birds and shorebirds for foraging, and also important breeding sites for species such as Green Herons. Common Yellowthroats and Red-winged Blackbirds are typical nesters in vegetation along shorelines, and swallows and swifts often forage over lakes and ponds. Bald Eagles and Ospreys nest and/or forage at these sites, and waterfowl roost, loaf, and feed during migration and winter. Double-crested Cormorants are becoming common year-round residents at most coastal lakes. Anhingas are sometimes seen during summer, nesting at millponds and/or natural lakes. In addition, these water bodies are popular destinations for human recreational activities such as canoeing, fishing, crabbing, and swimming.

Multi-year droughts in the last several decades have produced long periods of low water. Most lakes are large enough that water level fluctuations are expected to affect the shoreline but not have major effects on the majority of the aquatic community. However, because the slope of most lake beds is very shallow, a large band of lake bed can become exposed during a multi-year drought. Mussels and any other sessile animals near the shore may be affected. Low water may combine with the effect of warmer water to produce low oxygen levels that will stress the aquatic community.

Temperature and DO concentrations control the distribution of fish species in lakes (Stefan et al. 2001 in DeWan et al. 2010), which will have significant impacts on shallow waters as ambient temperatures increase. In ponds and lakes deep enough to exhibit summer thermal stratification, warmwater habitat will increase in depth, potentially forcing cool water organisms into deeper waters (Allan et al. 2005 in DeWan et al. 2010; Ficke et al. 2007). In Mohseni et al. (2003), changes in habitat for cool and warmwater fishes was dependent on the assumptions for minimum temperature tolerance (32°F vs. 35.6°F) and ranged from a 12% to a 15% decrease in habitat for coolwater fishes and a 0% to a 31% increase in habitat for warmwater fishes (DeWan et al. 2010).

Development and loss of associated riparian habitats are concerns where Bald Eagles have found shorelines to use as perch/foraging sites. Lake Ellis Simon in Craven County is productive and holds a sizable Anhinga colony. These sites and immediately adjacent cover provideforaging and breeding habitats for species such as Green Herons. Terrestrial animals that use lake communities for forage, refugia, or during parts of the reproductive cycle will also be affected by any changes in aquatic habitat or species community structure.

Exotic species (e.g., Hydrilla, Asian Clam, carp) negatively affect native frogs and turtles due to decreased native plant and animal diversity. Avian Vacuolar Myelinopathy (AVM) is a disease that affects birds that use these habitats. It has killed nearly 100 Bald Eagles in the Southeast and is associated with a novel Cyanobacterial species found in aquatic plants such as Hydrilla.

4.2.12.6 Recommendations

Priority should be placed on protecting the remaining undeveloped, unprotected natural lakes and controlling invasive species on those that are protected to promote resilience. Section 4.2.2 provides recommendations appropriate for all aquatic communities, statewide. Actions specific to the Coastal Plain portions of river basins that contain natural lakes are provided in Section 4.5.

Surveys. Distributional and status surveys are needed for aquatic snails, crayfish, mussels, and fish (in order of general need).

Monitoring. Monitoring of aquatic taxa is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These monitoring efforts will inform future decisions on how to manage aquatic species. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of priority species to specific threats and studies should provide recommendations for mitigation and restoration. Aquatic species propagation is an area of current and ongoing research. Developing techniques for propagation of aquatic species is critical for preserving those species and their genetic stock, particularly those that are rare, at high risk of extinction or extirpation, and difficult to propagate in a laboratory setting.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

4.2.13 Reservoirs & Impoundments

4.2.13.1 Ecosystem Description

Reservoirs and impoundments are found statewide and vary greatly in size; however, the systems considered in this community description include waterbodies of approximately 100 acres or larger. These systems formed when dams were built on large riverine systems, most often constructed to generate hydroelectric power or provide drinking water for nearby communities. The diverse nature of the impounded streams and rivers contributes to their unique configuration, flow pattern, water chemistry, and biota. Water depths in many of these systems may be subject to some fluctuation because water is released to maintain downstream flow regimes or to release flood waters. Farm ponds and smaller lakes constructed as local storm water or flood control facilities are not included in this description.

These man-made systems will likely have a combination of maintained shoreline with hardened structures and natural shoreline covered by vegetation. Where the shorelines are marshy, such as shallow margins and wetlands affected by the lake's hydrology, the vegetation is expected to include emergent aquatic plants while the upper banks will be covered by a mix of herbaceous and woody vegetation. Reservoirs, mill ponds, and other impounded waterbodies provide habitat for a variety of fully and semiaquatic species including reptiles, amphibians, and aquatic mammals. They provide habitat that supports prey species and foraging areas for many terrestrial species, such as birds and bats.

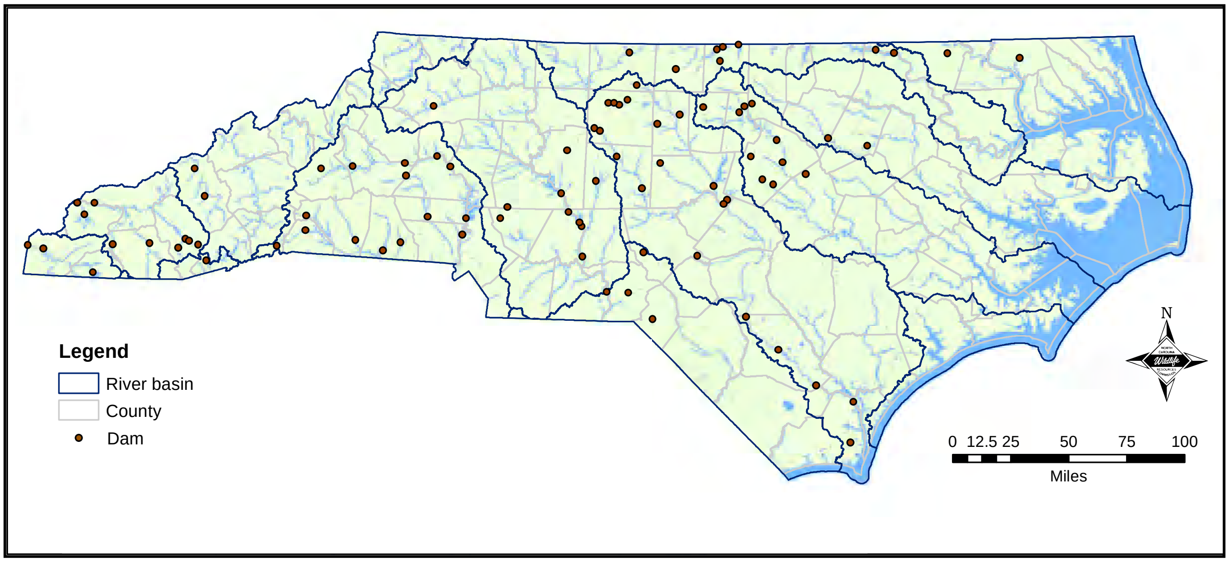
4.2.13.2 Location of Habitat

There are numerous reservoirs and impoundments with various sized drainage areas located across the state. Notable examples include the B. Everett Jordan Lake Dam on the Haw River (Cape Fear River Basin); Hiwassee Lake Dam on the Hiwassee River (Hiwassee River Basin); East Fork, Cedar Cliff, and Bear Creek dams on the Tuckasegee River (Little Tennessee River Basin); Falls of the Neuse Dam on the Neuse River (Neuse River Basin); Lake Gaston and Roanoke Rapids Lake dams on the Roanoke River (Roanoke River Basin); and the Tillery/Norwood and Blewett Falls Lake dams on the Pee Dee River (Yadkin–Pee Dee River Basin).

4.2.13.3 Problems Affecting Habitats

The protection of aquatic ecosystems under an expanding human population is of global concern and water quantity is becoming a major issue for urbanizing landscapes (Armstrong et al. 2001). Aquatic systems in North Carolina have been threatened by a variety of perturbations in the past and many of those same threats continue today. Water impoundment imposes fundamental changes on natural landscapes by transforming rivers into

FIGURE 4.3 Location of reservoir and impoundment dams (NCDEMLR 2014)



reservoirs. The dramatic shift in physical conditions accompanying the loss of flow creates novel ecological and evolutionary challenges for native species (Haas et al. 2010).

Land Use. Aside from converting extensive reaches of stream habitat into standing water, reservoirs flood large areas of land, change the magnitude and timing of water flows, reduce the sediment load, form barriers for fish migration, and extirpate shallow-water species through fluctuation of water levels (Malmqvist and Rundle 2002). Impoundments on major rivers and tributaries drastically alter the hydrologic regime of many North Carolina waterways and result in habitat fragmentation, blockage of fish migration routes, and physical habitat alterations.

Erosion and sedimentation are the primary forms of nonpoint source pollution affecting many surface waters. Sources of erosion are primarily ground disturbance from development activities (residential, commercial, transportation, and utility construction) and agriculture. Other nonpoint sources of pollution include the quantity and quality of runoff from built-up areas and roadways. Sediments can build up behind an impoundment and over time can cause a degradation of underwater habitat quality above the dam. Plant diversity can be altered by sediment pollution. Streambank and other erosion from poorly managed cattle pastures (primarily caused by lack of fenced buffers along streams) and erosion from row crops contribute most of the sediment from agriculture. Timber harvest with insufficient erosion controls may be another source of sediment.

Many species associated with lakes and aquatic habitats rely on shoreline vegetation for shelter, foraging, breeding, and nesting. Shrubs and trees growing around shorelines provide important nesting, roosting, and feeding sites for birds, especially colonial waterbirds such as herons. Development of lake shores causes loss and fragmentation of this riparian habitat. In many cases, reservoirs and impoundments are subject to management for recreational activities such as boating and fishing. Excessive human use of lake shores can lead to increased trampling and erosion of the banks. Human intrusion can disrupt natural behaviors of animals using this habitat.

Water Quality. Pollution can cause problems for many aquatic organisms and their predators. Heavy metals can be a particular concern because they can bioaccumulate in animal tissues. Smaller water bodies near agricultural or residential areas can suffer from excess nutrient run-off, leading to algal blooms and low DO levels. Contaminants can be carried by sediment that washes into surface waters.

Changes in hydrology and water chemistry can impact water quality negatively. Nonpoint source pollution and the effects of dams and impoundments pose historic and current threats to freshwater mollusks (Bogan 1993; Neves et al. 1997; Richter et al. 1997). Impacts from hydropower development in large river basins have altered and degraded a substantial portion of habitat for most native aquatic species, primarily in large streams and rivers. Irregular flooding during the growing and nesting seasons can affect the reproductive success and survival of species that depend on this habitat type.

The mainstem Hiwassee and Nottely rivers, for example, are significantly altered by direct and indirect impacts from impoundment. Fifty-seven miles of historically free-flowing riverine habitats are now either seasonally or permanently flooded by Chatuge, Mission, Hiwassee, and Appalachia reservoirs or are affected indirectly by impoundment. The unimpounded reaches of the Nottely and Hiwassee rivers are affected by cold water, altered hydrologic regimes, and periodic low levels of DO due to hypolimnetic discharges and peaking power production releases from Chatuge and Nottely dams. Impoundment and thermal alteration may further affect native species by fragmenting suitable habitat and isolating historically contiguous populations in tributaries.

Invasive Species. Reservoirs can be a barrier to upstream movement of invasive species, but more often they act as stepping-stones for the dispersal of exotic and nonnative species across landscapes. Exotics are species that are not native to the United States, and species that are not native to North Carolina, but that may be native to other areas of the United States, are considered nonnatives. Havel and colleagues (2005) conducted a study called “Do Reservoirs Facilitate Invasions into Landscapes?” that examines how reservoirs might facilitate the spread of invasives across landscapes. Populations often become invasive because there are no natural predators or conditions to control growth. A variety of passively dispersing species have invaded reservoirs, spread through interconnected waterways and been unwittingly transported on boating equipment and in bait buckets. Exotic plant species such as Hydrilla, Giant Salvinia, and Purple Loosestrife can form large mats that displace native vegetation and entangle boat motors. Exotic aquatic animals such as the Asian Clam, carp (e.g., Common, Grass, Bighead) and snails (e.g., Chinese and Japanese Mystery Snails, Red-Rim Melania) are often vectors for parasites and diseases that can affect native species.

Climate Impacts. Many of the water quality and water quantity impacts resulting from climate change are analogous to impacts from economic development and population growth in North Carolina. Climate change is predicted to decrease rainfall and therefore limit water supply, while growth and development have been increasing and continue to raise demands for water supply. Historical stream flow patterns are projected to be altered due to climate change impacts; however, these are already being altered due to rapid urbanization.

Global warming scenarios predict a possible decrease in precipitation and increase in evaporation (Jacobs et al. 2000), which together with sediment accumulations in our aging reservoirs is likely to propel new constructions such as those being considered and pursued in the southeastern region of the country (Kashiwagi and Miranda 2009). During drought periods when stream flows are reduced in the study streams, fish in reaches above impoundments are apparently forced downstream to seek shelter in the impoundment, or survive in wetland areas that provide temporary refuge (Kashiwagi and Miranda 2009). Despite annual fluctuations, fish communities of unimpounded headwater streams can remain fairly stable over time but require connectivity with the downstream community to preserve their integrity (Moyle and Vondracek 1985; Ross et al. 1985).

4.2.13.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While climate change in many cases is not the most severe threat, a combination of synergistic effects with other existing conditions could stress aquatic systems to the point where native species are unable to persist. A comparison of climate-related impacts to other threats is not included in this description because the NCNHP vulnerability assessments completed in 2010 did not include reservoirs and impoundments as a community type. Concerns are expected to be similar to the comparison results for other aquatic systems; however, sedimentation and erosion, invasive species, and pollution are primary concerns for this community type.

4.2.13.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gap and management concern priorities. Appendix H identifies SGCN that use reservoirs and impoundments.

Impoundments are major contributors to habitat degradation and fragmentation in aquatic ecosystems (Baxter, 1977; Dynesius and Nilsson, 1994; Downing et al. 2006), threatening many freshwater taxa (Dudgeon et al. 2006). Reservoir construction in the United States reached its peak in the 1960s (Pringle et al. 2000) and more than 50 years have passed since habitat alteration may have affected fish populations in impounded riverine systems. Habitat modification, combined with stocking practices, has contributed to the replacement of unique local assemblages with widespread species that are better able to tolerate human activities, which can lead to homogenization of freshwater biota (Rahel 2002). Comparison of historical and contemporary fish assemblages indicate that the structure of fish assemblages upstream of inundated reaches have been altered in most impounded systems (Franssen and Tobler 2013).

The condition of stream ecosystems depends on the appropriate quantity, quality, timing, and temporal variability of water flow to which aquatic species have adapted (Poff et al. 1997; Bunn and Arthington 2002). Water withdrawal can lead to reduced stream flow (Weiskel et al. 2007), and the presence of impoundments can further impact temporal variability of stream flow through their water storage capacities (Poff et al. 1997). Results from Kanno and Vokoun's 2010 study of New England streams evaluating the effects of water withdrawals and impoundments on fish assemblages suggest that water withdrawals have contributed to measurable alterations of fish assemblages. These impacts should be considered when developing in stream flow regulation and aquatic conservation (Kanno and Vokoun 2010).

In their 2011 study of the effects of a small dam on freshwater mussel growth in Alabama, Singer and Gangloff found numerous locations where mussels were abundant and larger in size in reaches immediately downstream from the small dams. Analysis of length-at-age data using multiple growth models found that mill reach mussels grew faster than both up- and downstream populations, and evidence suggests that this phenomenon is geographically and taxonomically widespread in eastern North America. These results suggest that some small impoundments enhance conditions for freshwater mussel growth and some older dams may warrant protection or restoration if downstream reaches support imperilled mussel populations (Singer and Gangloff 2011).

Thermal stratification of impoundments occurs mostly during the warmer seasons, when direct solar radiation and increased air temperatures heat surface layers faster than deeper layers (Sherman 2000; Sherman et al. 2007) resulting in the formation of a lighter, warmer surface layer of water (epilimnion) and a cold bottom layer (hypolimnion) (Smith and Smith 1998). Many impoundments have fixed-level off-takes that are situated below the thermocline, hence releasing waters from the colder hypolimnion which causes downstream coldwater pollution (Sherman 2000; Preece and Jones 2002; Marshall et al. 2006). The biological impacts of coldwater pollution on warmwater fishes have been documented in a number of studies (Clarkson and Childs 2000; Todd et al, 2005; Sherman et al. 2007; Olden and Naiman 2010) and include impeded spawning, lower survival rates, retarded growth rates, and displacement of native species (Martinez et al. 1994; Clarkson and Childs 2000; Todd et al 2005; Sherman et al. 2007; Miles and West 2011).

Introduction of species native to the state into areas where they normally would not occur creates competitive pressure on the native local populations. For example, the Piedmont Shiner, native to the Broad River, and Yellowfin Shiner, native to the Savannah River Basin, have been introduced to the Little Tennessee River Basin where they compete with native species for food, spawning, and cover resources. Their range could expand into other coldwater systems with warming water temperatures associated with discharges or changes to riparian buffers.

4.2.13.6 Recommendations

Section 4.2.2 provides recommendations appropriate for all aquatic communities, statewide. Recommendations specific to the river basins that contain reservoirs and impoundments are provided in Section 4.5.

Surveys. Distributional and status surveys are needed for aquatic snails, crayfish, mussels, and fish (in order of general need).

- Determine the status and distribution of reservoir-associated birds (e.g., ospreys, herons, swallows, possibly rails) and help identify threats to populations.
- Survey for shorebird migration activity on large reservoirs (e.g., Falls Lake, Kerr Lake) in spring, summer and fall.
- Conduct frog call surveys and support the volunteer and citizen science programs that participate in these surveys.

Monitoring. Monitoring aquatic taxa is critical for assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These monitoring efforts will inform future decisions on how to manage aquatic species. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Continue monitoring Bald Eagle breeding activity.
- Conduct monitoring for waterbirds and rails to help determine population trends.
- Monitor Pond Turtles and Common Ribbonsnakes to track population trends.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of priority species to specific threats and studies should provide recommendations for mitigation and restoration. Aquatic species propagation is an area of current and ongoing research. Developing techniques for the propagation of aquatic species is critical for preserving those species and their genetic stock, particularly those that are rare, at high risk of extinction or extirpation, and difficult to propagate in a laboratory setting.

- Track and identify problems associated with avian vacuolar myelinopathy that cause mortality in American Coots, other waterfowl and Bald Eagles (Augspurger et al. 2003).

- Assess the impacts of Federal Energy Regulatory Commission-mandated changes in water releases at hydroelectric dams on priority species.

- Study the impacts of commercial collecting of turtles on population dynamics, and the impact that the 2003 turtle law may have on the trade. This 2003 Session Law amended General Statute 113-333(a) to limit possession and commercial taking of certain amphibian and reptile species when NCWRC determined the species requires conservation measures to prevent addition of the species to the protected animal lists. Section 3.1.1 provides additional information about General Statutes in North Carolina.

Management. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Maintain natural shoreline vegetation and the structure of adjacent terrestrial habitats if possible (many wetland-related amphibian and reptile species rely on both aquatic and drier upland sites for their life history and seasonal migrations).

- Retain or create snags, logs, rocks, and other structures used by basking reptiles.

- Reduce disturbance and development along raceways and near Bald Eagle nest trees.

- Identify invasive and exotic species, their impacts on native wildlife, and practical methods for removal or control.

- Plant native vegetation where appropriate to provide aquatic and terrestrial habitat and to reduce erosion and sedimentation.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Limit lakeshore development at sites where there is no protected buffer land.
- Acquire lakeshore buffer lands (as was done at Jordan and Falls reservoirs) to exclude development.
- Implement conservation strategies where appropriate to protect downstream reaches of relic dams where there are known populations of priority mussel species.

4.2.14 Estuarine Aquatic Communities

4.2.14.1 Ecosystem Description

Estuarine aquatic communities are represented by the sounds and near-shore waters along North Carolina's coast. North Carolina's estuarine aquatic communities represent the largest estuarine systems along the US Atlantic coast and include the Albemarle, Pamlico, Core, Back, and Bogue Sounds. These sounds are collectively a part of the Albemarle–Pamlico National Estuary Partnership (APNEP), a cooperative effort jointly sponsored by NC and Virginia state resource agencies. They receive freshwater drainage from rivers and tributaries of the Lumber, Cape Fear, White Oak, Neuse, Tar–Pamlico, Roanoke, Pasquotank, and Chowan River basins. Near-shore waters are those located within three nautical miles of North Carolina's coastal land area and are marine waters. Through tidal influences and storm surge events, near-shore waters contribute saline water to the sounds. This mixing of freshwater from rivers and tributaries with saline waters from near-shore and ocean marine waters contributes to seasonal and temporal variability of salinity in the brackish waters within the sounds. This habitat is closely associated with estuarine and freshwater marsh wetland communities (See Section 4.3.2).

Coastal freshwaters generally have salinity levels between 0 and 0.5 ppt as defined by the Venice System (Cowardin et al. 1979). Average ocean water salinity levels are between 25 and 35 ppt (Reshetiloff 2004). Salinity is typically less than 5 ppt in the sounds and can be vertically homogeneous in the water column according to the South Atlantic Fishery Management Plan (SAFMC 1998). Coastal shallow water temperatures along the North Carolina coast typically reach 31°C–33°C (Burkholder et al. 1992, 1994; Mallin et al. 2000a).

The NC Coastal Habitat Protection Plan (CHPP) refers to these waters as essential fish habitat (EFH) (Deaton et al. 2010). EFH supports the different life cycles of approximately 1,000 aquatic species managed under the SAFMP, including anadromous species such as striped bass, herring species, and sturgeon species that migrate to freshwaters to reproduce (SAFMP 1998). The CHPP and South Atlantic Fisheries Management Plans describe five EFH components of the estuarine aquatic communities in North Carolina and are described below:

- Soft Bottom is the unconsolidated, unvegetated sediment that occurs in freshwater, estuarine, and marine systems. It is an important component of designated Primary Nursery Areas (PNAs), Anadramous Fish Spawning Areas (AFSA), and Anadramous Nursery Areas (ANA) (Street et al. 2005).
- Shell Bottom habitats are the oyster beds, rocks, reefs, and bars found in estuarine intertidal or subtidal areas. It is composed of surface shell concentrations of living or dead oysters (*Crassostrea virginica*), hard clams (*Merceneria merceneria*), and other shellfish (Street et al. 2005).
- Ocean Hard Bottom varies in topographic relief from a relatively flat, smooth surface to a scarped ledge with vertical, sloped, or stepped relief. It is formed of exposed rock, consolidated sediments, or relic reef, and may be covered by algae, sponges, corals, other live animals, and live plants attached to the hard surface (Street et al. 2005).
- Submerged Aquatic Vegetation (SAV) is defined as bottom vegetated by living structures of submerged, rooted vascular plants, (i.e., roots, rhizomes, leaves, stems, propagules), as well as temporarily unvegetated areas between vegetated patches. Native aquatic grasses are the primary species and can occur in fresh, brackish, and saline waters. SAV beds can be transient communities comprised of a few plants or many and cover small patches or extensive areas. They provide important habitat for most fish and shellfish species in the sounds, while also creating oxygen and removing excess nutrients in the water (APNEP 2012).
- Water Column is an aquatic environment and its physical, chemical, biological characteristics, and connectivity to other habitats will determine which species use it.

4.2.14.2 Location of Habitat

The Albemarle–Pamlico estuary system is comprised of eight sounds, including Back, Bogue, Core, Croatan, Currituck, and Roanoke sounds, and is located along the Atlantic coast of North Carolina and southern Virginia.The Albemarle Sound is located at the confluence of several freshwater rivers, with the largest being the Chowan and Roanoke rivers. The sound is separated from ocean saltwaters by the northern Outer Banks barrier islands and freshwater drainages help maintain the fresh to brackish waters in the sound. The Pamlico Sound is located between the mainland and Outer Banks barrier islands and hydrologically connects the freshwaters of the Neuse and Tar–Pamlico river basins to the Atlantic Ocean. To the north end it is linked with Albemarle Sound and joins the

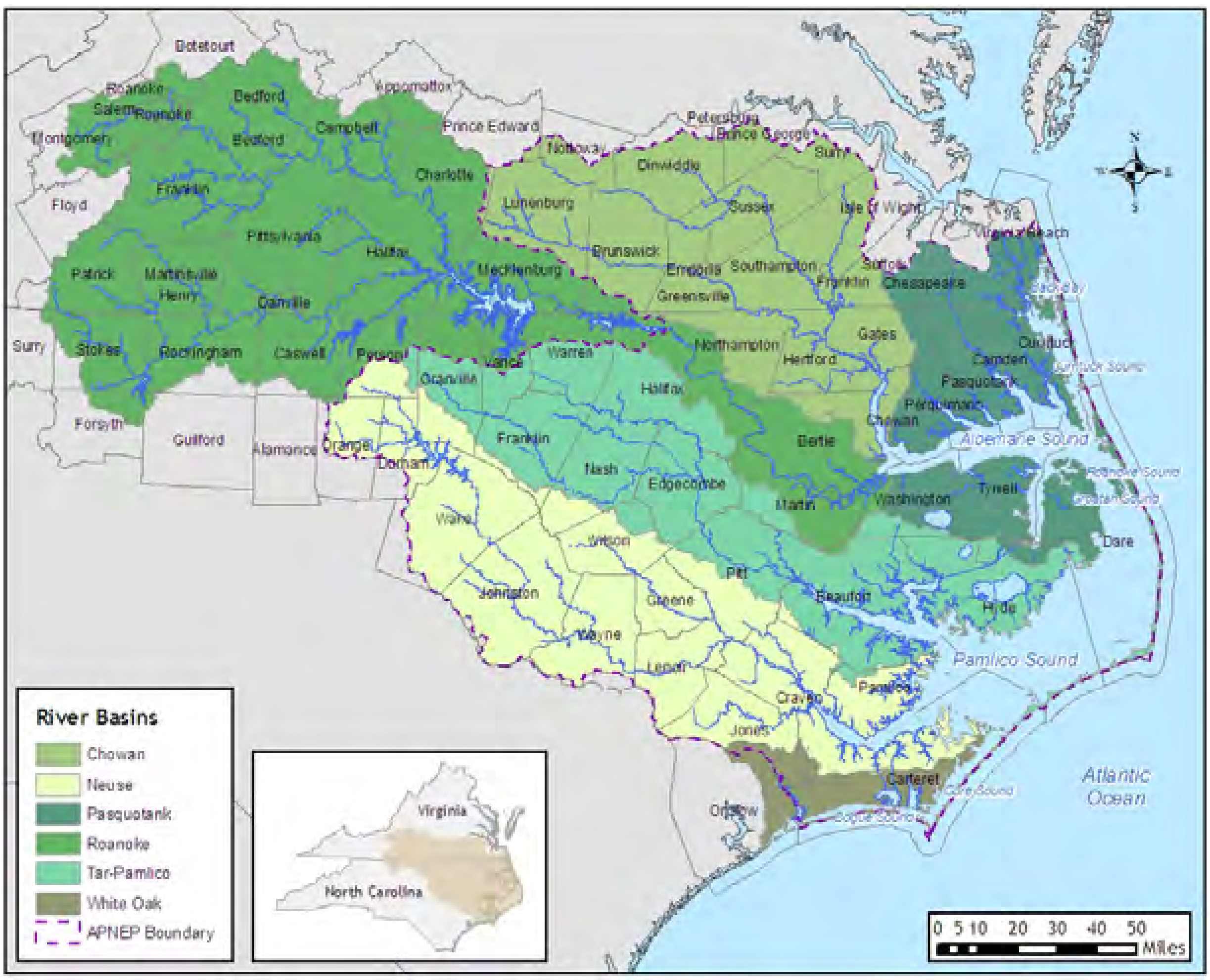
Oregon Inlet. The south end connects to Core Sound. Figure 4.4 depicts the location of the Albemarle–Pamlico estuary system.

4.2.14.3 Problems Affecting Habitats

The CHPP compiles the latest scientific information on all habitats within the river basins that drain into coastal North Carolina and provides information on management needs that protect, enhance, and restore associated fish populations (Deaton et al. 2010). This Section provides highlights representing a small portion of the information provided in the CHPP; please refer to the CHPP for complete information.

Land Use. Land-use patterns along the coast will continue to change with population growth and increases in property values. Development of coastal land is expected to continue, especially in Pamlico, Chowan, Bertie, Washington, Brunswick, and Carteret

FIGURE 4.4 **Location of the Albemarle–Pamlico National Estuary System**
***Source*: Comprehensive Conservation and Management Plan 2012-2022, APNEP**



counties, which are being marketed as the "Inner Banks." Land conversion for development and shoreline alterations are a major cause of wetland loss in estuarine systems (Deaton et al. 2010).

Historically, the major causes of wetland loss and degradation have been conversion to agriculture, silviculture, and upland development (including road construction). Ditching and draining for agriculture is currently maintained by drainage districts to accommodate existing agriculture and forestry operations. Residential and commercial development continues to create wetland impacts, with approximately 1,700 acres of permitted impacts occurring between 2001 and 2008 (Deaton et al. 2010). In North Carolina, proposed and completed bridge projects cause loss and degradation of SAV habitat, wetlands, and adjacent uplands. However, a lack of updated wetland and shoreline maps makes tracking the changes to this resource difficult.

Dredging. Dredging for creation or maintenance of navigational channels and inlets will result in degradation or elimination of SAV habitat. The change in bottom depth, bottom sediment characteristics, and water clarity that accompanies dredged channels prevents or discourages future growth or establishment of SAV. Dredged channels connecting marinas and small docking facilities (including boat ramps) to major navigation channels are another source of SAV habitat loss and degradation. Vertical shoreline stabilization and docking facilities associated with marinas may also impact SAV (Stevenson and Confer 1978; Funderburk et al. 1991; Deaton et al. 2010).

Energy Development. Although wind farms are generally considered a source of green energy, the construction of towers and infrastructure can impact immediate and adjacent marine or estuarine habitats (Ó Cléirigh 2000; Deaton et al. 2010). Legislative requirements in North Carolina call for utilities to develop renewable and alternative energy resources and will increase the likelihood that offshore wind turbines or oil drilling remain a threat to coastal habitats. There is an increasing interest in the development of wind farms in Albemarle and Pamlico sounds, as well as off the coast of Cape Hatteras and Cape Lookout, as these areas have some of the most abundant wind resources in the state (Deaton et al. 2010; Kalo and Schiavinato 2009). Offshore mining would disturb the ocean bottom and drill operations would introduce oil and chemical contaminants to the water column. Wind turbines pose a risk of strikes to sea birds and waterfowl.

Water Quality. Sources of water quality degradation cover a wide range of structures (houses, businesses, impervious surfaces), facilities (marinas, boat ramps), and conditions (temperature, runoff). Marinas are located immediately adjacent to shorelines where upland pollutants coming from boats, parking lots and hull maintenance areas can often flow directly into coastal waters (Deaton et al. 2010). Water quality impacts can be caused by nutrient enrichment, turbidity, toxic chemicals, desalinization, marine debris, microbial contamination, DO deficiencies, and high concentrations of toxic metals in the water column and bottom (McAllister et al. 1996; Deaton et al. 2010).

Of all the sources of sediment loading, sedimentation from agriculture has been cited as one of the largest contributors to water pollution in the southeastern states (SAFMC 1998; Deaton et al. 2010). Other upland sources of runoff and contaminants also contribute to water quality degradation in estuarine aquatic communities. For instance, development and associated runoff and sewage inputs in the upper end of a watershed and confined animal operations (primarily swine, poultry) and associated nutrient and microbial contamination in the lower end of a watershed contribute significantly to poor water quality (Deaton et al. 2010).

Algal blooms tend to occur when nutrient loads are not flushed because water flow is slow, water depths are low, and where mixing of the water column is reduced due to salinity and/or temperature gradients. Blue-green algae are usually associated with blooms in freshwater areas and they have lower nutritional value to aquatic life than other types of algae. Dinoflagellates and other flagellated algae are usually responsible for algal blooms in estuarine and marine waters (Smayda 1989; NC Sea Grant 1997; Mallin et al. 2000b; Deaton et al. 2010). Some dinoflagellate species release toxic chemicals into the water column that harm fish and shellfish by affecting their nervous systems and paralyzing their respiratory systems (Tyler 1989; Deaton et al. 2010).

Invasive Species. Foreign organisms in the discharge of ships' ballast water at or near ports have resulted in the introduction and spread of nonnative invertebrate animals, algae, bacteria, and dinoflagellates (Deaton et al. 2010). Removal of dams and other passage barriers (locks) create a pathway for nonnative species to move between freshwaters and brackish water environments, including movement upstream from brackish estuarine waters into river drainages as a saltwater wedge expands into freshwaters.

The water mold *Aphanomyces invadans* is an invasive fungal pathogen that infects schooling fish species in low-salinity or fresh water and is suspected to have been introduced to the United States through another infected invasive species, the Northern Snakehead Fish (Blazer et al. 2002; Deaton et al. 2010).

The Australian Spotted Jellyfish can consume large quantities of plankton, eggs, and larvae in the water column and has been found in Bogue Sound and at Sunset Beach. The invasion of the Indo-Pacific lionfish in marine waters off North Carolina will likely impact estuarine aquatic communities through direct predation, competition, and overcrowding (Deaton et al. 2010).

There are also a number of noxious weeds that can be found in fresh and moderately brackish waters of slow moving streams or waters protected from strong tidal currents and wave action. These include Eurasian Watermilfoil, Alligator Weed, and the Common Reed (see Appendix E for scientific names). The most troublesome species in low salinity, estuarine waters is Eurasian Watermilfoil (Deaton et al. 2010).

Climate Change. Climate change will influence water quality, salinity, water depth, and temperature, which will in turn alter fish distribution and abundance (Deaton et al. 2010). There are expected increases in temperature and sea level for the immediate future based on a history of measurement data (Bin et al. 2007; Bin 2008; UNCW 2008; Deaton et al. 2010). Long-term changes in temperature and salinity suggest expansion of some species at the expense of others. There is also a predicted increase in storm events and other extreme weather conditions (i.e., drought) (Deaton et al. 2010).

If the predicted rate of sea level rise occurs too quickly, natural coastal wetland accretion processes may not keep pace. Increasing frequencies and severity of coastal storms and storm surge will contribute to inlet breaches along barrier islands and lead to significant increases in salinities in Pamlico Sounds and its tributaries. There could also be a loss of barrier islands and wetlands as coastal areas are submerged by rising water elevation. Marsh islands provide shelter that protects SAV beds from wind and wave action during the growing season (Deaton et al. 2010).

Warming trends pose a threat to Eelgrass because it is growing near its southern limits; however, studies suggest the decline in Eelgrass is offset by increases in shoal grass beds (Deaton et al. 2010). When water temperatures are above 25°C–30°C (77°F–86°F), Eelgrass does poorly. Eelgrass thrives only where water temperatures are lower (i.e., deeper areas and tidal flats with continuous water flow) (SAFMC 1998; Deaton et al. 2010).

4.2.14.4 Climate Change Compared to Other Threats

Current research suggests that climate change and associated sealevel rise will be a significant stressor in the region for the near future (APNEP 2012). Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While climate change is a threat to estuarine aquatic communities, it is likely that a combination of synergistic effects with other ongoing threats will be the source of stress to this system to the point where several species are unable to persist. Table 4.14 provides a review of expected climate change impacts in order of importance in comparison with other types of threats.

Table 4.14 Comparison of climate change with other threats to estuarine aquatic communities

Threat	Rank Order	Comments
Bottom Trawl Fishing Gear	1	The weight and movement of bottom trawl fishing gear disturbs bottom sediments, displaces SAVs, and damages shell and hard bottom habitats. Mobile species may temporarily disperse but cumulative impacts from repeated use of bottom trawl gear in the same areas can lead to long-term habitat loss.
Dredging	1	Dredging disturbs and damages soft, shell, and hard bottoms, SAV beds, and suspends sediments that cause turbidity within the water column. Localized impacts may allow dispersal of mobile species but long-term damage can occur to bottom habitats.
Pollution	1	Pollution includes chemicals and toxins from point source discharges (e.g., industrial effluents and smoke stacks, stormwater discharges, wastewater treatment facilities) and nonpoint sources (e.g., roads, surface water runoff, marinas, boatyards). Aging infrastructure and rising sealevels are two challenges that must be addressed to reduce bacteria, viruses, and other microorganisms from entering public waters through identified sources (APNEP 2012).
SAV Loss	1	Loss of SAV beds or meadows reduces connectivity between spawning areas, primary nursery areas, and water column habitats for larval, juvenile, and adult aquatic species (DiBacco et al. 2006).
Shoreline Hardening	2	Hardened shorelines will prevent natural migration of marsh habitats toward inland areas as inundation occurs from rising sea levels. Use of natural and living shorelines should be encouraged and regulatory impediments removed.
Baseflow Reductions	2	Low flow conditions can occur due to drought, hydraulic drawdown, and upstream impoundment. Reductions in freshwater inputs from rivers and tributaries will allow influence salinities. Saltwater intrusion and concentrations upstream are likely to increase. Occurrence of temperature stratification and anoxic conditions are likely to increase.
Offshore Development	3	Mineral mining, gas and oil exploration, and wind energy turbines will damage bottoms, introduce contaminants into the water column, and displace species assemblages through loss of habitat.
Climate Change	3	Climate change impacts will be cumulative and to some degree mitigation options are limited. Mobile species can be expected to disperse to more favorable conditions.
Invasive Species	4	Warmer water can allow range expansion of nonnative species into open waters previously not colonized.
Infrastructure	5	Dams block the passage of diadromous fish species and limit access to upstream spawning habitat for anadramous fish species.

4.2.14.5 Impacts to Wildlife

Appendix G includes a list of SGCN and species for which there are knowledge gap and management concern priorities. Appendix H identifies non-marine SGCN and federally listed protected marine species that use estuarine aquatic communities.

Seagrass habitats are one of the most productive systems in the world, providing not only cover and forage resources for numerous organisms but also as an important carbon dioxide sink relative to other terrestrial and aquatic habitats (Deaton et al. 2010). In North Carolina, annual Eelgrass beds are common in shallow, protected estuarine waters in the winter and spring when water temperatures are cooler.

The South Atlantic Fishery Management Council reports 40 species of fish and invertebrates have been captured on seagrass beds in North Carolina. Larval and juvenile fish and shellfish such as Gray Trout, Red Drum, Spotted Seatrout, Summer and Southern Flounder, Blue Crabs, Hard Shell Clams, and Bay Scallops utilize the SAV beds as nursery areas. SAV meadows are also frequented by adult Spot, Spotted Seatrout, Bluefish, Menhaden, Summer and Southern Flounder, Pink and Brown Shrimp, Hard Shell Clams, and Blue Crabs. Offshore reef fishes include Black Sea Bass, Gag, various snapper species, and Spottail Pinfish. They are the sole nursery grounds for Bay Scallops in North Carolina (SAFMC 1998). Negative interactions between commercial fishery operations and wildlife often include Diamondback Terrapins, endangered sea turtles, Red-throated Loons, and other diving birds getting caught and drowning in crab pots, fishing gear, and gill nets. Recreational boaters may accidentally strike turtles, Manatees, and birds that use estuarine waters.

Meteorological processes influence coastal and estuarine circulation, which influences larval transport in the estuarine system and colonization of nursery locations for flounder species. For flounder, a combination of winds determine the overall supply of larvae to the system and some combination of wind and river discharge determines migration and settlement into specific nursery locations (Taylor et al. 2010).

Concentrations of prey organisms (worms, algae, crustaceans, mollusks, other invertebrates) associated with soft, shell, and ocean bottoms provide forage for numerous species of fish, shrimp, and crabs (NCDMF 2010, 2015). Ospreys, egrets, herons, gulls, and terns feed on fauna in SAV beds, while swans, geese, and ducks feed directly on the grass itself. Green sea turtles utilize Seagrass beds and juveniles may feed directly on the Seagrasses (SAFMC 1998). Increased salinity will affect species assemblages and influence food-web dynamics by reducing available habitat for species adapted to a specific range in water chemistries.

Warming trends can impact corals and SAVs (CSCOR 2012) and disrupt normal processes such as timing of phytoplankton blooms and larval development (NFWPCAS 2012), thus affecting food chain dynamics. Larval dispersal will be affected by changes in water circulation patterns, flooding, and intense storm events (DiBacco et al. 2006; Cowen and Sponaugle 2009; Tisseuil et al. 2012), which will influence geographic distribution of marine species (Block et al. 2011; Haase et al. 2012).

4.2.14.6 Recommendations

SAV beds and water column habitats act as nursery areas for most planktivorous larvae and juvenile pelagic species (e.g., Bluefish, River Herring, Menhaden, Spanish Mackerel) (NCDMF 2010). In addition to fully aquatic species, these habitats are also important foraging areas for sea turtles and migratory and resident pelagic seabirds and waterfowl associated with open water areas. Section 4.2.2 provides recommendations appropriate for all aquatic communities, statewide. Actions specific to the river basins that contribute waters to estuarine aquatic communities are provided in Section 4.5.

Surveys. Distributional and status surveys are needed for aquatic snails, crayfish, mussels, and fish (in order of general need).

- Facilitate the mapping of significant ecological, bathymetric, geologic, demographic, and cultural features (APNEP 2012).
- Conduct surveys of fish populations, including collecting fish samples for toxicological and water quality studies, to evaluate the efficacy of management practices, detect changes in fish communities, and to identify trends which may be occurring within the fishery resources.

Monitoring. Monitoring of aquatic taxa is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These monitoring efforts will inform future decisions on how to manage aquatic species. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Develop and maintain an integrated monitoring network to collect information for assessment of ecosystem outcomes and management actions associated with the implementation of management actions (APNEP 2012).
- Facilitate the development of protocols and conduct rapid assessments to determine presence and potential threat of invasive species (APNEP 2012).
- Develop sensors for biological and chemical sensing to determine status and trends, as well as tagging and tracking of wildlife (NIEPS 2010).
- Coordinate and enhance water quality, physical habitat, and fisheries resource monitoring (including data management) from headwaters to the nearshore ocean.

Research. Most species and their interrelationship associated with this habitat are poorly understood. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of priority species to specific threats and studies should provide recommendations for mitigation and restoration. Aquatic species propagation is an area of current and ongoing research. Developing techniques for propagation of aquatic species is critical for preserving those species and their genetic stock, particularly those that are rare, at high risk of extinction or extirpation, and difficult to propagate in a laboratory setting.

- Support research on adapting to impacts associated with climate change and sea level rise (APNEP 2012).
- Facilitate risk assessments of targeted personal care and pharmaceutical products in the aquatic system (APNEP 2012).
- Facilitate risk assessments of heavy metals and other toxic contaminants in sediments (APNEP 2012).
- Assess the impact on fisheries productivity from changes in estuarine habitats due to climate change (NIEPS 2010).

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Planning and locating wastewater treatment facilities to areas above sea level will minimize or eliminate risks (APNEP 2012).
- Restore areas capable of supporting SAVs. This will require study of effective restoration techniques, bathymetric mapping, water quality monitoring, and other efforts (APNEP 2012).
- Develop and refine ecological flow requirements for each major river (APNEP 2012) that drains to estuarine waters.
- Reduce potential water pollution by protecting critical buffer areas of upstream drainages, sound planning, adopting low-impact development (LID) criteria, and other best practices.
- Establish contaminant management strategies for waters not meeting water quality standards. Strategies that address pathogens, toxics, and nutrients are needed, not just the traditional total maximum daily load (TMDL) plans which primarily manage industrial point sources and municipal stormwater (APNEP 2012).

- Where practical, restore marsh habitat by filling drainage ditches and install tide gates in agricultural fields so that sea water does not flow inland through them (DeWan et al. 2010).
- Consider closing fisheries for declining species during the spawning season.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the greatest extent possible to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Facilitate the development of state and local policies that support the use of LID practices to reduce runoff (APNEP 2012).
- Facilitate the use of BMPs on agricultural and silvicultural lands (APNEP 2012).Runoff can carry sediments, nitrogen, phosphorus, pesticides, and other substances into the sounds.
- Facilitate protection of designated anadromous fish spawning areas and inland primary nursery areas from marina impacts (APNEP 2012).
- Establish marsh habitats in cleared areas that are likely to become wetlands in the future due to inundation or frequent flooding.
- Protect conservation corridors that run from shorelines inland to facilitate habitat migration (DeWan et al. 2010).
- Establish oyster reefs and SAV beds offshore to help buffer shorelines (DeWan et al. 2010; Pearsall and Poulter 2005).
- Consider establishing marine reserves to provide refuge from fishing pressure, facilitate adult migration patterns and larval dispersal pathways, and support fisheries restoration efforts (DiBacco et al. 2006).

4.3 Wetland Natural Communities

Wetlands perform many ecosystem services, including flood protection and pollution control, and they provide essential breeding, rearing, and foraging sites for numerous fish and wildlife species. Wetlands are defined by hydrology (wetness), plant community composition, and soil characteristics (FGDC 2013; Cowardin et al. 1979). From a landscape perspective, they function as transitional lands between terrestrial and aquatic systems where the water table is at or near the land surface or where the land is covered by shallow water (FGDC 2013; Cowardin et al. 1979).

Wetlands are regulated under the Clean Water Act, Sections 404 and 401, and the USACE has regulatory authority over impacts to sites that have been delineated as jurisdictional resources (USACE 1987). Wetlands that fall under regulatory authority have one or more of three attributes: they support predominantly hydrophytic vegetation at least periodically; the substrate is predominantly undrained hydric soil; or the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season each year (FGDC 2013). Hydrophytic vegetation are plants that grow in water or on a substrate (e.g., soil) that is at least periodically deficient in oxygen as a result of excessive water content (Cowardin et al. 1979). Hydric soils are wet long enough to periodically produce anaerobic conditions, thereby influencing the growth and type of plants that occur (Cowardin et al. 1979).

There are several methods for characterizing wetlands that are based on dominant vegetation communities, dominant soil characteristics, or dominant hydrologic factors. One method defines them based on the relationship between hydrology, geomorphology, and function (Brinson 1993). The approach places emphasis on the importance of abiotic features such as the chemical characteristics of water, habitat maintenance, and water storage and transport. In this document wetland communities are defined based on descriptions by Schafale and Weakley (1990) and Schafale (2012), which use dominant vegetation characteristics and hydrology as a basis for their descriptions.

Wetland community descriptions are provided in alphabetical order in Sections 4.3.1 through 4.3.11. Floodplain communities have been included in this Section as a wetland community type; however, depending on the location of some floodplains the landscape may also be interspersed with upland communities.

4.3.1 Bogs and Fens

4.3.1.1 Ecosystem Description

Mountain and Piedmont bogs are among the rarest natural communities in the Southern Appalachians and in North Carolina. Unlike northern bogs of glacial origin, Southern Appalachian bogs form in poorly drained depressions or on gentle slopes, generally in relatively flat valley bottoms which are not subject to flooding. They may vary from being permanently wet to intermittently dry and are generally fed by seepage. They are underlain by wet organic or mucky mineral soils, which are very acidic.

The factors responsible for creating and maintaining bog communities are not well known. Grazing has been nearly universal in bogs, and few examples exist in pristine condition. Most are experiencing invasion of shrubs or trees at the expense of the herbaceous zones. This tendency toward rapid succession suggests that some form of periodic or chronic natural disturbance, now disrupted, may have kept the bogs open. Potential past disturbances include flooding by Beavers, grazing by herds of large mammals, fires, and clearing by Native Americans.

There are three community types within this ecosystem: Southern Appalachian bog, Southern Appalachian fen, and swamp forest–bog complex:

- The Southern Appalachian bog and Southern Appalachian fen types have a mosaic or zoned pattern of shrub thickets and herb-dominated areas, mostly underlain by sphagnum mats. Trees may be scattered throughout or may dominate on the edges. The shrub and herb layers of the bog, while not highly diverse, are uniquely adapted to the acidic, nutrient-poor environment of the bog and may include numerous rare species. Fens occur on high pH (basic) soils, but otherwise have the same vegetative zones as bogs; only one Southern Appalachian fen is known in North Carolina (in Ashe County).
- Swamp forest-bog complex types occur along streams and are dominated by trees, but may have boggy herbs and sphagnum moss in canopy openings.

The 2005 WAP described bogs and associated wetlands (mountain bogs) as a priority habitat in the Southern Blue Ridge Mountains ecoregion (see Chapter 5) (NCWRC 2005).

4.3.1.2 Location of Habitat

Mountain bogs (including fens and 'wet meadow' bogs) are distributed throughout the Mountains and upper Piedmont of North Carolina, with examples as far east as Forsyth and Gaston Counties. Most of the known occurrences of Southern Appalachian bogs and fens are situated above the Blue Ridge escarpment, in the northwestern (Ashe and Alleghany) and southern (Henderson, Transylvania) counties. On the other hand, 'wet meadow' bogs can be found in the western half of the Piedmont and throughout the Mountain counties. Over 60% of the wetlands identified in the Southern Appalachian Assessment (SAMAB 1996 in NCWRC 2005) occurred on privately owned lands and it is likely that overall, the percent of mountain bog habitat in private ownership is even greater.

4.3.1.3 Problems Affecting Habitats

Invasive Species. Invasive species are already a problem in some areas and may increase with drought and warmer temperatures. Some bogs are subject to invasion by exotic plants such as Japanese Stiltgrass, Multiflora Rose, and Asian Dayflower. Many of these communities contain pines, hemlocks, or spruces, which are susceptible to insect pests.

Drought and warm temperatures may allow generalists and upland species to invade. Many of the rare species associated with mountain bogs and fens are herbs and are vulnerable to competition from woody species and more aggressive habitat generalists. If changes in hydrology make these sites drier, this problem is likely to be exacerbated.

Climate Impacts. Besides stream flooding, overland runoff from adjacent uplands during severe storms would be a problem in many bogs. The nutrient input and potential scouring of severe floods would be detrimental to bog communities. Droughts would have significant effects on competitive relationships among species and on the community as a whole. Many bogs may reduce in size if margins dry out due to drought. Some estimates indicate that fewer than 500 acres of mountain bogs in North Carolina remain (USFWS 2002).

Fragmentation. The most common types of fragmentation occur when streams are impounded to form lakes, highways are built across inhabited wetlands, and wetland habitat units are drained for agricultural use or development. Roads that bisect Bog Turtle wetlands are the single most detrimental threat to turtle populations. Highway mortality is high in areas where turtles must cross roads to get from one wetland to another (Somers et al. 2000).

Successional Conversion. Bog communities can undergo ecological succession, from open canopy fens and bogs to closed canopy swamps (where hydrologic conditions do not change), leading to the loss of habitat suitable for Bog Turtles and other species dependent on these types of wetlands (Klemens 1993; Herman and Tryon 1997; Rosenbaum et al. 2007).

4.3.1.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While climate change is not the most severe threat, a combination of synergistic effects with other existing conditions could stress these systems to the point where several species are unable to persist.

Climate change effects such as droughts and severe flooding may be particularly problematic in these communities. Climate change, however, is not likely to be as detrimental compared to impacts caused by a number of immediate threats that can cause more drastic destruction than climate change is likely to. The largest scale problem affecting mountain bogs and wetlands in general has been and continues to be the conversion of these habitats to other land uses. Table 4.15 summarizes the comparison of climate change with other existing threats.

4.3.1.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

Table 4.15 Comparison of climate change with other threats to mountain bogs and fens

Threat	Rank Order	Comments
Development	1	Significant amounts of mountain bog habitat have been destroyed by development (roads, housing, or other development). Ongoing residential and commercial development and conversion to pasture or agriculture continues to destroy or degrade examples, through direct and indirect effects. Conservation of riparian buffers will benefit these communities as well as aquatic communities of the streams.
Conversion to Agriculture/ Silviculture	1	Mountain bog habitat has been converted to other uses, primarily through draining, filling, or impoundment. Protection of upland buffers around bogs, to reduce the impact of runoff, is also important.
Invasive Species	2	Droughts in the present climate appear to have exacerbated the ongoing invasion of upland and generalist wetland plants in some bogs. Protected examples are subject to ecological problems such as invasion by woody plants or by exotic species.
Groundwater Depletion	2	Caused by hydrological alteration that includes loss of ground water input or entrenchment/channelization of streams that lowers water tables. Drainage, water diversion, and ground water depletion make these wetlands more vulnerable to drought and increased temperatures than they would otherwise be.
Flood Regime Alteration	3	Many bogs are located in bottomland locations that do not regularly flood but which would flood in extreme events. Damaging floods, scouring, and nutrient/ sediment input are threats to mountain bogs and fens.
Impoundments	4	Beaver control measures should be considered at sites where potential loss of rare species may occur due to the creation of impoundments or use of certain rare plants as food by the Beavers. These measures include use of pond levelers, protective screening of rare plants, or as a last resort, removal of the Beavers. Where extirpation of rare species is not expected, however, development of Beaver pond complexes should be allowed, particularly where it may lead to restoration of higher water tables or clearings that favor the regeneration of wetland herbs and shrubs.
Climate Change	5	The level of threat posed by climate change is unclear, while the other threats are ongoing and result in more drastic effects. Drought is likely to exacerbate ongoing problems and warmer temperatures may as well.

Some of the wildlife species associated with mountain bogs require open, herbaceous habitat (e.g., Bog Turtles, Golden-winged Warblers, Meadow Voles, Meadow Jumping Mice, Bog Lemmings) while others prefer closed canopy wetlands (salamanders). In fact, for the Bog Turtle and the Southern Bog Lemming, bogs are the primary or sole habitat type in the state.

The priority amphibians associated with mountain bogs are all salamanders, though there certainly are a much larger number of amphibians found in mountain bogs. These salamanders (Mole, Four-toed, Marbled, Three-lined, and Spotted Salamanders) for the most part require pools of water, preferably without fish, for breeding purposes. They are associated with mountain bogs, to the extent that mountain bogs (as defined here) often contain pools of water that are utilized as breeding habitat. Their association with mountain bogs is less related to the bog being spring fed, muddy, or with specific plant associations than many of the other priority mountain bog species. These species are more suited to treatment of their threats/problems within the depression community's habitat type and surrounding upland and intact forest corridor habitat. Loss of wetland habitat in general is a significant problem for these species.

Beavers represent an additional unknown factor in mountain bogs and fens. Beaver impoundments may kill bog plants and flood habitats used by wildlife, including rare species. Situations such as Beaver control and fire suppression by humans may not have occurred at all mountain bog sites, but their indirect impact upon mountain bog habitats through facilitation of secondary succession certainly has occurred at some sites. However, some characteristic species, such as Bog Turtles, may have benefitted from Beaver activity in the long run.

4.3.1.6 Recommendations

Bogs and fens occur as small, widely separated patches in certain landscapes and will not be able to migrate in response to climate change. They occur in specialized hydrological environments that are not driven primarily by climate. Much of their biota ranges far to the north and little, if at all, to the south. Because the composition and suite of rare species associated with each site varies dramatically, it is important to protect many examples, and to manage appropriately.

Protecting the remaining unprotected examples and conducting appropriate management in the protected examples are the most important actions for these communities. This includes determining the best vegetation management practices and understanding and correcting artificial alterations to hydrology.

Surveys. Priorities for conducting distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive communities (NCWRC 2005).

- For many of the priority species associated with mountain bogs, we do not have a clear understanding of their current distribution within the state. We must undertake surveys to gather baseline information on the distribution and status of most of these species.

Monitoring. Monitoring of taxa is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These monitoring efforts will inform future decisions on how to manage species. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Given the limited availability and number of threats facing mountain bog habitat, considerable effort needs to be expended to determine if populations are increasing, decreasing, or remaining stable.
- Monitor amphibian populations to detect incidence of fungal and viral infections (e.g., iridoviruses, chytridiomycosis).
- Monitor connectivity of populations separated by fragmentation.
- If Beaver activity is detected in nearby streams, monitor to detect problems from flooding or inundation.

Research. Most species and their interrelationship associated with this habitat are poorly understood. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of priority species to specific threats and studies should provide recommendations for mitigation and restoration. Species propagation is an area of current and ongoing research. Developing techniques for propagation may become critical for preserving species and their genetic stock, particularly those that are rare, at high risk of extinction or extirpation, and difficult to propagate in a laboratory setting.

- Genetic studies to determine degree of gene flow between populations and to assess overall population health for species restricted to this habitat (i.e., Bog Turtle), given the isolated nature of mountain bogs.

- Study amphibian movements to and from breeding habitats and examine upland habitat use (e.g., Ambystomatid Salamanders, Junaluska Salamander, Mountain Chorus Frog).

- Investigate minimum hydroperiods needed by priority amphibian species that utilize ephemeral pools and wetlands. Results can be used to determine when supplemental or interventive measures are needed to support breeding periods and metamorphosis during drought periods.

- Establish a captive breeding program for Bog Turtles and work with land conservation partners to identify sites for population augmentation.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Specific bog management needs to include the control of woody encroachment and succession, the maintenance (and where necessary, restoration) of natural surface water and groundwater hydrology (using ditch plugs, temporary dams, level spreaders, or other engineering devices), the restoration of herbaceous vegetation, and the prohibition of taking rare bog-related species (e.g., Bog Turtle).

- Use clearing methods that create the least impacts; avoid use of chemicals. Where appropriate, use prescribed burning to control encroachment by hardwoods. If mowing, limit to once a year or less and set blade height between 1 and 2 feet to avoid destroying nesting bird and small mammal habitat. If using heavy equipment, disturb only one patch of the site at a time and minimize ruts and compaction of soils and vegetation to the extent possible (Somers et al. 2000).

- If livestock grazing is allowed, limit number of animals to one per acre and allow light to moderate seasonal (winter only) grazing where possible (Somers et al. 2000).

- Provide native vegetation buffers around wetlands to filter pollutants and benefit wildlife (Somers et al. 2000).

- Limit application of fertilizers and lime to lawns and fields surrounding wetlands (Somers et al. 2000).

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the greatest extent possible to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Focus habitat protection measures on utilizing existing regulatory frameworks to protect both the habitat and these species (e.g., state and federal endangered species laws, wetland protection laws, etc.).
- Fully utilize government conservation programs and incentives (e.g., Farm Bill programs) and partnerships with private landowners to stem the conversion of suitable bogs to other uses.
- Actively pursue conservation ownership through acquisition of mountain bogs in concert with state and federal agency partners (e.g., US Fish and Wildlife Service [USFWS], US Forest Service, National Parks Service, Natural Resources Conservation Service, NC Division of Parks and Recreation, NC Natural Heritage Program, local governments, etc.) as well as private conservation partners (e.g., The Nature Conservancy, land trusts).

4.3.2 Estuarine Wetland Communities

4.3.2.1 Ecosystem Description

Estuarine wetland communities are affected by tidal waters in and along the sounds and drowned river mouths (see Section 4.2.14). The community includes brackish marsh, salt marsh, salt flats, and salt shrub components. In addition to the components described here, sand flats, mud flats, and algal mats are part of the estuarine community.

- Salt marshes occur where tides regularly flood the area with undiluted sea water. This environment of repeated flooding and exposure and higher salinity levels limit the diversity of plant species that occur in salt marshes to only a few species. Much of the productivity in salt marshes is likely below ground in organic materials. Saltmarsh and Saltmeadow cordgrasses dominate these communities, and only a few other vascular plants occur. Algae may also be an important part of plant productivity. The abundance of invertebrates such as mollusks and crustaceans indicates the transitional nature of these communities between terrestrial and marine systems.
- Brackish marshes occur in areas where the tidal waters are partly diluted by fresh water. They are low in plant diversity, with Black Needlerush usually dominating vast areas.
- Salt flats occur in fairly small areas of slight depression at the upper edge of salt or brackish marshes. Salty water floods these areas only occasionally. Once flooded, the water is trapped in the depression and evaporates, leaving salt concentrated in the

soil. Vegetation is usually a sparse collection of extremely salt-tolerant plants such as Saltgrass and Glasswort. The center of the salt flat may be completely barren.

- Salt shrub communities occur on the upper edge of salt and brackish marshes, where saltwater rarely reaches or where salt is diluted by fresh water seepage. They are dominated by salt-tolerant shrubs with marsh herbs often occurring in openings.

Estuarine islands are not considered a wetland community but they are particularly important for nesting terns, skimmers, pelicans, wading birds, and American Oystercatchers. Most have been created by deposition of dredged material but there are a few that are natural islands. Dredged material islands are usually devoid of mammalian predators and have the added advantage of being high enough in elevation that ground nesting birds do not lose their nests during normal high tides. Estuarine communities were described as a priority habitat in the 2005 WAP (see Chapter 5) (NCWRC 2005).

4.3.2.2 Location of Habitat

Lower river portions of aquatic communities in the Roanoke, Tar–Pamlico, Neuse, Cape Fear, White Oak, Chowan, and Pasquotank river basins are associated with estuarine wetland communities. The shorelines of the Albemarle–Pamlico estuary system and the sound-side of the Outer Banks barrier islands are also fringed by estuarine wetlands.

4.3.2.3 Problems Affecting Habitats

Dredging. Dredging and dredge material placement can also affect these sites through draining of marshes or filling of wetlands. Dredged material placement has been used very effectively in some areas to create marsh or upland bird nesting areas within the estuaries. Competition with coastal towns that use dredged sand for nourishment projects along developed beachfronts and constraints to navigation channel dredging projects limits access to dredged material for bird nesting islands.

Land Use. Development has impacted much of this habitat type and armoring shorelines to prevent erosion is a growing problem. Predation by nonnative predators and disturbance by people and their pets of nesting birds and the lack of fire to maintain the vegetation structure in marsh sites is also of concern. Beach stabilization projects (e.g., inlet channel relocation and efforts to restrict channel movement) reduce availability of microhabitats such as mud and algal flats around inlets. Ditching can drain estuarine wetlands, disrupt normal hydrologic cycles, contribute to water quality problems by conducting point source discharges into nearby surface waters, and be a conduit for saltwater intrusion.

Water Quality. Water quality impacts from pesticide use (related to mosquito control), secondary impacts from development, and water flow impacts caused by ditching and canals have greatly affected this habitat. Failing septic systems, sewage treatment and marina cleanout effluents, stormwater runoff, industrial organic waste discharge, and agricultural fertilizers or animal wastes contribute excessive nutrients that can result in eutrophication and algal blooms. Mats of algae block sunlight from penetrating the water and will impact sea grasses. Low DO levels can result from algal die-off and decay and excessive algae growth can result in brown or red tides and harmful blooms, such as *Pfiesteria piscicida,* that have been associated with fish kills (EPA 2012b).

Climate Change. Climate change impacts, primarily sea level rise, will lead to shifts in plant composition and more open water habitats. An increase in the number of storm events and storm severity will result in more flooding and erosion of vegetation. The presence of drainage ditches will facilitate saltwater intrusion into more inland natural communities and rapid decomposition of peat soils by sulfate-reducing bacteria (Hackney and Yelverton 1990). Other problems will include subsidence and increased inundation of freshwater communities and release of previously sequestered carbon as carbon dioxide and methane (Hackney and Yelverton 1990).

4.3.2.4 Climate Change Compared to Other Threats

Climate change, particularly rising sea level and the potential erosion of barrier islands, is the greatest threat to estuarine wetland communities. Table 4.16 summarizes the comparison of climate change with other existing threats.

4.3.2.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with estuarine wetlands.

Many bird species associated with these community types have experienced significant declines according to inventory and survey data. Several priority bird species, such as the Seaside Sparrow, Northern Harrier, American Bittern, and Black Rail, are ground nesters in estuarine marsh habitats. If marsh habitat does not migrate inland at comparable rates to habitat losses, these birds may be displaced permanently due to fragmentation and competition pressures. Waterbird species that are colonial nesters are vulnerable to loss of habitat because they have relatively few nesting locations. Beach-nesting birds, sea turtles, and terrapins are more likely to have their nests washed over as sea level rises.

Table 4.16 Comparison of climate change with other threats to estuarine wetland communities

Threat	Rank Order	Comments
Climate Change	1	Estuarine communities are extremely vulnerable to the effects of rising sea levels and the potential erosion and inundation of barrier islands. Loss of barrier islands would expose the mainland side of estuarine areas to open ocean, leading to changes in salinity, tides, and wave action that would likely cause major changes to the mainland coastline.
Development	2	Development near coastal communities has resulted in pollution and water quality declines that impact SAVs. Buildings along shoreline introduce night lighting and light pollution. Development on uplands will prevent inland migration of marshes. Increased movement of sediment and nutrients from inland areas by increasingly intense storms will worsen water quality problems in estuaries, though this effect may be less important than the effects of increased urban development in general. Encroachment on public lands and public trust waters creates impacts to hunting and fishing access.
Pollution	3	Water pollution from rivers and from nearby development has caused fish kills and shellfish closures in some estuaries.
Dredge and Fill Impacts	4	Dredging and dredge material placement can drain marshes or fill wetlands. Dredged material placement has been used very effectively in some areas to create marsh or upland bird nesting areas within the estuaries. However, there is limited funding for dredging projects and increased competition with coastal towns for sand placement for beach nourishment projects. Other beach stabilization projects (e.g. inlet channel relocation and efforts to restrict channel movement) reduce availability of microhabitats such as mud and algal flats around inlets.
Predation and Disturbance	4	Ground-nesting birds are impacted by human disturbance, pets (especially free roaming and feral cats), and wildlife predation by nonnative species.
Invasive Species	4	Nutria are considered a serious pest species in the United States because they eat a variety of wetland and agricultural plants and their burrowing damages streambanks, impoundments, and drainage systems. Herbivory and burrowing damage from Nutria impact estuarine communities. As plant roots are removed and substrates damaged from excavation, soil loss and land subsidence can occur from sea level rise, tidal flooding, and storm surge. *Phragmites* can colonize disturbed areas quickly and can dominate native species.
Alternative Energy Systems	5	Development of wind power turbines will impact birds and bats (major activity zones for both).

Black Ducks also nest in brackish marshes. This species will lose nesting habitat as inundation drowns currently occupied marshes. Climate change will have a significant effect on brackish waterfowl impoundments, which provide high-quality habitats to breeding and wintering waterfowl and other shore and wading birds. Many of these areas will be lost to sea level rise.

Losses, drastic alteration, or disturbance of estuarine communities (especially marsh habitats) could have serious consequences for nutrient cycling and for reproduction of marine and estuarine organisms (Schafale and Weakley 1990). Some reptile species, including sea turtles, terrapins, and American Alligators, exhibit temperature-dependent sex determination. With predicted increases in overall temperatures associated with climate change, it is possible that offspring sex ratios of these species may be affected (Hawkes et al. 2009).

Several rare, disjunct, or endemic species—Carolina Watersnake, Aaron's Skipper, and several moths—are associated with brackish marsh habitats in the sounds of the northern Coastal Plain. The drastic changes in salinity and wave action that are likely to occur if the Outer Banks are breached may drastically affect these species, possibly leading to their extirpation or extinction. If they survive the initial effects of the barrier island breach, however, they may be able to spread to new areas of brackish marsh that will form farther inland on the mainland side of the sounds.

Nutria are a nonnative and invasive mammal in freshwater and coastal marshes and wetlands, inland freshwater streams and rivers, and surface water impoundments. As warming trends increase, the range of Nutria is likely to expand and populations currently limited by intolerance to cold winters will quickly expand. There is some anecdotal evidence Nutria will take over and expand smaller next burrows of native wildlife such as Muskrats, thereby displacing native species. Nutria may also be a vector for diseases (tuberculosis and septicemia) or parasites (*Giardia, Fasciola*, Liver Flukes, and nematodes), with fecal contamination in water the likely pathway (Carr 2010).

4.3.2.6 Recommendations

Land acquisition will play a vital role in protection of the future shoreline. Because dramatic movement of these communities is probably inevitable as sea level rises, one of the most important things that can be done to help them adapt is to protect areas where they can migrate to. Protection of low-lying shoreline areas that would allow for inland migration is difficult but would provide important benefits.

Surveys. Priorities for conducting distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Gather baseline information on sex ratios for species with temperature-dependent sex determination (all sea turtles, terrapins, alligators) to characterize impacts from climate change.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions.

Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Continue monitoring beach-nesting birds due to their high vulnerability.
- Begin monitoring potential changes to offspring sex ratios for species with temperature-dependent sex determination (all sea turtles, Diamondback Terrapins, American Alligators).
- Collect spatial information on the distribution of estuarine habitats, document their characteristics, such as salinity, water levels, plant community struction and density, and monitor marsh die-back events.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of SGCN and other priority species to specific threats and studies should provide recommendations for mitigation and restoration.

- Determine the migration pathways and wintering grounds for marsh birds.
- Investigate the mortality factors of sea turtles within the estuaries.
- Determine the habitat use, population levels, and distribution of priority marsh birds such as the Seaside Sparrow, Willet, Least Bittern, American Bittern, King Rail, and Black Rail.
- Investigate Nutria population densities, population growth rates, dispersal range, and extent of property damage from burrowing and herbivory.
- Conduct research to better characterize the use of estuarine habitats by American Alligators.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Allow barrier islands to migrate, as it increases their chance of survival and reduces the chance of sudden and drastic changes in tidal regime in the estuaries.

- Where practical, restore marsh habitat by filling drainage ditches and installing ditch plugs and water control structures. Ditches may accelerate erosion and the effects of rising sea level such as saltwater intrusion.

- Protect suitable nesting habitat for sea turtles and beach-nesting birds to maintain robust populations as disturbance and sea level rise issues mount.

- Continue working with the US Army Corps of Engineers and others to direct dredged material or conduct other management actions to refurbish waterbird nesting islands.

- Continue coordination with the NC Division of Marine Fisheries to minimize bycatch of protected/priority species in fishing gear.

- Control or minimize the amount of large gull depredation on other beach-nesting birds. These large gulls did not nest in the state until recent decades but are now greatly increasing in number and are causing more pressure on beach-nesting bird populations.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Protect tidal freshwater wetlands in rivers and upper sounds, some of which will become the extensive estuarine communities in the future. Salt and brackish marshes will benefit from this.

- Protect buffers and floodplain rivers, as this will benefit estuaries by reducing pollutant input and reducing drastic changes in freshwater input.

- Protect inland tidal freshwater wetlands, which will become extensive estuarine communities in the future, and allow the barrier islands to migrate and new inlets to form.

- Focus on land acquisition and protection for a number of heronries (e.g., Rawls Island) on the mainland side of Pamlico Sound where brackish marshes are in private ownership. Acquisition targets should include brackish marsh impoundments, which will then require continued management for maintenance.

- Protect habitats in large enough patches to sustain priority species, reconnect fragmented habitats, restore habitats that have been lost or converted, enhance the function and structure of habitats that have been degraded, and manage habitats for priority species (ACJV 2004).

- Work with partners (e.g., NC Coastal Federation, Audubon NC, TNC, Ducks Unlimited) to leverage funding programs such as the North American Wetlands Conservation Act that target conservation of coastal wetlands.

- Implement conservation measures outlined in the Albemarle–Pamlico National Estuary Partnership (see http://portal.ncdenr.org/web/apnep).

4.3.3 Floodplains—Blackwater Systems

4.3.3.1 Ecosystem Description

Floodplains are defined as "areas of low lying land that are subject to inundation by lateral overflow water from rivers or lakes with which they are associated" (Junk and Welcomme 1990; Tockner and Stanford 2002). Other terms frequently used to refer to floodplains include alluvial forests, bottomlands, fluvial systems, riverine forests, or stream or riparian zones. Floodplains can be comprised of more than one community type since the timing, depth, and duration of flooding are considered the primary influence on plant species composition (Wharton et al. 1982; Kellison et al. 1998; Mitsch and Gosselink 2000; Burke et al.2003). The floodplain community will also be influenced by variations in soils and microenvironments that occur in the landscape adjacent to the aquatic community. In its natural state, floodplains have high biodiversity and productivity as well as providing recreational and aesthetic values (Tockner and Stanford 2002).

Blackwater floodplains include the vegetated communities on the floodplains of blackwater rivers. Blackwater rivers are lowgradient rivers in small watersheds where hydroperiods are characterized by short duration floods that may be deep and widespread, followed by extensive periods of lower discharge (Burke et al. 2003). The flow often is not sustained, and extended droughts during the growing season can occur in these floodplains (Wharton et al. 1982; Burke et al. 2003).

Contrary to brownwater rivers, they carry little mineral sediments (e.g., clay and silt). Instead, the water chemistry in blackwater rivers is dominated by dissolved organic matter leached from decomposing vegetation and is generally low in pH and nutrients. The water is tea-colored but not cloudy. The soils of blackwater floodplains are usually sandy or mucky and are acidic and relatively infertile. Many floodplains, particularly the larger ones, have at least some development of depositional features such as natural levees, point bars, and ridge-and-swale systems, but these are not as large or prominent as on brownwater rivers. Many smaller blackwater floodplains are filled with muck and are flat and featureless.

Communities that occur in blackwater floodplains include: Coastal Plain levee forest and bottomland hardwoods on the larger floodplains, cypress-gum swamps in the wettest and forested parts of the floodplain, Coastal Plain small stream swamps, Coastal Plain semi-permanent impoundments (e.g., Beaver ponds, millponds), oxbow lakes along the large rivers in abandoned channel segments, and sand and mud bars along the rivers (Schafale and Weakley 1990).

4.3.3.2 Location of Habitat

Blackwater rivers originate in the Coastal Plain ecoregion and many are located in the lower portion of the river basins that drain to the Atlantic coast. Examples of blackwater streams and rivers include the South River, Black River, Waccamaw River, and the Northeast Cape Fear River. The Lumber River mainstem is the only North Carolina blackwater river designated as a National Wild and Scenic River.

4.3.3.3 Problems Affecting Habitats

The floodplain forest systems of the Coastal Plain in the southeast are now only small fragments and sections of the original millions of acres present before European settlement that have been lost or altered by development, drainage, agriculture, and logging (Weller and Stegman 1977).

Climate Variability. Milder winters will result in potentially longer growing seasons and earlier bloom times for plants and earlier breeding periods for reptiles and amphibians. Most species in this habitat type have a southeastern distribution and are fairly well adapted to higher temperatures. Increased temperatures will likely result in decreased winter kills of nonnative species and will likely allow these species native to areas further south to survive and reproduce. Insect infestations may increase and negatively affect forest health. Drought conditions will allow invasion of upland species (e.g., Red Maples and beech). Some more southern species may migrate into these communities. Conversion of lower river areas to tidal marsh will allow the Common Reed to invade. Increased temperatures and decreased winter kills will allow southern species to move farther north (e.g., the Asian Dayflower, Japanese Climbing Fern, Chinese Tallow Tree).

Storms. Increased hurricane intensity will increase blow down, especially near the coast. Bottomland hardwoods are more likely to be affected by windthrow than other floodplain communities. Increased canopy gaps may result from increased storm wind damage and from flood scouring. Flooding could benefit canebrakes and their associated species, but both the magnitude and direction of the effects are uncertain. Species composition could change following storm damage, resulting in loss of mast-producing species. Increased severity of flooding may destabilize channels, alter sediment load and deposition, and increase erosion. Increased frequency may have beneficial effects but increased duration may kill species not adapted to long periods of inundation. More large floods might mean increased river area with increased instability of bars. This would come at the expense of forests along the river banks, which are often the least altered forests in the floodplains. If flood frequency increases, it might also cause the boundaries between bottomland hardwoods and cypress-gum swamp to shift. Effects on species composition are unknown but changes to the overall community structure are likely, especially in lower reaches that may eventually convert to marsh.

Sea Level Rise. Saltwater intrusion associated with sea level rise is expected to have significant adverse effects on lower reaches of blackwater floodplains where it is likely to affect long-term survivability of canopy species. Saltwater intrusion will affect long-term survivability of canopy species in the lower floodplain reaches. Wetlands close to the Cape Fear River near Wilmington and the lower portion of the Scuppernong River near Columbia have already been impacted. No expansion of this community type is possible upstream and expansion into the Piedmont is not possible for this ecosystem. Consequently, the net effect from climate change will be an overall loss of acreage. Because there is not substantial potential for the floodplain systems to expand inland, there will be a net loss in area.

4.3.3.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While climate change is not the most severe threat, a combination of synergistic effects with other existing conditions could stress these systems to the point where several species are unable to persist.

Changes in flood regimes and rising sea level are the most important climate effects. Most Coastal Plain wetland communities, including blackwater systems, may be moderately vulnerable to climate change, depending on importance of precipitation and riverine flooding for hydrologic inputs. Direct loss of wetlands due to sea level rise is expected to be the greatest threat in coastal landscapes (DeWan et al. 2010). However, these systems will remain common. Table 4.17 summarizes the comparison of climate change with other existing threats.

4.3.3.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

Table 4.17 Comparison of climate change with other threats to blackwater floodplains

Threat	Rank Order	Comments
Flood Regime Alteration	1	Effects of changed flooding regime are very uncertain. If floods become more extreme, channels may begin to migrate more. Levee communities, where present, are the forested floodplain community most likely to be affected by changes in flooding regime and channel stability. Increased canopy gaps may result from increased storm wind damage and from flood scouring.
Logging/ Exploitation	1	Logging will remain a large source of altered canopy age and structure. This might benefit species that depend on canopy openings.
Pollution/Siltation	2	In particular, nutrient loads have the potential to greatly increase with the construction of new poultry processing facilities in coastal counties. Untreated stormwater runoff from large cities and towns is a major problem that impacts both aquatic life and terrestrial wildlife associated with floodplain forests.
Groundwater Depletion	2	Increased drought may lead to demand for more water withdrawal.
Invasive Species	2	Chinese Privet, Japanese Stiltgrass, Japanese Honeysuckle, and Asian Dayflower are already problems and are expected to increase with climate change. If not controlled, these species will greatly expand the acreage severely affected, regardless of climate. Canopy gaps could allow invasive species to become established, especially Japanese Stiltgrass.
Climate Change	3	The effects of rising sea level would be felt only in the lower reaches of the rivers. Large expanses in these areas would shift to tidal swamps. Saltwater intrusion could occur during floods or high storm surge.

Loss of old growth characteristics (canopy gaps, vine tangles, hollow trees, dead and downed woody material) and fragmentation of stands is a major concern. A lack of standing dead or older trees has impacted the availability of quality bat and Chimney Swift roosting and breeding sites and nesting productivity for species such as Wood Duck and Hooded Merganser. Removing woody debris from streams after storms has influenced in-stream habitat structure and food webs. Lack of downed woody debris has impacted a variety of amphibians and reptiles.

Fragmentation of floodplain forest stands has contributed to the loss of intact large riparian corridors and the width of many riparian corridors has been greatly reduced. Breeding area-sensitive bottomland-hardwood birds have likely been impacted by the loss of intact woodland systems. Large patches of floodplain habitat are lacking in much of the Coastal Plain. High-grading logging practices have changed plant species diversity and stand vegetative structure. Logging has reduced colonial waterbird and Bald Eagle nesting areas.

Alteration of hydrology due to dam creation and the draining of wetlands are one of the primary problems affecting species in this habitat type. The impacts of development adjacent to rivers and streams includes potential problems associated with direct input of contaminants and sediment, alteration of hydrologic patterns and processes, temperature regimes, and loss of critical habitat adjacent to aquatic habitat that may be of equal importance to species that only spend a portion of their lives in the water, like some amphibians. Drainage of wetlands has exacerbated the problems in and adjacent to floodplain forest habitats. This habitat loss impacts all floodplain species, including furbearers, breeding amphibians, overwintering birds, and migrant species that use these areas as stopover sites. Water quality is also an issue in certain major river drainages that negatively affects many invertebrates, fish, amphibians, and reptiles.

This ecosystem contains some extremely rare disjunct and near endemic plant species. Their rarity makes them vulnerable to changes in habitat. Random events in specific locations can have major impacts on the expected viability of whole species. Two cane-feeding moths are endemic (or nearly so) to the North Carolina Coastal Plain. Habitat for these species is divided between blackwater and brownwater floodplains, as well as peatlands. All of these species, plus the larger guild of cane-feeding insects, is likely to benefit from increased canopy gaps and other disturbances associated with climate change.

Diversity of "native" species may potentially increase due to movement of more southerly species northward into this habitat type (e.g., Wood Storks, Swallowtail Kites, water elms, water locusts). The Wood Stork has expanded its breeding range in the state and is now nesting at several blackwater stream/river sites. More substantial changes may occur in floodplains north of North Carolina, beyond the current range of widespread southern floodplain species.

4.3.3.6 Recommendations

Surveys are needed to document the distribution, relative abundance, and status of many wildlife species associated with these habitats. Priorities for conducting surveys need to focus on species believed to be declining, at risk, or mainly dependent on these communities (like rails). Secondary priority for surveys should be for species for which current distribution information is already available or for species that are considered common. Many bird species associated with these community types are not sampled well or at all by the Breeding Bird Survey (BBS).

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Document Bald Eagle nesting sites.
- Survey for poorly known or secretive semi-aquatic snakes—Rainbow Snake, Glossy Crayfish Snake, and Black Swamp Snake.

- Determine the breeding and roosting status and distribution of Chimney Swifts in natural conditions along major floodplains with appropriate habitat conditions (e.g. older, hollow trees).

- Design specific surveys to determine status and distribution of birds not adequately picked up by the BBS in floodplain forests (e.g., the Cerulean Warbler, Swainson's Warbler, Kentucky Warbler, Worm-eating Warbler, Hooded Warbler, Prothonotary Warbler, etc.).

- Survey for bat species that roost or forage in blackwater systems.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Continue nest monitoring for colonial waterbirds, especially Wood Storks.

- Continue long-term monitoring of active Bald Eagle territories, successful breeding pairs, and fledged eagles.

- Establish Monitoring Avian Productivity and Survivorship (MAPS) and migration banding stations, as well as specialized long-term monitoring for hard-to-sample species such as the Cerulean and Swainson's warbler (Graves 2001).

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Explore techniques for restoration of tidal swamp forest and wetlands.

- Investigate the past, current, and potential future impact of nutria on both floral and faunal communities and individual species.

- Research the genetic makeup of the coastal population of the Black-throated Green Warbler.

- Research the genetic relationships among floodplain salamanders.

- Determine the conservation and restoration efforts needed for priority species in this habitat.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Wherever possible, maintain or restore floodplain forest connectivity, as floodplain forests are important distribution and dispersal corridors for many species (Bailey et al. 2004). This would benefit floodplain forest species such as the Northern Parula, Yellow-Throated Warbler, Prothonotary Warbler, Wood Thrush, Swainson's Warbler, and Acadian Flycatcher, as well as amphibians, Timber Rattlesnakes, and forest bats.

- Ensure floodplain buffers of 300 to 600 feet in as many areas as possible. Where possible, forest patches should be connected along river systems to provide connectivity.

- Make an attempt to protect waterbird nesting colonies.

- Further expand the Forest Landbird Legacy Program (a cooperative effort between the Commission, the USFWS, and the Natural Resources Conservation Service) to influence habitat for birds and other wildlife in mature floodplain forests through canopy gap management and other options.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Initiate partnerships with the Natural Resources Conservation Service to begin cane restoration projects and research.

- Continue cooperative efforts with colonial waterbird (wading bird) working groups and follow future management recommendations from the North American Waterbird Management Plan (Kushlan et al. 2002).

- Work to develop eight patches of forested wetlands at least 10,000 acres in size throughout the South Atlantic Coastal Plain, as called for in the South Atlantic Coastal Plain Partners in Flight Bird Conservation Plan (Hunter et al. 2001b).

4.3.4 Floodplains—Brownwater Systems

4.3.4.1 Ecosystem Description

This ecosystem group includes the vegetated communities that occur on brownwater floodplains. In contrast to blackwater rivers, they carry heavy loads of mineral sediment, particularly clay and silt. The water is generally near neutral pH and high in nutrients. The deposition of sediment in the floodplain provides a periodic nutrient input that keeps the soils rich. Depositional topographic features such as natural levees, point bars, ridge-and-swale systems, and sloughs are well developed, with their size depending on the size of the river.

There are seven communities that occur in Coastal Plain brownwater floodplains: Levee Forests, Bottomland1 Hardwoods, Small Stream Swamps, Cypress–Gum Swamps, Semipermanent Impoundments, Oxbow Lakes, and Sand and Mud Bars (Schafale and Weakley 1990).

4.3.4.2 Location of Habitat

Brownwater rivers originate in the Mountains or Piedmont and flow eastward into the Coastal Plain ecoregion. Brownwater floodplain forests of various conditions and sizes can be found throughout the Coastal Plain ecoregion; however, the majority of them are associated with the Roanoke, Tar–Pamlico, Neuse, and Cape Fear rivers. The condition of Coastal Plain floodplain forests of all types have been greatly reduced in recent years throughout North Carolina and the entire southeast (Weller and Stegman 1977; Schafale and Weakley 1990) by a variety of anthropogenic factors.

4.3.4.3 Problems Affecting Habitats

Flooding. Factors that impact these systems include flooding regime patterns that have been changed by dams and other development, habitat fragmentation, changes in water chemistry and organic matter loads, increased nitrogen from agricultural and development-related runoff, exotic species and high-grading of stands and logging that reduces wide buffers. All of these factors individually or interactively produce abrupt or gradual changes in floodplain plant and wildlife communities. In particular, the sediment load in many brownwater rivers is now a major problem in the Coastal Plain, and even many blackwater systems now have high sediment loads (Schafale and Weakley 1990).

Increased frequency and/or severity of flooding will likely have a mix of positive and negative influences. Changes in rainfall regime may also induce water management that produces more floods of unnatural, destructive long duration. If floods become more extreme, channels may begin to migrate more. Increased scouring by more severe floods would create more early successional bar communities at the expense of mature communities on the banks. Increased magnitude of floods could affect higher terraces that now see little flooding. Leigh (2008) and Leigh et al. (2004) suggest that Coastal Plain rivers may be near a threshold for switching to a braided channel morphology. More large floods might mean increased area but reduced stability of sand and mud bars. Given the water availability in floodplains, drought is unlikely to stress floodplain ecosystems. The effect will be mostly in the form of allowing upland species to invade.

Climate Variability. Inundation from sea level rise will create wholesale change to a tidal system in the downstream portions. Large expanses in these areas will shift to tidal swamps. Saltwater intrusion would likely affect long-term survivability of canopy species in the lower floodplain reaches. Saltwater intrusion could occur further upstream during floods or high storm surge.

Increased wind disturbance may cause some shifts in species composition, such as favoring sweetgum and loblolly pine over oaks in bottomland hardwoods. These will be relatively small compared to the past and ongoing similar effects of logging, but will exacerbate them. Increased wind damage would decrease average canopy age and increase the proportion of gaps. Increased tree growth rates may offset the structural effect to some degree. Bottomland hardwoods will likely be most affected by structural and compositional changes from increased wind storms.

No significant inland migration is possible for this community so there will be a net loss of acreage, mostly caused by inundation from rising sea level. Some Coastal Plain species may be able to expand into the Piedmont as the climate warms, but many of the differences between brownwater and inland floodplains are the result of geology rather than climate. There is an expectation that nonnative plants (e.g., Chinese Privet, Japanese Stiltgrass, Japanese Honeysuckle) will increase and there will likely be additional invasive species, such as the Chinese Tallow Tree.

4.3.4.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While climate change is not the most severe threat, a combination of synergistic effects with other existing conditions could stress these systems to the point where several species are unable to persist. Other than rising sea level, the effects of climate change are particularly uncertain in these systems.

Changes in flood regimes and rising sea level are the most important climate effects. Climate change effects upstream of the tidal zone are likely to be limited and other existing threats are likely to be more significant. Table 4.18 summarizes the comparison of climate change with other existing threats.

4.3.4.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H provides a list of the SGCN that depend on or are associated with this habitat type.

The few brownwater floodplains generally occur far apart on the landscape, are not hydrologically connected, and few have north–south courses, making it difficult for plants and animals confined to brownwater floodplains to move northward as suitable conditions are lost.

Table 4.18 Comparison of climate change with other threats to brownwater floodplains

Threat	Rank Order	Comments
Logging/ Exploitation	1	This is the most destructive recent force and may get worse if drought allows more access to currently wetter areas.
Utility Corridors/ Fragmentation	1	Floodplains are highly susceptible to fragmentation by sewerlines, gaslines, powerlines, and highways that are constructed within them. Nonnative, exotic, and invasive species can gain a foothold in openings within these corridors.
Climate Change	2	Temperature and rainfall averages are expected to increase. More important will be changes in frequency and magnitude of extreme rainfall events, which will affect flood regimes. An increase in droughts is also expected.
Invasive Species	2	Temperature increases create potential for invasion by exotic species that are already problematic farther south, such as the Chinese Tallow Tree. Invasive exotic species already spreading in these systems, such as Tree-of-heaven, Asian Dayflower, and Japanese Stiltgrass, will continue to spread regardless of the climate, but any increased disturbance by flooding or wind storms may accelerate it.
Flood Regime Alteration	2	Alteration of hydrology due to dam creation and the draining of wetlands is one of the primary problems affecting this habitat type. Upstream dams are significant on some rivers but not others. Increased drought may lead to demand for more reservoirs upstream and to more water withdrawal and interbasin transfer in all large river systems.
Conversion to Agriculture/ Silviculture	3	Very significant in the past but most feasible conversion is already done.

Large patches of floodplain habitat are absent in much of the Coastal Plain. Fragmentation of stands has contributed to the loss of intact large riparian corridors and the width of many riparian corridors has been greatly reduced. Breeding area–sensitive bottomland-hardwood birds have likely been impacted by the loss of large patches of intact woodland systems. Swallow-tailed Kite is an area-sensitive species and is now known to breed within the state along the Cape Fear River. High-grading of stands has changed plant species diversity and stand vegetative structure. Forestry activities (e.g., logging) have reduced colonial waterbird and eagle nesting areas, but wading birds make more use of timber-cleared wetlands for foraging.

Two cane-feeding moths are endemic to the region but also occur in blackwater floodplains and non-riverine swamp forests. Another cane-feeding moth appears to be significantly disjunct within the lower Cape Fear floodplain. Two hawthorn-feeding moths also appear to have disjunct populations in the lower Roanoke floodplain, as does the Cerulean Warbler. None of these species appear likely to be affected by climate change-related impacts.

Drainage of wetlands has exacerbated the problems in and adjacent to floodplain forest habitats. This habitat loss impacts all floodplain species, including furbearers, breeding amphibians, overwintering birds, and migrant species that use these areas as stopover sites. Water quality is also an issue in certain major river drainages that negatively affects many invertebrates, fish, amphibians, and reptiles (NCWRC 2005).

Long-duration flooding has had impacts on all ground-nesting bird species. Loss of old growth characteristics (canopy gaps, vine tangles, hollow trees, dead and downed woody material) and fragmentation of stands is a major concern. A lack of standing dead or older trees has impacted the availability of quality bat and Chimney Swift roosting and breeding sites and nesting productivity for species such as the Wood Duck and Hooded Merganser. Lack of downed woody debris has impacted a variety of amphibians and reptiles (NCWRC 2005).

4.3.4.6 Summary and Recommendations

In general, protection and restoration of natural composition and function, and protection of surrounding natural areas are the best way to improve the ability of these communities to adapt to climate change. Protection of a large and diverse pool of examples is the best way to ensure that many survive the future stresses.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Conduct surveys to document the distribution, relative abundance, and status of wildlife species associated with brownwater floodplain forest habitats. Priorities include Swallow-tailed Kite, Cerulean Warbler, Wood Stork, bats, and species believed to be declining, at risk, or mainly dependent on floodplain forest communities.
- Give secondary priority to surveys of species for which current distribution information is already available or for species that are considered common.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Expand and/or target monitoring systems to be able to assess current population status and trend information for all wildlife species associated with floodplain forest habitats.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Ensure that research studies targeting birds are long-term, large-scale, replicated studies that have controlled experimental approaches and focus on population demographics and the response of species to habitat manipulations where appropriate (as outlined by the National Partners in Flight Research working group) (Donovan et al. 2002; NCWRC 2005). Similar research priorities are needed for other floodplain forest taxa including bats, small mammals, amphibians, and reptiles.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Make efforts to retain old growth floodplain forest (for Chimney Swifts, bats, and herpetofauna).

- Ensure floodplain buffers of 300 to 600 feet in as many areas as possible. This would benefit floodplain forest species such as the Northern Parula, Swallowtailed Kite, Mississippi Kite, Prothonotary Warbler, Wood Thrush, Swainson's and Cerulean warblers, and Acadian Flycatcher, as well as amphibians, Timber Rattlesnakes, and forest bats.

- Restore natural hydrology where dams have altered hydrology, such as on the Roanoke River.

- Work with partners to institute more natural water release regimes from dams.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Pursue land acquisition and easements through cooperation with land trusts with an effort to increase the width of riparian buffers and create larger patches of connected habitat. Priority should be given to brownwater bottomlands, as these are the most species-rich and are more susceptible to clearcutting and other timber harvest than cypress-gum swamps (i.e., wetter sites) (NCWRC 2005).

- Wherever possible, maintenance or restoration of floodplain forest connectivity should be pursued; floodplain forest are important distribution and dispersal corridors for many species (Bailey et al. 2004 in NCWRC 2005).

4.3.5 Floodplains—Inland Systems

4.3.5.1 Ecosystem Description

For this natural community description, Inland Floodplains are forested communities associated with freshwater systems of various conditions and sizes and are located primarily in the Mountain, Piedmont, and Sandhills ecoregions. Depending on landscape position and soil moisture gradients, some of the wetland communities described in Section 4.3 may also be part of the inland floodplain community; however, in this description, floodplain forests are considered the dominant community type. For this natural community description, inland floodplains are forested communities associated with freshwater systems of various conditions and sizes and are located primarily in the Mountain, Piedmont, and Sandhills ecoregions.

Floodplain systems in the Coastal Plain ecoregion may be associated with blackwater rivers (originating in the Coastal Plain) or brownwater rivers (originating in the Piedmont or Mountains but flowing into the Coastal Plain). Floodplains in the Coastal Plain are typically characterized as broad alluvial features that may be inundated for prolonged periods every year with low gradient meandering streams that terminate in tidal estuaries (Hupp 2000). Separate community descriptions are provided for the blackwater and brownwater floodplains (see Sections 4.3.3 and 4.3.4, respectively) because of their unique characteristics.

In the Piedmont and Sandhills ecoregions, floodplain forests generally do not contain the significant recognizable elevation differences seen in the larger coastal floodplain systems. In these smaller floodplains, the relief and size of the fluvial landforms (levees, sloughs, and ridges) that differentiate the communities in large floodplains become smaller and harder to find (Schafale and Weakley 1990). In larger and more expansive examples of these floodplains, the forest canopy contains a good mixture of bottomland and mesophytic (moderately moisture tolerant) plant species.

Floodplain forests of the Mountain ecoregion are relatively narrow and do not contain well-developed levees, sloughs, and ridges. Smaller high gradient streams often do not have representative floodplains, but instead have riparian zones embedded within other habitat types such as isolated patches of various wetland communities (Schafale and Weakley 1990). Mountain floodplains are subject to sporadic high-intensity flood events of short duration.

4.4.5.2 Location of Habitat

Floodplain forests of some type are found beside most rivers and streams in the Piedmont and Sandhills ecoregions. They are of varying widths, depending on the topography of land adjacent to the river, and the transition between floodplain and upland forest is often gradual. Mountain floodplains are generally restricted to larger streams and rivers with relatively low gradients of the valley landscape.

4.4.5.3 Problems Affecting Habitats

Flooding. Natural floodplains are biologically productive and diverse ecosystems that are among the most threatened due to habitat alteration, flow and flood control, invasive species, and pollution (Tockner and Stanford 2002). The condition of floodplain forests of all types has been greatly reduced in recent years throughout North Carolina and the entire southeast (Weller and Stegman 1977; Schafale and Weakley 1990) by a variety of anthropogenic factors. Factors that impact these systems in North Carolina include flooding regime patterns that have been changed by dams and other development, habitat fragmentation, changes in water chemistry and organic matter loads, increased nitrogen from agricultural and development-related runoff, exotic species, and high-grading of stands and logging that reduces wide buffers. All of these factors individually or interactively produce abrupt or gradual changes in floodplain plant and wildlife communities.

Long-duration flooding has had impacts on all ground-nesting bird species. Loss of old growth characteristics (canopy gaps, vine tangles, hollow trees, dead and downed woody material) and fragmentation of stands is a major concern. A lack of standing dead or older trees has impacted the availability of quality bat and Chimney Swift roosting and breeding sites and nesting productivity for species such as Wood Duck and Hooded Merganser. Lack of downed woody debris has impacted a variety of amphibians and reptiles.

Land Use. Logging and clearing land for agriculture, development, recreational use, and reservoir construction all cause direct loss and alteration of floodplain forests. In the past half century, an estimated 52% of bottomland forests in the south have been cleared for agriculture or development (Smith et al. 2002). Land clearing activities conducted adjacent to, and up and downstream of floodplain forests can cause indirect impacts to the floodplains, particularly related to hydrology. Areas adjacent to floodplains are often prime targets for general development and subdivisions, and buffer size is often inadequate to provide any protection from a variety of anthropomorphic disturbances over time. For instance, flooding events may occur with greater frequency in some areas due to increased upstream impervious surfaces and clearing of vegetation near buffers.

Snags play a very important role in providing nesting, foraging, and roosting areas for many cavity-nesting birds, bats, arboreal mammals, reptiles, and amphibians. Lack of snags and den trees is often a limiting factor for several species of wildlife, especially secondary cavity users (McComb et al. 1986). Younger riparian forests can also lack dead wood on the ground, which is important for some songbirds (like the Kentucky Warbler), many reptiles, amphibians, and some small mammals.

Dams can alter the timing and duration of flood events. Alteration of hydrology due to dam creation and the draining of wetlands changes plant communities and also affects the availability of ephemeral wetlands for breeding amphibians. Building ditches and canals in floodplains dramatically alters hydrology and is often done to prepare a floodplain for agriculture, forestry, or development. Even in abandoned sites, ditches will continue to alter the hydrology for many decades. Habitat loss from wetland drainage impacts all floodplain species, including furbearers, breeding amphibians, overwintering birds, and migrant species that use these areas as stopover sites.

Fragmentation of forest stands has contributed to the loss of intact large riparian corridors and the width of many riparian corridors has been greatly reduced. Breeding area-sensitive bottomland-hardwood birds have likely been impacted by the loss of intact woodland systems. High-grading of stands has changed plant species diversity and stand vegetative structure. Forestry activities (e.g., logging) have reduced colonial waterbird and eagle nesting areas. Clearing of adjacent uplands can increase edge effects and limit the effective size of floodplain forest habitat.

Water Quality. Sewer lines have been constructed along many floodplain corridors, especially in urbanized areas. These corridors fragment floodplain forests and allow conditions for invasion of exotic plant species. Poor water quality due to nutrient inputs, reduced dissolved oxygen (DO) levels, sedimentation, and chemical contamination (among others) can have a strong impact on amphibians, turtles, and other animals associated with floodplain forests that forage or breed in aquatic areas, in addition to the direct impacts on fully aquatic species. Sediment pollution is a major problem in the Piedmont and Coastal Plain. Beaver activity and the creation of beaver ponds in floodplain forest can have substantial impacts on trapping sediment and associated pollutants.

Invasives. Increases in amounts of non-native plants (e.g., Chinese Privet, Japanese Stiltgrass, Japanese Honeysuckle) and the overall loss of large canebreaks are partly due to the lack of infrequent fire and also certain logging practices. Understory vegetative diversity has declined in many areas due to modified flooding regimes and increases in invasive nonnative plant species. The reduction in overall plant diversity is often extensive due to these invasive nonnative plants and may cause problems for native fauna, though the extent of wildlife impacts is largely unknown.

4.3.5.4 Climate Change Compared to Other Threats

While climate change may not be the most severe threat, a combination of synergistic effects with other existing conditions could stress these systems to the point where several species are unable to persist.The effect of a changed climate is likely to vary widely among examples of this community type, depending on topographic sheltering, configuration of soil type and depth, elevation of groundwater, and the timing and duration of precipitation. Table 4.19 summarizes the comparison of climate change with other existing threats.

4.3.5.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H provides a list of the SGCN that depend on or are associated with this habitat type.

The vegetative cover of some floodplains was historically maintained in Switch Cane and herbaceous plants through fire and other periodic disturbance. Small remnants of "canebrake" communities still exist throughout the Piedmont, but management strategies to

Table 4.19 Comparison of climate change with other threats to inland floodplains

Threat	Rank Order	Comments
Logging/ Exploitation	1	This is the most destructive recent force and may get worse if drought allows more access to wetter areas.
Utility Corridors	1	Sewerlines and gaslines have already created much damage to inland floodplains. Transmission lines also fragment these floodplains. As human population increases, corridor impacts will continue to increase, as well.
Climate Change	2	Temperature and rainfall averages are expected to increase. More important will be changes in frequency and magnitude of extreme rainfall events, which will affect flood regimes. An increase in droughts is also expected.
Invasive Species	2	Temperature increases create potential for invasion by exotic species that are already problematic farther south, such as Chinese Tallow Tree. Invasive exotic species already spreading in these systems, such as privet, Japanese honeysuckle, and Japanese grass will continue to spread regardless of the climate, but any increased disturbance by flooding or wind storms may accelerate it.
Flood Regime Alteration	2	Alteration of hydrology due to dam creation and the draining of wetlands are one of the primary problems affecting this habitat type. Upstream dams are significant on some rivers but not others. Increased drought may lead to demand for more reservoirs upstream and to more water withdrawal and interbasin transfer in all large river systems.
Conversion to Agriculture/ Silviculture	3	Somewhat significant in the past but most feasible conversion is already done.

maintain this feature are almost nonexistent. Migratory landbirds that use switch cane areas for breeding include Hooded Warblers, Kentucky Warblers, and Swainson's Warblers.

Floodplains are also important as movement corridors for mammals, reptiles, and amphibians. Birds use riparian corridors at all times of the year and these areas are especially important to neotropical migrants during the migration periods. Indeed, floodplain forests generally have the highest nesting bird concentrations in the state and they are arguably the most important habitats for birds. Floodplain pools that occur in small depressions and are flooded for a portion of the year generally have few or no trees and are especially important sites for breeding amphibians such as Spotted Salamanders, Marbled Salamanders, Four-toed Salamanders, and many frogs.

4.3.5.6 Recommendations

In general, protection and restoration of natural composition and function, and protection of surrounding natural areas are the best ways to improve the ability of these communities to adapt to climate change. Protection of a large and diverse pool of examples is the best way to ensure that many survive the future stresses.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Design specific surveys to determine status and distribution of birds not adequately picked up by the Breeding Bird Survey in floodplain forests (e.g., the Cerulean Warbler, Swainson's Warbler, Kentucky Warbler, Worm-eating Warbler, Hooded Warbler, Prothonotary Warbler, etc.).
- Determine the status and distribution of Wayne's Black-throated Green Warbler.
- Determine the status and distribution of the Swallow-tailed Kite, Mississippi Kite, Yellow-crowned Night-heron, and Anhinga (as well as other colonial nesting waterbirds).
- Determine the breeding and roosting status and distribution of the Chimney Swift in natural conditions along major floodplains with appropriate habitat conditions (e.g., older, hollow trees).
- Determine the status and distribution of priority bat species, including Northern Long-eared Bat, Rafinesque's Big-eared Bat, Northern Yellow Bat, Seminole Bat, Southeastern Bat, Little Brown Bat, and Tricolored Bat.
- Conduct small mammal surveys, especially for the Eastern Woodrat, with a focus on circumneutral soils (other small mammal survey needs include the Cotton Mouse and Southern Pygmy Shrew).
- Determine the status and distribution of snakes using floodplain forest habitats (Taylor and Jones 2002).
- Document Bald Eagle nesting sites.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Continue long-term monitoring of active Bald Eagle territories, successful breeding pairs, and fledged eagles.

- Develop monitoring for any North Carolina floodplain forest bird species that require specialized attention, since neither BBS nor standard point counts can adequately sample irregularly distributed or clumped species like Kentucky, Cerulean, and Swainson's warblers.

- Develope or enhance long-term monitoring for amphibians and reptiles (Taylor and Jones 2002).

- Develop or enhance long-term monitoring for most bat species (Ellis et al. 2002).

- Conduct long-term monitoring for floodplain forest birds (breeding, migration, and winter periods) in forest patches of varying size (Robbins et al. 1989; Doherty and Grubb 2000).

- Establish long-term monitoring for herpetofauna using floodplain forest habitat (especially breeding salamanders and snakes).

- Examine demographics and habitat use of bats in floodplain forests; there is also a need to identify, monitor, and maintain (or recruit) key bat habitats and microhabitats in floodplain forests (Ellis et al. 2002).

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Ensure that research studies targeting birds are long-term, large-scale, replicated studies that have controlled experimental approaches and focus on population demographics and the response of species to habitat manipulations where appropriate (as outlined by the National Partners in Flight Research working group) (Donovan et al. 2002). Similar research priorities are needed for other floodplain forest taxa including bats, small mammals, amphibians, and reptiles.

- Research the genetic makeup of the coastal population of the Black-throated Green Warbler.

- Research the genetic relationships among floodplain salamanders.

- Examine the impacts of long-term flooding regimes on ground-nesting birds (e.g., Swainson's Warbler) (Swift et al. 1984). Similar studies are also needed for salamanders.
- Determine the conservation and restoration efforts needed for canebrake rattlesnakes in floodplain forests (Brantley and Platt 2001).
- Conduct bird productivity research (especially neotropical migrants) with a focus on nest searching studies to determine the predator community and bird nesting success in patches of different sizes and with various landscape contexts (Rodewald and Yahner 2001).
- Study the effects of riverine buffer width characteristics on bird species diversity, richness, survival, nest success, and productivity (Perkins et al. 2003). Similar studies are also needed for small mammals, bats, amphibians, and reptiles to determine long-term productivity in buffers of various widths.
- Examine the demographics, habitat-use patterns, and impacts of feral hogs on ground-nesting birds, salamanders, and small mammals (Warren and Ford 1997).
- Study the impacts of beaver and beaver ponds on species composition (both flora and fauna) to determine negative or positive impacts of beaver or beaver control measures.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Wherever possible, maintain or restore floodplain forest connectivity, as floodplain forests are important distribution and dispersal corridors for many species (Bailey et al. 2004).
- Floodplain buffers of 300 to 600 feet provide the most benefit for species such as Northern Parula, Yellow-throated Warbler, Prothonotary Warbler, Wood Thrush, Swainson's Warbler, Worm-eating Warbler, and Acadian Flycatcher, as well as amphibians, snakes, and forest bats.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Make an attempt to protect waterbird nesting colonies. Continue cooperative efforts with colonial waterbird (wading bird) working groups and follow future management recommendations from the North American Waterbird Management Plan (Kushlan et al. 2002).

- Make efforts to retain old growth floodplain forest for chimney swifts, bats, and herpetofauna.
- Work to develop eight patches of forested wetlands at least 10,000 acres in size throughout the South Atlantic Coastal Plain, as called for in the South Atlantic Coastal Plain Partners in Flight Bird Conservation Plan (Hunter et al. 2000b).
- Initiate partnerships with the Natural Resources Conservation Service to begin cane restoration projects and research.
- Further expand the Forest Landbird Legacy Program (a cooperative effort between the Commission, the US Fish and Wildlife Service [USFWS], and the Natural Resources Conservation Service) to influence habitat for birds and other wildlife in mature floodplain forest through canopy gap management and other options.
- Concentrate conservation efforts on the Pee Dee and Dan River basins, as they contain some of the larger tracts of intact floodplain forest left in the Piedmont and offer some of the best opportunities for large-scale habitat conservation.

4.3.6 Freshwater Tidal Wetlands

4.3.6.1 Ecosystem Description

Freshwater tidal wetlands occur in sites where flooding occurs in response to lunar or wind tides, but where the water has less than the 0.5 parts per thousand (ppt) salt content used to define freshwater. Tidal freshwaters occur in rivers, where freshwater flow keeps out saltwater, and along the large sounds where distance from seawater inlets keeps the water fresh. Components of this habitat include: tidal cypress-gum swamps and tidal freshwater marshes:

- Tidal cypress-gum swamps occupy vast areas at the mouths of large rivers and also occur at the mouths of smaller creeks and occasionally along the sound shoreline. They are dominated by Swamp Black Gum, Water Tupelo, and Bald Cypress. Understory tree, shrub, and herb layers are generally sparse and low in diversity.
- Tidal freshwater marshes occur in the lowermost parts of some tidal rivers and creeks and, more commonly, in large flats along the shorelines of freshwater sounds. The vegetation is generally strongly zoned and often very diverse in at least some zones. Two distinct variants are recognized, one with very slightly salty (oligohaline) water, the other completely fresh.

The 2005 WAP describes tidal swamp forest and wetland communities as a priority habitat (see Chapter 5) (NCWRC 2005).

4.3.6.2 Location of Habitat

These habitats occur along rivers or sounds in areas where flooding is influenced by lunar or wind tides. Fresh water input may heavily influence the salt content (NCWRC 2005). Tidal cypress–gum swamps are extensive along shorelines and along drowned river valleys (e.g. Cape Fear, Neuse, and Chowan rivers). The most extensive examples can be found around Albemarle Sound areas, Alligator River, and at the mouths of the Cape Fear, Neuse, Tar, and Roanoke rivers. Tidal freshwater marshes are common around the margins of Currituck Sound, and occur in smaller areas, such as in the Cape Fear River just west of Wilmington.

4.3.6.3 Problems Affecting Habitats

Erosion. Erosion control measures may help protect these communities, but measures that alter the shoreline, whether sea walls, "soft" structures, or planting off-site species, are potentially destructive to these communities. Shoreline armoring and hardening to protect infrastructure will prevent ecosystems such as tidal marshes from migrating inland (DeWan et al. 2010). As development continues inland, water demandsin the Piedmont will affect freshwater flows from the major rivers that feed this system through water removals.

Flooding. Alteration of flood regimes in rivers may affect these systems. Some areas are fresh largely, or at least partly, because of the dilution of sea water by river input. Increased water withdrawal or interbasin transfer may increase this problem in the future. The effects are local, affecting primarily the mouth of the altered rivers, but could be important cumulatively. Existing drainage ditches and canals bringing saltwater into wetlands is a serious threat. Saltwater intrusion is already impacting former forests in Alligator River National Wildlife Refuge near the intersection of US 64 and US 264, and in the lowest portion of the Scuppernong River at Columbia. Tide gates or blocking ditches are needed to slow, if not eliminate, some saltwater intrusion. However, saltwater intrusion into Albemarle Sound and into the Scuppernong River cannot be controlled by tide gates or blocking ditches.

Logging. This ecosystem group is likely to experience drastic changes in extent and significant movement of communities that are logged. Logging is a threat to some tidal cypress–gum swamps, while others are in protected status or are too wet for logging equipment. Drying may create opportunities for logging these wet areas.

Small plants of low interior marshes appear to need fire to maintain their habitat. Lack of fire allows unnatural vegetation succession in some freshwater marshes. Common Reed, Chinese Tallow Tree, Alligator Weed, and Nutria are primary invasive species concerns.

The disruptions created by shifting communities and catastrophic events may increase the spread of Common Reed. Giant Salvinia could become a problem. Early control of species that have proven more invasive farther south will be less costly and less ecologically disruptive than allowing populations to become large.

4.3.6.4 Climate Change Compared to Other Threats

Changes caused by rising sea level are the greatest threat, but increased intensity of storms, both in rainfall and wind, are also important. Because these systems are so subject to sea level, tidal movement, water salinity, and storms, these effects of climate change are the greatest threats. Table 4.20 summarizes the comparison of climate change with other existing threats.

4.3.6.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H provides a list of the SGCN that depend on or are associated with this habitat type.

No terrestrial animals are endemic to this ecosystem group within North Carolina. Manatees, Roseate Spoonbills, and possibly other species may be able to persist in North Carolina in the future climate with warmer weather. Coastal freshwater wetlands provide important habitats for bitterns, rails, and a variety of other wading and shore birds. Conversion of other habitats, especially tidal forests, to tidal freshwater marsh will occur over time, which means availability of this habitat for nesting, cover, and forage may briefly increase; however, in the long term, location and amount of such marshes is uncertain (DeWan et al. 2010).

Tidal freshwater wetlands provide nursery habitat for aquatic species that live in saltwaters but rely on fresh and brackish waters for larval recruitment and development. Many of these species are economically or commercially important, such as crabs, shrimp, and flounder species (DeWan et al. 2010). Coastal freshwater wetlands are also important to furbearers, waterfowl, and other game species.

The Rare Skipper (*Problema bulenta*) occurs solely within tidal freshwater marshes throughout its range, from New Jersey to southern Georgia. Dukes' Skipper (*Euphyes dukesi*) is also restricted to these habitats along the Atlantic coastal portion of its range, although it also occurs inland in Florida, and in the Midwest region. Although the reasons for these restrictions are not clear, the larvae of both species feed on plants that occur well inland from the coast, even in North Carolina. Both of these species are potentially

Table 4.20 Comparison of climate change with other threats to freshwater tidal wetlands

Threat	Rank Order	Comments
Climate Change	1	This ecosystem group is likely to experience drastic changes in extent and significant movement and composition of communities. Sea level rise, drought, increased storm activity, and saltwater intrusion are threats to freshwater tidal wetlands.
Invasive Species	2	Common Reed, Chinese Tallow Tree, Alligator Weed, and Nutria are primary concerns. The disruptions created by shifting communities and catastrophic events may increase the spread of Common Reed. Giant Salvinia could become a problem. Early control of species that have proven more invasive farther south will be less costly and less ecologically disruptive than allowing populations to become large.
Shoreline Hardening	2	Erosion control measures may help protect these communities, but measures that alter the shoreline, whether sea walls, "soft" structures, or planting off-site species, are potentially destructive to these communities. Shoreline armoring and hardening to protect infrastructure will prevent ecosystems such as tidal marshes from migrating inland (DeWan et al. 2010).
Logging/ Exploitation	3	Logging is a threat to some tidal cypress-gum swamps, while others are in protected status or are too wet for logging equipment. Drying may create opportunities for logging these wet areas.
Fire	3	Many herbaceous plants of tidal freshwater marshes appear to need fire to maintain their populations. Lack of fire allows unnatural vegetation succession, especially invasion by woody species, in some freshwater marshes.
Flooding Regime Alteration	4	Alteration of flood regimes in rivers may affect these systems. Some areas are fresh largely, or at least partly, because of the dilution of sea water by river input. Increased water withdrawal or interbasin transfer may increase this problem in the future. The effects are local, affecting primarily the mouth of the altered rivers, but could be important cumulatively. Existing drainage ditches and canals bringing saltwater into wetlands is a serious threat. Tide gates or blocking ditches are needed.
Freshwater Withdrawal	5	As development continues inland, water demands in the Piedmont will affect freshwater flows from the major rivers that feed this system through water removals.

susceptible to extirpation from the state if they or their specialized habitats cannot keep pace with the effects of sea level rise and saltwater intrusion.

Nutria are considered a serious pest species in the United States because they eat a variety of wetland and agricultural plants and their burrowing damages streambanks, impoundments, and drainage systems. Nutria may also be a vector for diseases (tuberculosis and septicemia) or parasites (*Giardia, Fasciola*, Liver Flukes, and nematodes), with fecal contamination in water the likely pathway. As warming trends increase, the range of Nutria is likely to expand and populations currently limited by intolerance to cold winters will quickly expand (Carr 2010).

4.3.6.6 Recommendations

Priority to increase resilience in these systems should be placed on protecting areas that will be likely to persist or migrate, blocking ditches that are now allowing saltwater into freshwater wetlands, and controlling Common Reed in these areas. While many existing marshes are likely to be lost, there is a need to protect the examples that will be the seed sources for newly developing marshes. There is also a need to protect the areas that will become tidal freshwater marshes as sea level rises. Most of these are likely tidal cypress-gum swamps at present. Tidal cypress-gum swamps with mature cypress trees in them may lead to marshes with a tree component that will improve their resistance to erosion.

There is a corresponding need to protect sites that will become tidal cypress-gum swamps in the future. Because most of the dominant trees are the same and can persist in the transition to tidal conditions, protecting mature nonriverine swamp forest and brownwater or blackwater cypress-gum swamp areas will allow more rapid development of tidal cypress-gum swamps.

Surveys. Priorities for conducting distributional and status surveys need to focus on SGCN believed to be declining or mainly dependent on at-risk or sensitive natural communities.

Monitoring. Monitoring is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Begin long-term monitoring, following survey data, for all marshbirds, mammals, and reptiles in this habitat type.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of SGCN and other priority species to specific threats and studies should provide recommendations for mitigation and restoration.

- Investigate how reduction in freshwater marsh and increases in higher salinity areas affect alligators.

- Conduct research on fire management in marsh habitats to determine optimal frequency, timing, and firing techniques (e.g., flanking fire, back fire) to benefit priority birds.

- Investigate population densities, population growth rates, dispersal range, and extent of property damage from Nutria burrowing and herbivory.

- Determine what circumstances cause organic soils to rapidly decay in coastal wetlands.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Explore techniques for restoring tidal swamp forest and wetlands.

- Consider planting bald cypress to create the next shoreline as sea level rises and blocking ditches to slow saltwater flow into the interior of freshwater tidal marsh as a measure to reduce erosion and buy time for habitat migration inland.

- Use prescribed fire to burn portions of tidal freshwater marshes to eliminate or set-back competing woody species. Mechanical cutting of woody vegetation may be more feasible in wetter areas that cannot be reached by fire.

- The use of bulkheads should be discouraged when other possibilities are available.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience. Work with land trusts and The Nature Conservancy to identify priority sites needing protection.

- Priorities for protection include colonial waterbird nesting sites, eagle nesting sites, Wood Stork foraging areas, and important Black Rail habitat once it is better identified. Adjacent nesting habitat for snakes and turtles should also be protected.

- Acquisition of freshwater tidal marsh habitat in the Currituck Sound area is important.

4.3.7 Nonalluvial Mineral Wetlands

4.3.7.1 Ecosystem Description

Nonalluvial mineral wetlands occur on flat, poorly drained areas of the outer Coastal Plain and occasionally in shallow depressions such as Carolina bays. There may also be sites that fit this community description located in the Sandhills ecoregion. The soils in these sites are saturated in the wetter seasons, may have shallow standing water, and do not experience overflow flooding. The wetness comes from poor drainage and sheet flow from adjoining peatlands. The soils are less acidic and infertile than the peat soils of pocosins, but they do not have the regular nutrient input of river floodplains. Organic deposits are generally lacking, though occasional examples are found on organic soils where some other factor offsets the tendency of these soils to support pocosins.

In the wettest areas, bald cypress, swamp black gum, and red maple dominate. Where these areas transition to peatland, loblolly pine, pond pine, and Atlantic white cedar may also be present. In less saturated nonalluvial wetlands, trees characteristic of bottomland hardwood systems dominate: cherrybark oak, laurel oak, swamp chestnut oak, tulip poplar, sweetgum, American elm, and red maple. There are three community types that differ in wetness and the nature of the soil: non-riverine swamp forests, non-riverine wet hardwood forests, and wet marl forest.

- Non-riverine swamp forests occur in the wettest sites. They are dominated by trees tolerant of extreme wetness, such as bald cypress, swamp black gum, and red maple. A distinctive variant, transitional to peatland communities, has these species mixed with loblolly pine, pond pine, and Atlantic white cedar.

- Non-riverine wet hardwood forests occur in less wet areas. They are dominated by trees typically called "bottomland hardwoods." The undergrowth is usually open beneath the closed canopy, but sometimes dense cane or shrubs occur.

- The wet marl forest type occurs where marl or limestone occurs near the surface and affects the soil. This extremely rare community is completely isolated, and is fragmented. Although they are wet, these soils are not acidic and are more fertile than most Coastal Plain soils. The vegetation is dominated by a diverse mixture of tree, shrub, and herb layers. Dwarf palmetto is an abundant and distinctive part of the shrub layer.

The 2005 WAP described Mid-Atlantic Coastal Plain nonalluvial mineral wetlands as a priority habitat (see Chapter 5) (NCWRC 2005).

4.3.7.2 Location of Habitat

Examples of this habitat type can be found in the Alligator River, Swanquarter, and Great Dismal Swamp National Wildlife Refuges, Hoffmann Forest, Rocky Point, and several swamps (Van and East Dismal) in Washington County.

4.3.7.3 Problems Affecting Habitats

The condition of nonalluvial mineral wetlands in the Coastal Plain is generally poor due to alteration of hydrology (primarily from draining for farmland and conversion to loblolly pine plantations) and is rather fragmented. Some of the best remaining examples are on public lands such as on Alligator River National Wildlife Refuge, Swanquarter National Wildlife Refuge, and the Great Dismal Swamp National Wildlife Refuge.

Nonalluvial mineral wetlands tend to be converted for forestry and agriculture more readily since the mineral soils can support heavy equipment better than organic soils, and they are more fertile. Much of this type existed in Beaufort and Pamlico counties until recent years; relatively little remains. A higher percentage of this habitat type has probably been destroyed than any other type in the Coastal Plain, with the exception of dry longleaf pine.

Fire suppression has led to a decline in diversity of these habitats but the alteration of hydrology from ditches associated with farming and forestry practices is the biggest factor impacting this habitat type. Altered hydrology that drains these wetland types will decrease the ability to use prescribed fire as a management tool and increase the risk of catastrophic damage from wildfire. Non-native plant species (e.g., Chinese Privet, Japanese Stiltgrass) are also competing with native vegetation in many areas, especially those frequently disturbed. Although little of this quality habitat remains, it can be burned more safely than those sites with organic soils. Therefore, the potential still exists to reestablish some high-quality nonalluvial mineral wetlands on the Coastal Plain of North Carolina, where it has not already been converted to farmland or ditched for pine plantations.

4.3.7.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While climate change is not the most severe threat, a combination of synergistic effects with other existing conditions could stress these systems to the point where several species are unable to persist.

Climate change is a significant threat primarily because of the likelihood of inundation from sea level rise. Rising sea level will be more of a concern in the larger riverine wetlands at lower elevations, such as those around the Alligator River, than wetlands further inland. However, other threats such as logging and the alteration of hydrology, in the form of ditches, pose equal threats to these systems.

Impacts to the non-riverine swamps and hardwood stands in the Albemarle–Pamlico Peninsula, which include the largest blocks of habitats of this ecosystem group in the state, are likely to be catastrophic. These stands are unlikely to be replaced by the development of new stands located farther inland. Table 4.21 summarizes the comparison of climate change with other existing threats.

4.3.7.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with nonalluvial mineral wetlands.

These sites are important for variety of neotropical migrants during the breeding season and migration periods (Hunter et al. 2000b; Johns 2004), and also several reptiles of conservation concern (NCWRC 2005). Wayne's Black-throated Green Warbler is nearly confined to non-riverine swamp forests throughout its narrow range from Virginia to South Carolina. This taxon is declining throughout its range, and loss of the population on the Albemarle–Pamlico Peninsula (believed to be the largest remaining) due to rising sea levels would significantly reduce the chances of its survival overall. Storm-related impacts to the Wayne's Black-throated Green Warbler could be particularly severe, since it is a canopy-dwelling species that is often found in the vicinity of tall conifers (likely nesting sites) that emerge above a canopy of hardwoods (Fussell et al. 1995). Likewise, the coastal population of the

Table 4.21 Comparison of climate change with other threats to nonalluvial mineral wetlands

Threat	Rank Order	Comments
Climate Change	1	Much of the protected acreage is in low elevation areas that are particularly threatened by rising sea level. Areas in Dare and Tyrrell Counties are already being converted to tidal communities and this effect is likely to accelerate.
Flood Regime Alteration	1	Hydrological alteration, in the form of ditches, increases the threat of rising sea level. Ditches bring tidal water into low-lying examples, causing it to penetrate inland into the nonalluvial wetlands.
Conversion to Agriculture/Silviculture	1	Nonalluvial mineral wetlands tend to be converted for forestry and agriculture more readily since the mineral soils can support heavy equipment better than organic soils, and they are more fertile. The condition of nonalluvial mineral wetlands is generally poor due to alternation of hydrology (primarily from draining for farmland and conversion to Loblolly Pine plantation) and is rather fragmented.
Invasive Species	2	Nonnative plant species (e.g., Chinese Privet, Japanese Stiltgrass) are also competing with native vegetation in many areas, especially those frequently disturbed. Several potential threats, including Chinese Tallow Tree and Gypsy Moth may become significant even if the climate does not change. Invasive species are currently a significant problem only in the rarer community types. Wet marl forest is highly threatened by invasive plants.

Worm-eating Warbler uses this habitat type heavily and is isolated from other populations that breed in the Mountains of North Carolina.

Even more likely to become extirpated is the sole population of Wood Frogs known to occur in the Coastal Plain of North Carolina. This population exists on the Albemarle–Pamlico Peninsula in the vicinity of hardwoods near Scranton and likely represents a relic from the Pleistocene epoch, as do several other animals and plants recorded in this area (e.g., cranberry, Sundew moth, undescribed shrew). The reasons for its restricted range in this area are unknown, but it may not be able to migrate inland to keep pace with sea level rise.

Nonriverine mineral wetlands are the primary habitat for the Red Wolf in the state, with most individuals being present at Alligator River and Pocosin Lakes refuges. Other large mammals also utilize these habitats, such as Black Bear, Bobcat, and White-tailed Deer.

Other terrestrial vertebrates and invertebrates associated with this ecosystem group occupy other types of habitat, including floodplain forests and peatlands, and are more likely to survive impacts associated with climate change. Two species of Canebrake Moths, however, are endemic to the North Carolina Coastal Plain and the portion of the Great Dismal Swamp in Virginia: *Lascopia roblei* and the still-undescribed *Apameine*, new genus 2, species 3. Some of their largest known populations are associated with non-riverine habitats, the loss of which would be significant, if not as damaging as for Wayne's Black-throated Green Warbler.

4.3.7.6 Recommendations

Recommendations are to restore or maintain hydrology, protect remaining Coastal Plain nonalluvial mineral wetlands, and control invasive species in these areas to intervene against climate change effects. The maintenance of contiguous gradients between wetland and adjacent upland sites is critical for seasonal migration and dispersal of herpetofauna. Site protection and protection of surrounding areas through land acquisition or easements and cooperation with land trusts are urgently needed, as large acreages (>500 acres) are frequently clearcut all at once for agriculture, pine conversion, or development.

Regional land trusts and The Nature Conservancy can be valuable partners in these efforts. Identified funding sources for acquisition include the Clean Water Management Trust Fund, Coastal Wetlands Grants, Natural Heritage Trust Fund, Forest Legacy Grants, and Recovery Land Acquisition Grants. Restoration efforts may be possible in some cases through partnerships with land trusts, the Nature Conservancy, and state and federal agencies.

The use of fire at the remaining unconverted nonalluvial mineral wetland sites is the single most important factor to restore these sites. Plowed firelines along transition zones between habitats should be rehabilitated (smoothed over) where possible. If feasible, fires should be allowed to sweep through the habitat or at least into the edges of the wetland from the adjacent upland sites. New firelines should be constructed when necessary. These areas should be maintained as a permanent narrow opening by discing with a tractor or by wetting with water or foam prior to a burn.

The maintenance of contiguous gradients between wetland and adjacent upland sites is critical for seasonal migration and dispersal of herpetofauna. Roads, agriculture, or forestry operations between complimentary sites may still render them ineffective at supporting amphibian and reptile populations. Where fire cannot be introduced back into the site for smoke management or other reasons, the use of a hydro-ax or other chipping machinery should be considered to control midstory (where funds allow).

Surveys. Priorities for conducting distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive communities:

- Determine the status of Yellow-crowned Night-heron, other colonial nesting birds, Wayne's Black-throated Green Warbler, as well as other neotropical migrants that are not well sampled by BBS.
- Document the status and distribution of priority bat species (e.g. Rafinesque's Big-eared Bat, Northern Yellow Bat, Seminole Bat, Southeastern Bat, and Northern Long-eared Bat) in this habitat.
- Conduct Eastern Woodrat surveys and subsequently establish standardized long-term monitoring of the species in this habitat.
- Determine the status and distribution of Timber (Canebrake) and Pigmy rattlesnakes.
- Survey for other SGCN and high priority species, especially snakes and lizards.

Monitoring. Monitoring is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible:

- Establish long-term monitoring for neotropical migrants that are not well tracked by BBS in this habitat type.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of SGCN and other priority species to specific threats and studies should provide recommendations for mitigation and restoration.

- Conduct home-range and movement research on Timber (Canebrake) and Pigmy Rattlesnakes (possibly on other snakes of conservation concern as well).
- Conduct genetics research to determine if the Coastal Worm-eating Warbler is a separate sub-species.
- Explore alternatives (herbicides or mechanical) to using fire for the initial restoration of severely fire suppressed non-alluvial wetlands.
- Determine why some priority species use this habitat on the coast, when the same species primarily is found in the Mountains using completely different habitats (e.g., Wayne's Black-throated Green Warbler, Worm-eating Warbler, Wood Frog).

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Reintroduction of fire to unconverted nonalluvial mineral wetland sites is the single most important factor to restore these sites.
- Plowed firelines along transition zones between habitats should be rehabilitated (smoothed over) where possible. New firelines should be constructed when necessary. These areas should be maintained as a permanent narrow opening by discing with a tractor or by wetting with water or foam prior to a burn.
- Control tide water penetration and saltwater intrusion with tide gates where feasible.
- Where fire cannot be introduced back into the site for smoke management or other reasons, the use of a hydro-ax or other chipping machinery should be considered to control midstory.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Site protection and protection of surrounding areas through land acquisition or easements and cooperation with land trusts are urgently needed, as large acreages (>500 acres) are frequently clearcut all at once for agriculture, pine conversion, or development.
- Restoration efforts may be possible in some cases through partnerships with land trusts, the Nature Conservancy, and state and federal agencies.

4.3.8 Pocosins

4.3.8.1 Ecosystem Description

Pocosin habitats are those parts of eastern North Carolina characterized by flooded, acidic, anaerobic soils with limited decomposition and accumulating biomass. Peat deposits develop where the soil is saturated for long enough periods that organic matter cannot completely decompose. Once peat has developed, it holds water, raising water levels in the soil and making the site wetter. The shallow water tables and patterns of normal flooding result in anaerobic soil conditions that slow decomposition of biomass. Soils are acidic and nearly sterile, with available nutrients provided from periodic surface flooding of adjoining landscapes and from precipitation. The soils of streamhead pocosin habitats are flooded, acidic, and infertile.

Peatland pocosins occur on nearly flat, poorly drained areas of the outer Coastal Plain and in large shallow depressions such as Carolina bays. Streamhead pocosin habitats are patchy and limited to ravines that are permanently flooded by acidic seepage and run-off from adjacent hills. Fire history, hydrology, and drainage influence the composition of the community type, with some unfragmented examples occupying many thousands of acres.

Natural community types are determined by variation in wetness, depth of peat, and fire dynamics and include: streamhead pocosin, low pocosin, high pocosin, Pond Pine woodland, peatland and streamhead Atlantic White Cedar forest, and bay forest. The distinction between these community types may seem clear, but there are significant overlaps in the characteristics of the soils, wildlife, and plant species that occur across them.

- Streamhead pocosin plant community compositions can range from dense shrub thickets to treeless canebrakes. The natural fire cycle results in open canopy pond pine forests. However, fire suppression leads to pond pine forests with a dense shrub understory. The understory is dominated by a dense evergreen shrub layer including several members of the laurel and holly families and is frequently tangled with Laurel-leaf Greenbrier. Herbs are nearly absent except in the edge (ecotone) with neighboring sandhill communities. These ecotones often support a high diversity of herb and shrub species including many rare ones.

- Low pocosins occur on the deepest peats, in the interior of large domed peatlands, and in the largest peat-filled Carolina bays. They are the wettest, most nutrient-poor sites and support only low shrubs and scattered stunted pond pine trees. Often beds of pitcher plants and sphagnum moss cover large areas and bog species such as cranberries occasionally occur.

- High pocosins occur in somewhat less deep peats. The shrubs, up to six or eight feet tall and impenetrably dense, are generally laced together with greenbriers and punctuated with sparse stunted pond pines.

- Pond Pine woodlands occur on shallow organic deposits on the edge of peatlands and in shallow swales and bays, where tree roots can grow through the thin organic layer to reach mineral soil below. Pond Pines are tall and often fairly dense and the shrub layer is tall and usually very thick. In some pond pine woodlands the dense shrub layer is replaced by canebrakes.

- Peatland Atlantic White Cedar forests occur in sites similar to pond pine woodland or high pocosin but are dominated by Atlantic White Cedar instead of pond pine. In the few remaining places where fire is frequent, streamhead Atlantic White Cedar forests are dominated by Atlantic White Cedar, though any of the species of the streamhead pocosin type also may be present in small numbers. The canopy is often dense enough that the shrub layer is fairly open. Atlantic White Cedars are sensitive to fire, but depend on fire to prepare a seedbed for regeneration. These communities probably can persist only where fire is infrequent; however, fire suppression for many decades can lead to the cedars being overtaken by widespread hardwood species such as Red Maple or Sweetgum.

- Bay forests may occur in similar sites, but they are usually more associated with creeks draining out of peatland pocosins. They have a canopy dominated by evergreen hardwood Loblolly Bay, Redbay, and/or Sweetbay.

The 2005 WAP describes Mid-Atlantic Coastal Plain pocosin communities as a priority habitat (see Chapter 5) (NCWRC 2005).

4.3.8.2 Location of Habitat

Extensive examples of pond pine woodlands exist in the Green Swamp, at Alligator River National Wildlife Refuge, Pocosin Lakes National Wildlife Refuges, Holly Shelter Game Land, and in Dare County at the Dare Bombing Range. Atlantic White Cedar-dominated communities still exist at Alligator River and Pocosin Lakes National Wildlife Refuges, and in the Great Dismal Swamp. There is a significant sized stand of Atlantic White Cedar in the Buckridge Preserve (Tyrell County), the only inland site that is part of the NC Coastal Reserve.

Examples of fire-managed streamhead pocosin can be found on Sandhills Game Land, Fort Bragg, Croatan National Forest, and Camp Lejeune Marine Corps Base. The Croatan National Forest, Dare Bombing Range, Camp Lejeune, and Holly Shelter Game Land do conduct some pocosin burns, but all other fire introduced into pocosin habitats tends to be on small acreages (less than 100 acres).

4.3.8.3 Problems Affecting Habitats

Peatland pocosin is a large, dominant habitat in the eastern part of the state and once occupied nearly 3 million acres from Virginia to Florida, with about 70% occurring in North Carolina. Only about 750,000 acres remain, with most of the area lost used for agriculture, forestry, and peat mining.

Land Use. Logging, particularly of Atlantic white cedar and pond pine stands, altered flood regime through ditching, constructing impoundments to store water, fire suppression, and conversion to agriculture or silviculture that fragment communities can significantly impact pocosin ecosystems. The hydrologic changes resulting from ditches and canals developed to drain peatland pocosins for agriculture and forestry reduce the water holding capacity of the ecosystem and can alter the chemistry of nearby estuaries. The ditches and canals result in the rapid drainage of rainwater into estuaries that become loaded with sediment and nutrients. The deluge of freshwater into estuaries causes salinity values to plummet while the nutrients cause eutrophication and oxygen depletion. The result is severe alteration of habitat needed for wildlife in river mouths and estuaries near shore.

Fire Suppression. Fire return intervals vary widely depending on vegetation, hydrology, and extent of organic soils. Fire suppression takes the peatland pocosin out of the normal 25- to 50-year burn cycle and allows the build up of fuel, because the acidic habitat has slow decomposition and rates of soil formation. The build-up of fuel increases vulnerability to fires during dry summers. Impacts of fire suppression lead to larger, hotter fires in the vegetation and can cause ignition of peat fires that are difficult to extinguish. Similarly, the streamhead Atlantic White Cedar forest composition is affected by the fire cycle: fire suppression leads to accumulating fuel loads and a layer of thick, understory shrubs, and hardwood saplings.

4.3.8.4 Climate Change Compared to Other Threats

Overall, climate change is not the most significant threat to peatland pocosins. The most pressing climate change impacts on peatland pocosins will be from intense precipitation events and intense fire events. Other important climate change events will be from wind damage to tree species that do not regenerate and saltwater intrusion from storm surge and sea level rise. Tropical storms are predicted to become more frequent, larger, and more intense with rainfall larger than in the past. Larger rainfalls connected with violent storms will add to drainage problems in estuaries.

Pocosins play an important role in climate change by acting as a carbon sink, thereby mitigating CO_2 emissions from human activities. The carbon gained by pocosin ecosystems through photosynthesis is taken from the atmosphere and stored in biomass that does not decompose. So the primary productivity of pocosins offsets CO_2 emissions produced through use of fossil fuels and land use activities.

Pocosin communities can also be large carbon sources, adding CO_2 to the atmosphere. For example, if vegetation burns, CO_2 is released into the atmosphere adding to the greenhouse gas effect driving climate change. If peat burns, the CO_2 release will be much larger than from just the vegetation alone.

Predicted warmer temperatures and longer summer droughts will lead to increased fires. Burning vegetation and peat will generate large amounts of greenhouse gases. The change in landscape from large fires fed by climate change factors and fire suppression will burn hotter, longer, and cover more area than occurred in the natural fire cycle. The new burning cycle will compromise the quality of the habitat needed by wildlife. Table 4.22 summarizes the comparison of climate change with other existing threats.

4.3.8.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

In general, little detailed information exists for many wildlife species that use pocosin habitats because of the impenetrable nature of these communities. Few surveys have been done on a long-term basis, which makes land management decisions difficult. We also lack detailed information about populations of small mammals, bats, reptiles, and amphibians in pocosin habitats (Mitchell 1992). Black Bears are dependent on the large undisturbed areas that pocosins offer in the east. Further reduction in this habitat type could impact bear populations.

The remoteness and thickness of the vegetation in the peatland pocosin makes it the ideal habitat for resident and migratory species and protects them from human disturbance. Pocosins are particularly important for wintering birds because of the high amount of soft mast available. Greenbrier, Red Bay, Sweet Bay, and many ericaceous shrubs produce large

Table 4.22 Comparison of climate change with other threats to pocosins

Threat	Rank Order	Comments
Logging/ Exploitation	1	Unprotected white cedar and pond pine stands continue to be logged and often do not regenerate.
Flood Regime Alteration	2	Ditching for drainage and for road construction alters communities, increases wildfire damage, and likely exacerbates effects of droughts. Ditches will bring tidal water into peatlands and will hasten their destruction. Impounding effects of roads also alter hydrology in some peatlands, and may have increasing impact if rainfall events become more extreme.
Fire	3	Loss of natural fire has altered communities and ecosystem processes. Deep peat fires in artificially drained areas cause lasting damage to communities. Increased wildfire or increased temperature may actually be ecologically beneficial in some areas, but could be detrimental in others that have been ditched and could cause excessive peat consumption. Extreme wildfires in deep peat can result in depressions several feet deep. These areas could fill with water in wet years and create freshwater marsh type conditions.
Conversion to Agriculture/ Silviculture	3	Pocosins on private land have largely been ditched and converted to loblolly pine plantations by the forest products industry. While deeper peats resist conversion, pine plantations continue to replace pond pine woodland and peatland Atlantic white cedar forest.
Climate Change	4	Areas that occur in the lowest elevations may be lost to sea level rise due to saltwater intrusion and inundation. Loss of significant minority acreage is a likely threat. Other threats are very uncertain.

quantities of berries that are persistent through much of the winter. In more extensive pocosins, such as the Alligator River refuge, Prairie Warblers and Prothonotary Warblers are quite common in the breeding season, and Gray Catbirds are numerous as well. A study by NCWRC in the Sandhills demonstrated a high territory density of shrub nesting birds in fire-managed streamhead pocosin, including Common Yellowthroat, Indigo Bunting, Eastern Towhee, and Yellow-breasted Chat. This same study found a relatively high density of cavity nesters such as Brown-headed Nuthatch, Red-headed Woodpecker, and Carolina Wren. Fire-suppressed streamhead pocosins supported significantly lower densities of nine bird species but had higher numbers of Carolina Chickadee, Hooded Warbler, and Red-eyed Vireo. Red-cockaded Woodpeckers exist in some of these Pond Pine-dominated sites. However, loss of this fire maintained habitat has caused fragmentation of Red-cockaded Woodpecker habitat across the landscape.

There is a significant lack of information about populations of small mammals, bats, reptiles and amphibians in pocosin habitats (Mitchell 1992). Sandhills Salamander (*Eurycea* n. sp. 9) is endemic to this habitat (in streamhead pocosins) and is the species most at risk to alterations of hydrology and fire frequency due to climate change. Other species associated with this ecosystem include Pinebarrens Treefrog, a species with strong associations to

Sandhill streamheads. These species occur in other types of habitat and are not as confined to the Sandhills ecoregion.

Pocosin habitats are important for a variety of shrub-scrub birds, though we lack status and distribution data (Karriker 1993). Red-cockaded Woodpeckers exist in some of these pond pine-dominated sites where suitable habitat also occurs in the uplands. A study by the NC Wildlife Resources Commission (NCWRC) in the Sandhills demonstrated a high territory density of shrub-nesting birds in fire-managed streamhead pocosin, including the Common Yellowthroat, Indigo Bunting, Eastern Towhee, and Yellow-breasted Chat. This same study found a relatively high density of cavity nesters such as the Brown-headed Nuthatch, Red-headed Woodpecker, and Carolina Wren. Loss of this fire-maintained habitat has caused fragmentation of Red-cockaded Woodpecker habitat across the landscape. Fire-suppressed streamhead pocosins supported significantly lower densities of nine bird species but had higher numbers of Carolina Chickadees, Hooded Warblers, and Red-eye Vireos.

4.3.8.6 Recommendations

Though extensive amounts of pocosin lands are already protected, some specialized types require more protection, such as Carolina bays (Bladen Lakes area) and white cedar stands. Land managers and planners need to address management issues related to pocosin habitats in their conservation and land-use planning efforts. They should also work to understand what the public wants and is willing to accept regarding the management of pocosin habitats and the wildlife associated with these habitats (Thompson and DeGraaf 2001 in NCWRC 2005). Protecting additional inland examples will help mitigate the loss of those that lie near sea level.

The most important management needed for these systems is restoration of fire, which will over time reverse the alteration in natural composition and structure. While of general ecological benefit, burning will also reduce the risk of uncontrollable or damaging wildfires during droughts caused by climate change, and the more robust natural vegetation will be better able to withstand all kinds of climate-related stress.

Surveys. Priorities for conducting distributional and status surveys need to focus on species believed to be declining, at risk, or mainly dependent on pocosin communities.

- Determine status and distribution for Wayne's Black-throated Green Warbler, Worm-eating warbler, Swainson's Warbler, Black-billed Cuckoo (may warrant further documentation), and other neotropical migrants.

Monitoring. Monitoring is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Develop or enhance long-term monitoring for breeding and wintering birds, amphibians and reptiles, and mammal populations (including bats) that use this habitat (Ellis et al. 2002; Taylor and Jones 2002).

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of SGCN and other priority species to specific threats and studies should provide recommendations for mitigation and restoration.

- Examine the relationship between habitat patch size and nesting success of shrubland birds (Burhans and Thompson 1999) and habitat use by small mammals (Litvaitis 2001).

- Determine the best ways to burn these sites, or alternative management that will mimic the effects of fire at sites where birds, mammals, reptiles, and amphibians are being monitored.

- Determine how the use of chipping (using a hydro-ax or other heavy chipping machinery) midstory and understory vegetation affects the plant and animal communities. This practice is becoming more common, particularly in areas where Red-cockaded Woodpeckers are present.

- Conduct studies to obtain basic demographic information on priority birds, small mammals, amphibians, and reptiles.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Restore hydrology by reversing the effects of artificial drainage, as this is probably the most important action to protect pocosins.

- Institute a prescribed fire regime, especially on conserved lands. Burning can often be accomplished on uplands without the use of fire-lines in transition zones between upland sites and pocosin habitats (especially in winter). This promotes a healthy transition zone between the two habitats that is critical for many plant species and allows for nutrient flow to some pocosin habitats.

Conservation Practices and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Focus land acquisition on consolidating these areas into larger holdings so that they may be managed through fire.
- Discern and offer increased protection to specialized pocosin types. Though extensive amounts of pocosin lands are already protected, some require more protection, such as Carolina bays (Bladen Lakes area) and white cedar stands.

4.3.9 Upland Pools and Depressions

4.3.9.1 Ecosystem Description

Small, isolated wetlands, such as upland pools and depressions, are important areas of diversity for plants and animals, especially specialized amphibians that require these habitats for breeding. Upland pools and depression communities occur in all regions of North Carolina. Typically, they include shallow depressions which hold water in wetter parts of the year. Many are ephemeral, drying during some part of the year (often in summer), but are flooded long enough into the growing season to contain wetland vegetation that contrasts with the surrounding uplands. Water levels usually fluctuate over the course of a season, and also from year to year. Communities differ in overall hydroperiod, in soil, in slope, and in depth. Hydroperiod is the length of time that there is standing water at a particular location; it can also be defined as the number of days per year that an area of land is dry (Gaff et al. 2000). Some ephemeral (temporary) pools are wet enough to accumulate muck on the bottom, while others remain sandy.

Upland pools and depressions can be categorized into one of several types, including the following:

- Upland pools that occur in sites where the water is deep enough or long-standing enough to prevent development of a closed tree canopy. The vegetation varies widely, and it is likely that this type could be split into several community types. Trees of the upland depression swamp forest community type may occur around the edges.
- Upland depression swamp forests that occur in shallower depressions than upland pools, and are flooded for shorter periods. They usually occur on broad upland flats but

occasionally on high ridgetops. They have a closed canopy of wetland trees. Understory, shrubs, and ground cover are usually sparse.

- Ephemeral (temporary) pools that are small, seasonally flooded depressions with gently sloping sides and are usually found in sandy uplands.
- Seeps that occur along slopes where groundwater trickles out of the surface and collects in small pools and will often trickle into streams.
- Clay-based upland depressions that typically occur as oval or round depressions with a clay base that allows them to hold water for at least a portion of the year. In the Sandhills and Coastal Plain, these depressions historically have had a Longleaf Pine upland where hot season fires burned regularly, creating an open-canopy, grassy wetland system with long hydroperiods.

In the Coastal Plain and Sandhills ecoregions, pond basins may also be limesink depressions, Carolina bays, or swales between recent or older sand dunes.

- Limestone sinks occur over limestone formations. Scattered trees (Pond Cypress and Swamp Blackgum) may be present in both deep and shallow water zones and most ponds are surrounded by a dense shrub layer. These shrubby zones provide breeding habitat for shrub-scrub-nesting birds (Hunter et al. 2001a; Johns 2004) and these sites are used by wading birds for foraging/nesting and amphibians for breeding.
- Swale wetlands occur on barrier islands, such as in the Outer Banks, in areas where the freshwater aquifer saturates the soil and collects on the surface between sand dunes. These ponds will also have dense maritime shrublands in areas where water is shallow; in deeper water, they are characterized by emergent and submerged aquatic vegetation.
- Carolina bays with organic/peat substrates are relatively deep closed basins associated with pocosins, depression swamps, Pond Pine woodlands, bay forests, or Atlantic White Cedar forests. Occasionally they occur in shallow depressions associated with nonriverine communities such as swamp forests, wet hardwood forests, and wet marl forests with nonalluvial mineral soils (NCNHP 2010).

All of these natural community types often have abundant amphibian species. Those that dry annually or semi-annually benefit amphibians the most, due to the absence of fish, which would typically eat amphibian eggs and larvae. During heavy storm events, however, fish can be swept in by overbank flooding, reducing the suitability of these pools for amphibian breeding until they dry out again.

4.3.9.2 Location of Habitat

Upland depression communities occur throughout North Carolina but are often overlooked features on the landscape mainly because they are difficult to discern on aerial photographs unless they are quite large. In the Piedmont and in the Mountains, these small wetland communities can be found on broad upland flats and occasionally on high ridgetops. Ephemeral (temporary) pools are usually found in sandy uplands. Those that occur in the Piedmont are associated with mafic rocks or shale. Those in the Mountains occur on quartzite. Examples include Frogsboro Upland Depression Forest in Caswell Game Land; Badin Upland Depression Swamps in the Uwharrie National Forest; Meadow Flats in Duke Forest; and Bog Hole (Seventeen Frog Pond, Grassy Pond) in Sandhills Game Land in Scotland County (an unusually wet example, transitional to Small Depression Pond).

Carolina bays and limestone sinks are probably the best known examples of isolated wetlands in NC because they are easy to view on aerial or infrared photos of the region and they are generally obvious on the landscape. Carolina bays and clay-based upland depressions occur throughout the Coastal Plain, whereas limestone sinks tend to occur in clusters in areas along the lower Coastal Plain—numerous limestone sinks are visible around the Boiling Spring Lakes area in Brunswick County, NC.

4.3.9.3 Problems Affecting Habitats

Isolated, ephemeral wetlands are regarded as one of the most endangered, and simultaneously one of the most biologically productive habitats in North America. Wetlands of this type are characterized by unique assemblages of flora and fauna that are not associated with permanent-water wetlands. In the Southeast, they serve as critical breeding habitat for several endangered species of amphibians. Many declining species of plants and animals depend on or use isolated, temporary wetlands. Across the Southeast, most of these systems have been lost to draining for agriculture, commercial silviculture, and development. Others have been altered to retain the permanent water necessary to support fish populations. Further, many of the temporary wetlands that remain on the southeastern landscape have been greatly affected by lack of fire that would have naturally maintained them in an early successional condition. The resulting colonization by large overstory trees significantly alters these wetland systems such that they no longer support many of the rare species that depend on them.

The vegetation of upland ephemeral pools varies widely because of natural and human-induced differences among ponds. Factors related to human-induced changes such as ditching and lowering of water tables through agricultural and urban uses has caused some pools to completely dry or revert to forested wetlands. Some upland ephemeral pools are maintained as open-canopy emergent wetlands because of naturally long hydroperiods that prevent the colonization of trees and shrubs (e.g., limestone sinks with a groundwater connection).

However, many upland, isolated wetlands would have historically been maintained as open, "grassy" ponds through a combination of hydroperiod and fire regime processes (DeSteven and Toner 2004). In these situations, summer fires would occasionally burn through the dry basins, limiting the establishment and growth of fire-intolerant woody species and controlling the buildup of excessive amounts of peat (Florida Natural Areas Inventory 1990). Specifically, vegetation of clay-based depressions has been altered by fire suppression or exclusion in adjacent uplands, ditching of wetlands, or by intentional fire exclusion by maintaining fire lines around wetland habitats. Even where fire has been reintroduced into the Longleaf Pine ecosystem in the Southeast, most managers use winter or spring burning instead of hot, summer fires that would have naturally occurred in the past. Winter or spring fires usually do not burn through wetlands because water is often present in the pond basin at that time of year. Indeed, fire suppression or exclusion has been linked to the encroachment of trees into historically treeless ponds in the Southeast (Kushlan 1990; Kirkman et al. 1999; De Steven and Toner 2004).

The reduction of open-canopy, ephemeral ponds is a major reason for the loss of populations of some southeastern amphibian species (e.g., Gopher Frog) that depend on them exclusively for breeding (LaClaire 2001). Additionally, the encroachment of trees into temporary wetlands can have multiple adverse effects on the larvae of many amphibian species (Schiesari 2006; Thurgate and Pechmann 2007; Werner and Glennemeier 1999). The most obvious effect is increased evapotranspiration in the pond resulting in a shorter hydroperiod (Sun et al. 2001). Shorter hydroperiods may not allow larval amphibians enough time to reach metamorphosis (Skelly 2004).

Shading of ponds can also lower the pond's water temperature, slowing the growth and development of larval amphibians (Blaustein et al. 1999; Skelly et al. 2002). Ponds with significant canopy cover may also suffer from lowered oxygen availability (Skelly et al. 2002) and reduced algal communities (Skelly and Golon 2003), both of which have detrimental effects on larval amphibian growth and survival. Further, increases in leaf litter associated with the establishment of overstory trees can substantially lower the pH in these degraded wetlands. Evidence exists that breeding habitats can indeed become too acidic for the successful hatching and rearing of some southeastern amphibian larvae (Braswell 1993 and references therein).

4.3.9.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. In this comparison, the greatest threat to depression communities is likely to be habitat conversion. Habitat conversion occurs for various reasons, including suppression of natural fire regimes, development, and land use changes. Drier basins are destroyed by development or conversion to pine plantations, while wetter ones are degraded by these activities on the surrounding uplands. In protected examples, alteration of hydrology and effects of fire suppression are usually the most serious threats.

Climate change is likely to exacerbate existing effects, increasing the number and severity of droughts and increasing the amount of evaporation even in years of normal rainfall. If increased drought and severe weather reduces the ability to conduct prescribed burning, this may reduce fire even in the few examples that are getting burned. With respect to climate change, however, upland pools and their associated species are likely to respond differently from the surrounding forests. Table 4.23 summarizes the comparison of climate change with other existing threats.

4.3.9.5 Impacts to Wildlife

Appendix G contains a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN and other priority species that depend on or are associated with this habitat type.

Members of this community all make use of upland pools for breeding, but make use of floodplain pools as well, at least where they are fairly well isolated from frequent overbank flooding. Windthrow pits may also be used and Four-toed Salamanders, in particular, make frequent use of seepage habitats. All Piedmont wetland habitats are especially important as breeding sites for amphibian species. Small wetlands can also be important breeding habitat for crayfishes. Wading birds, waterfowl, and songbirds may also use small wetland communities for nesting and feeding areas.

While often small in size, cumulatively these habitats provide critical breeding habitat for many amphibian species. Ephemeral and isolated wetlands are very valuable to amphibians because they typically do not support fish and other predators of amphibian eggs. The loss of ephemeral wetland communities in the Piedmont has strong ramifications for future amphibian populations. Amphibians in these communities depend on the surrounding uplands, and populations are lost or much reduced if the surrounding habitat is destroyed or altered. Pool-breeding amphibians that make use of these pools may potentially be as adversely affected by these changes as those associated with upland pools are by increased frequency of drought.

Increased road densities are correlated with declines in amphibian diversity and abundance (Vos and Chardon 1998; Findlay et al. 2001; Fahrig et al. 1995). Roads can cause heavy mortality for

Table 4.23 Comparison of climate change with other threats to upland pools and depressions

Threat	Rank Order	Comments
Logging/ Exploitation	1	Shallower examples may be destroyed by development or heavily altered by logging. Logging when the ground is wet creates permanent ruts as well as altering canopy structure and composition. Clearcutting near ephemeral wetlands causes higher solar radiation and an increase in the probability of wetlands drying out; also, timber harvest may introduce weedy plant invasions of wetlands.
Development	1	Piedmont wetland habitats are heavily impacted by, and have been greatly reduced by, development, roads, and drainage throughout the region. Wetter examples are degraded by development of surrounding areas.
Climate Change	2	Some models predict that rainfall will be concentrated during the fall and that there will be increased droughts in the spring and summer. This may reflect an expectation of increased hurricane activity rather than well-distributed rainfall. There is also a general expectation that both droughts and extreme rainfall events will become more common.
Flood Regime Alteration	3	Drainage ditches have affected some examples, and alteration of drainage by roads has altered some other examples. Includes artificial drainage and Beaver impoundment effects. Beaver ponds can be a nuisance to landowners when they flood farm fields or commercial timber. Pools located in floodplain terraces that now rarely flood may experience greater flooding in the future due to more frequent severe storms.
Invasive Species	3	Invasive species are not a significant problem in these systems at present. Increased canopy opening and shortened hydroperiod will make them more susceptible to invasion by Japanese Honeysuckle, Japanese Stiltgrass, and possibly Asian Dayflower. Fire Ants, which are not abundant in the Piedmont at present, are likely to increase with warmer temperatures. They represent a threat to these communities, and may represent an additional indirect threat if they harm amphibians in the uplands. The introduction of fish, bullfrogs, and other predatory species can devastate the breeding effort of amphibians in small wetlands.

reptiles and amphibians and can effectively isolate breeding populations, or separate wetland habitats from upland habitats that are used during non-breeding portions of amphibian and reptile life cycles. The increase in impervious surfaces from the proliferation of roads causes excess stormwater runoff and pollution from point and nonpoint sources, which degrades water quality. Most amphibians are highly sensitive to changes in water quality.

All are likely to be strongly affected, particularly upland populations, by increases in prolonged droughts associated with climate change. Increased drawdown of groundwater levels, also the result of prolonged drought as well as increased human utilization, particularly in times of surface water scarcity, is another major threat for populations associated with floodplain pools or seeps. Floodplain pool populations are additionally likely to be adversely affected by increases in overbank floods that carry fish into their breeding sites. These impacts may be offset to some extent, however, by increases in the number of windthrow pits resulting from heavier storm damage.

4.3.9.6 Recommendations

These communities are isolated and contrast strongly with the surrounding uplands. They will be unable to migrate. The most important actions needed for these communities are to protect unprotected examples and to protect or restore the surrounding uplands for as many of these wetland communities as possible. As more examples are lost, the remaining ones will become increasingly important for the survival of amphibian populations.

Seasonal wetlands must have sufficient surrounding habitat to support the life history requirements of amphibian and reptile populations. It is particularly important to protect the larger and wetter examples, which are more likely to persist in drier conditions. With more extreme weather, species populations in individual basins may become less stable and more dependent on metapopulation dynamics for their long-term survival. Where they can be protected or established, connections between examples will become even more important than at present.

Surveys. Priorities for conducting distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Investigate the status and distribution of species associated with Piedmont wetland habitats (e.g., Three-lined Salamander, Common Ribbonsnake).
- Survey for all amphibian species associated with small wetland communities.

Monitoring. Monitoring is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Determine population trends and persistence of small wetland breeding amphibian populations, particularly Mole Salamander, Eastern Tiger Salamander, Dwarf Salamander, and Four-toed Salamander.
- Monitor amphibian populations to detect incidence of fungal and viral infections (e.g., iridoviruses, chytridiomycosis).

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of SGCN and other priority species to specific threats and studies should provide recommendations for mitigation and restoration.

- Determine minimum upland buffers required to sustain at-risk amphibian populations.
- Explore management strategies to eradicate undesirable species, such as bullfrogs, from wetlands.
- Study the efficacy and practicality of "toad tunnels" and other wildlife crossings that allow passage under roadways and help maintain connectivity between wetland metapopulations.
- Investigate minimum hydroperiods needed by priority amphibian species that utilize ephemeral pools and wetlands. Results can be used to determine when supplemental measures or intervention is needed to support breeding periods and metamorphosis during drought periods.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Employ hydrological restoration methods such as plugging ditches where ditches are affecting the hydrology of the pools.
- Promote the adoption of agricultural and forestry best management practices (BMPs) that reduce run-off, erosion, and pollution. The federal Farm Bill and other cost share programs provide incentives for land stewards to adopt these practices.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the greatest extent possible to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but overall it promotes ecosystem resilience.

- Make every effort to maintain continuous gradients between wetland and upland sites; roads, agriculture, or forestry operations between complimentary sites may render them ineffective at supporting amphibian and reptile populations (Bailey et al. 2004; NCWRC 2005).

- Provide for habitat connectivity between nearby upland pools and other wetlands or surface waters.
- Place high priority on protecting wetlands and adjacent uplands through acquisition or easement.

4.3.10 Upland Seepages and Spray Cliffs

4.3.10.1 Ecosystem Description

The communities included in upland seepages and spray cliffs are wetlands that occur on sloping uplands and can be found across the state. The soils are generally saturated permanently or for long periods. They are generally fairly small and contrast sharply with adjacent communities, though boundaries may be gradational. There are four communities in this ecosystem group: spray cliffs, hillside seepage bogs, low elevation seeps, and high-elevation seeps. Spray cliffs are areas kept wet by spray from waterfalls. The other three community types are fed by groundwater seepage and their soils are saturated for much or all of the year, but they are seldom, if ever, flooded.

- Most spray cliff areas are vertical cliffs, but gentle slopes, talus, and soil at the base of cliffs are also included. Vegetation is very patchy, reflecting the patchiness of soil accumulations. The microclimate is generally moderated by the flowing water and sheltered position of the cliffs. Though water flow may vary with rainfall, these are probably among the most stable environments in North Carolina. Trees rooted in crevices and between rocks often grow to large size and may shade the entire area. The bare wet rocks generally have a great diversity of mosses and liverworts. Herbs in small soil pockets include a wide variety of forbs, ferns, and sedges.
- The rarest type is the hillside seepage bog. These communities, in a few Piedmont locations, are wet enough to have boggy vegetation. The vegetation is generally a patchy mix of shrubs and herbs with an open tree canopy. Many species characteristic of the Coastal Plain occur in these communities. Fire may have played a role in keeping hillside seepage bogs open enough to allow persistence of light-requiring bog species.
- Low elevation seeps, occurring in uplands or edges of floodplain throughout much of the state, are also very wet but differ in vegetation. The factors which cause these differences are poorly known. Trees such as red maple may be present, or the seep may be shaded by canopy species from adjacent forests.
- High-elevation seeps occur in the higher Mountains, where they are surrounded by spruce–fir forests, northern hardwood forests, or grass and heath bald communities. High-elevation seeps are quite variable in vegetation and setting. Some are open and

somewhat boggy, with peat moss, sundews, and even cranberries present. Others are shaded by canopy and more closely resemble a rich northern hardwood forest.

4.3.10.2 Location of Habitat

This group of communities covers a wide geographic range in the Mountains and Piedmont ecoregions. High-elevation mountain seepage communities are usually surrounded by spruce–fir forests, northern hardwood forests, or grass and heath bald communities. Low-elevation seeps tend to occur at the bases of slopes in the Piedmont and lower Mountains, just above a floodplain. Spray cliffs are more likely to occur in gorges and riverine areas. Examples of spray cliffs can be found in the Nantahala National Forest, Bonas Defeat Gorge on the Tuckasegee River in Jackson County, Reid Branch waterfalls in Transylvania County, Phillips Branch waterfalls in Caldwell County, and the Dismal Creek waterfalls in Transylvania County (Stevenson 2015).

4.3.10.3 Problems Affecting Habitats

Threats to individual seepages and spray cliffs are extremely variable and include: invasive plants; death of Canada hemlock trees due to the Hemlock Woolly Adelgid; development on or adjacent to the community; recreational trampling; stream flooding and scouring or downcutting; depletion of ground water pools that supply seepage; ditching or drainage; increased temperatures in sheltered refugia; and vegetational succession in the absence of fire or other natural disturbance. This ecosystem is highly threatened overall, with or without climate change.

The communities located at high elevations are the most likely to be affected by increased temperatures. Some distinctive high-elevation species may be lost, while some lower elevation species may be able to migrate into them. Warmer temperatures may allow exotic species to invade. Some seeps have increased in tree cover due to fire suppression or other alterations, and loss of tree cover may be positive in some examples.

4.3.10.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While climate change is not the most severe threat, a combination of synergistic effects with other existing conditions could stress these systems to the point where several species are unable to persist.

The effect of a changed climate is likely to vary widely among examples of these communities, depending on topographic sheltering, configuration of rocks, soil depth, size of groundwater pools, and amount of overland runoff. These systems are tied to specialized small environments and will be unable to migrate as the climate changes. Many may change very little, while a few will shrink, be disturbed by wind or flood, or change substantially because of temperature changes or drought. A small net loss of acreage may occur, but more seeps may be temporarily affected by drought. Table 4.24 summarizes the comparison of climate change with other existing threats.

4.3.10.5 Impacts to Wildlife

Appendix G provides a list of the SGCN and other priority species for which there are knowledge gap and management concerns. Appendix H identifies SGCN associated with this habitat type.

Seepage communities have very limited distribution and availability across the landscape and are one of the most significant habitat types of the state for rare plants and animals (TNC and SAFC 2000). Several animal species that are state-listed or rare are associated with seepage habitats, including the Bog Turtle, Mole Salamander, Four-toed Salamander, Long-tailed Salamander, Seepage Salamander, Alder Flycatcher, and the common Gray Treefrog.

The priority amphibian associated with mountain bogs are all salamander species, though there certainly are a much larger number of amphibians found in mountain bogs. These salamanders (e.g., Mole, Four-toed, Marbled, Three-lined, and Spotted Salamanders) for the most part require pools of water (preferably fishless) for breeding purposes. The community association is less related to the system being spring fed, muddy, or with specific

Table 4.24 Comparison of climate change with other threats to upland seepages and spray cliffs

Threat	Rank Order	Comments
Groundwater Depletion	1	Droughts may cause seeps supplied by shallow ground water to dry up. If drought increases wildfire, it might be of benefit to some examples, but fires are generally easy to control in the uplands around seeps.
Flood Regime Alteration	1	Spray cliffs may be subject to scouring if intensity of floods increases. Some low elevation seeps are on the edge of floodplains, and increased intensity of rainfall events might increase flooding of them.
Development	1	Development may not have direct impact, but may increase access (and therefore trampling) or lead to utility easements (e.g., sewer lines) that cross seepage habitats.
Climate Change	1	Climate change may pose a significant threat, but no more than these other problems.
Invasive Species	1	These communities are susceptible to invasive species, which may be exacerbated by climate change.

plant associations than for many of the other priority species associated with the seepage habitats.

Some of these communities serve as refugia for species for which the current climate is not suitable. They are likely to continue to do so, but warming temperature and changed moisture regimes may make some of them less hospitable to some of these species. At the same time, these communities may become refugia for additional species that are currently common, if the regional climate becomes unsuitable for them. They may be crucial for the survival of some species in the state.

While moisture levels are probably the most important factor in these communities, some species may be directly affected by increased average or extreme temperatures. Warmer temperatures may cause some species to be lost at certain sites, and this may include some of the most unusual and rarest species in these communities. Warmer temperatures may also allow some more southern species to enter these communities, but the small and isolated nature of these distinctive environments will limit movement of species. The species that depend on cool, moist conditions are more likely to be extirpated if warmer temperatures (especially combined with drought) reduce the suitable habitat and/or allow other species to invade the habitat.

4.3.10.6 Recommendations

In general, protection and restoration of natural composition and function, and protection of surrounding natural areas, under current conditions are the best way to improve the ability of these communities to adapt to climate change. Protection of a large and diverse pool of examples is the best way to ensure that many survive the future stresses.

Surveys. Priorities for conducting distributional and status surveys need to focus on SGCN species and those believed to be declining or mainly dependent on at-risk or sensitive natural communities.

Monitoring. Monitoring is critical to assessing species and ecosystem health and for gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

Research. Research topics that facilitate appropriate conservation actions include habitat use andpreferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of SGCN and other priority species to specific threats and studies should provide recommendations for mitigation and restoration.

- Perform genetic studies to determine the degree of gene flow or degree of isolation between populations and to assess overall population health for species restricted to this habitat.

- Document how priority species are utilizing the habitat and whether specific hydrological and biological requirements are being met under current management regimes.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Specific management needs include the control of woody encroachment and succession, the maintenance (and where necessary, restoration) of natural surface water and groundwater hydrology (using ditch plugs, temporary dams, level spreaders, or other engineering devices), the restoration of herbaceous vegetation, and the prohibition of take of rare bog-related species (e.g., Bog Turtle).

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Actively pursue acquisition of conservation ownership of mountain bogs in concert with state and federal agency partners as well as private conservation partners.

4.3.11 Wet Pine Savannas

4.3.11.1 Ecosystem Description

The communities in wet pine savannas are Coastal Plain mineral soil wetlands that under natural conditions were frequently burned. With frequent fire, they have an open canopy dominated by longleaf or pond pine over a grassy herb layer. Shrubs are short and sparse with frequent fire, but become dense if fire is suppressed for more than a couple of years. There are three community types in this ecosystem group: pine savanna, sandhill seeps, and wet pine flatwoods.

- The pine savanna type occurs in flat areas that are saturated or even slightly flooded during the wetter parts of the year. The herb layer is dominated by grasses and sedges and a variety of low shrubs may be present, but are low and open if the savanna is frequently burned. The herb layer usually contains many showy composites, orchids, and insectivorous plants. One of the most notable features of pine savanna communities is their tremendous plant diversity at small scales.

- Sandhill seeps occur on sloping seepage areas, where the wettest parts are essentially permanently saturated. They share many species with the pine savanna type but are more heterogeneous and more bog-like in character. In frequently burned seeps, grassy and sedgy areas can have a high diversity of plants, rivaling the pine savannas in species richness at small scales.

- Wet pine flatwoods communities usually occur in flat areas, though sloping areas are possible. They resemble pine savannas in general structure, with an open pine canopy over a grassy ground cover with low shrubs. Wiregrass is always the dominant herb. Shrubs become dense if fire is excluded. Unlike pine savannas, the herb diversity is low: in many cases, only one to five species may be present in a square meter.

The 2005 WAP describes Mid-Atlantic Coastal Plain wet pine savannas as a priority habitat (see Chapter 5) (NCWRC 2005).

4.3.11.2 Location of Habitat

The Green Swamp, Holly Shelter, and Sandhills Game Lands and the Croatan National Forest contain good examples of this habitat.

4.3.11.3 Problems Affecting Habitats

Intensively managed pine plantations, urban development, a lack of fire, and subsequent habitat fragmentation continue to threaten these communities. Climate change may exacerbate some of these problems. New alternative energy development in the region, such as natural gas fracking and biofuel harvesting, may be an emerging threat but it is uncertain what direct effect these will have on wildlife. Anticipated indirect impacts will include displacement from loss of habitat and loss of connectivity due to habitat fragmentation. Table 4.25 identifies the most important threats and summarizes the anticipated impacts.

Although no invasive exotic plants are a serious problem in these systems now, early detection and control of invasive exotic species (such as Cogon Grass) will reduce the ecological damage caused by invasives and the cost of controlling them. Preventative measures such as forbidding sale and transport of invasive species will help reduce the risks and cost. Fire Ants are already a serious cause for concern for many of the animal species that inhabit savannas.

These systems occur mostly in low-lying areas that are unlikely to become extremely dry even in droughts. Sandhill seeps are probably more vulnerable than other community types in this group because they depend on movement of shallow ground water. Droughts would dry them up, perhaps enough for plants to experience water stress. Many species excluded from them at present by wetness may be able to invade with drought.

Increased drought conditions and increased thunderstorm intensity may lead to more wildfires. These systems depend on fire and are often degraded by lack of fire. An increase in wildfires may allow some occurrences to burn in a way that is ecologically beneficial. However, wildfires in drought may be more likely to be too intense or extensive and to harm some species.

If droughts are frequent enough, species of drier communities that are currently excluded by wet periods may be able to establish in them. While species of dry Longleaf Pine communities are presumably excluded from wet pine savannas by moisture, most other species are excluded more by frequent fire. Composition is unlikely to change much for sites that can be burned.

Longleaf Pines are among the least susceptible trees to wind destruction, and it is unclear how significant increases in wind storms will affect them. Pines with nest cavities of the endangered Red-cockaded Woodpecker frequently snap at the cavity site because much of the internal wood has been removed by the birds. General forecasts suggest an increase in severe storms may cause more wind damage to canopy trees, especially to those with woodpecker nest cavities.

Flammability of pocosins varies with season and a change in seasonal phenology that makes them flammable earlier in the season would limit prescribed burning in savannas. Changes in phenology can disrupt pollinator and predator–prey relationships. Warmer temperatures may allow an increase in abundance or rate of spread of Fire Ants and other invasive species. Mild winters, with decreased cold damage, may allow species from the south to move into North Carolina.

These systems range well to the south of North Carolina. They and their component species are well adapted to warm temperatures. Increased temperatures might increase the range of these systems in the northern Coastal Plain and in Virginia. Most plants in these systems have limited dispersal ability even locally, so any influx of native species from the south is likely to be slow. The widespread conversion of potential sites in this region, the fragmented distribution of examples, and their dependence on fire make natural expansion difficult.

4.3.11.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While climate change is not the most severe threat, a combination of synergistic effects with other existing conditions could stress these systems to the point where several species are unable to persist.

The effect of a changed climate is likely to vary widely among examples of these communities, depending on topographic sheltering, configuration of rocks, soil depth, size of groundwater pools, and amount of overland runoff. These systems are tied to specialized small environments and will be unable to migrate as the climate changes. Many may change very little, while a few will shrink, will be disturbed by wind or flood, or will change substantially because of temperature changes or drought. A small net loss of acreage may occur, but more seeps may be temporarily affected by drought. Table 4.25 summarizes the comparison of climate change with other existing threats.

Table 4.25 Comparison of climate change with other threats to wet pine savannas

Threat	Rank Order	Comments
Development	1	Conversion for subdivisions, businesses, and golf courses permanently reduces available habitat and increases stormwater runoff.
Conversion to Agriculture/ Silviculture	2	The threat of agricultural conversion has reduced in recent years (having greatly reduced habitat historically), but conversion to pine plantation continues.
Logging/ Exploitation	2	Many of the drier areas have been cleared for agriculture, or converted to intensive forestry operations or development. Increased habitat fragmentation can create islands that become population sinks. Conversion of pine production to biofuel production will increase rotation periods and remove slash debris.
Fire	3	In the current settled landscape, these systems depend on prescribed burning for the fire they need. Inadequate fire is the greatest threat to protected examples. Severe wildfires in droughts, burning in excessive fuel loads, may cause ecological damage. Because many examples are now fragmented and isolated, uncontrolled fire that burns whole patches is a significant threat to many insect populations. Prescribed burning is crucial for retaining these systems in both the present and the expected future climate. Smoke management becomes an issue along with wildfires that result from unsafe landowners burning debris. Firefighting methods can damage the habitats through use of heavy equipment and fire suppression chemicals.
Climate Change	4	Wet pine savannas are likely to be resilient to climate change effects. With drought, fuel loads could increase and contribute to catastrophic fire events. Increased high wind storm events causes wind throws that damage tree stands, especially Red-cockaded Woodpecker cavity trees.

4.3.11.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with wet pine savannas.

These habitats are particularly important for reptiles and amphibians where ponds are embedded in savannas or flatwoods; such species include Carolina Gopher Frog, Ornate Chorus Frog, and Southern Chorus Frog. Several reptile species, such as Pigmy and Timber (Canebrake) rattlesnakes and Mimic Glass Lizard, are found in savannas and pine flatwoods away from pools and ponds. Many of the bird species of highest conservation concern inhabit these communities and depend on frequent fire to create suitable habitat conditions (e.g., the Red-cockaded Woodpecker, Bachman's Sparrow, Henslow's Sparrow, Brown-headed Nuthatch, American Kestrel, Prairie Warbler) (Hunter et al. 2001b; Johns 2004). Game species such as the White-tailed Deer, Northern Bobwhite Quail, Wild Turkey, Eastern Cottontail Rabbit, Gray Squirrel, and Eastern Fox Squirrel also utilize this habitat for forage and cover.

Red-cockaded Woodpeckers use these habitats, because they typically have a sparse overstory and open midstory that is preferred by the woodpeckers. Increased wind storm damage could affect canopy structure and topple some nesting cavity trees. Because of the slow reproductive rate and long life span of Longleaf Pine, increased wind mortality would reduce average age and might reduce natural canopy density. This would be detrimental to Red-cockaded Woodpeckers and other species that depend on older longleaf pine trees.

Three species of insects are endemics or near-endemics to wet pine savanna habitats in North Carolina. Five others are major disjuncts, with their next nearest populations in New Jersey, Florida, or in the case of Rattlesnake-Master Borer moth, the tallgrass prairies of the Midwest. The Coastal Plain Apamea moth appears to have a highly disjunct population in the coastal savannas but also occurs in the Southern Appalachians.

Fire suppression and a lack of growing-season prescribed burning causes a thick shrubby understory to develop which shades out grasses and herbaceous ground vegetation and greatly reduces overall plant and animal diversity. Microhabitats and ecotones can be impacted by fire line construction, and a lack of woody debris particularly impacts reptiles, amphibians, and small mammals.

While all of these species are associated with fire-maintained habitats, the majority depend on having a metapopulation structure to cope with fire, as well as other environmental perturbations. Five of these species have substantially lost their metapopulation structure and have become highly vulnerable to the effects of single catastrophic events, including wildfires. Because many examples of this habitat are now fragmented and isolated, uncontrolled fire that burns whole patches is a significant threat to many insect populations. In Summer 2009, a backfire to control a wildfire in Croatan National Forest burned the entire known habitat of the Arogos Skipper; this butterfly has not been seen there or anywhere else in the state since that fire.

4.3.11.6 Recommendations

Protection of remaining examples and restoration of degraded examples would help the Coastal Plain landscape adapt to future climates, as well as provide benefits under the current climate. Keeping or restoring fire to these systems, through prescribed burning, is crucial to their long-term survival in both the present and any future climate.

Most of their component species range well to the south of North Carolina. They are tolerant of drought, fire, and wind. Many have broad tolerance of varying moisture and nutrient conditions. However, they have been drastically reduced by conversion to other uses and degraded by lack of fire. This makes them more vulnerable to loss of species and degradation both by climate change and by other threats.

Surveys. Priorities for conducting distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive communities.

Monitoring. Monitoring is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Initiate long-term monitoring once baseline surveys have been conducted. Focus should begin with herpetofauna and bird species in decline, or for which little is known about the population fluctuations and demographics.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Research must also be conducted to determine vulnerability of SGCN and other priority species to specific threats and studies should provide recommendations for mitigation and restoration:

- Determine better ways to construct fire lines and better ways to burn around populated areas where smoke would otherwise be a concern when burning.

- Determine how to effectively restore altered portions of this habitat type and develop methods to manage them without fire.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Establish examples of well-maintained and burned savannas as demonstration sites for landowners to emulate. Burning should be accomplished without placing firelines in transition zones from uplands to wetlands and with the fire allowed to burn through transition zones.
- Habitat restoration should primarily occur through growing season prescribed burning, to develop and maintain the herbaceous layer and open pine stands. Where growing season burns cannot be administered, winter burns can be constructive. Burning should be accomplished without placing firelines in transition zones from uplands to wetlands and with the fire allowed to burn through transition zones.
- Snags should be retained during logging operations to increase the numbers available for cavity-using wildlife species.
- Maintain sufficient levels of woody debris in stands for reptiles, amphibians, and small mammals.
- Create borrow sites or ponds for breeding use by amphibians. Otherwise, amphibians are scarce in most flatwoods and savannas devoid of pools or open water.
- Watch for arrival of Cogon Grass and other new invaders and control promptly.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.Land acquisition and easements should be promoted through cooperation with local conservation organizations and state and federal agencies.

4.4 Terrestrial Communities

Terrestrial and aquatic systems are highly connected to the extent that upland land clearing activities can result in increased erosion and sedimentation in adjacent riparian communities. Water quality impacts can reduce aquatic species population sizes, leading to food limitations for terrestrial species with an aquatic food base. Unfortunately, the Southeast contains some of the most endangered ecosystems in the country: southern Appalachian spruce–fir, Longleaf Pine forest and savanna, eastern grasslands, coastal communities, and forested wetlands (Noss et al. 1995).

Threats to habitats across the region include fragmentation, conversion to other habitat types, suppression of fire, and outright loss due to development (Noss et al. 1995; Ricketts et al. 1999). There are numerous other threats that can affect a broad range of terrestrial or upland communities and the natural community descriptions provided in this Section include information about the problems that affect specific community types. Additional information about threats most likely to impact fish and wildlife and their habitats is provided in Chapter 5.

The natural communities described in this Section are based on descriptions published by the NC Natural Heritage Program (Schafale and Weakley 1990; NCNHP 2010; Schafale 2012). The recommendations provided within each of the natural community descriptions represent priorities specific to those habitats. Numerous state, regional, and national efforts have been used as a resource on which to build the conservation priorities addressed in this chapter. To the greatest extent possible and where applicable, the guidance provided by these important efforts has been incorporated into this Plan.

There are numerous threats that can affect a broad range of terrestrial or upland communities and some of the most common and widely occurring are described in this section. The natural community descriptions provided in this Chapter provide information about the problems that affect specific community types. Additional information about threats likely to impact wildlife and habitats is provided in Chapter 5.

The natural community descriptions in Sections 4.4.1 through 4.4.18 are generally arranged in elevational order as they occur on the landscape, beginning in the western Mountains and proceeding eastward toward the coast. Those that are found statewide are provided at the end of this section. Common names are used throughout this document for species discussions except for those animals for which there is taxonomic uncertainty or for invertebrates that are not Species of Greatest Conservation Need (SGCN); in those few instances the scientific name is provided in the text for the species.

Appendix E contains lists of common and scientific names for invasive, exotic, and non-native species and the common and scientific names of the native plants identified in the community descriptions. Appendix G provides a list of common and scientific species names for SGCN and priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN and the habitats they are associated with.

4.4.1 Caves and Mines

4.4.1.1 Ecosystem Description

The majority of documented caves occur in the Mountain ecoregion, though there are some caves present in all regions of the state, including the Coastal Plain. There are several different types of natural caves; however, the most common types are solution caves, fissure caves, and rock shelter/boulder caves. These types differ primarily in the way they are formed.

Solution caves are created by the action of water dissolving the underlying rock to form tunnels. Over time, solution caves get larger and larger and are generally the most extensive (size and length of passage). There are a few areas of North Carolina with underlying limestone geology which lend themselves to solution cave formations. Most notably the Nantahala Gorge and North Fork Catawba River/Linville Mountain area of western North Carolina and parts of the Coastal Plain are underlain with limestone (marble, dolomite, and marl respectively).

Fissure caves are formed by movement of the earth's surface, which results in cracks in the rock layers. Depending on the actual events which spawn the development, fissure caves have varying sizes and configuration. Fissure caves occur in many places in North Carolina, though one of the most well-known and largest fissure cave systems in the world occurs in Hickorynut Gorge in Rutherford County.

Rock shelter/boulder caves are formed by erosive forces, weather events, earth surface movements, and other factors which essentially leave spaces underneath/behind surface rock. The vast majority of caves in North Carolina are rock shelter/boulder caves. Owing to their diversity of formation, geology, and range in the state, caves in North Carolina are quite variable in terms of both the plant and animal communities adapted to, and found in them.

In addition, an extensive mining history in North Carolina has provided numerous subterranean excavations which can and do mimic the environmental conditions of natural caves. Like caves, mines come in many shapes and forms, depending upon numerous factors. There are many mines which do not provide conditions similar to those found in caves, such as open pit mines, strip mines, and quarries. Our definition of the caves and mines habitat type is intended to include only mines which include subterranean excavations with conditions inside the mine shafts and tunnels that resemble conditions in natural caves. That being said, the range of variability of those conditions is extensive.

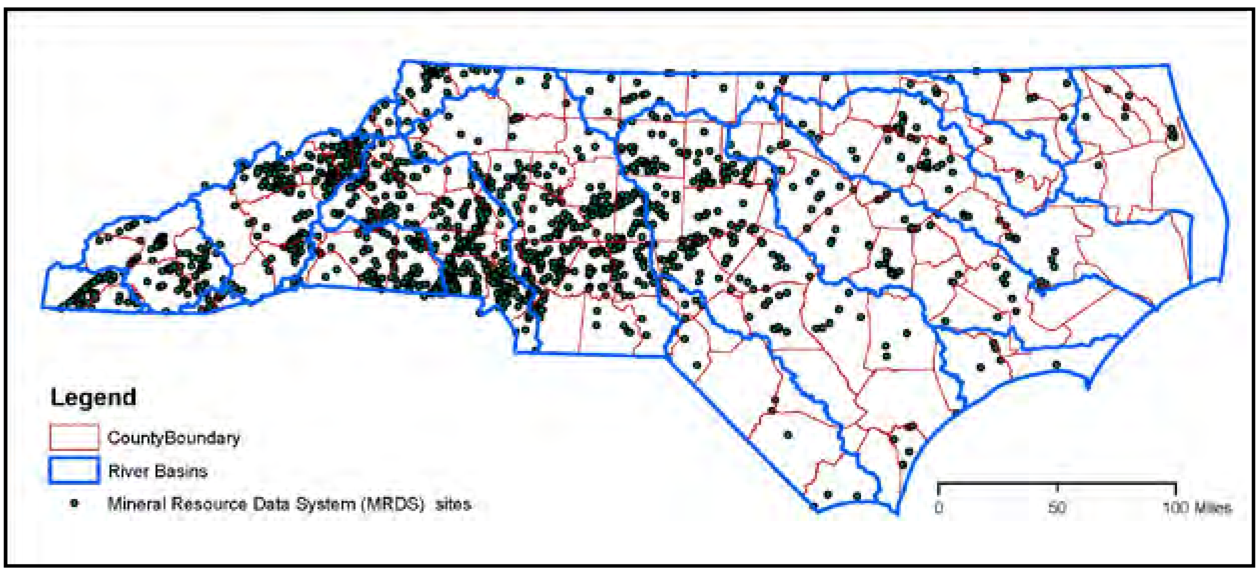
Caves and mines were described in the 2005 WAP as a priority habitat (see Chapter 5) (NCWRC 2005).

4.4.1.2 Location of Habitat

According to Christman and Culver (2001), caves are common in the United States. Details about cave locations in North Carolina are not provided in this document in order to protect them from vandalism and degradation that can occur when used by casual or recreational visitors. Old mines that may pose a geologic hazard (pre–North Carolina Mining Act) and have subsurface workings have been documented in a database previously maintained in the Mineral Resource Data System (MRDS) of USGS and the Mineral Availability System/Mineral Industry Locator System (MAS/MILS) in the US Bureau of Mines (USBM), which is now part of USGS.

Figure 4.5 represents generalized location information of this dataset (McFaul et al. 2000); however, we have made no attempt to verify the type of subsurface feature or location represented by the data. While this data set was developed by USBM/USGS to portray the distribution of old mine workings in North Carolina and contains non-confidential data, it should be recognized that these sites are located on privately owned land in most cases.

Figure 4.5 Statewide location of subsurface mines (McFaul et al. 2000)



4.4.1.3 Problems Affecting Habitats

Given the variability in cave types, mine types, and a host of different substrates, orientations, positions on the landscape, etc., the condition of caves and mines in North Carolina is quite variable. Caves and mines occur across all land ownership types. Several of the most significant sites have received attention in the past to protect resources (wildlife or geological in most cases). Bat-friendly gates have been installed in some locations to prohibit or regulate human entry and subsequent impacts upon cave resources. However, modifications at cave entrances and gate design and placement will potentially impede air exchange, ultimately exerting influence on the ambient and substrate temperatures inside caves, which in turn will influence the body temperature and metabolic rates of hibernating bats (McNab 1974; Humphrey 1978; Martin et al. 2006).

We have no accurate assessment of the wildlife habitat potential of abandoned mines in North Carolina, and certainly have little idea as to their individual suitability for use by cave-dwelling animals or plants. Some portion of abandoned subsurface mines are likely to function similarly to caves in providing the range of microhabitat conditions which cave-obligate species need, especially larger mine excavations that can provide the volume and air flow needed by cave-dwelling species (particularly bats of various species). Smaller mines may support minor levels of use, or use by small numbers of individuals.

Seasonal variations in surface climate, entrance characteristics (Tuttle and Stevenson 1978) and physical structure of the cave itself (Twente 1955; Raesly and Gates 1987) are thought to have the greatest impact on the climate of cave interiors (Martin et al. 2006). Changes in precipitation may contribute to variation in moisture and temperature but may not be drastic. Drought conditions cause moisture gradients in caves and mines to change, especially those with groundwater seepage contributing to the humidity level. Warmer temperatures will change the suitability of this habitat for species adapted to historic microclimate conditions.

Human activities alter the microclimate, biogeochemistry, and balance of organic matter in caves, which also impacts microbial communities (Saiz-Jimenez 2012). Several research articles have reported on declines of cave-obligate bats caused by human disturbance at caves (Martin et al. 2006). In many states, and throughout the world, many caves have been developed into tourist attractions, often with lighting, tours, gates, etc. All of these activities have resulted in degraded habitat conditions for cave-dwelling animals as well as disrupted normal behavior patterns, effectively eliminating habitat for many cave animals. The Southern Blue Ridge Ecoregional Conservation Plan noted recreation, including developed tourist caves and recreational caving/exploration, to be the greatest threat to cave and cave species conservation (TNC and SAFC 2000).

4.4.1.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While climate change is not the most severe threat, a combination of synergistic effects with other existing conditions could stress these systems to the point where several species are unable to persist. The Southern Blue Ridge Ecoregional Conservation Plan identifies recreation as the greatest threat to cave and cave species conservation (TNC and SAFC 2000). Communities and species associated with cave and mine habitats are likely to be affected by changes in temperature and mild winters associated with climate change. Table 4.26 summarizes the comparison of climate change with other existing threats.

4.4.1.5 Impacts to Wildlife

Appendix G provides a list of the SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type. Subterranean aquatic communities are described in Section 4.2.6.

White-nose syndrome (WNS), a fungal disease that affects hibernating bats, is reported to be caused by *Pseudogymnoascus destructans* (Blehert et al. 2009; Frick et al. 2015), formerly

Table 4.26 Comparison of climate change with other threats to caves and mines

Threat	Rank Order	Comments
Pathogens/Disease	1	White-nose syndrome (WNS) has devastated bat populations roosting in caves in the northeastern states, including North Carolina, over the past 5–10 years. Several bat species have declined in the state by over 95% due to the death caused by this fungus.
Recreation	2	Disturbance from human intrusions can disrupt normal animal activities (hibernation, roosting) and introduce contamination from other sites (fungal spores, disease). Most accessible caves or mines experience some level of human visitation by caving and rock climbing enthusiasts.
Development	2	Caves are at risk of being developed into tourist attractions, often with lighting, tours, gates, etc. These activities result in detrimental impacts to habitat conditions for cave-dwelling animals, as well as disrupted normal behavior patterns, effectively eliminating habitat for many cave animals. Linville Caverns is the only cave complex that has been commercially developed as a recreational destination in the state.
Climate Change	3	Caves and mines provide unique microclimates that some species require during key phases of their life history (e.g., bat hibernation). Even slight increases in temperature can change the humidity in these environments and increase the potential for fungal and bacterial growth. Evidence of temperature variability is the increased occurrence of WNS in winter hibernating bats.

Geomyces destructans (Lorch et al. 2011; Hayes 2012). The first evidence of the disease was documented in 2006 and since then there has been widespread evidence of its impact on bats. WNS has already decimated populations of most cave-dwelling species of bats in the state, especially Northern Long-eared Bat and Little Brown Bat. Chapter 5 provides additional information on disease and pathogens affecting wildlife, including WNS.

Nearly a thousand species and subspecies known from caves and associated subterranean habitats in the United States have been described (Culver et al. 2000; Christman and Culver 2001). Various surveys and investigations have been conducted in many caves and mines in attempts to document significant wildlife or geological resources in North Carolina. However, no comprehensive evaluation has ever occurred in the state other than for bats in caves. Caves also provide important habitat for cavespiders (*Nesticus* spp.), millipedes, crustaceans, pseudoscorpions, and crickets (TNC and SAFC 2000). Not only is the condition of caves and mines quite variable in North Carolina, but our state of knowledge about the use of caves and mines by plants and animals is extremely variable. Habitat specialists and species with restricted ranges will likely be some of the greatest affected by the combined effects of habitat loss and climate change.

Troglobites are cave-dwelling organisms that have adapted to darkness, have no skin pigment, and are blind because they spend their entire lives underground. Troglobites include fish, salamanders, crayfish, insects, and spiders. They cannot live outside a cave and their survival may be threatened if the cave environment is damaged or altered. The National Speleological Society (NSS) notes that water pollution, visitor traffic, trash, flooding, and a change in air patterns and temperature contribute to disturbing a cave's fragile food web and ecosystem.

One cave complex has been developed as a recreational destination in North Carolina and many other cave or mine systems have experienced some level of human visitation. Many of the wildlife species that use caves, if not the caves themselves, have been impacted by human activities, including both direct impacts (e.g., repeated disturbance during bat hibernation) and indirect impacts (e.g., habitat changes that make microhabitat conditions inside the cave or mine unsuitable). Human use of caves can cause alteration of the physical structure of the caves themselves, changes in the water chemistry or hydrology within the cave, or destruction of cave structures and cave-dwelling organisms (Fleury 2009). Dripwater flows are critical both to cave biota and to the microclimates of the caves themselves, and if those flows carry surface-level contaminants, the entire cave environment is affected (Fleury 2009).

It is believed many smaller caves and mines have been impacted by nearby development, though there is little to no documentation of the occurrences. Careless disposal of wastes or excessive fertilization in agricultural areas can have devastating impacts on cave life by altering the water chemistry (Watson et al. 1997; Gillieson 1996). Though it rarely happens, caves can also be destroyed by aquifer drawdown, as sinkholes can form on the surface and collapse so they fill in the cave. It is usually not possible to restore a cave to its original condition after it has been degraded by human activity; for that reason, conservation is a preferred strategy (Elliott 2004).

4.4.1.6 Recommendations

Caves and mines occur across all types of land ownership. Several of the most significant sites have been identified as conservation priorities. The North Carolina Cave Survey has documented over 1,300 caves in the state (NCWRC 2005). We have no accurate assessment of the availability of abandoned mines in North Carolina, nor do we possess information on their individual suitability for use by cave-dwelling animals or plants.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Create a comprehensive, prioritized list of significant caves, including the factors which add significance (e.g., roost of endangered bats, rare geologic formations, other rare plants or animal use).
- Survey for potential nesting birds in caves such as Turkey Vultures, Black Vultures, and Common Ravens.
- Inventory salamander communities associated with cave habitat (particularly in the twilight zone of caves).
- Conduct bat surveys in caves and mines that have not been previously evaluated.
- Conduct surveys for Cave Salamanders (*Eurycea lucifuga*) in areas along the Tennessee/North Carolina border.

Monitoring. Long-term monitoring of caves and mines is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Establish and implement long term monitoring protocol to document bat use of significant cave/mine roosts, especially in those caves and mines that are affected by WNS.

- Develop protocols and procedures for long-term bat banding study and data storage throughout the state.
- Establish protocol for periodic monitoring and assessment of Allegheny woodrat populations.
- Develop and implement systematic, long-term population monitoring protocols for cave-dwelling salamanders.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- In some areas of its range, the Longtail Salamander is associated with caves or portions of caves. Investigate its habitat use in North Carolina in conjunction with more generalized research on this species' distribution, status, and habitat in the state.
- Conduct studies to document maternity sites used by bats from specific hibernacula (e.g., find maternity colonies utilizing radio telemetry of individual Virginia Big-eared Bats that hibernate in known caves/mines, or track any Indiana or Gray bats captured to their maternity sites or hibernacula).

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Where feasible and cost effective, install gates to limit access (similar to protective measures used at Cranberry Mine). Inspection and monitoring may be needed to detect vandalism and illegal entry.
- Identify ways to address the effects of WNS where it occurs in the state.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable.

Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Acquire cave habitat through purchase, conservation easement, or other perpetual management agreements (potential for partnerships with NC Natural Heritage Program, The Nature Conservancy).
- Develop plans to protect caves where roosting bats or other cave resources are at risk from human intrusion.

4.4.2 Spruce–Fir Forests

4.4.1 Ecosystem Description

Red Spruce–Fraser Fir forests are considered an endangered community in North Carolina and are ranked the second most endangered ecosystem in the United States (White et al. 2012; Noss et al. 1995, Christensen NL et al. 1996; Rentch et al. 2007). These forests are dominated by Red Spruce and Fraser Fir and occur on the high mountain tops in western North Carolina, generally over 5,500 feet in elevation. The cold climate of the high elevations is equivalent in some ways to the boreal forests of Canada. However, the climate differs from the north in that it is less continuously cold and much wetter, with both rain and fog tending to concentrate on the mountain tops.

Spruce–fir forests are divided into two natural community types: Fraser Fir forest and Red Spruce–Fraser Fir forest, each with several variants (Schafale 2012). Both communities tend to have dense canopies under natural conditions. A variety of distinctive shrubs and herbs, many of them more common in the northern United States, but some endemic to the southern Appalachians, occur beneath the canopy. Lush beds of moss and ferns cover the rocky soil and abundant fallen logs in some areas.

- Fraser Fir forests occur on the highest mountain tops, where the Fraser Fir is the only tree species able to survive the cold, wind, ice, and storms in large numbers. Most Fraser Fir forests now exist as patches of dense young trees due to infestations of Balsam Wooly Adelgid, an introduced insect pest that kills adult Fraser Firs.
- Red Spruce–Fraser Fir forests occur in slightly less hostile environments where Red Spruce and Yellow Birch can also persist in large numbers. Red Spruce–Fraser Fir forests have canopies of remnant spruce trees, many of which are also dying. The least affected sites are the lowest elevation examples, which have relatively little fir.

Estimates of the amount of spruce–fir habitat are quite variable depending upon a number of factors including the estimation methods and habitat definition. The Partners in Flight Bird Conservation Plan for the Southern Blue Ridge (Hunter et al. 1999) identifies over

66,000 acres of spruce–fir forest in the southern Blue Ridge physiographic province and the Southern Appalachian Assessment (SAMAB 1996) identifies over 75,000 acres in North Carolina and Tennessee. The vast majority of these areas occur in North Carolina.

The 2005 WAP described Southern Blue Ridge Mountain spruce–fir forests as a priority habitat (see Chapter 5) (NCWRC 2005).

4.4.2.2 Location of Habitat

Spruce–fir habitats in North Carolina are now found within a narrow range of suitable conditions, isolated from each other and the rest of their range. There are currently six significant areas of spruce–fir habitats in western North Carolina, including portions of Grandfather Mountain, Roan Mountain, the Black/Craggy Mountains, the Great Balsam Mountains, the Plott Balsam Mountains, and the Great Smoky Mountains.

Most of the spruce–fir habitat in North Carolina is located on public land, or private lands with permanent conservation easements, with estimates of 90%–95% in conservation ownership in the southern Blue Ridge physiographic province including North Carolina, Tennessee, and Virginia (Hunter et al. 1999; SAMAB 1996). However, significant private ownership of spruce–fir habitat occurs in the Plott Balsams and Black/Craggy Mountains, and to lesser extents in several other ranges.

Red Spruce habitats of lesser size or with somewhat different ecological community associates occur in a few other locations, including Long Hope Valley, Beech Mountain, Unaka Mountain, Unicoi Mountains, and Alarka Laurel.

4.4.2.1 Problems Affecting Habitats

Given the high number of endemic and disjunct species that use the spruce–fir habitat, it is the one community where threats to biodiversity are the greatest. Much of the spruce–fir habitat in North Carolina and throughout the southern Appalachians has been significantly altered due to a number of factors including historic logging, fire, exotic insects, historic grazing, and recreational development. Much of the spruce was logged in the early 20th century and in some areas (notably the Great Balsams) slash fires burned not only the coarse woody debris, but also the organic soil, which has subsequently inhibited the redevelopment of spruce and fir forests over large areas (Schafale and Weakley 1990).

The removal of mature Fraser Fir from the canopy has profound implications for the spruce–fir ecosystem and the continued existence of several unique plants and animals (Nicholas et al. 1999). Following extensive logging during the last century, it is estimated that as much as 50% of all Appalachian spruce–fir forests were replaced through successional growth of hardwood species (White et al. 2012; Pyle 1984). Several of the species face outright extinction and others, if lost, are unlikely to ever recover within the region.

The Blue Ridge Parkway was completed through western North Carolina during the latter part of the 20th century. The Parkway traverses most of the high-elevation islands of spruce–fir habitat. The Parkway and its associated development (the motor road, vistas, and visitor facilities) have contributed to fragmentation and had a significant impact on the amount of spruce–fir habitat available.

In the latter part of the 20th century, the Balsam Wooly Adelgid (*Adelges piceae*) began to have severe negative impacts on Fraser Firs throughout the region, resulting in the death of most of the mature fir of the high-elevation forests (White et al. 2012). Recent negative impacts include insect outbreaks in several areas including Roan Mountain, the Black Mountains, and the Great Balsam Mountains.

Some research has shown that recent increases in acid precipitation in the Mountains of western North Carolina may have impacts on forest health and productivity, particularly in the high Mountains (Schafale and Weakley 1990; Hunter et al. 1999). While some Fraser Firs remain in certain locations, the majority of late successional fir has been killed and often replaced by young fir, mixed northern hardwoods, and open, herbaceous habitats.

4.4.2.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. Balsam Woolly Adelgid, air pollution, and climate change are all major threats; however, this habitat is among the most vulnerable to climate change.

Many species are currently excluded from these high-elevation communities because of the extreme climate, with winter cold the most likely cause. Mild winters presumably will lead to invasion by species from lower elevations. This will eventually lead to competitive exclusion of distinctive spruce–fir species from the lower parts of their elevational range (DeWan et al. 2010). The fact that these habitats are so small and isolated from each other could have a negative impact upon genetic health of individual populations, as well as demographic effects upon populations. Table 4.27 summarizes the comparison of climate change with other existing threats.

Table 4.27 Comparison of climate change with other threats to spruce–fir forests

Threat	Rank Order	Comments
Climate Change	1	This ecosystem is among the most vulnerable to the effects of climate change of any in the state. Warmer winters will result in reduced snow fall and less snow pack, which in turn affects soil moisture gradients.
Invasive Species	1	The Balsam Woolly Adelgid is the most severe threat to Fraser Fir forests. Insect outbreaks have occurred in several areas, including Roan Mountain, the Black Mountains, and the Great Balsam Mountains (NCWRC 2005). Changes in seasonal temperatures may allow pest species to survive during warmer winters and thus exacerbate the threat of insect outbreaks (Logan et al. 2003).
Air Pollution	1	Air pollution (including acid rain, ozone, and lead deposition) generated in other areas is carried by prevailing winds and deposited through precipitation. Acid rain kills or stunts new growth and contributes to heavy metal toxicity in soils.
Fire	2	The natural vegetation virtually never burns under the current climate, and the biota are not adapted to fire. Spruce–fir habitats in North Carolina are now found within a narrow range of suitable conditions, isolated from each other and the rest of their range. This condition alone makes them more susceptible to perturbation and catastrophic events.
Development	3	The Parkway and its associated developments (the motor road, vistas, and visitor facilities) have had a significant impact on the amount of spruce–fir habitats available (NCWRC 2005). While wind turbine farms are unlikely to be built where stands of spruce–fir forests are still present, there is some potential for them to be sited on ridge-tops where spruce–fir once occurred and could be potentially restored.
Logging/ Exploitation	4	Much of the spruce was logged in the early 20th century and in some areas (notably the Great Balsams), slash fires burned not only the coarse woody debris, but also the organic soil, which has subsequently inhibited the redevelopment of spruce–fir forests over large areas (Schafale and Weakley 1990).

4.4.2.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

Spruce–fir provides critical habitat for numerous plant and animal species found nowhere else in North Carolina. Twenty species or subspecies of invertebrates are endemic to spruce–fir forests in the southern Appalachians. Another nine are highly disjunct within this region, with their next nearest populations located in New England or Canada (some may turn out to be distinct species once genetic studies are done). Still more such species exist within other insect orders and in other invertebrate taxa such as myriapods, Tardigrades, and land snails. For terrestrial animals, this level of endemism/disjunction is unmatched by any other habitat group in the state.

Carolina Northern Flying Squirrel, a federal listed endangered subspecies, forages on conifers and fungi found in high-elevation spruce–fir and hardwood forests. The moist, boreal conditions support the mycorrhizal fungi that grow in association with the tree roots. Habitat destruction and fragmentation from development, as well as alteration from logging, mineral extraction, pollution, and pest species, has reduced available habitat for the Carolina Northern Flying Squirrel. The highest quality habitat for the squirrel is the transition zone between spruce–fir forest and the northern hardwood forest, a mix of Red Spruce, Fraser Fir, Yellow Birch, Buckeye, Sugar Maple, and even some beech at elevations above 4,000 feet. Information about Carolina Northern Flying Squirrel can be found in Chapter 3.7 of this document.

Spruce–fir communities provide critical breeding habitat for many landbirds of conservation concern according to Partners in Flight (Brown Creeper, Northern Saw-whet Owl, Black-capped Chickadee) that are likely endemic to these high peaks (Pashley et al. 2000; Rich et al. 2004; Johns 2004). Local relative abundance of many birds and mammals (e.g., the Red Crossbill, Brown Creeper, Pine Siskin, Black-capped Chickadee, Northern Saw-whet Owl, Northern Flying Squirrel) has decreased as the availability of spruce–fir habitats has declined. The fact that these habitats are so small and isolated from each other could have a negative impact upon genetic health of individual populations, as well as demographic effects upon populations.

Many species using spruce–fir forests are flightless, including salamanders and eight species of ground beetles (*Trechus* sp.). Weller's Salamander is at the highest risk of being pushed off the top of the mountain because of climate change. As is generally true for "sky island" species, even those capable of flight (or ballooning in the possible case of the Spruce–fir Moss Spider), they rarely disperse out of their habitat, if at all.

All of these species depend on cool, moist microclimates, but the Spruce–fir Moss Spider, ground beetles, and salamanders are particularly susceptible to desiccation and are among the species most likely to be affected by climate change of any in the state.

4.4.2.6 Recommendations

Most of the spruce–fir habitat in North Carolina is located on public land, or private lands with permanent conservation easements, with estimates of 90%–95% in conservation ownership in the southern Blue Ridge physiographic province (North Carolina, Tennessee, and Virginia) (Hunter et al. 1999; SAMAB 1996). Since virtually all examples are located on public lands and are already managed to preserve their natural features, implementation of recommended interventions should be more feasible than for privately owned lands.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Determine the distribution, relative abundance, and status of all wildlife species associated with spruce–fir forests.

- Focus survey priorities on species believed to be declining, at risk, or exclusively dependent on spruce–fir forest communities (e.g., the Red Crossbill, Brown Creeper, Black-capped Chickadee, Rock Vole, Rock Shrew, Carolina Northern Flying Squirrel, Weller's Salamander, Northern and Southern Pigmy Salamanders, etc.).

- Focus secondary survey priorities on species for which current distribution information is more available (e.g., the Northern Saw-whet Owl), or for species associated with additional, more extensive habitats (e.g., the Masked Shrew, Smoky Shrew, Hairy Woodpecker, Canada Warbler, Sharp-shinned Hawk, Northern Slimy Salamander) to collect distribution and abundance data.

- Collect baseline microhabitat and microclimate characteristics in spruce–fir salamander communities.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Expand and/or target monitoring systems to assess current population status and trend information for all wildlife species associated with spruce–fir forests.

- Establish mechanisms for monitoring the distribution and condition of spruce–fir habitats over time.

- Monitor phenology of priority species and spruce–fir communities in relation to climate change.

- Monitor microhabitat and microclimate characteristics in spruce–fir salamander communities in relation to climate change.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions

for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Conduct studies to explore the degree of endemism of southern Appalachian populations (e.g., Pine Siskins, Red Crossbills, Northern Saw-whet Owls, Black-capped Chickadees, etc.).
- Conduct studies to explore the degree of genetic isolation of species restricted to high elevations (e.g., Carolina Northern Flying Squirrels, Rock Voles, Rock Shrews, Weller's Salamanders, Northern Saw-whet Owls, etc.).
- Conduct research on population demographics including trends, population structure, survivorship, reproduction, and population viability for all spruce–fir associated species/groups.
- Species phenology needs to be investigated, especially where there are endemic populations.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Develop and/or implement techniques for managing pure spruce stands to include habitat components of the entire spruce–fir/northern hardwood community (i.e., thinning).
- Test silvicultural techniques to reintroduce spruce into formerly disturbed areas that have regenerated in northern hardwood or Northern Red Oak communities (i.e., thinning and underplanting).
- Protect spruce–fir communities from wildfire, as this is an important action that can be taken to save the remnants of these communities.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Eliminate or minimize negative effects of future development in state and federal government holdings (state and federal parks, US Forest Service recreation developments).

- Acquire additional acreage of spruce–fir habitat through purchase, conservation easement, or other perpetual management agreements (particularly in the Plott Balsams and Black/Craggy Mountains).

4.4.3 Northern Hardwood Forests

4.4.3.1 Ecosystem Description

Northern hardwood forests are found on high mountain slopes with a cool climate and high levels of rainfall in western North Carolina and are concentrated in many of the same high-elevation areas as spruce–fir forests. The name refers to the resemblance of these forests to those in the northeastern United States, which have similar canopies, but the presence of southern Appalachian endemic species makes the community types in North Carolina different from those in the north. High-elevation climate, slope, aspect, and past disturbance are critical ecological determinants of the distribution of northern hardwood forests today. In general, they are widespread throughout the region owing to their lower elevation range.

Northern hardwood forests are dominated by combinations of moist-site hardwoods such as Yellow Birch, beech, Yellow Buckeye, and Sugar Maple. The herb layer is often lush, and may range from low to fairly high diversity. These forests are subject to periodic widespread disturbances, such as ice storms or severe winds, which provide canopy openings, but probably seldom or never remove the whole canopy at once.

Three recognized variants of this community type are determined primarily by topography and soil chemistry: boulderfield forest, beech-gap, and typic subtypes.

- In the boulderfield forest, Ice Age freeze–thaw processes have left the ground completely covered with large boulders with very little soil. These areas are dominated by Yellow Birch with a distinctive undergrowth of gooseberries and moss on the rocks.
- The beech gap subtype occurs in high-elevation gaps and peaks, where beech trees stunted by the wind predominate. In the most extreme cases, the tree canopy may be reduced to shrub size. The trees may be quite old, although small, as growth and reproduction are relatively slow.
- The typic subtype varies in composition and diversity. Some have a lawn-like ground cover of just a few species of sedges and grasses, while others have a lush and diverse herb layer.

While the northern hardwood habitat can be defined in general terms, ecologically, it should be considered in association with spruce–fir forest for the purposes of maintaining ecological relationships and sustainability. Often components of spruce–fir habitats are present in sub-dominant numbers within northern hardwood communities, and increase in dominance along the elevation gradient to a point where spruce–fir becomes the dominant community.

The 2005 WAP described Southern Blue Ridge Mountain northern hardwoods as a priority habitat (see Chapter 5) (NCWRC 2005).

4.4.3.2 Location of Habitat

Northern hardwood forests are found throughout western North Carolina on high-elevation sites with abundant rainfall and a cool climate. Generally these conditions occur above 4,000 feet, but more often it is above 4,500 feet. The majority of northern hardwood forests are on public lands and many are in protected status. Significant amounts of northern hardwood forest occur on federally owned lands including US Forest Service (Pisgah and Nantahala National Forests) and National Park Service lands (Blue Ridge Parkway and Great Smoky Mountains National Park), in the Great Smoky Mountains, Great Balsams, Plott Balsams, Black/Craggy Mountains, Unicoi Mountains, and in the vicinities of Roan Mountain and Grandfather Mountain. While most of the available northern hardwood forest is associated with these high-elevation mountain ranges, significant amounts are present in other areas of suitable elevation throughout the region, such as in the Amphibolite Mountains in Ashe and Watauga counties. A small percentage does occur on state-owned lands, and other conservation ownerships (e.g., The Nature Conservancy, local land trusts, etc.).

4.4.3.3 Problems Affecting Habitats

Development pressure includes threats from a large increase in second homes and recreation facilities. Many nonnative pathogens are a potential problem for several tree species in this ecosystem, including the Hemlock Woolly Adelgid, Balsam Woolly Adelgid, Gypsy Moth, Emerald Ash Borer, and beech scale. The isolated nature of several populations of wildlife, such as the Carolina Northern Flying Squirrel, Northern Saw-whet Owl, Black-capped Chickadee and Weller's Salamander, is likely detrimental to the genetic flow and overall long-range health of the species.

Many of the former fir forests and logged or grazed areas are regenerating into northern hardwood stands, without a conifer component (spruce or fir). Development on private lands, and logging on private and some public lands remain threats, and are likely the most immediate and greatest threats to a significant number of good examples. Climate change, particularly associated drought and wildfire, is the greatest threat to protected examples. However, the threat of climate change is less severe than in spruce–fir forests and the threat of logging and development are relatively greater.

The aging of many northern hardwood stands has resulted in closed canopy conditions and decreasing habitat for bird species that rely on diverse understory development, such as the Canada Warbler. Lack of disturbance has reduced available habitat for disturbance-dependent species such as the Golden-winged Warbler and Yellow-bellied Sapsucker (Hunter et al. 2001a). In turn, the impacts to other wildlife from stand-level disturbance will need to be examined. For example, small mammals in the family Soricidae, such as Masked and Smoky shrews, can respond favorably to forest disturbance in northern hardwoods (Ford et al. 2002), but this may not be true for other small mammals or salamanders.

4.4.3.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. The effect of a changed climate is likely to vary widely among examples of these communities, depending on topographic sheltering, configuration of rocks, soil depth, size of groundwater pools, and amount of overland runoff. These systems are tied to specialized small environments and will be unable to migrate as the climate changes. Many may change very little, while a few will shrink, will be disturbed by wind or flood, or will change substantially because of temperature changes or drought. A small net loss of acreage may occur, but more seeps may be temporarily affected by drought. Table 4.28 summarizes the comparison of climate change with other existing threats.

4.4.3.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

Northern hardwood forests provide habitat for numerous wildlife species that also rely heavily on spruce–fir forests. Because of the spatial relationship between them, and the fact that they share many ecological components and plant species, northern hardwood forests are critical to maintaining many species of birds and mammals dependent upon spruce–fir habitats. In addition, northern hardwood plant species may be critical components of spruce–fir habitats even in their sub-dominant role. Consider, for example, the fact that many spruce–fir dependent wildlife species are cavity nesters. Yellow Birch, beech, Sugar Maple, and Buckeye often provide more natural cavities and decaying wood than spruce or fir for species such as Northern Flying Squirrels, Yellow-bellied Sapsuckers, Black-capped Chickadees, Northern Saw-whet Owls, and other wildlife.

Table 4.28 Comparison of climate change with other threats to northern hardwood forests

Threat	Rank Order	Comments
Climate Change	1	Expected climate changes include warmer average temperatures, longer growing season, probably more hot spells, more drought, and more intense storms. We do not know the effect on rainfall and fog. Much of the climate in this zone is orographically determined, and may not follow the same patterns as the general regional climate.
Development	2	Fragmentation and increased edge areas can increase predation on forest interior species and increase competition from more common species. Warmer winters and more hot spells may fuel increasing desire for housing development at the higher elevations where these communities occur.
Logging/ Exploitation	2	Logging alters forest structure and composition by removing mature canopy trees and can cause fragmentation in larger stands. Clearcutting negatively affects the availability of mycorrhizal fungi and lichens that are a major part of the Carolina Northern Flying Squirrel diet (as reviewed in Loeb et al. 2000). However, cleared areas may provide increased flowering plant food and nesting resources for native bee species (Romey et al. 2007). In one study, significant increases in native bee species diversity, richness, and abundance was a direct response to logging (Romey et al. 2007).
Invasive Species/ Pathogens	3	Gypsy Moth, Emerald Ash Borer, and other invasive species can lead to local destruction of habitat, which may contribute to changes in animal community composition.

There is a major concern about salamanders, as this is a key ecosystem group for rare and southern Appalachian endemic species. On the other hand, the bird species are all more common and widespread farther northward, though a few species may become rare in the state. The aging of many northern hardwood stands has resulted in closed canopy conditions and decreasing habitat for bird species that rely on diverse understory development, such as the Canada Warbler.

At least six taxa are endemic to northern hardwood forests in the southern Appalachians; three others may also fall in this category, but have not yet been formally described as separate subspecies. Additionally, one moth appears to be a major disjunct from the northern Appalachians and several others are likely to have a similar distribution but are presently too poorly known. All species listed for this ecosystem group are likely to be strongly affected by climate change, as well as the effects of increased fragmentation.

4.4.3.6 Recommendations

Although occupying a larger area and probably somewhat more resilient than spruce–fir forests, this habitat group contains a similar high proportion of endemics and major disjuncts, the loss of which cannot be replaced. Along with the spruce–fir forests, northern hardwood forests should be considered as one of the most threatened by climate change and should receive a high priority for intervention. Like the spruce–fir forests, a substantial amount of the acreage of this group is located on public lands or on other conservation lands. Consequently, intervention should be easier to implement for northern hardwood forests than for many others.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Fill in distribution gaps for Carolina Northern Flying Squirrel. Continue survey work on distributions within and between known populations.

- Obtain baseline data on SGCN and priority species, especially species that depend on high-elevation forests.

- Conduct shrew surveys to determine the distribution of Long-tailed, Pygmy, and Water shrews and surveys to document the response of shrews to disturbance/management.

- Conduct surveys for rare salamanders like Weller's, Northern and Southern Pygmy, Seepage, and Tellico, as well as more common species such as Ravine Salamanders, to determine their actual distribution and better define their habitat associations.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Establish monitoring systems and protocols and implement programs to monitor population trends for all high-elevation species.

- Develop and implement monitoring systems and protocols for population trends for all high-elevation species, including those associated with northern hardwood forest, with top priority toward rare species and secondary priority toward all species occurring in this relatively rare community of the North Carolina landscape.

- Establish more Monitoring Avian Productivity and Survivorship (MAPS) stations, point counts, and migration banding stations; montane birds are not adequately picked up in BBS routes.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Conduct genetic studies across taxonomic groups to assess degree of population isolation/gene flow and determine taxonomic status (primarily bird taxa thought to be southern Appalachian endemics).
- Initiate habitat use studies for many species to assess use of microhabitats, forest age classes, and habitat spatial relationships.
- Conduct research on habitat management techniques to successfully establish mixed spruce–northern hardwood stands in non-forested areas or appropriate pure/young northern hardwood stands.
- Research phenological relationships of priority species to better understand how changing climate conditions will affect seasonal availability of food resources.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Consider and implement silvicultural management at appropriate locations to enhance understory development, provide regeneration and habitat for disturbance-dependent species or early successional species, such as Golden-winged Warbler, and enhance mature forest conditions in young to middle-aged pure stands.
- Expand management of existing northern hardwood forests and adjacent habitats (particularly spruce–fir forests) to ensure the complete mix of age class, composition, and conditions necessary to sustain populations of a wide range of species that utilize this community.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable.

Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Make particular effort to protect examples at the higher elevations, where the community is likely to persist and where the seed source for migration to higher elevations will primarily come from.
- Protect the current habitat and connectivity of isolated patches through conservation ownership acquisition or easement.
- Increase connectivity among habitat patches, both through acquisition or management of adjacent stands. Preservation of large tracts of minimally disturbed older forests may be key to maintaining forest litter amphibian populations.

4.4.4 Cove Forests

4.4.4.1 Ecosystem Description

Cove forests are some of the most well-known and recognized community types in the Mountains, occurring on sheltered, moist, low to moderate elevation sites. They are characterized by a dense forest canopy of moisture-loving trees. There are three community types in this ecosystem: rich cove forest, acidic cove forest, and basic mesic forest (montane calcareous subtype).

- The rich cove forest type, occurring in the most fertile sites, has a lush herb layer and relatively few shrubs. The high diversity in all vegetation layers makes this forest of great interest to botanists and ecologists.
- The acidic cove forest, which occurs in less fertile but otherwise similar sites to those occupied by rich cove forests, is dominated by the more acid tolerant species, and has undergrowth dominated by ericaceous shrubs such as rhododendron, rather than by herbs. Canada Hemlock forests have similarly dense shrub layers and relatively few herbs.
- The basic mesic forest (montane calcareous subtype) is a geologically restricted community that occurs on rare outcrops of limestone, marble, or dolomite, and is dominated by trees that favor high pH soils. These communities are naturally relatively stable, uneven-aged climax forests, with trees up to several centuries old.

The 2005 WAP describes Southern Blue Ridge Mountains Cove Forest as a priority habitat (see Chapter 5) (NCWRC 2005).

4.4.4.2 Location of Habitat

Cove hardwood habitat is well represented in the Mountain ecoregion of western North Carolina, including in the Pisgah and Nantahala National Forests. According to the most recent Southeast Gap Analysis Project (GAP), cove forests comprise a little over 558 thousand acres (nearly 226 thousand hectares) of land cover in North Carolina (SEGAP 2007; NatureServe 2007). This represents slightly more than 1.6% of all land cover in the state.

4.4.4.3 Problems Affecting Habitats

The most pressing problem affecting the cove hardwood habitat is the advent of several exotic pest species which could have a significant impact upon the health of the forest, including the Hemlock Wooly Adelgid, Gypsy Moth, and beech scale, as well as several nonnative plants. Evans and Gregoire (2007) that aldelgid infestation can move across the landscape at 15 km (about 9 miles) per year or faster and can kill trees in two to three years (Trotter and Shields 2009). In fact, the adelgid has already devastated most of the Canada Hemlock stands in the state, such that former mixed hemlock–hardwood stands are now mostly hardwoods, with much lessened evergreen cover available for wildlife during the cooler months.

Though estimates of the amount of cove hardwoods lost to development are unavailable, the most significant problem affecting this community type is its conversion to other uses. Residential development in mountain coves often differs from development in other habitats of the region because the homes and associated open spaces are often interspersed within the forest. The result may be that direct habitat loss as a result of the houses and associated structures may be more limited than other types of development.

Timber harvesting and conversion to other forest types (White Pine) or other uses on private lands in certain areas can also decrease the availability of this habitat in the future. The reduction in quality of the habitat through fragmentation by roads and driveways and human intrusion can have significant impact upon the wildlife species of the forest (Rosenberg et al. 2003).

4.4.4.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. The effect of a changed climate is likely to vary widely among examples of these communities, depending on topographic sheltering, configuration of rocks, soil depth, and amount of overland runoff. Unprotected examples of these forests are most threatened by development and logging. Table 4.29 summarizes the comparison of climate change with other existing threats.

Table 4.29 Comparison of climate change with other threats to cove forests

Threat	Rank Order	Comments
Invasive Species	1	Exotic species represent a growing threat, including the hemlock wooly adelgid, Gypsy Moth, and beech scale, as well as several nonnative plants. The Hemlock Wooly Adelgid has already caused widespread devastation in hemlock forests. Emerald Ash Borer and several other destructive insects represent large potential threats. Invasive plants are a serious and growing problem in lower elevation examples, particularly in those that are disturbed by logging or that occur near developed areas. Invasive plants, such as Garlic Mustard and Oriental Bittersweet, are likely to increase regardless of climate change. Oriental Bittersweet is already a significant problem in some cove forests in the Mountains and has greatly altered vegetation composition and structure.
Logging/ Exploitation	2	Logging causes more drastic alterations to structure and composition than expected from climate change. Timber harvesting and conversion to other forest types (White Pine) or other uses on private lands in certain areas can also decrease the availability of this habitat in the future.
Development	2	Development can cause indirect effects as well as outright destruction of these communities, creating an edge effect and developing seed sources for invasive species. Residential development in mountain coves often differs from development in other habitats of the region, in that homes and associated spaces are often interspersed within the forest. The result may be that direct habitat loss as a result of the houses and associated structures may be more limited than other types of development. However, the reduction in quality of the habitat by virtue of being bisected by roads and driveways, other infrastructure, and domesticated plants and animals can certainly have significant impact upon the wildlife species of the forest (Rosenberg et al. 2003)
Climate Change	3	Climate change poses several threats, including loss of area in more marginal sites, alteration by increased wind, flood, and fire disturbance, and increased problems with invasive plants. For some protected examples, this is the most severe threat.

4.4.4.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

Appalachian cove hardwood forests represent some of the most diverse ecosystems in the world outside of tropical zones (Hunter et al. 1999). An amazing assortment of trees and herbaceous vegetation, coupled with topographic, microclimatic, and soil characteristics combine to provide an extremely productive habitat for numerous mammals, amphibians, and birds. High numbers of endemic salamanders are present (Petranka 1998), and population densities of these animal groups in cove hardwood forests make these extremely important habitats.

Problems of individual species associated with cove hardwood forests include isolation or extremely limited ranges of populations (e.g., Cerulean Warblers, Crevice Salamanders, Green Salamanders). That could lead to increasing chances of genetic depression or stochastic events having negative consequences for the sustainability of populations. Some bird species which require a diverse understory may be impacted by the aging of stands, which can result in decreased plant diversity until the stand reaches age classes sufficient to produce canopy gaps (Hunter et al. 2001a).

Junaluska and Tellico salamanders are highly restricted to habitats within this ecosystem group. Both occupy extremely small global ranges and are likely to be strongly affected by increased drought-, fire-, or storm-created openings in the canopy. Several other salamanders with extremely limited global ranges also have significant amounts of habitat within this community and are also likely to be threatened by the same set of climate change factors. The same is true for several species of Lepidoptera (such as the Dusky Azure) that are associated with mesic habitats and occur in the southern Appalachians as major disjuncts from the north.

Some high-elevation cove forests now serve as refugia for species for which the current climate in lower areas in North Carolina is not suitable. They are likely to continue to do so, but warming temperature and changed moisture regimes may make some of them less hospitable to some of these species. At the same time, these communities may become refugia for additional species that are currently common, if the regional climate becomes unsuitable for them. They may be crucial for the survival of some species in the state.

4.4.4.6 Recommendations

Rich cove forests host a great diversity of trees and herbs, and provide habitat for a large number of rare plant species in North Carolina. Climate change is not expected to be a major threat to these species overall. While many examples of cove forests are protected from development and logging, protecting more examples would help these communities weather climate change. It would reduce the loss of acreage as protected examples shrink, and would allow larger, more robust populations of their species to survive. Landscape connectivity will become more important as individual patches become smaller.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Direct initial efforts toward surveys to determine current baseline distribution and status of species associated with cove hardwood forest for which that information is lacking.
- Focus initial survey efforts on state-listed species and others that may be declining,- such as the Cooper's Hawk, Sharp-shinned Hawk, Brown Creeper, Black-billed Cuckoo,

Cerulean Warbler, Yellow-bellied Sapsucker, Green Salamander, Seepage Salamander, Pigmy Salamanders, Tellico Salamander, and Southern Zigzag Salamander.

- Conduct surveys to understand current status of species believed to be more common, from which we can measure future population changes (e.g., the Swainson's Warbler, Silver-haired Bat, Long-tailed Weasel, Woodland Jumping Mouse, Eastern Mole, Smoky Shrew, Masked Shrew, Spotted Salamander, Marbled Salamander, Ravine Salamander, Eastern Hognose Snake, Eastern Box Turtle, and Eastern Smooth Earth Snake).

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible. Protocols and procedures developed during surveys for these various taxa should subsequently provide a means to convert from a baseline survey mode, to a long-term population trend monitoring mode at all times of the year.

- The health of Canada Hemlocks needs to be monitored, and efforts to halt the spread of the Hemlock Woolly Adelgid needs to be pursued.
- An integrated pest management strategy is needed; detection and monitoring of plant pest infestations needs to be an integral part of the strategy.
- Investigate treatment options (e.g., foliar sprays, systemic soil treatments, aerial fungal pathogens, biological controls) and monitor applications to determine best method for stand-level treatments (Onken and Reardon 2005; MDA 2010).

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Conduct studies of bird, amphibian, reptile, and vegetation responses to gap management or specific timber harvest regimes (e.g., the Cerulean Warbler, Swainson's Warbler, Yellow-bellied Sapsucker, and various reptiles and plethodontid salamanders).

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- With the vast majority of cove hardwood habitat in mid-successional stages, efforts should be directed toward increasing older age classes of cove hardwoods by both lengthening harvest rotation recommendations for timberland owners, and exploring whether we can mimic old growth gap dynamic conditions through selective harvesting techniques in mid- to late-successional cove hardwood stands.

- Protect riparian areas and control impervious surfaces and stormwater runoff to reduce flood damage to cove forests in altered watersheds, as well as protect the aquatic systems.

- Protect cove forests from severe wildfire during drought periods to prevent catastrophic disturbance. In more favorable periods, prescribed burning of surrounding landscapes would help reduce the risk of controllable wildfire, as well as benefitting the upland communities.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Add to our base of conservation ownership for future generations of the wildlife species associated with the habitat, as well as the use and enjoyment of them by future generations of North Carolinians.

- Protect examples in the most sheltered sites, and those that serve as landscape connections to other patches.

4.4.5 Mafic Glades and Barrens

4.4.5.1 Ecosystem Description

There are three types of barrens in the state: ultramafic outcrop barren, diabase glade, and high-elevation mafic glade. Glades located in the Mountain ecoregion are adapted to a cooler, moister climate and may be more drought tolerant than locations in the Piedmont ecoregion. However, mountain locations may be more susceptible to alteration than Piedmont glades because of residential development.

- Ultramafic outcrop barrens occur on dunite, peridotite, or serpentinite. These rocks are associated with unusual vegetation and endemic species throughout the world because of their unusual chemistry. North Carolina's only well-developed ultramafic outcrop barren is tied to specialized soils and is an open savanna-like community with a scattered pitch pine canopy and grassy ground cover.

- Diabase glades occur in the Piedmont over outcrops of diabase and potentially over other mafic rocks. As with other glade communities, the soil and vegetation are patchy and range from nearly bare rock to patches deep enough to support trees. The vegetation includes many species shared with other high pH soil communities and some species found on granitic flatrocks.

- High elevation mafic glade communitiesies are an extremely rare community type, with only three examples known globally. A single known location in North Carolina occurs on a flat exposure of amphibolite in Ashe County. Lichens, including a species found nowhere else (*Cladonia psoromica*), dominate much of the area. Herbs on thin soil mats and in crevices include both lowland species and northern disjunct species. Woody species occur in deeper soils and crevices.

This natural community description is a new addition to the WAP.

4.4.5.2 Location of Habitat

This natural community has locations in both the Piedmont and Mountain ecoregions. Piedmont examples are less rare, but a couple of the community types occur only in the Mountains. According to the most recent Southeast GAP analysis, glades and barrens comprise approximately 11 acres (about 5 hectares) of land cover in North Carolina (SEGAP 2007; NatureServe 2007).

4.4.5.3 Problems Affecting Habitats

These communities have been substantially altered by fire suppression, and some of these changes may shift them toward more natural composition. Fire is believed to be a natural part of these communities. Low intensity fires may benefit these communities, but climate change may bring higher potential for wildfires to be severe.

Species adapted to mafic glade habitats are tolerant of drought and heat. Higher average temperatures, coupled with drought conditions, will likely increase occurrence of fire. Drought appears to be an important factor in keeping these communities from becoming dense forests. While these are among the driest sites in the Piedmont region, if droughts become much more extreme they may be beyond the tolerance of some of the species.

Drought may also allow this community type to expand into adjacent forests, though this expansion is likely to be limited by soil conditions. An increase in hurricanes or other severe storms may increase the wind damage in forests that creates canopy openings which often favors herbaceous growth. Some of the changes associated with climate change may shift them more toward more natural composition, and may even allow these communities to expand into adjacent forests.

4.4.5.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. Climate change is not expected to be a major threat for these communities. Development, logging, habitat fragmentation, and changes caused by fire suppression are the most severe threats. In some areas, excessive deer browse is also a major threat. Climate change appears less of a threat. Table 4.30 summarizes the comparison of climate change with other existing threats.

4.4.5.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

Table 4.30 Comparison of climate change with other threats to mafic glades and barrens

Threat	Rank Order	Comments
Development	1	Warmer winters and more hot spells may fuel increasing desire for housing development at the higher elevations where these communities occur. Development may not directly impact these communities, but may increase access and therefore trampling. Development of adjacent landscapes is likely to introduce pollution and sediment through stormwater runoff. There may also be increased opportunity for invasive species to disperse into this habitat.
Logging/ Exploitation	2	Land ownership patterns, proximity to markets, accessibility, and other factors influence short-term habitat alterations like forestry operations. Full scale high-grading and poor logging practices will have very negative impacts on the structure and composition of adjacent forests.
Fire	3	Fire suppression has shifted these communities toward denser vegetation and more mesophytic plant composition than would naturally occur, making them more susceptible to climate change. Burning would increase their resilience to warmer climate and drought, as well as make them less prone to destruction by wildfire Prescribed burning will have to account for younger canopies whose trees may be more susceptible to fire than in the past.
Climate Change	4	Mafic glades and barrens may actually benefit from a changed climate, at least among the Piedmont examples. This benefit will only be realized if sites are protected from other forms of destruction, and for most, if fire is restored to them.

It is uncertain how many priority species are associated with this habitat. Bog Turtles are known from a bog wetland at a mafic glade in Ashe County. For animal species, mafic glades and barrens are probably best regarded as a minor component. There may be land snail and moth species that utilize this habitat type; otherwise, mammals such as Bobcats and Raccoons are expected to utilize this community primarily as a movement corridor. The Gorgone Checkerspot Butterfly is known in the state primarily from an ultramafic outcrop barren community at Buck Creek in Clay County.

4.4.5.6 Recommendations

These communities are naturally rare in North Carolina, due to limited availability of suitable habitat. All of these communities are tied to specialized sites, and are unable to migrate. Examples need to be protected and managed appropriately.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Determine the effects of current drought conditions on vegetated communities.
- Map these sites in a GIS format to facilitate tracking changes over time in the habitat, as well as the associated species and facilitate landscape scale management of this rare habitat.
- Conduct detailed surveys, such as moth trapping, at Buck Creek Barrens, the largest mafic barrens site in the state.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Monitor drought conditions and potential for catastrophic wildfire.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions

for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Study population responses to a prescribed fire regime.
- Study the impact of various management scenarios on the habitat and associated species.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Initiate a prescribed fire regime to prevent invasive plants and prevent habitat conversion.
- Protect this habitat through active management to remove invasive species.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Close sites to stop direct (trampling, loss of habitat to recreation developments such as trails, vistas, etc.) and indirect (disturbance) human impacts.
- Use easements and land acquisition to protect from long-term impacts such as housing development.

4.4.6 Grass and Heath Balds

4.4.6.1 Ecosystem Description

Balds are treeless shrub- or herb-dominated communities of the high Mountains. The treeless areas do not represent a climatic timberline, and often occur near higher peaks that are forested. The ecological factors creating balds are not well understood. Harsh climate and shallow soil seem to be a factor in some, particularly heath balds, but many examples of both community types are being invaded by trees and, in the case of grassy balds, shrubs. Fire may have been a factor, but many bald sites do not appear prone to fire, and are surrounded by vegetation that apparently did not burn. There are two community types in this ecosystem:

- Grassy balds are open meadows typically dominated by mountain oatgrass and sedges, with a fairly diverse mixture of other species. They usually occur on broad ridgetops.
- Heath balds are dense thickets of tall shrubs. Catawba Rhododendron and Mountain Laurel are the most common dominants. An unusual dominant at Roan Mountain is Green Alder, not found elsewhere in North Carolina. Most heath balds are on sharp spur ridges, but some occur on rounded peaks or ridgetops.

High-elevation communities are characterized by cool temperatures, relatively high moisture levels within forests, short growing seasons, exposed rock and acidic soils, and extreme weather events. Canopy trees are often misshapen due to persistent strong winds. Open (sparse-to-no tree canopy) communities such as heath or grassy balds and rock outcrops are scattered throughout. Spreading Avens (a federally listed endangered plant species) is endemic to high-elevation grassy balds (Wear and Greis 2012).

It has been discovered that some places that superficially resemble balds were cleared of forest in historical times, but other balds apparently were open throughout history. The presence of disjunct species which require open habitat suggests that some balds have been open since the Ice Age. Large herbivores, such as Elk and Bison may have kept grassy balds open through grazing. Another possibility is that Native Americans worked to keep grassy balds open for game by burning or by other clearing methods.

This natural community description is a new addition to the Wildlife Action Plan.

4.4.6.2 Location of Habitat

Grass and heath balds occur only in the highest mountain ranges of western North Carolina, notably in the Great Smokies, Plott Balsams, Great Balsams, Black/Craggy Mountains, Grandfather Mountain, Roan Mountain, and in the Amphibolite Mountains of Ashe County (NCWRC 2005).According to the most recent Southeast GAP analysis, grass and heath balds comprise approximately 4,761 acres (about 1,927 hectares) of land cover in North Carolina (SEGAP 2007; NatureServe 2007). This represents only 0.2% of land cover in the state.

4.4.6.3 Problems Affecting Habitats

Warmer temperatures, changes in precipitation or fire regime, or climate-change induced competition from offsite plants may threaten grassy balds (Wear and Greis 2012). Grassy balds and some of the heath balds are already seriously threatened by invasionfrom native trees and shrubs. The current invasion of native trees and shrubs, development, and conversion to pastures or Christmas tree plantations are much greater concerns than impacts from climate change.

4.4.6.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. The effect of climate change on the species of balds is particularly uncertain. Some species are at their southern range limits and some are northern disjuncts, and these may be directly harmed by warmer temperatures. Some are dependent on seeps or wet areas, and may be harmed by more frequent or more intense drought. Habitat specialists and species with restricted ranges will likely be some of the greatest affected by the combined effects of habitat loss and climate change. Such populations are more vulnerable to extinction by rare events and susceptible to additional stressors such as climate change (DeWan et al. 2010). Table 4.31 summarizes the comparison of climate change with other existing threats.

Table 4.31 Comparison of climate change with other threats to grass and heath balds

Threat	Rank Order	Comments
Woody Succession	1	Trees and shrubs have been invading grassy balds in recent years. The ecological processes that kept them open in the past are not well known, and appear to no longer operate.
Conversion to Agriculture/ Silviculture	2	Conversion to pasture land has historically degraded some grassy balds and continues to be a threat even at otherwise protected sites. Agriculture activities that threaten these areas include Christmas tree production.
Development	3	Development (primarily housing) has had an impact upon both the habitat and the species utilizing it.
Invasive Species	4	The invasion of native shrubs and trees is a greater concern than exotic species in grassy balds. Problems with exotic species invasion in grassy balds may increase with warmer temperatures and increased fire, but this is not certain. Pasture grasses, Coltsfoot, and Angelica are the most common exotic species likely to invade grassy balds. In addition to these, the Roan Mountain area has been invaded by thistle, Spotted Knapweed, and Garlic Mustard. Some of these are currently restricted to the roadsides, but others (thistle in particular) have been found on the balds. Seeds are brought in on vehicles (trucks and tractors) and boots, and spread from roadsides and trails. Invasive exotics may be more of a problem than currently acknowledged.
Climate Change	4	Heath balds are probably less likely to be strongly affected by climate change than grassy balds. Communities and species associated with this ecosystem are likely to be affected by changes in temperature and mild winters associated with climate change.
Fire	5	It is unclear if fire is likely to be harmful or beneficial. If wildfires increase, it could offset the problem of tree and shrub invasion and could allow balds to expand.

4.4.6.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

Many wildlife species that use grass and heath balds are threatened by impacts other than habitat loss. Timber Rattlesnakes are threatened not only by habitat loss but also by being subject to collection, disturbance of hibernacula/gestation sites, and persecution. There has been considerable effort undertaken in the northeastern United States to determine the impact upon Allegheny Woodrat populations from a roundworm parasite (McGowan 1993; Stone et al. 1993), though no studies have been conducted within North Carolina to assess the level of threat posed to woodrat populations.

4.4.6.6 Recommendations

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Obtain baseline data on high-elevation bird species of grassy and heath balds, especially Golden Eagle, Vesper Sparrow, and Alder Flycatcher.
- Obtain baseline data on mammal and reptile communities and habitat use (e.g., identify Timber Rattlesnake den sites).

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Monitor priority small mammal and reptile population trends and habitat use.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions

for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Investigate the feasibility of using some form of controlled grazing regime to control invasive plants.
- Study Timber Rattlesnake movements, use of hibernacula, and reproductive success at gestation sites.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Initiate a prescribed fire regime to control invasive plants and prevent habitat conversion.
- Control invasive species and protect or restore areas, as this is critical to protect these habitats against threats.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Collaborate with partners to develop a management plan for high-elevation communities.

4.4.7 High-Elevation Cliffs and Rock Outcrops

4.4.7.1 Ecosystem Description

High-elevation rock outcrops are extremely rare, have a very restricted range, and are subject to extreme environmental conditions. These communities occur on ridge tops, peaks, and upper slopes where soils are thin and discontinuous and rock dominates the surface. Even in the most rugged high Mountains they represent only a small minority of the landscape, generally at 4,000 feet in elevation and higher. In contrast, mid-elevations range from 2,000 to 4,000 feet and low elevations are below 2,000 feet. The vegetation is likely to be very patchy, reflecting the variability of the soil. Two community types are part of this ecosystem: high-elevation granitic domes and high-elevation rocky summits.

- High-elevation granitic domes occur on the exfoliated outcrops that form when massive granitic rock breaks off in sheets parallel to the surface. Exfoliation produces smooth dome-shaped outcrops that lack crevices. Lichens and mosses occur on the bare rock. Soil and vegetation develop together on the rock surface as moss mats gradually deepen and are invaded by a succession of herbs. Soil mats are not anchored to the rock below and eventually fall off or are pulled up by falling trees, leaving the rock bare again. The shallow soils are generally dry, but some zones of seepage are usually present on the edge of the soil of adjacent forests. A number of wetland plants can occur in these saturated areas.

- High-elevation rocky summit communities occur on fractured rock. The bare rock is similarly vegetated by patches of lichen and moss, and shallow soil mats may develop locally. The presence of fractures, however, offers patches of deeper, more permanent soil that can support deeper rooted plants, and can provide an opportunity to anchor soil mats. The vegetation pattern is less likely to shift over time.

The 2005 WAP describes high elevation rock outcrops in the Southern Blue Ridge Mountains as a priority habitat (see Chapter 5) (NCWRC 2005).

4.4.7.2 Location of Habitat

High-elevation cliffs and rock outcrops occur only in the highest mountain ranges within the Mountain ecoregion in the Great Smokies, Plott Balsams, Great Balsams, Black/Craggy Mountains, Grandfather Mountain, Roan Mountain, and in the Amphibolite Mountains of Ashe County. According to the most recent Southeast GAP analysis, rocky summit and granitic domes comprise approximately 1,180 acres (about 478 hectares) of land cover in North Carolina (SEGAP 2007; NatureServe 2007).

4.4.7.3 Problems Affecting Habitats

The conditions present at individual rock outcrops are unique, owing to geology, geography, elevation, moisture, and landscape position. They may contain discrete communities or they may be dispersed among a variety of other community types that are connected through local geology and landscape conditions. As such, the extent of habitat that each rock outcrop provides is dependent upon the entire set of conditions in and surrounding the surface rock. Those conditions influence its use by plants and animals dependent upon the surface rock and may include significant amounts of adjacent ecological community types.

Common threats across the range of high-elevation rock outcrops include recreation, development, and forest succession. The two major problems most associated with low-elevation rock outcrops include development and recreational impacts. However, low-elevation rock outcrops are subjected to short-term habitat alterations (e.g., forestry operations) more often than high-elevation rock outcrops due to land ownership patterns, proximity to markets, accessibility, and other factors.

4.4.7.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While climate change is not the most severe threat, a combination of synergistic effects with other existing conditions could stress these systems to the point where several species are unable to persist.

The effect of a changed climate is likely to vary widely among examples of these communities, depending on topographic sheltering, configuration of rocks and soil depth. These systems are tied to specialized small environments and will be unable to migrate as the climate changes. Many may change very little, while a few will shrink, will be disturbed by wind or flood, or will change substantially because of temperature changes or drought. Table 4.32 summarizes the comparison of climate change with other existing threats.

Table 4.32 Comparison of climate change with other threats to high-elevation cliffs and rock outcrops

Threat	Rank Order	Comments
Climate Change	1	Changes in temperature and mild winters will likely create the most impacts. Given the high number of endemics and disjuncts, climate-related changes greatly threaten biodiversity. Reduced winter snow and lack of seasonal snow packs will have negative effects on soil moisture.
Trampling	2	Trampling from recreational users (hikers and rock climbers) is probably the most immediate anthropogenic threat.
Development	3	Logging and development are possible on private tracts. Development may not directly impact outcrops, but may increase access and therefore trampling.
Woody Succession	3	Trees and shrubs may invade if enough water is available during the growing season. Intrusion by alder, rhododendron, and other woody plants can cause rock outcrops to become overgrown.
Invasive Species	4	As temperatures increase, native and exotic species from lower elevations may be able to invade these areas more easily. Coltsfoot is the most common exotic species in high-elevation rock outcrops.
Pollution	5	There has been suggestion that air pollution could be having an impact upon the high-elevation rock communities of western North Carolina (TNC and SAFC 2000); however, there has not been definitive evidence of air pollution impacts upon wildlife species associated with high-elevation rock outcrops.

4.4.7.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

While high-elevation rock outcrop habitat and low-elevation cliffs/rock outcrops support many of the same animals and plants, there are species of both plants and animals that are found exclusively at high-elevation rock communities (e.g., the Rock Vole, Long-tailed Shrew, Allegheny Woodrat, and several rare plant species), and others found only in low-elevation cliffs/rock outcrop habitats (e.g., the Southern Appalachian Woodrat, Spotted Skunk, and Crevice, Green, and Southern Zigzag salamanders). The elevation limit for each of these species varies; however, there are distinctions in animal assemblages in rock habitats that are defined by elevation.

For many species associated with high-elevation rock outcrops, we do not currently know the entire spectrum of threats that are affecting populations due to inadequate levels of study or knowledge. Individual wildlife and plant species may face threats specific to either their particular location or the species itself. For example, Timber Rattlesnakes face threats in addition to habitat loss, including being subject to collection, disturbance of hibernacula/gestation sites, and persecution. There has been considerable effort undertaken in the northeastern United States to determine the impact upon Allegheny Woodrat populations from a roundworm parasite that may have impacted populations in that region (McGowan 1993; Stone et al. 1993), though no studies have been conducted within North Carolina to assess the level of threat posed to North Carolina woodrat populations.

The decline of Peregrine Falcons during the last half of the 20th century has been widely attributed to the use of DDT and its concomitant effect on bird reproduction. The use of DDT was banned and Peregrine Falcon restoration efforts occurred in the late 1980s and 1990s; however the falcons still face threats due to habitat loss to development and recreation impacts at individual cliff sites. Furthermore, the North Carolina population remains at fairly low density, thereby increasing the threat of stochastic events having significant population impacts.

The insect fauna of high-elevation rock outcrops is not yet well studied and a number of additional species may yet be added. The landscape requirements of these guilds also need more study. Two endemic spiders in the Lampshade genus (*Hypochilus*) would be particularly vulnerable to extinction if they are intolerant to increases in temperature and drought, which seems likely (Huff and Coyle 1992). Their current restriction to extremely small ranges suggests that they have only a low level of dispersal ability and may be unable to shift their ranges fast enough to keep up with environmental change. Competition with the more widespread Lampshade Weaver (*H. pococki*) spider may further limit their ability to shift their ranges.

4.4.7.6 Recommendations

Of all the habitats in the state, this ecosystem is among the most vulnerable to the effects of climate change. This habitat type cannot be created, thereby making conservation the only option for these unique areas. Given the high number of endemics and disjuncts, climate-related changes greatly threaten biodiversity here. Several of the species face outright extinction and others, if lost, are unlikely to ever recover within the region.

Priority should be given to several measures that may secure them enough time and space to survive both short term environmental disturbances as well as adapt to longer term changes in the climate. Since virtually all examples of this theme are located on public lands and already managed to preserve their natural features, implementation of recommended interventions should be feasible.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Survey for new Peregrine Falcon nests.
- Obtain baseline data on small mammal communities and reptile communities and habitat use (e.g., identify Timber Rattlesnake den sites).

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Monitor endemic species closely for declines in the near future. Transplantation may be required to prevent extinction.
- Continue monitoring the Peregrine Falcon population.
- Monitor priority mammal and reptile population trends and habitat use.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Reintroduce rare species to patches or mountain ranges where they have been lost, as well as to restored areas, to improve their prospects for survival in the future climate.

- Study Timber Rattlesnake movements, use of hibernacula, and reproductive success at gestation sites.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Maintain biologically significant areas, including Peregrine Falcon nesting areas, reptile den sites, and significant salamander occurrences through active management of outcrops to reduce the intrusion by alder, rhododendron, and other species that contribute to the disappearance of some vertebrates.

- Control invasive species and protect or restore areas already affected by invasive species to protect against changing climate conditions.

- Use a hand crew to manually cut down encroaching woody vegetation with chainsaws or brush blades. Any use of herbicides and surfactants will need to be of low toxicity to wildlife.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Protect from trampling to allow the species pool to expand through suitable habitat, producing larger, more robust populations that would be better able to survive climate-related changes.

- Ensure that all existing high-elevation rock outcrops are high priorities for conservation action, as they are extremely rare, have a very restricted range, and are subject to extreme environmental conditions.

- Close sensitive areas at certain times (e.g., during Timber Rattlesnake emergence or Peregrine Falcon nesting) or permanently to stop direct trampling, loss of habitat to recreation developments, trails, vistas, etc., and indirect human impacts (disturbance).

4.4.8 Low Elevation Flatrocks, Cliffs, and Rock Outcrops

4.4.8.1 Ecosystem Description

This broad ecosystem group encompasses many, though not all, of the community types at low to mid-elevations that are too steep or rocky to support a closed tree canopy. The vegetation of these communities is generally very patchy, reflecting extreme variability in the depth and composition of soil and of available moisture. Plants include forest species with broad site tolerances, species characteristic of a wide range of open habitats, and species specialized for rock outcrops. Rock outcrops typically are very dry, but seepage zones are often present and may support wetland vegetation. This community type generally occurs below 2,000 feet in elevation. In contrast, mid-elevations range from 2,000 to 4,000 feet and high elevations are above 4,000 feet.

The nine natural cliff and rock outcrop community types are separated based on rock chemistry, topographic location, and geographic region, and the latter is an important factor in determining flora. The community types are: Piedmont/Coastal Plain heath bluffs and acidic cliffs; Piedmont mafic and calcareous cliffs; montane mafic, calcareous, and acidic cliffs; and low-elevation granitic domes and rocky summits.

- Low-elevation rocky summit communities occur in exposed positions on peaks, ridgetops, and upper slopes in the Mountain ecoregion. Low-elevation rocky summits have fractured rock which allows growth of deep-rooted woody plants in places. Soil accumulates in pockets of varying depth and produces heterogeneous vegetation. Many variants potentially occur, but are not well known.

- Low-elevation granitic domes occur on exfoliated outcrops of granitic rock, where peeling of sheets of rock parallel to the surface produces a dome-shaped outcrop of solid rock. Soil mats that begin as moss clumps gradually thicken over time and follow a characteristic vegetational succession from herbs to shrubs and stunted trees. The unanchored mats are periodically destroyed by falling off or by being pulled up by falling trees, leaving the rock bare and beginning the succession anew.

- Cliff communities occur on lower, more sheltered topographic sites. They are generally created by streams undercutting a bluff, but may occur somewhat above a stream. Like rocky summits, the rock is usually fractured and supports very patchy vegetation that includes woody plants rooted in crevices, as well as herbs in soil pockets, and mosses and lichens on bare rock. The Mountain and Piedmont/Coastal Plain types have flora typical of their regions, often combining plants from adjacent communities with typical outcrop plants.

- North-facing cliffs have a cooler microclimate than the surrounding areas and sometimes harbor disjunct or regionally rare species characteristic of cooler, moister regions. In some cases these species are believed to be remnants from more widespread populations that existed in the Ice Ages. In the Mountain ecoregion, south-facing cliffs may support species more typical of the warmer Piedmont or even Coastal Plain.

- The acidic, mafic, and calcareous types support different flora that reflect the rock chemistry. Mafic and calcareous cliffs contain calcium-loving species that do not occur on the more common Acidic cliffs. The floristic differences between calcareous and mafic cliffs are more subtle, and reflect differences in the balance of basic elements.

- Piedmont/Coastal Plain heath bluffs differ somewhat from the other community types in that they have little bare rock. They do, however, lack a closed tree canopy, apparently because of steepness. They are characterized by a dense shrub layer of Mountain Laurel or Catawba Rhododendron, which are otherwise essentially absent in the Piedmont and Coastal Plain. These communities occur on north-facing bluffs, and the cool microclimate is believed to be important to these species.

- Granitic flatrock communities occur on flat to gently sloping exfoliated outcrops of granitic rocks and are scattered throughout the Piedmont region, from Virginia to Alabama. The rock outcrop is generally flush with the surrounding soil and has only minor irregularities. These communities are somewhat related to the granitic dome communities of the upper Piedmont and Mountains in that vegetation is sparse and very patchy. On bare rock, soil mats that accumulate in moss clumps undergo a gradual development, deepening and being invaded by a succession of plants.

The 2005 WAP describes low-elevation cliffs/rock outcrops in the Southern Blue Ridge Mountains as a priority habitat (see Chapter 5) (NCWRC 2005).

4.4.8.2 Location of Habitat

Low-elevation cliff and rock outcrop habitat is spread throughout the Mountain and upper Piedmont ecoregions. Piedmont examples include Sauratown Mountains inclusive of Pilot Mountain, and the Crowders, Uwharrie, and South Mountains. Flatrock communities are found primarily in the eastern Piedmont. Other habitat types are present even into the Coastal Plain, such as heath bluffs.

4.4.8.3 Problems Affecting Habitats

Conditions vary considerably within this habitat type, with a significant number having been impacted and/or lost due to numerous factors, while others remain functional "natural sites" and still others are specifically managed to minimize human impacts.

Low-elevation cliffs and rock outcrops are diverse communities that are expected to have a variety of responses to climate change. While some are dependent on moisture and may be harmed, others may actually benefit from increased drought and fire. This benefit will only be realized if sites are protected from other forms of destruction, and for most, if fire is restored to them through prescribed burning. These communities are naturally rare in North Carolina, due to limited availability of suitable habitat. Examples need to be protected and managed appropriately.

As with high-elevation rock outcrops, two major problems most associated with the low-elevation rock outcrops include development and recreational impacts. However, low-elevation rock outcrops are subjected to short-term habitat alterations (e.g., forestry operations) more often than high-elevation rock outcrops due to land ownership patterns, proximity to markets, accessibility, and other factors. The extent and degree of impact associated with such temporary habitat alterations is unclear for most species. Regardless of the impacts or problems associated with short-term habitat modifications, the relative scarcity of low-elevation rock outcrop habitat across the landscape of North Carolina, and reliance upon it by numerous wildlife species lends greater significance to the need to identify and manage these habitats appropriately to conserve wildlife.

Some climate change models predict that rainfall will be concentrated during the fall, and there will be increased droughts in the spring and summer. Droughts could favor herbaceous species and grasses in open, dry outcrops, which tend to be rarer than the woody species associated with outcrops. Drought will kill trees on edges and soil islands. This already happens in current droughts, and is part of the mechanism keeping flatrocks open. Increased length or severity of droughts might cause flatrocks to expand at the expense of adjacent shallow-soil woodlands. Herb species associated with granitic flatrocks tolerate drought at present, or grow in the moist early growing season. It is unclear if they are at the margin of their tolerance, or whether they could withstand longer or more severe droughts. Drought in spring would be detrimental, while drought in other seasons might not be. A few additional flatrocks may be opened up by wind throw or drought mortality. Increased storms may blow down trees and pull up soil mats more frequently. Amount of bare outcrop and shallow soil mats may increase at the expense of deeper mats.

Low intensity fires could expand the open area and benefit some of the rare plants of outcrops. More mesic outcrops such as heath bluff communities are more likely to be harmed by fire. Landscape fragmentation and fire suppression practices likely will continue to prevent most fires from spreading very far. The central parts of granitic flatrocks are unlikely to burn even in droughts. Fire could affect the dry woodlands that form the edge zone of the flatrocks. However, most flatrocks occur in fragmented landscapes where fire is unlikely to spread. They are likely altered by lack of fire.

Increased temperatures could increase demand for water, a limited resource in these sites. Phenological shifts (earlier bloom periods, emergence from hibernation, nesting and breeding) in seasons may occur in a warmer climate. Exotic plants readily invade favorable microsites on many outcrops. Increased disruption of adjacent forests may bring seed sources closer to many outcrops.

Dense woody vegetation around edges may become more open. Increased drought or fire might produce beneficial structural changes. Some outcrops have been altered by fire suppression and these changes may help return to more natural composition. Others will lose characteristic mesophytic species. The effect may be severe in a small number of outcrops. Some dry outcrops may expand into adjacent forests, while heath bluffs may shrink.

4.4.8.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. Granitic flatrocks are tied to specialized sites and cannot migrate. Communities will change in situ but it is uncertain how much. As with high-elevation rock outcrops, the two major problems most associated with the low-elevation rock outcrops include development and recreational impacts. For animals associated with cool, moist slopes or cliffs, particularly in relict situations, climate change represents the most significant threat, particularly in the Piedmont where their populations are typically small and highly isolated. For the plants associated with this theme, climate change is not expected to be a major threat. Development and changes caused by fire suppression are the most severe threats. In some areas, excessive deer browse is also a major threat. Table 4.33 summarizes the comparison of climate change with other existing threats.

4.4.8.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

Many wildlife species utilize the rock outcrop habitat without regard to arbitrary elevational distinction (e.g., Peregrine Falcon), and others will utilize only high-elevation rock outcrop habitats, at least according to what we currently know (e.g., Rock Voles and Rock

Table 4.33 Comparison of climate change with other threats to low-elevation flatrocks, cliffs, and rock outcrops

Threat	Rank Order	Comments
Mining	1	Surface mining (e.g., gravel pits) would effectively eliminate this community.
Invasive Species	2	There are significant problems with invasive plants, at least in edge zones. Climate change will probably not make invasion worse, but drought disturbance of surrounding woodlands and edges may make them more susceptible. It is possible that some of the invasive species, such as Japanese Honeysuckle, Wineberry, and Asian Dayflower, will be harmed by drought more than the native species. Cliffs and rock outcrops have some problems with invasive plants, which can invade edge zones and more favorable soil pockets. Cogon Grass may not already be present but is likely to increase with climate change. If climate change increases disturbance of adjacent forests, it may allow invasive plant seed sources to develop closer to rock outcrops that are now remote from them.
Development	2	Development on granitic flatrock communities may involve blasting or other fracturing methods to remove rock. Development of adjacent landscapes is likely to introduce pollution and sediment through stormwater runoff. There may also be increased opportunity for invasive species to disperse into this habitat. Development can have both direct and indirect impacts that severely threaten many unprotected examples. Improved access may increase recreational use that leads to trampling and poaching of rare plants.
Human Disturbance	2	Trampling from hiking and recreation activities, trash dumping, and other damage could occur from human disturbance. Where granitic flatrocks occur within forested habitats, timber removal can disturb vegetation on flatrocks.
Climate Change	3	These species tolerate drought at present, or grow in the moist early growing season. It is unclear if they are at the margin of their tolerance, or whether they could withstand longer or more severe droughts. More southerly flatrock species could find their way to our flatrocks.
Fire	3	It is unclear how much climate change will change fire frequency in the fragmented landscapes of the Piedmont and lower Mountains. Fire suppression has been a major factor degrading some of these communities. Fire may allow dry rock outcrops to expand, while mesic cliff and heath bluff communities could be harmed by intense fires. Fires during severe drought may be too intense and may cause damage to the characteristic plants and the shallow soils as well.
Logging/ Exploitation	4	Land ownership patterns, proximity to markets, accessibility, and other factors influence short-term habitat alterations like forestry operations.

Shrews). However, many wildlife species and even more plant species (Schafale and Weakley 1990) are either associated with high-elevation rock communities or low-elevation rock communities. The elevation limits for each species, however, are quite variable. Many low-elevation rock outcrop species of plants and animals are restricted to ranges outside high-elevation areas (e.g., Crevice Salamanders are only found in and around the relatively low-elevation Hickorynut Gorge). Still other wildlife may occur in both high- and low-elevation rock communities, but for various reasons may reach higher densities or have wider distribution in low-elevation rock outcrops (e.g., Timber Rattlesnakes).

The extent of habitat that each rock outcrop provides is dependent upon the entire set of conditions in and surrounding the surface rock. Those conditions influence its use by plants and animals dependent upon the surface rock and may include significant amounts of adjacent ecological community types. Water seepage through rock crevices may provide moisture for amphibians, mosses, lichens, and wetland vegetation. Reptile species may use rocky areas exposed to direct sunlight for basking or use openings amongst rocks for dens.

No species belonging to these guilds appear to be vulnerable to complete extinction due to the effects of climate change. However, both the Hickory Nut Gorge population of Crevice Salamander and the Piedmont populations of Red-backed Salamander exist as isolated disjuncts and are likely to be highly vulnerable to the effects of climate change. In both cases, extirpation of these populations would constitute loss of significant ecological as well as genotypic variants of their species.

DeWan et al. (2010) suggest that habitat specialists and species with restricted ranges will likely be some of the greatest affected by the combined effects of habitat loss and climate change. They also note such populations are more vulnerable to extinction by rare events and susceptible to additional stressors such as climate change.

4.4.8.6 Recommendations

Given the relative rarity of low-elevation rock outcrops across the state, measures need to be taken to conserve as much of this habitat as possible. This includes preservation measures, as well as conservation/management measures to ensure that species which rely upon these outcrops continue to be afforded the desired variety of habitat conditions into the future. Certainly a high priority should be placed upon acquisition or easement of land tracts which support low-elevation rock outcrops due to the fact that they are not abundant, they have numerous rare plant and animal associates, and remaining sites are subject to significant threats associated with both recreational and other development pressures.

In addition, necessary conservation actions include assigning appropriate management schemes to rock outcrops upon conservation lands to minimize negative impacts from human activities such as recreational use and development. Appropriate restrictions upon use of the areas need to be developed where none currently exist to minimize the direct impact upon the habitat and its occupants. The results of studies on the impact to low-elevation rock outcrops from surrounding habitat modification should be incorporated into appropriate management recommendations to minimize impacts upon wildlife species utilizing the rock outcrop. Mapping of these sites in a GIS format would facilitate tracking changes over time in both the habitat and the associated species, and would facilitate landscape scale management of this rare habitat. Maintenance of biologically significant areas, including Peregrine Falcon nesting areas, reptile den sites, and significant salamander occurrences, is critical.

Flatrocks are naturally isolated, so migration is presumably very limited. However, presence of characteristic species across a number of widely separated outcrops suggests some potential for dispersal. Planting of species to facilitate movement of species to new locations is probably not appropriate. Since this unique habitat type cannot be recreated, it is more important to protect good quality flatrocks with the goal of protecting the range of variability, as well as the locations for future colonization and dispersal.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Map these sites in a GIS format to facilitate tracking changes over time in both the habitat and the associated species, and to facilitate landscape scale management of this rare habitat.
- Obtain baseline data on amphibian, small mammal, and reptile communities and habitat use (e.g., identify Timber Rattlesnake den sites).

Monitoring. Monitoring is critical to assessing species and ecosystem health and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Long-term monitoring is needed to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Continue monitoring the Peregrine Falcon population.
- Continue monitoring Green Salamander populations, as well as other salamanders of this habitat type (e.g., Crevice and Southern Zigzag salamanders).

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics.

- Study the impact of various management scenarios on the habitat and associated species.
- Study Timber Rattlesnake movements, use of hibernacula, and reproductive success at gestation sites.

- Initiate genetic and morphological studies to clarify taxonomic status of plethodontid salamanders.

- Study habitat use by rock outcrop salamander communities, including movements in and among rock outcrop habitats (e.g., Green Salamander metapopulations).

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Protect these habitats through active management to remove invasive species.

- Burn around open, dry outcrops that naturally burned to restore more natural structure around the margins, and favor species that will tolerate drought and wildfire better.

- Maintain biologically significant areas, including Peregrine Falcon nesting areas, reptile den sites, and significant salamander occurrences.

- Assign appropriate management schemes to rock outcrops on conservation lands to minimize negative impacts from human activities, including recreational use and development.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Protect remaining examples and surrounding forests.Sites should be protected from human disturbance, including locations that are already protected through conservation measures. This may be through closure during particular times of the year or permanently prohibiting use of the site.

- Given the relative rarity of low-elevation rock outcrops across the state, measures need to be taken to conserve as much of this habitat as possible. This includes preservation measures, as well as conservation/management measures to ensure that species that rely upon these outcrops continue to be afforded the desired variety of habitat conditions into the future.

4.4.9 Mesic Forests

4.4.9.1 Ecosystem Description

Mesic forests occur on sites that are moist but not wet. Mesic sites are among the most favorable environments for plant growth. They tend to support dense forests dominated by moisture-loving non-wetland trees such as beech, Tulip Poplar, and Northern Red Oak. They usually have well-developed understory, shrub, and herb layers. They often contain species that are common in the mountain parts of the state or farther north but are rare in the southern Piedmont and Coastal Plain. Some species may be disjunct long distances from cooler areas. At least some of these disjuncts are remnants of wider distributions in the past, such as during the cooler, moister climate of the Ice Age.

- Mesic mixed hardwood forests in the Piedmont are generally on north-facing slopes, sheltered ravines, or high terraces on the edges of floodplains. In the Coastal Plain, mesic forests occur in similar sites and also on moist portions of broad upland flats and on small island ridges surrounded by swamps. These sites are naturally sheltered from the fires that are a major natural shaper of vegetation in the Coastal Plain.

- Basic mesic forests are much rarer than the mesic type and occur on soils that are neutral to slightly basic in pH. They are more diverse than the mesic mixed hardwood forests and they have species that require high pH. The basic mesic forest subtype often has rare and disjunct plant species and both variants of basic mesic forest (marl outcrop and terrace slope) are rare because of the scarcity of basic substrates on the Coastal Plain (Schafale and Weakley 1990).

The 2005 WAP describes the Piedmont ecoregion and Mid-Atlantic Coastal Plain ecoregion Mesic Forest as a priority habitat (see Chapter 5) (NCWRC 2005).

4.4.9.2 Location of Habitat

The Coastal Plain and Piedmont subtypes cannot be separated by any particular species, but differ in their overall flora. In the Piedmont, mesic mixed hardwood forest communities occur on mesic sites that have typically acidic soils. Good examples can be found at Umstead State Park, Duke Forest, Hill Demonstration Forest, Raven Rock State Park, and Eno River State Park in the central Piedmont and also examples in parts of Uwharrie National Forest. Basic mesic forest communities are scattered across the Piedmont; good examples are found in Caswell Game Land, Uwharrie National Forest, and Raven Rock State Park.

Several distinctive variants of these subtypes are recognized in the Coastal Plain, including the swamp island, mesic flat, and bluff/slope variants of mesic mixed hardwood forest, and the terrace slope and marl outcrop variants of basic mesic forests. Examples of the mesic mixed hardwood forest bluff/slope variant are found in Croatan National Forest, Merchant's Millpond State Park, and Cliffs of the Neuse State Park. Examples of the swamp island variant are found in the Great Dismal Swamp National Wildlife Refuge and along the Waccamaw River in Columbus County, and examples of the upland flat variant are found in Perquimans and Bertie counties.

4.4.9.3 Problems Affecting Habitats

There may be an increase in natural fires (due to increased drought and higher average temperatures), but landscape fragmentation and fire suppression practices will likely continue to prevent most fires from spreading very far in the Piedmont and in the dissected lands in the Coastal Plain where mesic forests occur. Mesic forests occur in sites sheltered from most fires, but wildfire during drought may increase the likelihood or severity of fires in them.

The importance of drought and hot spells in mesic sites is unclear. Most of these sites are mesic because of topographic sheltering such as north-facing slopes or deep ravines. These sites are buffered from extremes of weather. However, because they contain many species that are not adapted to hot and dry conditions, they may suffer stress from even slightly drier conditions. Although we are not aware of any identified problems from phenological disruption, there may be higher potential for it in these communities than others, because they have many spring ephemeral plants.

An increase in hurricanes or other severe storms likely would increase wind damage in forests. Increased storm disturbance will increase the potential for exotic plant invasion, especially if a seed source is present in nearby developed or disturbed areas, or has already entered the community. Wind damage is often more severe in forests if there are adjacent openings such as logged or developed areas. If more intense storms increase flood heights, this will affect lower lying mesic forests. If wind throw stimulates salvage logging, this will further increase the damage to natural areas.

4.4.9.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. The greatest threats to Piedmont and Coastal Plain Mesic Forests are those from development and logging which are ongoing land uses. Climate change is less of a threat than ongoing concerns, but will exacerbate some of them. Although expected threats associated with climate change are the least significant to these forests, increased wind damage, droughts, and warmer temperatures may alter their structure and size. Table 4.34 summarizes the comparison of climate change with other existing threats.

Table 4.34 Comparison of climate change with other threats to mesic forests

Threat	Rank Order	Comments
Development	1	Destruction and indirect effects such as fragmentation and edge effect result from land development in suburban areas and even in many rural areas.
Logging/ Exploitation	1	Logging severely alters canopy structure and composition, and is a threat to all but the steepest unprotected examples. Invasive plants are a present and increasing threat. Both development of nearby areas and logging increase the potential for invasion.
Invasive Species	2	Plants such as Autumn Olive, Japanese Stiltgrass, Japanese Honeysuckle, Princess Tree, Tree-of-heaven, and Chinese Privet have taken resources from native vegetation and altered habitat structure and species composition. The extent of negative (and positive) impacts of exotic species on populations of native fauna is largely unknown.
Climate Change	3	The severity of climate change effects on these sheltered sites is uncertain. It is expected that the boundary with drier communities will shift, so that peripheral portions are lost, smaller or more marginal examples may be lost, and the total acreage will shrink. These communities often support species disjunct from cooler areas, and some of these species may be lost.
Fire Suppression	4	Fires that would have naturally swept through these sites (relatively infrequently in the Piedmont, perhaps more frequently in the Coastal Plain) have been suppressed, likely affecting the community composition of mesic plant species and exotics.

4.4.9.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

Fragmentation of mesic forests into smaller or narrower contiguous blocks is a concern for forest interior birds (like the Wood Thrush, Hooded Warbler, and Worm-eating Warbler), which may occur in lower densities or suffer lower productivity or survival in small habitat patches. Fragmentation by roads and development can be problematic for reptiles (especially Timber Rattlesnakes and Eastern Box Turtles), amphibians, and small mammals (particularly Eastern Mole) that suffer high mortality on roads when traveling between forest patches or between mesic forest and other habitats.

A lack of canopy gaps in this habitat type has probably lead to a reduced number of some avifauna such as the Eastern Wood-pewee, Hooded Warbler, and Kentucky Warbler. This reduction in canopy gaps has also caused a decline in midstory and understory vegetation, which has impacted species such as the Swainson's, Kentucky, and Hooded warblers, and Wood Thrush. The reduction in standing snags negatively impacts primary and secondary cavity nesting species and the lack of dead wood on the forest floor impacts herpetofauna and small mammals.

4.4.9.6 Recommendations

These communities occur in specialized microsites and are unlikely to migrate. To reduce the possible impacts from climate change, conservation or restoration of landscape connections to allow migration is most important. These sites often occur adjacent to riparian areas and floodplains, and protection of these sites will be dually beneficial to nearby streams.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Direct initial efforts toward surveys to determine the current baseline distribution and status of species mainly associated with mesic forests (especially those that are state-listed or believed to be declining) for which that information is lacking.
- Focus secondary efforts on conducting surveys to understand current status, from which we can measure future population changes over time.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Enhance current monitoring systems and protocols (e.g., MAPS and BBS) to better cover certain species not well covered by current monitoring efforts.
- Establish long-term monitoring for small mammals and bats following initial surveys.
- Conduct general long-term herpetofauna monitoring to track the effects of the loss of old growth characteristics in this habitat type.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Collect demographic information on all bat species; investigate specific habitat needs and conduct life history studies.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Maintain connections between habitat blocks, not only to allow adjustments in range in response to climate change, but to maintain population resilience and adaptability more generally.

- Create transportation facilities that utilize longer bridges at streams and wetlands to minimize impacts (and thereby reduce mitigation requirements) and provide crossing options for wildlife that often travel riparian corridors and disperse to upland communities.

- For protected and unprotected sites, control the exotic plants that are present or may potentially invade.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Create cooperative programs with non-industrial foresters that promote and increase silvicultural practices (e.g., canopy gap management, longer rotations, introduction of fire), as this could benefit birds of conservation concern as well as small mammals, bats, reptiles, and amphibians.

- Give high priority to protecting movement corridors that allow dispersal between habitat blocks, especially as development and roadways fragment the few remaining large tracts of habitat.

- Give priority to restoring connections that are lost due to construction of four-lane highways and other roads that create near-impassible barriers for all animals except those capable of flight.

- Ensure that conservation actions include land acquisition, easements, and protection to promote remaining large, unfragmented tracts as well as management to maintain and reestablish mesic forest. This is a relatively rare forest type and great effort should be made to protect mesic forests and their species assemblages. Conservation of larger natural areas that include adjacent communities will lead to greater viability for all communities present.

4.4.10 Piedmont and Mountain Dry Coniferous Woodlands

4.4.10.1 Ecosystem Description

The vast majority of land in the Piedmont and Mountain ecoregions is dominated by hardwood forests. Less common are dry coniferous forests, which occur at middle to lower elevations in several kinds of specialized sites that are drier than most environments. They occur primarily in the Mountains and are found in a few mountain-like sites in the Piedmont. Piedmont Longleaf Pine forests, although dominated by coniferous trees, are included with the more closely related dry Longleaf Pine forests ecosystem group rather than here. There are four community types associated with this ecosystem: pine–oak/heath, Carolina Hemlock bluffs, White Pine forests, and montane Red Cedar hardwood woodlands.

- The pine–oak/heath community occurs on sharp ridge tops and spur ridges, where shallow soils and exposure to drying winds and lightning prevent development of a closed hardwood forest. Extremely acidic soils, created by leaching and by the acidity of plant leaf litter, may also be a factor. The canopy, typically composed of Pitch, Table Mountain, and/or Virginia pines, is generally open with a dense, tall shrub layer dominated by Mountain Laurel or rhododendron occurring beneath the canopy. Herbs are few and sparse, but characteristic acid-loving species often occur in openings among the shrubs.

- Carolina Hemlock bluffs occur in settings similar to pine–oak/heath, but usually more on steep bluff-like side slopes. Carolina Hemlock dominates the canopy with a shrub and herb layer similar to pine–oak/heath but possibly more open.

- White pine forests are poorly understood communities. While White Pine is a common successional tree in mountain hardwood forests, natural forests of it most typically occur on the walls of steep gorges.

- Montane red cedar-hardwood woodland occurs on shallow soils on gentle slopes. Smooth rock outcrops are usually found in association with it. These woodlands have an open canopy with patchy shrubs and grassy openings. A number of the species suggest that the soils are less acidic than typical mountain soils.

Dry coniferous woodlands of the Piedmont and Mountain ecoregions are described as priority habitats in the 2005 WAP (see Chapter 5) (NCWRC 2005).

4.4.10.2 Location of Habitat

These communities occur through the lower to middle elevations, the foothills, and are particularly abundant in the escarpment in the Mountain ecoregion. Pilot Mountain, Hanging Rock, and Crowders Mountain State Parks all have examples of the pine–oak/heath community. Owing to the relatively low-elevations occupied by dry coniferous forests in the region, significant amounts of this habitat occur in western North Carolina upon state-owned lands (Thurmond Chatham, South Mountains, and Green River Game Lands; South Mountains State Park; Dupont State Forest).

4.4.10.3 Problems Affecting Habitats

Most dry coniferous woodlands depend on a combination of fire behavior and dry soils, both driven by topography. However, an increase in extreme fires may be detrimental. Increased drought may increase southern pine beetle outbreaks, a major threat to the pine canopy. Fire suppression has caused these habitats to shrink in recent decades. Increased drought may favor pines over hardwoods and allow them to regain some of their lost area even without fire. Increased drought and fire may allow expansion. These communities occur in the driest mountain and foothill sites, and increasingly dry climate may allow them to expand into a broader range of topography and to higher elevations.

The structural effects caused by fire suppression and southern pine beetles greatly exceed any effect likely from climate change. The Hemlock Woolly Adelgid has already impacted some stands of Carolina Hemlock, though not to the devastating effect as seen in Canada Hemlock stands. Restoration of the structure, composition, and, most importantly, disturbance regimes of these communities will increase their resilience to environmental stressors. Without fire to promote pine regeneration, increased Pine Beetle mortality could hasten the shift from pines to hardwoods.

Warmer temperatures should allow spreading to higher elevation, but the acreage gain is likely to be limited. It may not occur if fires are suppressed. Increased wind damage may increase loss of mature pines and contribute to ongoing encroachment of hardwoods. Because the characteristic plants are drought tolerant as well as fire tolerant, an increase in drought may help them retain or regain dominance. In addition, if drought contributes to an increase in wildfire, this may benefit these communities.

4.4.10.4 Climate Change Compared to Other Threats

The most significant threats vary among the different community types. Piedmont and mountain dry coniferous forests will likely be resilient to the effects of climate change and may actually benefit from increased fire frequency and drought. Lack of fire is the greatest threat to the majority of remaining pine–oak/heath. Not only will these forests not be able to reproduce themselves without fire, but those stands at higher elevations which are not regularly burned often develop dense Mountain Laurel/rhododendron understories that shade out other shrubs and herbaceous plants, thus lowering the habitat quality and diversity of wildlife which could utilize the area. Management efforts by multiple agencies to increase prescribed fire in fire adapted communities, including dry coniferous forests, are already positioning these communities for greater resilience. Table 4.35 summarizes the comparison of climate change with other existing threats.

4.4.10.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

Table 4.35 Comparison of climate change with other threats to dry coniferous forests

Threat	Rank Order	Comments
Fire	1	With the suppression of fire, many examples have disappeared or have become degraded by a lack of pine regeneration and invasion by hardwoods and shrubs. Suppression of fire has caused severe alteration and loss in pine–oak/heath.
Development	2	Development can lead to fragmentation and disrupt connectivity between patches for most wildlife except birds. Road crossings can lead to mortalities, especially for reptiles and amphibians. Development in or adjacent to this habitat often leads to a significant problems using prescribed fire as a management tool due to the proximity of residential or other development. Construction activities and other extensive removal of plant cover can make steep slopes prone to mud and/or rock slides, causing loss of topsoil and potentially causing property damage and threatening human safety.
Logging/ Exploitation	2	Logging is a threat to unprotected examples, particularly on pine–oak/heath and White Pine forest.
Invasive Species	3	A major factor in loss of pine dominance is southern pine beetle outbreaks, which are often triggered by droughts. There are numerous native and exotic pests that can impact coniferous trees in this habitat (e.g., Southern Pine Beetle, Tip Moth, Pine Webworm, Schweinitzii root and bud disease, and red heart of pine disease). Localized and nonlethal infestations can be beneficial for wildlife by creating snags, a food source, and habitat diversity. However, extensive lethal outbreaks can dramatically shift the composition of the tree community, with implications for conifer-specialists like the Brown-headed Nuthatch. Control of the Hemlock Woolly Adelgid is crucial for the Carolina Hemlock bluff communities. Without control, most or all of these communities may be lost in the near future.
Climate Change	4	Climate change will act somewhat counter to existing threats rather than exacerbating them. However, these benefits are far from certain.

While Red-cockaded Woodpeckers are almost exclusively associated with Longleaf Pine systems, most animals that are associated with pines and other dry conifers also occur in mixed stands of hardwoods and conifers. Brown-headed Nuthatches and Chuck-wills-widows are also associated with dry woodlands and/or heathlands more generally.

Additional problems faced by individual species associated with dry coniferous forest include the lack of early successional habitat of this type or conversion of this habitat to other pine habitat (i.e., White Pine) for species such as Prairie Warblers, woodpeckers, and nuthatches. Timber Rattlesnake persecution in these habitats also remains a significant problem. Lack of management of the stands decreases the quality of habitat for woodland hawks by decreasing prey abundance and limiting their ability to hunt in dense understory growth.

The two species of moths that feed on Bear Oak have a highly confined distribution in North Carolina (as does their host plant). While climate change may create conditions such as increased fire that may favor the oak, the moths are likely to be highly vulnerable to extirpation if fires completely consume all available habitat in the few areas where the moth currently exists.

4.4.10.6 Recommendations

Conservation of good examples of all community types remains important. Because of the widespread loss of pine–oak/heath and the likely loss of Carolina Hemlock bluff, restoration of degraded examples is also important. As in all communities, conservation of surrounding communities and protection or restoration of landscape connections will improve the viability of communities and allow native species to migrate to adjust to the changing climate.

- Conduct prescribed burns and control invasive species, as these are the most important conservation actions to take in order to restore degraded sites and allow these communities to be more stable and resilient in the face of climate change.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Determine the current baseline distribution and status of species mainly associated with dry coniferous forest (especially those that are state-listed or believed to be declining). Data is most severely lacking for reptiles, small mammals, and nocturnal birds.

- Survey White Pine forest for breeding birds and other fauna. This habitat might now be utilized by species that formerly occurred in Canada Hemlock stands that have now shifted to White Pine habitats.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Establish long-term monitoring efforts for small mammals and reptiles in the habitat. Monitoring protocols and procedures need to be developed or refined that will allow us to measure population trends of the priority wildlife species, as well as the health and distribution of this relatively rare habitat through time.
- Enhance current monitoring systems and protocols (e.g., MAPS and BBS) to better cover species not well covered by current monitoring efforts.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics.

- Continue research on topics including efficient and effective means to manage and improve the quality and quantity of dry coniferous forest, with a particular eye toward techniques that are applicable in our developing landscape (e.g., in the absence of fire, either as a natural event or as a management tool, what other means might be available to sustain this habitat across the landscape?).
- Research how the loss of hemlock affects salamander habitat use and microclimate.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Determine impacts of prescribed fire on these communities and the resulting effects on wildlife communities.
- Develop logistically and economically effective control strategies for controlling outbreaks of the most damaging insect pests and diseases.
- Regulate human activities on steep slopes that may cause excessive erosion or mud slides, and develop and implement BMPs to mitigate erosion.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Continue to support partnerships like the Southern Blue Ridge Fire Learning Network and the North Carolina Prescribed Fire Council to expand efforts at restoring disturbance regimes.
- Identify the best remaining examples of this habitat in the Mountains and western Piedmont and then to pursue easements or acquisition. The efforts of land trusts and government agencies should be coordinated to target the highest priority sites.
- Use land use planning to minimize development within large, unfragmented tracts of all woodland types in the western Piedmont.

4.4.11 Oak and Mixed Hardwood/Pine Forests and Managed Timber

4.4.11.1 Ecosystem Description

This ecosystem has an oak or mixed hardwood/pine component and occurs on both xeric and mesic sites, in the Piedmont and Coastal Plain ecoregions. (Oak and pine forests in the Mountains are covered in other sections in this chapter.) Oak forests were once the most common natural community type in the Piedmont ecoregion, occurring over most of the uplands. In the Sandhills and Coastal Plain ecoregions, they were much more limited, occurring primarily in dissected areas near streams. They also range across topographic gradients from the Piedmont to some of the highest Mountain ranges.

The following communities are present within this ecosystem; dry oak–hickory forest, dry-mesic oak–hickory forest, basic oak–hickory forest, xeric hardpan forest, and Piedmont monadnock forest (Schafale and Weakley 1990).

- Dry–mesic oak–hickory forest and dry oak–hickory forest are the most typical of the five community types, occurring on upland slopes and ridgetops on acidic soils. White Oak is usually the most abundant tree in both. Post Oak and Southern Red Oaks are the primary associates in dry oak–hickory forests and Northern Red Oak and Black Oak in dry–mesic oak–hickory forests.
- Piedmont monadnock forests, typically dominated by Chestnut Oak and Scarlet Oak, occur on scattered hills, which are resistant to the erosion affecting the surrounding land.

- Basic oak–hickory forests occur on upland flats and slopes in sites similar to dry and dry-mesic oak–hickory forests, but with soils that are not acidic. Most of the soils are apparently near neutral pH rather than truly basic and usually occur over mafic rocks such as gabbro and diabase. They are dominated by White Oak in combination with Post Oak or Black Oak, and a number of understory, shrub, and herb species that are scarce or absent on acidic soils are present.

- Xeric hardpan forests are the most distinctive of the Piedmont and Coastal Plain oak forests. They occur on flat to gently sloping uplands with clay hardpans that restrict water and root penetration. This situation is most common on mafic rocks, but it also occurs on acidic shales. These sites may have shallow standing water in wet seasons, but are extremely dry in dry seasons. The canopy is dominated by some of the most drought-tolerant species in the state, Post Oak and Blackjack Oak, and is often somewhat open.

In addition to these natural communities, there are numerous acres of managed pine plantations, primarily of Loblolly and Shortleaf pines, as well as successional stands of these pines scattered across North Carolina (Huang et al. 2015). Successional communities, which may have a pine stand component, are addressed in Section 4.4.17 in this chapter. Managed stands may be thinned to reduce overcrowding, subjected to prescribed fire to reduce fuel for wildfires, or herbicide applied to control insect or disease attacks. Scientific literature provides evidence that intensively managed Loblolly Pine stands can provide a diverse herbaceous plant community throughout a significant portion of a plantation's rotation that benefits conservation of biological diversity (e.g., Wigley et al. 2000; Loehle et al. 2005; Miller et al. 2009; Homyack et al. 2014), including species of special concern (Miller 2003; Duchamp et al. 2007; Wigley et al. 2007; Morris et al. 2010; O'Bryan 2014; Bender et al. 2015; Johnson 2015). Intensively managed pine forests may contain a diversity of habitat types and conditions, depending on different ages of intensively managed stands, different silvicultural treatments, presence of non-intensively managed stands, such as natural stands and riparian buffers, non-forested areas, and the interaction of these habitat conditions across the landscape (Wigley et al. 2000; Jones et al. 2008; Miller et al. 2009; Morris et al. 2010).

The Mid-Atlantic Coastal Plain ecoregion and Piedmont ecoregion oak forest (including mixed hardwoods and pine), another description for this community, is described in the 2005 WAP (see Chapter 5) (NCWRC 2005).

4.4.11.2 Location of Habitat

Mature hardwood and pine forests are found throughout the Piedmont ecoregion, though the total acreage has been declining in recent years. High-quality examples of oak forests in the Piedmont can be found on public lands such as Caswell Game Land, Umstead

State Park, and Uwharrie National Forest. Examples of large size and good quality oak-dominated communities are now lacking in the Coastal Plain.

4.4.11.3 Problems Affecting Habitats

Many of the problems impacting oak and mixed hardwood/pine forests, including fire suppression and even-aged forest management, result in a loss of habitat complexity and associated wildlife niches (Hunter et al. 2001a). Most Piedmont forests have been logged or cleared at least once within the past 300 years, and many have been cut multiple times. The quality of existing tracts ranges widely across the Piedmont and depends primarily upon the age of the canopy trees, management history, and size of the tract (Godfrey 1997). Some native forest stands are being replaced by even-aged pine plantations, resulting in decreased habitat value for forest species that rely on diverse forest composition and structure, such as Kentucky Warbler and Wood Thrush. Pine plantations do, however, provide increased opportunity to provide habitat for Brown-headed Nuthatches and Northern Bobwhite Quails, with proper management.

Sudden oak death disease, which was detected at plant nurseries within North Carolina in 2004, could potentially have devastating impacts on oak forests across the state.

North Carolina is a major timber producer, with an estimated average 23.2 million cubic meters of wood products produced annually (Huang et al. 2015). Shorter rotation forestry limits the creation of old-growth forest dynamics, such as creation of canopy gaps, hollow trees, snags, and woody debris. In 2002, less than 1% of both hardwood and pine trees in the Piedmont measured greater than 19 inches diameter at breast height (Brown and Sheffield 2003), indicating that there are few old, large trees that help provide these old growth conditions. It should be noted, however, that tree diameter does not always correlate with tree age. Older stands will be more likely to be established and maintained on public land than on commercial forestland, though niche markets for larger timber may entice some landowners to extend cutting rotations.

An increase in hurricanes or other severe storms may increase wind damage in forests. These effects are likely to be localized. Small scale wind disturbances can create canopy gaps, downed woody debris, and patches of early successional habitat which can be beneficial to both early successional and mature forest species. Large scale wind disturbances will benefit early successional species but will harm mature forest species.

Lack of fire is leading to slow changes in composition, including reduced oak regeneration. In spite of benefits from fire, there is a need to control wildfires in drought conditions, to prevent intense fires, and to prevent whole patches of fragmented forest from being burned at the same time. Low intensity fires would be beneficial, but intense wildfires would be destructive. Increased prescribed burning will produce a more open canopy, reduced understory, increased herb cover with more grasses, and longer lasting canopy gaps.

Direct effects of the warmer climate on these communities are likely to be limited. Similar oak forests range well to the south of North Carolina where normal temperatures are higher. The most severe droughts and hot spells of recent record have had only limited effects on them. They can occupy some of the driest places on the Piedmont landscape. Increased drought may possibly favor oaks, but increased wind damage favors the understory species. If drought leads to severe wildfires, it would be harmful to oak forests, but the ease with which fires may usually be controlled in them makes this unlikely.

4.4.11.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While climate change is a significant concern for these communities, several other threats are more severe and may be a more immediate threat. Both the extensive examples in the Piedmont and the more limited range in the Coastal Plain continue to be rapidly destroyed by ongoing urban, suburban, rural, residential and commercial development. Continued population growth makes this the most severe threat, in the current and the future climate. However, the fragmentation and loss of extent caused by it will increase the alteration caused by climate change, as isolated communities are unable to migrate and species are unable to move to more favorable sites. Table 4.36 summarizes the comparison of climate change with other existing threats.

4.4.11.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

Development causes direct loss of forest habitat and also fragments remaining forested patches. Fragmentation of forests into smaller contiguous blocks is a concern for forest interior birds (like Wood Thrush and Hooded Warbler), which may occur in lower densities or suffer lower productivity or survival in small habitat patches. Animals with large home ranges or dispersal needs may become isolated or absent in small tracts. Fragmentation by roads and development can be particularly problematic for reptiles (particularly Timber Rattlesnake).

Historical data suggests that oak communities benefited from periodic fires (Abrams 1992; Close 1996), and many oak species are fire tolerant. In pine stands, fire can play a very important role in reducing the midstory while enhancing structure in the understory. Fire helps

Table 4.36 Comparison of climate change with other threats to oak and mixed hardwood pine forest and managed timber

Threat	Rank Order	Comments
Development	1	Land use conversions in the Piedmont (primarily to suburban and exurban development) contribute significantly to the reduced condition of some tracts. The threat includes both direct and secondary impacts of development.
Logging/ Exploitation	2	Logging and exploitation are of greatest concern when accompanied by conversion to pine plantation or severe shifts in composition. Logged forests may be converted to successional pine forests or become dominated by maple or other hardwoods. Demand for biofuels may increase the risk of damage by logging or biomass harvest. However, logging remains an important source of income for many landowners and plays a role in helping to keep forested tracts from being sold for development.
Invasive Species	3	Nonnative plants such as Japanese Honeysuckle and Autumn Olive have seriously impacted many upland forest stands. Exotic diseases and pests have the potential to induce a large magnitude compositional change, as was seen with American Chestnut in the last century. Increased canopy disturbance by wind, drought mortality, or severe fire will hasten invasion. Gypsy Moths are the most destructive defoliating insect attacking Northern Red Oak, Chestnut Oak, and White Oak. The Asiatic Oak Weevil attacks Northern Red Oak seedlings and has the potential to seriously affect seedling growth because the larvae feed on the fine roots while the adults feed on the foliage.
Fire	4	There may be an increase in natural fires (due to increased drought and higher average temperatures), but landscape fragmentation and fire suppression practices likely will continue to prevent most fires from spreading very far in the Piedmont and in the dissected lands where oak forests occur in the Coastal Plain. Most oak forests are expected to benefit from increased fire frequency, as long as the fire intensity is not too high.
Climate Change	5	Piedmont and Coastal Plain oak forests are likely to be relatively resilient to the effects of climate change. These communities are tolerant of severe droughts, hot spells, and fires of low intensity. Development, logging, and invasive species are much more of a threat to these communities than climate change.

to create snags, woody debris, and canopy gaps, and prepares a fertile seed bed, while also improving vegetative structure. The benefit of fire to understory plant development is highly dependent upon the density of canopy trees, with closed-canopy stands suppressing the growth of grasses and forbs following fire. Cavity-nesting birds, arboreal mammals, and some frogs, lizards, and snakes are impacted by the lack of snags, while reptiles, amphibians, and small mammals are impacted by lack of woody debris. Many bird species, such as the Hooded Warbler, Red-headed Woodpecker, Eastern Wood-pewee, Northern Flicker, Nightjars, and many post-fledging juvenile birds utilize canopy gaps for cover, or for foraging habitat, as do some bat species. Lack of fire has also allowed some fire-intolerant mesophytic plant species to become quite common in oak-dominated communities, including the American Beech (Franklin and Kupfer 2004). The resulting loss of acorn production may be limiting for some wildlife in the future.

There are many potential and realized impacts by imported Gypsy Moths and other non-native insects, Kudzu, and other non-native pathogens, plants, and animals. Gypsy Moths are the most destructive defoliating insect attacking Northern Red Oak, Chestnut Oak, and White Oak. This insect repeatedly defoliates trees and has killed oaks in a wide area of the northeastern United States.

Rare invertebrate species associated with this ecosystem group occupy habitats at the dry to xeric extreme, with some occurring only on a few isolated monadnocks in the Piedmont. Moth species include Barrens Dagger Moth (*Acronicta albarufa*), Herodias Underwing (*Catocala herodias*) and Faded Gray (*Stenoporpia polygrammaria*), Northern Hairstreak (*Fixsenia ontario*), Rare Spring Moth (*Heliomata infulata*) and an unnamed moth (*Hemeroplanis* n. sp.), Mottled Duskywing (*Erynnis martialis*), Brown Elfin (*Callophyrs augustinus*), Frosted Elfin (*Callophyrs irus*), and a noctuid moth (*Ptichodis bistrigata*).

4.4.11.6 Recommendations

These communities occur in a fragmented landscape and migration may be problematic. Conservation of remaining examples and restoration of degraded sites and landscape-level connections would allow for adaptation in the future, as well as provide protection and promote the ecosystem viability under the current climate.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Conduct surveys to document priority and common species in areas poised for development (edge of urban expansion) to establish baseline populations and identify problems before development expands.
- Determine the current baseline distribution and status of species mainly associated with oak and mixed hardwood/pine forests (especially those that are state-listed or believed to be declining) for which that information is lacking.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Initiate long-term monitoring for breeding neotropical migrants (especially ground-nesters and cavity-nesters), bats and small mammals (e.g., moles, shrews, rodents), amphibians that use woody debris as a microhabitat, and Timber Rattlesnakes and other secretive reptiles.

- Monitor tree infestations and diseases to document potentially destructive organisms shortly after they show up, while there is still a chance to contain or eradicate the pest.
- Develop standardized monitoring programs analogous to the Breeding Bird Survey for reptiles, amphibians and small mammals. Of particular interest is trend information for those species dependent upon snags and woody debris.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Research and identify important wildlife crossing areas; evaluate connectivity issues between intact and fragmented habitats used by priority species; work with partners to improve crossing and connectivity.
- Conduct long-term and large-scale replicated studies that have controlled experimental approaches and that focus on population demographics and the response of species to habitat manipulations, where appropriate, for oak/mixed hardwoods forest taxa including birds, bats, small mammals, amphibians, and reptiles.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Create transportation facilities that utilize longer bridges at streams and wetlands to minimize impacts (and thereby reduce mitigation requirements) and provide crossing options for wildlife that often travel these riparian corridors and disperse to upland communities.
- Work with adjacent states on mutual planning and conservation for regional species concerns, especially since some priority species are likely to expand their range due to climate change impacts.

- Control invasive species in the short run, while populations are relatively limited and small, to prevent greater damage by them in the future.
- Use infrequent prescribed fire and canopy gap management to improve forest structural heterogeneity (frequent fire will limit shrub and understory development necessary to breeding bird species).
- Manage and protect mixed hardwoods/pine to promote future large, unfragmented tracts. This is especially important for amphibians, reptiles, small mammals, and bats.
- Target invasive and exotic species control at ecologically sensitive areas and at new and potentially manageable outbreaks.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Use landowner incentives to promote extending rotation lengths for timber.
- Give a high priority to protecting movement corridors that allow dispersal between habitat blocks, especially as development and roadways fragment the few remaining large tracts of habitat. Maintaining and restoring connections between habitat blocks is critical, not only for allowing adjustments in range in response to climate change, but to maintain population resilience and adaptability more generally.
- Give priority to restoring connections that are lost due to construction of four-lane highways and other roads that create nearly impassible barriers for all animals except those capable of flight.
- Direct county and state-level land use planning to minimize development within large, unfragmented tracts of forests. This would be most appropriate and effective in the regions that are, as yet, not heavily developed, including Montgomery, Stanly, Randolph and Richmond counties in the southern Piedmont, and the northern tier counties of Surry, Stokes, Rockingham, Caswell, Person, and Granville.
- Concentrate planning for future infrastructure (roads, water lines, etc.) closer to existing development and avoid dissecting larger tracks of unfragmented forest.
- Make attempts to provide large core areas of forest and to connect isolated patches of forests. Cooper (2000) recommends that core areas be at least 16,000 acres in size to

produce viable populations of forest-interior birds, like Scarlet Tanager. Large core areas will be important for reptiles like Eastern Box Turtle and Timber Rattlesnake, which suffer high mortality when crossing roads.

4.4.12 Montane Oak Forests

4.4.12.1 Ecosystem Description

Montane oak forests are found primarily in the Mountain ecoregion and once included a large component of American Chestnut, before the blight in the early part of the century eliminated it as a canopy species. The driest sites are dominated by Chestnut Oak and/or Scarlet Oak, often with an understory of Sourwood, Black Gum, and Red Maple. Today, chestnut persists only as short-lived sprouts from old root systems. Most of the four natural community types recognized within this ecosystem group are broad types with many variants that could be recognized: Chestnut Oak forests, montane oak–hickory forests, high-elevation Red Oak forests, and montane White Oak forests:

- Chestnut oak forests occur in the driest sites in low to intermediate elevation steep slopes and sharp ridges. Chestnut Oak or Scarlet Oak are the dominant trees, and an understory of acid-loving plants is usually present.
- Montane oak–hickory forests are dominated by a mixture of oaks, of which White Oak is a prominent part. Hickories are usually a minority component, but are sometimes absent. The understory is generally more diverse than in the other oak forests.
- High-elevation Red Oak forests occur at medium to high elevations. In the southern part of the state, where spruce–fir forests are absent and northern hardwoods rare, they may dominate the highest ridges and summits. Farther north, they occur below these communities, often in broad zones along mountain slopes. The canopy is usually nearly pure Northern Red Oak. The lower layers of vegetation vary greatly, but share many species with northern hardwood forests.
- Montane White Oak forests occur at fairly high elevations. They are dominated by White Oak with few other trees.

The 2005 WAP describes this habitat type as Southern Blue Ridge oak forest (including mixed hardwoods and pine) (see Chapter 5) (NCWRC 2005).

4.4.12.2 Location of Habitat

Montane oak forests occur in the Mountain ecoregion on exposed sites such as ridge crests and south- to west-facing slopes, typically from about 3,000 to 4,500 feet elevation.

According to the most recent Southeast GAP analysis, montane oak forest communities comprise over 272 thousand acres (about 110 thousand hectares) of land cover in North Carolina (SEGAP 2007; NatureServe 2007). This represents less than 1% of the state's land cover.

4.4.12.3 Problems Affecting Habitats

It is unclear if changes in fire regime will be beneficial or harmful to oak forests. Fire suppression has allowed non-fire-tolerant species, including tree species, to increase in montane oak forests. Many oak forests have seen a lack of oak regeneration that is likely related to lack of fire. If a warmer climate brought an increase in fire, it might offset some of the alterations caused by suppression of fire. Severe fires during droughts would cause extensive canopy mortality and be destructive to oak forests, especially if occurring with the increased fuel loads resulting from recent fire suppression.

Prolonged or severe drought stress has been associated with oak decline and with canopy mortality. Chestnut blight caused dramatic compositional shift by almost extirpating the American Chestnut. Some more southern or low-elevation species may migrate into these communities. Impacts from higher temperatures, drought, fire, and wind damage will likely lead to other community types, or different suites of species, more suited to the change in climate due to competitive interactions of species in the seed bank during succession. Unfortunately, this may lead to a greater need for nonnative invasive species control after stand replacing disturbances, natural or man-made.

Homogeneity of stand age has resulted in decreasing habitat for bird species that rely on diverse understory development (lack of understory development). Increased wind damage, fire damage, and drought mortality will result in more canopy gaps and a younger average tree age, but may benefit some herbaceous species.

Drought may allow pine forests to expand at the expense of oak forests, it will also allow oak forests to expand to higher elevations and into more mesic sites now occupied by cove forests. The overall extent of oak forests may increase moderately. These communities should be able to move to higher elevations, while they are unlikely to lose much acreage at lower elevations.

Princess Tree and Tree-of-heaven are threats. Gypsy Moths and exotic tree diseases (sudden oak death, chestnut blight) are potential future threats. Fire Ants may be able to invade these communities and cause significant impacts if temperatures become warm enough.

4.4.12.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. Montane oak forests will likely be resilient to the effects of climate change and are expected to continue to occupy most of the sites they currently occur in and to remain the most abundant communities. Development remains the most severe threat to these communities. Table 4.37 summarizes the comparison of climate change with other existing threats.

4.4.12.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

No endemic species are associated with montane oak forests. Only three moths associated with this ecosystem group appear to be major disjuncts. Montane species adapted to cooler high-elevation sites may become locally extinct in the lower elevations of their range as temperature gradients change (DeWan et al. 2010).

Table 4.37 Comparison of climate change with other threats to montane oak forests

Threat	Rank Order	Comments
Development	1	According to Taylor and Kurtz (2008), the conversion of forest to development is the leading land use change occurring in the Blue Ridge Mountains (DeWan et al. 2010).
Logging/ Exploitation	2	Full scale high-grading and poor logging practices of the past have had very negative impacts on the structure and composition of the resulting succession, but ensuring logging practices are geared toward restoration rather than purely short-term financial objectives will remove the negative impacts of logging.
Invasive Species	2	Past effects of chestnut blight, likely future effects of Gypsy Moth, and potential introduction of sudden oak death make this a severe threat. The Hemlock Woolly Adelgid's range is likely to expand as a result of climate change (Paradis et al. 2007).
Climate Change	3	Future climate is expected to include warmer temperatures, longer growing seasons, likely more hot spells and drought, and more severe storms. Mountainous regions are expected to experience some of the highest temperature changes. Orographic cloud cover, storms, and fog are less crucial in these communities than in those of the higher elevations, but are probably still significant. Since the readily available climate models don't account for these effects, the future climate experienced by these communities remains very uncertain.

Many species (e.g., Black-capped Chickadees, Green Salamanders, Seepage Salamanders, Crevice Salamanders, and Wehrle's Salamanders) have such a small range or clumped distribution within North Carolina that they are more susceptible to stochastic or genetic population declines or local extirpations than anticipated climate change impacts. Timber Rattlesnakes and other snake species are also subjected to persecution, which is an immediate threat.

Many neotropical migrant birds may also be experiencing winter range habitat loss. Since there is such abundance and diversity of species associated with oak forests, we may not know the exact habitat or life history requirements of individual species that are limiting factors to their population stability.

4.4.12.6 Recommendations

Because oak forest habitat remains abundant and widespread, the most critical conservation activities revolve around gathering information about the wildlife species that utilize it and the habitat itself. We must foster efforts to understand and implement appropriate management techniques (e.g., prescribed fire or thinning) for the benefit of the broadest array of oak forest-dependent wildlife, while taking into account specific needs of wildlife with more restrictive requirements (Artman and Downhower 2003; Ford et al. 2000).

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Give priority to gathering baseline information regarding the current distribution and status of oak forest-associated species that are rare or declining (e.g., Black-capped Chickadee, Eastern Fox Squirrel, Wehrle's Salamander, Timber Rattlesnake, and several bat species).
- Expand surveys to include species for which we know very little about current status and distribution (e.g., Whip-poor-will, weasels, moles, shrews, bats, certain salamanders, and reptile species such as the Eastern Box Turtle).

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Expand monitoring frameworks to account for species that are not suited to traditional long-term monitoring protocols (e.g., hawks, nightjars [goatsuckers], owls), or for species missed under systematic monitoring due to small population sizes or limited ranges in North Carolina.

- Track oak habitat trends (e.g., rate of loss or conversion of the habitat and disease or pest affects) and consider trends in the development of long-term monitoring strategies for oak forests of the region.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Initiate genetic and morphological studies to clarify taxonomic status of numerous birds and amphibians (e.g., high-elevation birds, plethodontid salamanders).

- Conduct life history and habitat use research on Northern Pinesnake.

- Conduct habitat use studies of neotropical migrants (Worm-eating Warblers, Black-capped Chickadees, and many others) using telemetry.

- Conduct habitat use and life history studies for bat species that may potentially use this habitat (Hoary, Silver-haired, Eastern Small-footed, and Northern Long-eared bats).

- Study population responses of plant and wildlife species to habitat manipulations (large scale prescribed burning, oak savannah creation, canopy gap creation, etc.).

- Conduct Green Salamander movement studies either around embedded rock outcrops or between rock outcrops.

- Establish studies to determine both direct and indirect impacts of pest control measures upon oak forest–dependent species. Example questions are 'What is the impact of Gypsy Moth control strategies upon local and landscape scale wildlife populations?' and 'What is the impact upon invertebrates that serve as food for vertebrates?'

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural

resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Restore highly degraded stands; options include clear cutting and managing succession to control invasive species (i.e., ecological forestry).
- Foster efforts to understand and implement appropriate management techniques (e.g., prescribed fire or thinning) for the benefit of the broadest array of oak forest-dependent wildlife, while taking into account specific needs of wildlife with more restrictive requirements (Artman and Downhower 2003; Ford et al. 2000).
- Manage the existing conservation lands, including the use of prescribed burning to diversify structure and composition of forest understory, and other silvicultural techniques to promote regeneration. This provides an array of age class and structural composition, and promotes long-term economic sustainability of montane oak forests.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Work with partners like Prescribed Fire Council and the Fire Learning Network to reinstate prescribed burning, which is perhaps the most important action that can make oak forests better able to withstand climate change.
- Create wildlife passages along highways and protect undeveloped connections.
- Identify and protect strategically important areas.

4.4.13 Dry Longleaf Pine Communities

4.4.13.1 Ecosystem Description

Dry Longleaf Pine communities range from moist sites to excessively drained coarse sands which produce near-desert conditions for plants. Longleaf Pine communities are scattered throughout the Sandhills and Coastal Plain ecoregions and extend into the southern Piedmont ecoregion. They were once the most abundant communities in the Coastal Plain, occupying most of the land that was not swamp or pocosin, but now occur as scattered remnants. With frequent fire, Longleaf Pine strongly dominates the canopy, which may range from sparse to fairly dense but is seldom completely closed. A number of variants are recognized within the community types, determined by variation in moisture, soil, and location: Coastal Fringe Sandhill, Xeric Sandhill Scrub, and Pine/Scrub oak Sandhill types, Mesic Pine Flatwoods, and Piedmont Longleaf Pine Forest.

These communities have in common a regime of frequent natural fires which once crept across vast areas of the landscape. The ground cover is dominated by wiregrass and has a variety of other herbs and low shrubs. The structure and composition of these communities at present strongly depends on the extent to which these fires have continued or have been replaced by prescribed fire.

- In the three Sandhill community types a sparse midstory of scrub oaks is present, with the species varying with the types and variants. In the mesic pine flatwoods type, oaks are absent and the community has a distinctly two-layered structure of trees and grass. The herb layer is often very diverse. With removal of fire, scrub oaks in the Sandhills community types and shrubs and hardwood trees in the flatwoods community types become dense and out-compete the herbs.
- Piedmont Longleaf Pine forests are more poorly known. Most existing examples have a mixed canopy of longleaf, loblolly, and shortleaf pine, often mixed with Southern Red Oak and Post Oak. These communities probably once also had a grassy understory, but it is not known if wiregrass was once dominant.

The 2005 WAP identified dry Longleaf Pine as a priority habitat (see Chapter 5) (NCWRC 2005).

4.4.13.2 Location of Habitat

The best remaining examples of the dry Longleaf Pine habitat in the Coastal Plain are on the military bases of Fort Bragg, Camp Lejeune, Sunny Point, and Cherry Point, the Croatan National Forest, Holly Shelter Game Land, Goose Creek Game Land, and Sandhills Game Land. Most of the acreages on the above sites are in fair to good condition, due to regular prescribed burning. There are many other sites on both public and private lands where little to no burning has depleted the value of the habitat; these sites would thus be considered to be in poor condition. Piedmont Longleaf Pine forest examples are found mainly in Uwharrie National Forest.

4.4.13.3 Problems Affecting Habitats

Severe wildfire in droughts or burning with excessive fuel loads may cause ecological damage. For particular species, especially insects, too frequent or too extensive burning (whether by wildfire or prescribed burns) can have major effects when coupled with loss of landscape integrity resulting from habitat loss. Effects may include some positive (longer growing season) and some negative (pest insect survival). Some of the insects most highly tied to dry longleaf habitats may be eliminated by increases in wildfires.

The most extreme Xeric Sandhill Scrub and Sand Barrens are dry enough that vegetation density is limited. Increased drought may possibly cause plant mortality and reduce vegetation density further. It may also cause sand barrens to develop in slightly less dry soils. These systems and their component species are well adapted to warm temperatures. Increased temperatures might increase the range of these systems in the northern Coastal Plain and in Virginia. However, the widespread conversion of uplands in this region, the fragmented distribution and lack of seed source for them, and their dependence on fire make natural expansion very unlikely. Warmer temperatures may allow some species of Longleaf Pine systems farther south to move into North Carolina. The limited tendency of most plants in these systems to invade new areas suggests that any such process would naturally be slow and limited.

Warmer temperatures may allow the invasion of Cogon Grass and Nine-banded Armadillos. Once established, they are likely to expand more rapidly with a warming climate. Fire Ants are already a serious invader in these systems.

General forecasts suggest an increase in severe storms. Increased drought conditions and increased thunderstorm intensity are likely to produce more wildfire Increased wind storm damage could affect canopy structure. Longleaf Pines are among the least susceptible trees to wind destruction, and it is unclear how significant increased wind will be to them. Some young planted coastal longleaf stands have shown significant damage from hurricanes and other strong winds. This usually occurs within a few years after the longleaf have emerged from the grass stage. Because of their slow reproductive rate and long life span, increased wind mortality would reduce average age and might reduce natural canopy density. This would be detrimental to red-cockaded woodpeckers and other species that depend on older Longleaf Pine trees. Increased plant productivity with a longer growing season may partially offset the effect of reduced tree age on structure.

4.4.13.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. The greatest threats to this system do not come from climate change. With their adaptation to dry conditions, fire, wind, and their range well to the south, these may be the most resilient systems to warming climate. Currently, the greatest threat comes from development pressure. Historically, conversion and exploitation destroyed most of this once extensive system, and these forces continue to consume the remnants. Table 4.38 summarizes the comparison of climate change with other existing threats.

Table 4.38 Comparison of climate change with other threats to dry Longleaf Pine communities

Threat	Rank Order	Comments
Development	1	Longleaf Pine stands are very desirable areas for housing developments and golf courses. Development within this habitat can lead to fragmentation that disrupts connectivity between patches for most wildlife except birds. Road crossings can lead to mortalities, especially for reptiles and amphibians. These systems occur on some of the highest lands in the outer Coastal Plain, where development may become even more concentrated as sea level rises.
Logging/ Exploitation	2	Intensive pine straw raking impacts understory habitat by removing understory grasses and forbs, preventing their growth, and sometimes creating an almost bare sandy forest floor. Slow reproductive rates may limit regrowth once Longleaf Pines have been removed.
Conversion to Agriculture/ Silviculture	2	The threat of agricultural conversion has reduced in recent years (having greatly reduced habitat historically), but pine plantation conversion continues. Genetic improvements to planting stock have resulted in getting longleaf to gain height growth quickly, with most trees coming out of the grass stage within three years. However, these trees clearly have a less developed root system and are more susceptible to wind throw.
Fire	2	Prescribed burning is crucial for retaining these systems in both the present and the expected climate. Inadequate fire is an ongoing threat at many sites. For small, isolated habitat remnants, wildfires can cause permanent extirpation of insect and other animal populations. This is a problem at most unprotected examples and is the greatest threat to protected examples. Much of the plant diversity in these habitats is found in the transition zones between the Longleaf Pine communities and other adjacent wetter sites. Traditional use of plowed fire lines in these transition zones has resulted in the eventual deterioration of these transition zones.
Biofuel Production	3	Industrial timber operations will be likely candidates for conversion to biomass production. It will be important to consider competing resource needs as alternative energy production increases the demand for biofuel products (DeWan et al. 2010).
Invasive Species	3	Fire Ants are a threat to many terrestrial animals, especially amphibians. There are numerous native and exotic pests that can impact coniferous trees in this habitat (e.g., Southern Pine Beetles, Red-headed Pine Sawflies, Tip Moths, Pine Webworms, Schweinitzii root and bud disease, red heart of pine disease, etc.). Early detection and control of invasive exotic species (such as Cogon Grass) will reduce the ecological damage caused by invasives and the cost of controlling them. Preventative measures such as forbidding sale and transport of invasive species will help reduce the risks and cost.
Climate Change	4	Climate change will likely exacerbate some of these problems.

4.4.13.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

Habitat loss and lack of fire affects bird species that rely on a grass-dominant understory and open pine ecosystems (Red-cockaded Woodpecker, Bachman's Sparrow, Brown-headed Nuthatch, Henslow's Sparrow, and Northern Bobwhite). Old growth characteristics (canopy gaps, red-heart fungus, cavities, snags, hollow trees) are lacking throughout, except where Red-cockaded Woodpeckers are managed, impacting both primary (e.g., woodpeckers) and secondary (e.g., rodents, bats, and other birds) cavity users. High-grading of stands, lack of gap management, and overstocked stands are leading to a lack of structural diversity for many species. Roads cause particularly high mortality to reptiles and amphibians.

Microhabitat features such as large woody debris have been lost, impacting reptiles and small mammals (Loeb 1999). Localized and non-lethal infestations can be beneficial for wildlife by creating snags, a food source, and habitat diversity. Extensive lethal outbreaks of native and exotic pests can dramatically shift the composition of the tree community, with implications for conifer-specialists like the Brown-headed Nuthatch.

Wildfires in drought are more likely to be too intense or too extensive, and may harm some species. In small, isolated sites, an increase in wildfires may have catastrophic impacts on insects and other animals that depend on a metapopulation strategy for coping with environmental disturbances. For such species, lack of landscape connectivity can prevent restoration of populations through recolonization from unburned refuges. As a result, there may be a significant increase in local extirpations that may eventually lead to region-wide extirpations or even extinction of certain species. To protect sensitive insect populations, prescribed burns should include setting aside unburned refugias in every burn and preferably following a three year burn rotation among three different burn units.

Mild winters, with decreased cold damage, are likely to allow species from the south to move into North Carolina. In recent years, several Longleaf Pine-associated insects once thought to be restricted to Florida or the Gulf Coast have been found to be established in North Carolina. Although we lack the historic data to know for sure that these represent recent colonizations, this trend will undoubtedly accelerate with decreasingly cold winters. Fire Ant impacts are also a growing threat.

4.4.13.6 Recommendations

Because so few examples remain, at least outside of the Sandhills ecoregion, protecting and expanding remaining examples is crucial with or without climate change. Because these systems are likely to withstand the stresses of changing climate well, restoring more of them in the near future would produce more resilient natural landscapes. Protecting and restoring landscape connections is important to allow movements of mobile species and to improve the viability of small populations. The need for this is particularly important for disturbance-maintained habitats such as Longleaf Pine ecosystems and will increase with the stresses of a changing climate.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Conduct surveys to document the distribution, relative abundance, and status of priority wildlife species associated with dry Longleaf Pine habitats.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Develop monitoring for any North Carolina dry Longleaf Pine bird species that require specialized attention, since neither BBS nor standard point counts adequately sample for many species like Bachman's Sparrow, Nightjars, American Kestrel, Henslow's Sparrow, and Red-headed Woodpecker.

- Expand and/or target monitoring systems to be able to assess current population status and trend information for all wildlife species associated with dry Longleaf Pine habitats, in particular reptiles such as Northern Pinesnake, Southern Hognose Snake, and Coachwhip.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Develop long-term research studies to investigate various methods for restoring and maintaining Longleaf Pine ecosystems, including herbicides, fire, clearcutting, site preparation techniques, and management practices.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural

resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Where possible, allow fire to burn through transition zones to maintain these sites instead of plowing fire lines through them.
- Suppress Fire Ant colonies—particularly where multi-queen colonies have developed—in all protected natural areas.
- Restore landscape integrity to protect insect populations associated with Longleaf Pine habitats.
- Evaluate sustainable forestry criteria established by European countries that use woody biomass for fuel to generate preliminary guidelines for biomass production in North Carolina (Buford and Neary 2010 in DeWan et al. 2010).
- Develop strategies for pine straw raking that minimizes impacts to understory habitat structure.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Work cooperatively with other agencies to define sustainable forestry criteria for biomass production.
- Provide landowners with the option to purchase longleaf seedlings that stay in the grass stage longer. This will allow the trees to better establish their root systems in the hurricane zone, and will also provide a longer period of high-quality early successional habitat.
- Give high priority to protecting and expanding the few remaining examples regardless of climate change. Because these systems are likely to withstand the stresses of changing climate well, restoring more of them in the near future would produce more resilient natural landscapes.

4.4.14 Maritime Forests

4.4.14.1 Ecosystem Description

Woody vegetation on the barrier islands includes well-developed forests with canopies typically dominated by Live Oak, Sand Laurel Oak, and Loblolly Pine; Cabbage Palms are a distinctive component in the Cape Fear area. It also includes the distinctive scrubby woody growth of stabilized sand dunes, dune swales, and sand flats. A few areas on the mainland shore of the sounds share the characteristic species of the barrier island maritime forests. The much rarer maritime deciduous forests are dominated by beech, American Holly, Loblolly Pine, and Hickory on the northern barrier islands.

Schafale and Weakley's Third Approximation (1990) classifies maritime forested and shrub communities as Maritime Shrub, Maritime Evergreen Forest, Maritime Deciduous Forest, Maritime Swamp Forest, and Maritime Shrub Forest. Updates to the community description separates maritime forests into Maritime Upland Forest and Maritime Wetland types (Schafale 2012). The Maritime Upland Forest includes shrub, evergreen and deciduous forests, marsh hammock, and coastal fringe shell woodlands in the description. Maritime Wetland Forest includes grassland, interdune marsh and pond, and estuarine forests in the community type.

- Maritime Upland Forests have relatively low species richness, but a number of species are largely confined to these communities, at least in North Carolina. Such specialized species include Yaupon, Carolina Laurel Cherry, and Devilwood. Salt spray is a major ecological influence on these communities. Where the vegetation is frequently exposed to salt spray, it is significantly stunted. The forest cannot persist in areas with the most severe salt spray and are dependent on the shelter of dunes for their occurrence. Maritime Upland Forests are also subject to the catastrophic disturbances of coastal storms, including high winds, erosion, and saltwater flooding from storm tides and overwash.

- Maritime Wetland Forests occur in wet sites on barrier islands and near the sounds on the mainland. There are three community types: maritime swamp forest, maritime shrub swamp, and estuarine fringe Loblolly Pine forest.

- Maritime Swamp Forests and maritime shrub swamps occur on barrier islands in dune swales which are sheltered from the most extreme salt spray and from seawater overwash. The soils are saturated for much of the year and may be flooded for substantial periods. Maritime Swamp Forests have a canopy of tall wetland trees which vary from place to place. Dominants include swamp Black Gum, Red Maple, Ash, Water Oak, Sweetgum, Loblolly Pine, and Bald Cypress.

- Maritime Shrub Swamps have a canopy of tall shrubs or small trees, usually Red Bay or Swamp Dogwood, which may be tangled together with vines. They are apparently wetter than maritime swamp forests but also may be kept in shrub dominance by periodic disturbance.
- Estuarine Fringe Loblolly Pine Forests occur on wet flats adjacent to salt or brackish marshes along the sounds. There is often a fairly dense layer of shrubs and greenbriers. All of the dominant plants are species that occur in disturbed wet sites elsewhere in the Coastal Plain, but these communities appear to be of natural origin. It may be that periodic natural disturbances such as saltwater intrusion prevent succession to hardwoods. It has been suggested that fire occurred naturally in these communities and that the natural aspect was open and grassy rather than shrubby.

The 2005 WAP described Mid-Atlantic Coastal Plain maritime forest/shrub communities as a priority habitat (see Chapter 5) (NCWRC 2005). Components in this ecosystem include maritime shrub, evergreen forest, deciduous forest, coastal fringe evergreen forest, and Sandhills communities.

4.4.14.2 Location of Habitat

Maritime Evergreen Forest is found throughout the barrier islands and good examples can be found at Buxton Woods, Theodore Roosevelt State Natural Area on Bogue Banks, Brown's Island, and Bald Head Island. Maritime Shrub is found throughout the barrier islands, but good examples are rare. Some examples exist at Cape Hatteras National Seashore, Shackleford and Core Banks, Brown's Island, Bear Island in Onslow County, Fort Macon State Park, Bogue Banks, and Fort Fisher. Only one good example of Maritime Deciduous Forest remains at Nags Head Woods in Dare County; an additional example occurs in nearby Kitty Hawk Woods. Maritime Swamp Forest examples can be found in in Buxton Woods and Nags Head Woods. Examples of Estuarine Fringe Loblolly Pine Forests can be found on marsh islands at Swanquarter National Wildlife Refuge and higher uplands at Goose Creek State Park.

4.4.14.3 Problems Affecting Habitats

Any loss will be very significant for these already rare communities. The acreage completely lost from this system by community shifts and destruction may be catastrophic. New sites for these communities may be generated as the coastal landscape changes, but only in places not already destroyed by development. Most barrier island examples occur in complexes that are distant from each other, but connections within the complexes can be threatened both naturally by rising sea level and by human actions such as hydrological alteration.

With limited dune development in many parts, maritime swamp forests are vulnerable to erosion of the foredunes and increased overwash. If erosion breaches swales and exposes them to sea water intrusion or overwash in storms, they will likely become maritime grasslands. If they are low enough have irregular tidal inundation, they will become brackish marshes. A lack of fire to maintain some variants of these habitats is also leading to successional changes in many of these sites. Burning is almost impossible to conduct in areas surrounded by homes.

The net change in acreage of this type will likely be drastic only if sea level rises faster than new examples can develop. Increased natural disturbance by wind, salt spray, and storm surge intrusion will be significant. Some of these communities consist of species that can recover from these disturbances, but increased frequency will result in death and regeneration, more time spent in recovery stages, and shifts toward the most tolerant species.

4.4.14.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. Climate change may be the biggest threat to remaining examples of this ecosystem group, especially in places where topography or development limits potential for elevational migration. A combination of synergistic effects with other existing conditions could stress these systems to the point where several species are unable to persist. Residential and commercial coastal development leading to fragmentation and overall reduction of habitat is the single most important factor leading to the existing loss of this habitat. Table 4.39 summarizes the comparison of climate change with other existing threats.

Table 4.39 Comparison of climate change with other threats to maritime forests

Threat	Rank Order	Comments
Climate Change	1	Sea level rise may be the biggest threat, outside of development.
Development	1	Almost all maritime forest habitat is found in areas close to the beach, where human population growth is booming. The creation of numerous small clearings for houses will likely have far-reaching effects on the dynamics of these habitats (Schafale and Weakley 1990).
Drainage/ Impoundments	2	Construction of larger dunes can either prevent overwash saltwater from reaching these wetlands or trap water that might otherwise run off. Maritime wetland forests may be destroyed by impoundment, ditching, and by extensive well pumping that lowers the water table.
Groundwater Depletion	3	Control of groundwater extraction is likely to be difficult, as coastal towns seek water sources from perched aquifers that are shrinking due to erosion and saltwater intrusion. Groundwater pumping, ditching, and impoundment associated with development are threats which can be mitigated.

4.4.14.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

These habitats are important breeding and migration stopover points for many migratory birds, and key breeding areas for populations of the Eastern Painted Bunting (Hunter et al. 2000; Johns 2004). These communities are also important for some snake species for which we have little status, distribution, or demographic information. The presence of dense canopies are a key habitat element in maritime forests; many maritime forest-associated herpetofauna, and their prey, are adapted to survive under particular sun and shade regimes (Bailey et al. 2004).

There are feral animal impacts (horses, goats, cows, pigs, cats) on some of the barrier islands (e.g., Shackleford Banks and Brown's Island). Wood et al. (1987) reported that grazing by ungulates can inhibit expansion of maritime forests. Feral horses have been shown to alter the composition of entire communities through grazing and trampling, though trampling may be the greater impact because it degrades soil structure (Turner 1987; Jensen 1985; Porter et al. 2014). In addition, egg predators such as Raccoons and foxes that typically did not inhabit most of the Outer Banks are now widespread because of the increased amount of food available now that people inhabit the area.

The Buxton Woods White-footed Mouse might be the only animal essentially limited to this habitat type. The Dukes' Skipper occurs mainly in ecotones of maritime forests and adjacent marshes. All guilds linked to this group are associated with other ecosystems that provide greater acreage of habitat.

4.4.14.6 Recommendations

Most of the remaining maritime forests and swamps on the barrier islands are under conservation, as are many of the estuarine fringe communities. Substantial opportunities to protect additional examples are limited. There is value in protecting additional examples in the broader, more stable parts of barrier islands such as Kitty Hawk Woods, where these communities have the best chance of surviving. There is value in protecting estuarine fringe examples where there is opportunity for them to migrate inland.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Determine the status and distribution of amphibians and reptiles in maritime communities.

- Conduct migration surveys to determine bird use, especially during the fall.
- Conduct small mammal surveys on barrier island systems to verify species status, distribution, and community composition.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Establish MAPS and migration banding stations in this habitat type.
- Establish long-term monitoring of amphibians and reptiles, once survey data has been established.
- Carefully monitor loss of this habitat from sea level rise.
- Continue long-term monitoring and banding work (currently being done by the USGS) on Eastern Painted Buntings and support the goals and objectives of the Painted Bunting Working Group that involves Florida, Georgia, South Carolina, and North Carolina.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Conduct cooperative research with western states to determine the genetic relationships between Eastern and Western Painted Buntings.
- Conduct genetics research on all “Kingsnake” species.
- Document the habitat selection and competition factors related to Indigo Buntings and Painted Buntings in these habitats (Kopachena and Crist 2000).
- Initiate productivity and habitat use research on priority species such as Eastern Painted Bunting (Norris and Elder 1982; Lanyon and Thompson 1986; Kopachena and Crist 2000),

Southern Dusky Salamander, Eastern Spadefoot, Coachwhip, Northern Scarletsnake, Eastern Kingsnakes, and Eastern Coral Snake.

- Consider maritime forests in the far southeastern portion of the state to be potential Eastern Woodrat reintroduction sites, as they were historically supported in those locations.
- Examine demographics, population dynamics, and the specific habitat requirements of the Buxton Woods White-footed Mouse.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Where possible, remove or exclude feral animals. Exclosure plots and electric fences should be considered as methods to prevent grazing or trampling (Porter et al. 2014).
- Control the number of feral horses and contain populations of free roaming horses to reduce habitat damage (Porter et al. 2014).

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Make remaining coastal maritime habitats a priority for land acquisition efforts. Though coastal uplands are essentially the most costly areas to acquire in the state, it is essential to acquire remaining undeveloped maritime forests, both on barrier islands and on the mainland.
- Pursue reestablishment of maritime forest habitats, including initiation of prescribed burning of appropriate maritime habitats, where possible.

4.4.15 Maritime Grasslands, Dunes, and Beaches

4.4.15.1 Ecosystem Description

Maritime grasslands all occur along the coast and are unable to support trees because of heavy salt spray or overwash by saltwater during storms. This community includes four types: dune grass, maritime dry grassland, maritime wet grassland, and upper beach.

- Dune grass communities occur on the line of foredunes just behind the active beach and on unstable sand dunes farther back on barrier islands. The loose, shifting sand with its low water holding capacity and low nutrient reserves makes these environments habitable by only a handful of specialized plant species. Sea oats grass is the dominant plant in most examples, with American beach grass dominating examples in the northern part of the state. Artificial dune stabilization by planting of grasses or placing snow fences modifies the natural dune structure and dynamics. The higher, more continuous artificial dunes are more susceptible to erosion on the front because there are no passages through which seawater can wash.

- Maritime dry grassland communities occur on more stable sands in the interior of barrier islands. They may be on low, stable, old dunes, but are most typically found on sandy flats on low islands that lack continuous foredunes. Seawater overwashes the low islands during severe storms and kills any invading woody vegetation. The characteristic dominant grass in these communities is saltmeadow cordgrass, though Seaside Little Bluestem occurs in a few examples, and overall plant diversity is fairly low.

- Maritime wet grasslands may occur on low sand flats or in dune swales at the water table level and are resilient to salt spray and overwash. Some examples may even be flooded for substantial periods. Saltmeadow cordgrass is generally dominant but a great diversity of other species is present.

- The upper beach type is not technically a grassland, but is closely related to the other community types. It occurs above the mean high tide line behind the intertidal beach. The environment is very harsh for plants, with almost constant salt spray and with periodic flooding and reworking of sand during storms. A handful of mostly annual, salt-tolerant herbs occur as sparse patches and scattered individuals on the sand. Small mounds of sand may develop around the few perennial plants, such as sea oats and marsh elder, forming the beginnings of dunes.

The 2005 WAP describes the mid-atlantic Coastal Plain beach/dune community as a priority habitat (see Chapter 5) (NCWRC 2005).

4.4.15.2 Location of Habitat

Maritime grasslands are located in the Coastal Plain ecoregion on barrier islands and Atlantic Ocean shore areas.

4.4.15.3 Problems Affecting Habitats

These communities are well adapted to overwash and this may or may not be harmful to them. It may reverse the artificial exclusion of overwash that has altered some examples, such as those on parts of Bodie and Hatteras islands and the Currituck Banks. Overwash is important for transporting sand to the back of barrier islands, allowing them to migrate landward with rising sea level. Increased erosion of foredunes and possible disappearance of whole barrier islands will substantially reduce acreage.

This group will likely shrink drastically in the near future. The most extensive examples occur on narrow barrier islands which are most likely to disappear or be substantially altered by erosion. Examples should survive where barrier islands are able to migrate. Examples should survive on larger, more stable, higher islands, and may migrate to higher elevations or expand there at the expense of maritime upland forest and maritime wetland forest. Much of the narrower part of the Outer Banks could disappear entirely (Riggs 2010). With the loss of area will come increased fragmentation, which is already a problem in smaller examples that are isolated by developed areas.

Barrier islands can be expected to migrate landward, if allowed to, and could survive if sea level does not rise too rapidly. The wider, more stable, and generally higher parts of barrier islands are likely to remain. Grassland communities will also shift and change as the result of increased storm activity and its associated erosion, increased salt spray, overwash, and saltwater intrusion. Increased coastal erosion may breach the foredunes, allowing overwash, which can offset the effects of artificial barriers (e.g., sand fencing and plantings) installed to alter the structure of dune grass communities.

Increased natural disturbance and milder temperatures can be expected to change composition. Species native to comparable communities farther south may be able to migrate in. Because the harsh physical environment already limits species present, and because the expected changes on surviving islands are mostly increases in processes already active, the degree of compositional change is expected to be limited in most of these communities. Structural changes may be more significant. However the wet grasslands in particular may be more drastically affected. New exotic species may appear or become invasive in the warmer climate, though none are specifically known. Mild winters may allow new exotic species to invade, or may allow more natural compositional change that will be locally substantial but may be negligible over larger areas.

4.4.15.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. While the climate is expected to be warmer, and rainfall change estimates vary widely, the most important effects on these systems will be rising sea level and an increase in storms. Table 4.40 summarizes the comparison of climate change with other existing threats.

4.4.15.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps and management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

A genetic study of the Crystal Skipper (*Atrytonopsis* n. sp. 1) indicated that its population is subdivided into three distinct groups, one at Fort Macon and nearby dredged-material island, one at Emerald Isle, and one at Bear Island. These findings indicate that dispersal may .be fairly infrequent across ocean inlets as well as wide strips of maritime forest and development. The Seaside Dusted Skipper is one of the rarest species in the state. Even if it turns out to be an isolated population of the Loammi Skipper, that species is also highly threatened and currently only known to exist in Florida. The Fort Macon population of a moth (*Faronta aleada*) in the Noctuidae family appears to be associated with the same habitat as the Crystal Skipper, but not necessarily Seaside Little Bluestem. Sea level rise may have an effect through increased fragmentation of the restricted range of these species. However, the sites they occupy are among the most stable in this type of habitat and likely to persist.

The beach/dune habitat is particularly important to sea turtles, beach-nesting birds, and shorebirds. Many of the bird species rely on the dynamic nature of the beach, and need storms to recreate wide beaches with bare sand and shell overwash areas. The swash zone (the area between high and low tide) is particularly important to beach invertebrates which

Table 4.40 Comparison of climate change with other threats to maritime grasslands

Threat	Rank Order	Comments
Development	1	Ongoing development, including artificial foredune buildup, is the most severe threat to the remaining unprotected examples. Beach houses, motels, and other structures, and the infrastructure that supports them, have caused a significant stabilization effect on the beaches that will be very difficult to reverse.
Climate Change	1	Sea level rise and increased storm intensity associated with climate change are the most severe threats to the conservation areas where most of the remaining maritime grasslands occur.
Invasive Species	2	Feral populations of horses have been documented to have a severe effect on maritime herbaceous communities (Porter et al. 2014) and particularly on populations of Seaside Little Bluestem. Beach Vitex is the only invasive plant species that is a severe threat at present. Its abundance is limited, and control should be feasible with effort. Additional exotic species are likely to appear with a warmer climate.

are used as a food source by fish and waterbirds. These habitats are also well imitated by dredged-material islands within our sounds that are often devoid of the predators that have invaded the barrier beaches.

Several of the bird species we are most concerned about require early successional habitat for nesting and these habitats have been destroyed or severely altered. Predators (native and nonnative) have increased many-fold; many of these species (cats, herring, and Great Black-backed Gulls, Raccoons, foxes) were not present before the beach became populated with people and their associated trash. These predators have caused significant problems for beach-nesting birds and sea turtles. Vehicle use has also created disturbance issues as well as direct impacts to nesting turtles and birds. Chronic human disturbance is becoming a problem at many sites. People are now able to access even the most remote beaches via shallow draft boats and personal watercrafts. Direct and indirect disturbance, not only by humans but also by their pets, causes problems for nesting and non-nesting birds.

Grazing by feral horses is a significant threat to some protected areas, such as Shackleford Banks and the Rachel Carson Preserve and Currituck National Wildlife Refuge. Grazing and trampling contribute to loss of dune elevation (Porter et al. 2014) and has severely damaged the maritime grasslands in these sites. Patches of Seaside Little Bluestem, which support some of the rarest insects in the state, are now almost absent outside of artificial horse exclosures. Wild horses and other large mammals (including domestic dogs) are also generally incompatible with beach-nesting birds. These mammals inadvertently step on nests and chicks, and cause colony abandonment by adult birds.

Beach renourishment and beach bulldozing can cover or destroy macroinvertebrates in the swash zone and on the beach that foraging shorebirds and surf fishes depend upon. These activities can also destroy sea turtle nests when conducted between May and November. Even under the best survey conditions, all sea turtle nests cannot be found and marked or relocated to prevent take from these activities. Beach renourishment can also lead to more development and possibly decrease washover and increase vegetation, thus decreasing the amount of suitable nesting habitat for beach-nesting birds. Landscaping choices (e.g., introduced species such as Vitex) can also strongly affect the dune system.

4.4.15.6 Recommendations

In general, conservation and restoration of natural composition and function, and conservation of surrounding natural areas are the best way to improve the ability of these communities to adapt to climate change. Development and historically free-ranging livestock have destroyed much of the original maritime grasslands and continue to represent the most severe threats to remaining unprotected examples. Although massive changes are likely, at least some examples can survive if given sufficient protection and where natural beach cycles are allowed to operate.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Surveys are needed to document the distribution, relative abundance and status of wildlife species associated with these beach/dune habitats. Priorities for conducting surveys need to focus on species believed to be declining, at risk, or mainly dependent on these communities.
- Secondary priority for surveys should be for species for which current distribution information is already available or for species that are considered common.
- Conduct shorebird surveys throughout the year to better understand population fluctuations for breeding, wintering, and migratory birds (especially Piping Plover, American Oystercatcher, and Wilson's Plover).
- Determine distribution and status of wintering shorebirds (Sprandel et al. 2000).

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Continue support for regular colonial waterbird surveys (currently conducted coast-wide roughly every three years).
- Continue sea turtle nest and stranding monitoring.
- Monitor introduced nonnative species effects (especially plants and invertebrates) on native coastal wildlife, including sea turtles.
- Monitor status and reproductive success of Gull-billed Terns, Common Terns, Least Terns, Black Skimmers, Piping Plovers, and Caspian Terns.
- Determine seasonal numbers and distribution of shorebirds (Dinsmore et al. 1998).

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Identify causal factors responsible for low beach-nesting bird reproductive success; initiate predator impact studies (e.g., ghost crabs, Fire Ants, gulls, foxes, Raccoons, feral cats, etc.) (Wolcott and Wolcott 1999).
- Experiment more with creation of overwash fans or ephemeral ponds for nesting or foraging birds.
- Continue sea turtle DNA research to better determine nesting habits and needs.
- Work with owners and managers of buildings containing nesting least terns to increase reproductive success while allowing owners/managers to maintain good public relations.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Although protected by law in North Carolina, feral horse herds should be restricted from some areas where they currently roam free. Such restriction would be particularly beneficial at Shackleford Banks and Currictuck National Wildlife Refuge (Porter et al. 2014). Fence off portions of barrier islands where feral horses still occur to allow recovery of maritime grassland communities.
- Where sand supply is abundant and substrate is appropriate, restore overwash processes that carry sand from the seaward to the landward side of an island and may allow landward migration and improve prospects for survival.
- Collect seeds of the rarest plant species associated with maritime grasslands (especially annual species) to protect genetic diversity and maintain a source of local material that can be used to reestablish populations if species are extirpated or severely impacted within North Carolina.
- Control predators (not limited to exotic species) through education efforts, trapping, or other means to increase sea turtle and beach-nesting bird reproductive success.

- Make efforts to address beach lighting, sand fencing, sand pushing, and beach stabilization issues so that sea turtles have a better chance for nesting success.

- Continue the use of bird decoys and sound broadcasts to attract colonial nesting birds to better nesting sites.

- Continue coordination to influence where dredged material is placed to be most beneficial/least detrimental to beach-nesting birds, foraging shorebirds, and sea turtles.

- Reduce disturbance from off-road vehicles, people, and their pets on coastal beach and dune systems. Continued support for and enhanced coordination among coastal management agencies regarding existing restrictions and programs aimed at regulating beach activities is also critical.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Continue coordination with waterbird working groups such as the North Carolina Waterbird Committee, the Piping Plover Recovery Team, the American Oystercatcher Working Group, and the Royal Tern Working Group.

- Implement future recommendations from the North American Waterbird Conservation Plan (Kushlan et al. 2002).

4.4.16 Sand, Shell, and Wrack Active Shoreline

4.4.16.1 Ecosystem Description

North Carolina's Outer Banks are long and mostly narrow barrier islands formed by naturally occurring offshore sand or sediment deposited over geological time. They are separated from the mainland by relatively shallow sounds, bays, tidal inlets, or the mouth of large river systems that drain to the Atlantic coast (NOAA 2014). Maintenance dredging of the Atlantic Intercoastal Waterway and various tidal inlets along North Carolina's coast produces sand that has been used to create artificial spoil islands located near the natural barrier islands.

The active sand, shell, and wrack shoreline is comprised of sand, small shells, shell debris, seaweed, and other marine detritus deposited between the low and high tide line. Water movement within the swash zone (Kelly and Dodd 2010) and saltwater inundation from tidal flooding along the beach prohibits plant growth, so vegetation communities are not included in this community type. The structure and availability of beach landscapes is subject to naturally occurring changes caused by wave action (swash), high tides, and storm surge and can vary daily (FitzGerald et al. 2007). This habitat is often referred to as 'beach' but represents a different community than described in Maritime Grasslands, Dunes and Beach (Section 4.4.15). However, maritime grassland, maritime forest, tidal wetlands, and estuarine wetlands are the vegetated communities most likely to be located adjacent to this community.

This habitat provides important forage sites for several species of resident and migrating shorebirds as well as decapod crustaceans (e.g., ghost crabs) (Schlacher and Lucrezi 2010). Most shorebirds feed above the swash limit to a few meters into the water, while others feed on the beach above the active swash limit such as Ruddy Turnstones and Sanderlings (Burger et al. 1977; Nordstrom et al. 2006). Where the active shoreline transitions to other community types it may provide nesting sites. They are also vital nesting sites for sea turtles and Diamondback Terrapins and they support numerous other small mammals and invertebrates. Beach communities that are subject to low-energy wave action provide important spawning habitat for marine animals such as Horseshoe Crabs (family Limulidae) (Nordstrom et al. 2006; NOAA 2014). Sandy beaches also have a rich interstitial community comprised of both micro- and macrofaunal species (e.g., Hydrozoa, Turbellaria, Trematoda, Nematoda, Gastropoda, Arthropoda) (McLachlan and Brown 2010).

Sand, shell, and wrack shoreline is a new natural community description and was not included in the 2005 WAP (NCWRC 2005).

4.4.16.2 Location of Habitat

Sand, shell, and wrack shoreline is a coastal zone habitat found on barrier islands and other Atlantic Ocean shore areas between the low tide line and the vegetated lower sand dune (fore dune) communities.

4.4.16.3 Problems Affecting Habitats

Development along shorelines and other coastal waterfronts often result in use of bulkheads and other protective barriers meant to protect buildings and infrastructure from wave action and inundation hazards. Seawalls and groins built to protect beaches from erosion result in narrower intertidal zones and altered wrack assemblages, which in turn contributes to reduced numbers of invertebrate forage needed by shorebirds (Dugan and Hubbard 2006). Bulkheads and wave breaks can impede turtle access to nesting and foraging sites or reduce the amount of sandy areas that are accessible for nesting (Wnek et al. 2013; Roosenburg 1990).

Beach renourishment is often used as a coastal management strategy to restore shoreline, combat coastal erosion, protect coastal infrastructure, and to widen the beach in order to increase recreation opportunities. Dredge materials pumped from offshore marine sands or maintenance of boating lanes and inlets are often the source of material for renourishment projects. Adding sand to the beach is often considered an ecologically preferred option for erosion defense but there are associated detrimental ecological effects (Speybroeck et al. 2006; Manning et al. 2013; Viola et al. 2013) when materials are randomly mixed sediments that do not match the particle size and content of the receiving areas; sediments have high concentrations of organic solids; marine sediments have a high salt content; or there are high levels of contaminants in the material (Wnek et al. 2013).

Beaches near residential and commercial developments may be subject to raking or grooming to remove debris and trash or to improve aesthetics, especially during busy summer seasons. Beach grooming is likely to result in decreased species abundance and biomass because it damages or removes foraging resources (Dugan et al. 2003; Hubbard et al. 2013). Nordstrom et al. (2012) note that there is less natural swale and dune development on beach areas subject to raking because wrack materials were removed.

Pollution of aquatic systems has been linked to deformities in snapping turtle hatchlings and is suspected to be a contributing factor in nest failures (Wnek et al. 2013). Onshore vehicles are also a source of fuel and oil contaminants that introduce pollution to small areas of sand and the subsurface invertebrate community.

Vehicle use on the beach was found to have a significant negative effect on invertebrate abundance and diversity through compaction of the sand and interstitial habitats (Schlacher et al. 2008). Vehicles driven on sandy beaches leave vehicle tracks that make it difficult for female sea turtles and hatchlings to travel between the water and nesting sites (Schlacher and Lucrezi 2010). Inattentive drivers can kill turtles on the beach by running over them and illegal access by drivers into restricted beach areas can destroy shorebird nesting sites by crushing them or by disrupting nesting behavior. Unattended pets and children allowed to enter shorebird nesting areas also can destroy or disrupt nests.

It is likely that future tropical storms and hurricanes will become more intense with higher wind speeds and larger waves. Combined with sea level rise, storm surges may exceed 100-year coastal floods much more frequently by the end of the century. As sea level rises, storms of a given magnitude reach higher elevations and produce more extensive areas of inundation (FitzGerald et al. 2007). Climate change is expected to severely impact this habitat through inundation and erosion from rising sea levels and storm surge (DeWan et al. 2010; Karl et al. 2009; Band and Salvensen 2009).

The effects of sea level rise will be greater than the inundation caused by rising ocean waters because of the permanent or long-term loss of sand from beaches. The loss results from complex, feedback-dependent processes that operate within onshore coastal elements (e.g., nearshore, beachface, dunes, tidal inlets, tidal flats, marshes, and lagoons). Long-term beach erosion due to accelerated sea level rise may eventually lead to the deterioration of barrier island chains such as the Outer Banks and others along US East and Gulf coasts (Williams et al. 1992; FitzGerald et al. 2007).

Wild horses and other large mammals are also generally incompatible with beach nesting birds. These mammals inadvertently step on nests and chicks, and disturbance or encroachment on nesting sites can cause colony abandonment by adult birds. Feral horses graze dune vegetation, resulting in destabilization and erosion as well as trampling nests of several ground-nesting bird species (Sabine et al. 2006).

4.4.16.4 Climate Change Compared to Other Threats

A comparison of climate-related impacts to other threats is not included in this description because the NCNHP vulnerability assessments completed in 2010 did not include sand, shell, and wrack shoreline as a community type. In a report developed by the Faculty Committee on Global Climate Change at the University of North Carolina Wilmington on the potential impacts of climate change, significant loss in the width of several coastal North Carolina beaches was predicted to occur between 2003 and 2030.

4.4.16.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

Sea turtles typically nest at night from March through November, which encompasses the busy summer recreation season when proximity to residential and commercial development will increase the probability of encounters with people and domestic pets. Shorebird nests located on sand, shell, or wrack materials are usually well-camouflaged, making them subject to destruction by pedestrians and beach-driven vehicles and predation by dogs allowed to roam beach and dune areas. The presence and density of nest predators such as Raccoons, foxes, and Opossums may increase because they are attracted by easily accessible food waste that an increased human presence creates.

Habitat quality affects the survival of populations that utilize this habitat (Wnek et al. 2013) and animals that utilize beach habitats for nesting are particularly vulnerable to loss of habitat, to structures that restrict their access to foraging and nest sites, and to intrusions that disturb their nesting or foraging behaviors. Female terrapins are reported as showing nest site fidelity and return to the same beach for nesting (Roosenburg 1990). Piping Plovers, American

Oystercatchers, terns, skimmers, and sea turtles are additional examples of species that are vulnerable to loss of beach habitats for nesting or foraging.

Diamondback Terrapins and sea turtles nest on sand dunes, bay, and sound beach areas, and artificial spoil islands and shoreline structures built in these areas to reduce erosion can impede them from coming on shore to nest (Wnek et al. 2013). Trash and waste materials deposited along the shoreline creates another access hazard for hatchlings leaving nests and can become an ingestion or entanglement hazard for foraging animals (Nevins et al. 2014).

Sediment composition in nesting areas affects micro-environmental conditions such as temperature, carbon dioxide and oxygen levels, and moisture content, which in turn affects water exchange, metabolism, and development of embryos in the nest chamber (Wnek et al. 2013). Sex determination of turtle embryos is dependent on temperature of the nest during incubation and biophysical conditions such as soil temperature and moisture affect survivorship, length of incubation period, energy stores, and sex ratios of hatchlings (Roosenburg 1990; Jeyasuria and Place 1997; Wnek et al. 2013). Embryos that did not survive in nests constructed in dredge soils were dessicated, most likely due to high saline content or the presence of organic and inorganic contaminants (Brooks et al. 1991; Miller and Dinkelacker 2008; Wnek et al. 2013).

4.4.16.6 Recommendations

In general, conservation and restoration of natural composition and function, and conservation of surrounding natural areas are the best way to improve the ability of these communities to adapt to climate change. Protection of a large and diverse pool of examples is the best way to ensure that many survive the future stresses.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Conduct distributional and status surveys for pelagic and shore birds, small mammals, and reptiles that may utilize this habitat.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible. These monitoring efforts will inform future decisions on how to manage aquatic species.

- Develop long-term monitoring to identify population trends and to assess performance of conservation actions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Design an ecological monitoring system that can measure how the beach ecosystem responds to human pressures particular to the coastline. Use long-term monitoring to measure the changing health of the beach in response to long-term and cumulative pressures (Peterson and Manning 2001).

- Conduct ecological monitoring before, during, and after construction of shoreline hardening structures and beach renourishment projects to best understand the extent to which the beach ecosystem changes. Monitoring should also continue well after project completion to understand long-term effects of this anthropogenic disturbance, as well as cumulative effects of multiple nourishment projects. Scientists should use a scientifically and statistically robust monitoring design that looks at multiple indicators of beach ecosystem health. Analysis of data should include a test of statistical power (Peterson and Manning 2001).

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Research to facilitate appropriate conservation actions includes habitat use/preferences, spawning location and timing, fecundity, population dynamics, population genetics, feeding, competition, and predation.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Minimize the negative effects on beach ecology from beach renourishment projects by following a set of BMPs that include proper sediment choice, timing, spatial implementation, site-based design, ecological monitoring, and minimizing conflicts of interest (Hennessey et al. 2011).

- Break large renourishment projects into smaller project zones in order to minimize impacts of direct burial to turtle nests. Intersperse project zones with untouched beach to facilitate recolonization of invertebrate fauna (Speybroeck et al. 2006).
- Complete renourishment projects before the start of the warm season to improve chances of invertebrate recolonization. Project implementation should be avoided at times that coincide with critical life stages of sensitive species, such as beach-nesting turtles or piping plover nesting seasons (Speybroeck et al. 2006).
- Although protected by law in North Carolina, feral horse herds should be restricted from some areas where they currently roam free. Such restriction would be particularly beneficial at Shackleford Banks and Currituck National Wildlife Refuge (Porter et al. 2014). Use exclosures to fence off portions of barrier islands where feral horses still occur, allowing recovery of maritime grassland communities.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

4.4.17 Successional Communities (Herb, Shrub, Woody)

4.4.17.1 Ecosystem Description

Successional communities are also referred to as early successional habitats. Successional uplands are dominated by herbaceous vegetation and/or shrub cover because most trees have been removed, either through natural means or by human activity. Where tree species exist they are young and often not much taller than shrubs.

Successional wetlands are primarily dominated by herb and shrub communities that develop on frequently flooded, semi-permanently flooded, or other wetland sites following disturbance, either natural or manmade. Natural examples of successional wetlands include the communities that form as Beaver ponds become filled-in with sediments, particularly following abandonment of a pond by the Beavers. Artificial examples include habitats that form along routinely maintained corridors (e.g., power line easements, rights-of-way) and where borrow pits, farm ponds, drainage ditches, or larger reservoirs become filled-in.

Successional communities can be described as grassland, shrubland, or woody types.

- Grassland types are dominated by herbaceous vegetation such as mixed grasses, wildflowers, and vines. Examples of this habitat include fallow farm fields, hayfields, pastures with native grasses, savannas, prairies, meadows, and mountain balds. Grass balds are a unique community and are described in Section 4.4.5. While areas such as ball fields, golf courses, intensively managed horse farms, and mowed lawns are dominated by grasses, they do not provide quality grassland habitat for priority species.

- Shrubland types have a mixture of young saplings, shrubs, and woody plants typically less than ten feet tall with scattered open patches of grasses, wildflowers, and vines. Vegetation composition is generally dependent on disturbance frequency and patterns. Hedgerows, clear-cut and regenerating forests, field borders, large canopy gaps, and transportation or utility rights-of-way in dry to mesic uplands are often shrubland communities. Scattered mature trees may be present but not to the point that they shade out the beneficial understory vegetation. Shrubland habitats provide structural diversity that offers a variety of nesting sites, escape cover, and food for wildlife.

- Woody types represent late stage successional communities that have not developed the characteristics of a specific natural community. Dominant trees in the overstory and shrubs in the understory are often dense and most likely composed of common weedy species.

The niche that successional communities occupy probably has always existed, having once been associated primarily with openings created by natural disturbances such as storms, floods, or fire. Since they rely on patterns of disturbance to maintain them, these communities are characteristically transient, constantly emerging across the landscape. They are composed primarily of native species of annual plants, reptiles, small mammals, birds, and insects that are associated with successional habitats and are often found nowhere else. While early successional communities can be found statewide, composition and species associations will be highly correlated with the ecoregion where they occur.

Successional habitats in the Mountain ecoregion may range from broad ridge tops (containing a variety of unique grass and herb species) to lower elevation fields, meadows, pastures, and clear-cuts resulting from agriculture or forestry activities. Montane 'old fields' are open grassy areas that have occasionally been invaded by bald species but generally are either in agricultural use or have been abandoned to forest. Human influences, herbivore grazing, and environmental factors such as topographic position, climate, and natural fires have all played a role in the creation and maintenance of montane early successional areas.

All have been modified by human activity and all are subject to natural succession once controlling mechanisms, such as grazing or cutting, have been eliminated. Without the return of the management factors, natural succession will limit the longevity of these habitats and their dependent plant and animal species. Though many montane early successional habitat types support species uniquely dependent on them, other types provide little benefit to plant and animal species, especially those patches of small size, and thus could only be considered marginal wildlife habitat at best. These kinds of places generally reflect human use and activity as the primary goals of their management and include a number of places such as large lawns, monoculture hayfields, golf courses, residential development, and even urban development.

In the Piedmont, Sandhills, and Coastal Plain ecoregions, early successional habitats are often found associated with agricultural or forestry activities and can contain a diverse assemblage of plants, with Piedmont prairies being a notable example of this (Davis et al. 2002). Historically, the Piedmont contained some prairie-type habitats (Barden 1997) with high plant, and presumably insect, diversity that were maintained through fire and herbivore grazing. Today, remnant tracts of prairie are found primarily along powerline rights-of-way and sites managed specifically for prairie restoration and maintenance. Successional wetland communities associated with Beaver pond complexes are adapted to frequent disturbances and are likely to be among the most resilient and adaptable to the effects of climate change. By storing water during times of drought and mitigating the effects of flooding, they are also likely to enhance the survival of species found in adjoining habitats as well.

There are excellent opportunities for quality early successional habitat of large patch sizes for wildlife on industrial forestland in the Coastal Plain. Intensively managed habitats such as large lawns, golf courses, high production agricultural fields, monoculture hayfields, and intensively managed commercial timber stands often have low species and structural diversity that will have limited habitat value for wildlife.

4.4.17.2 Location of Habitat

This habitat type can be transient and is difficult to map but it occurs statewide. Powerline easements and other utility corridors are most likely to be perpetually maintained as successional habitat. Other examples are often found at the transition between agricultural fields and nearby woodlands, created by disturbances like clearcutting, disking, or burning.

4.4.17.3 Problems Affecting Habitats

Increased temperature is likely to have a strong effect on the composition of the plant communities in this group. These changes are also likely to affect host-plant specialist insects, but impacts to other animals are difficult to predict. Increased frequency of severe droughts is likely to have a strong effect on the composition of the plant communities in this group. These changes are also likely to affect host-plant specialist insects but impacts to other animals are difficult to predict. With milder winters and warmer average temperatures, Nutria populations could expand their range and become more invasive.

Beaver ponds can be a nuisance to landowners when they flood farm fields or commercial timber. Their activities cause damage to trees and property, which often results in the destruction of Beaver dams. Several techniques have been developed to minimize Beaver damage while maintaining some benefit from impounded waters. If allowed to continue their expansion, ecosystems in this group are likely to gain resilience and adaptability in the face of climate change. Wetlands associated with Beaver-pond complexes are among the best buffered against the effects of drought. However, prolonged droughts may cause significant local extirpation and hydrologic instability, with increased frequency of severe flooding as well as severe droughts likely to lead to degradation of these habitats.

Construction of new infrastructure to support development or to move facilities inland in response to sea level rise can lead to destruction of successional wetlands, especially smaller isolated patches. The hydrologic connectivity of larger wetlands may be affected when crossed by roads or underground utilities. Roads can cause heavy mortality for reptiles and amphibians and can effectively isolate breeding populations, or separate wetland habitats from upland habitats that are used during non-breeding portions of amphibian and reptile life cycles.

Routine land disturbance by agricultural operations provides the best opportunities for early succession habitat creation and maintenance in North Carolina. However, the value of modern farmland for early succession wildlife has been reduced as economic pressures, improvements in equipment and herbicides, and social factors have all led to larger, more uniformly shaped rowcrop fields, as well as “cleaner” fields with fewer weeds in the fields and less weedy edge. Few rowcrop fields are managed to include a fallow rotation. Some beneficial practices, such as no-till planting, have had mixed success in being adopted. In pastureland, the extensive use of exotic cool-season grasses has reduced habitat quality for wildlife. Cutting hay in mid-summer and overgrazing can adversely affect nesting grassland birds.

Clear-cutting timber creates early succession habitat for a short period of time until newly planted timber matures and the understory grass, forb, and shrub layers are shaded out, typically 7 to 15 years after replanting. Economic pressures, improvements in timber production practices (e.g., equipment, herbicides, genetically improved trees) have reduced the amount of time to canopy closure, contributing to loss of early succession habitat. Intensive site preparation can reduce the quality and quantity of herbaceous cover during the early phases of stand establishment.

Suppression of wildfires and lack of controlled burning eliminates an important source of early succession habitat creation and maintenance within many forested habitats.

Concerns about uncontrolled fire, liability, air quality, social acceptance, and smoke management, and lack of landowners with the experience and equipment to conduct controlled burns have limited the use of fire on private lands.

Fallow or unmowed areas are seen by many as “messy” and “weedy,” and an indicator of a lack of caring or effort by a landowner. This widespread public perception is partially responsible for fallow habitats being reduced in habitat quality or eliminated. Early succession cover in powerline rights-of-way and roadsides is often adversely affected by too frequent or poorly timed mowing. In addition, many areas of fallow ground near houses or businesses are frequently mowed to maintain a neat appearance, while opportunities exist to convert some of these areas to suitable wildlife cover.

Piedmont prairies contain highly diverse and specialized plant and insect communities. Currently, only small remnant tracts remain. Fire and/or low intensity agricultural operations are necessary to maintain prairie communities. Current restoration efforts are focused on plant conservation and have been implemented on small acreages that have limited value for area-sensitive grassland species such as Grasshopper Sparrow and Eastern Meadowlark. Grasslands larger than 20 acres should be pursued to benefit these species.

Successional communities are currently among the most heavily infested with exotic invasive species. With increases in overall temperature, more invasions are likely, especially from tropical and sub-tropical regions. Integrated pest management practices should be preferred over more indiscriminate application of pesticides. The effects of exotic plants, insects, and animals on early succession habitat and native wildlife populations are poorly understood. Impacts are likely to vary widely depending on the species involved, environmental conditions, and management activities. Fire Ants are a species of particular concern, especially regarding their potential impact on herpetofauna, small mammals, and ground-nesting birds. While invasive species should be treated aggressively with eradication as the goal wherever an exotic is just beginning to be established, control measures should always be carefully targeted, including the use of species-specific biological control agents.

4.4.17.4 Climate Change Compared to Other Threats

Comparing climate change to other ecosystem threats can help define short- and long-term conservation actions and recommendations. The effect of a changed climate is likely to vary widely among examples and many may change very little, while others will change substantially because of human reaction to the impacts of climate change such as temperature changes or drought.

Loss of habitat and fragmentation of landscapes are the most significant threats to this ecosystem group. While development of yet more intensive agricultural and silvicultural practices, and loss of still more areas to development, would continue even in the absence of climate change, these impacts are likely to be exacerbated both directly and indirectly by the effects of climate change. Climate change will contribute to the loss of the large blocks of habitat or fragmentation that creates barriers between blocks that are critical for the survival of species in this group. Development of habitat has become the limiting factor for priority species utilizing this habitat. Across the state more generally, increased exploitation of wild or semi-wild lands for energy production is likely to be the most important indirect effect of climate change on this group. Table 4.41 summarizes the comparison of climate change with other existing threats.

4.4.17.5 Impacts to Wildlife

Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN that depend on or are associated with this habitat type.

Upland Communities. The quantity of early successional habitat is generally not lacking but the quality is often questionable for most species of wildlife. Species found in successional communities occur widely throughout the state, although there are also some regional variations (e.g., Henslow's Sparrows are restricted to the Coastal Plain and Vesper Sparrows breed only in the Mountains). Changes in plant species composition may also have strong impacts on the composition of insect species, since many have narrow host plant preferences. The vertebrate fauna may show far fewer effects, however, since most, if not all, do not depend on a particular composition of plant species.

Two species associated with early successional habitats, Bewick's Wren and Regal Fritillary, are believed extirpated from North Carolina. Several other species are declining, with Eastern Henslow's Sparrows, Golden-winged Warblers, Appalachian Cottontails, and Grizzled Skippers listed as Federal Species of Concern, and a number of additional rare species tracked by NCNHP. Many of the species associated with this community type that are of conservation concern are primarily northern species and are likely to be significantly affected by the effects of climate change.

Species in this habitat group are completely dependent on their ability to disperse from one habitat patch to another: their habitats themselves are normally very transient and the species associated with them need to keep constantly on the move to keep up with their shifting landscape. Although many of the species associated with successional habitats are quite mobile, small mammals, reptiles, and at least some birds and insects are less mobile and highly vulnerable to the effects of habitat fragmentation. At least some of the declines

Table 4.41 Comparison of climate change with other threats to successional communities

Threat	Rank Order	Comments
Conversion to Agriculture/ Silviculture	1	The greatest threat to this habitat group is habitat loss due to development of more intensive agricultural and silvicultural practices. Modern, industrialized farming leaves fewer unutilized areas in and adjoining fields, such as hedgerows, groves of shade trees, and weedy forest-field ecotones. Fewer fields are left fallow for very long. Pastures and hayfields are more intensively managed, using heavier applications of herbicides, pesticides, and fertilizers. Mowing of hayfields is also now conducted much more frequently than it has been in the past.
Fragmentation	1	More pressure will be placed on the utilization of marginal agricultural or silvicultural lands for energy production, including the development of otherwise “green” sources such as biomass, wind, and solar energy. Increased frequency and severity of environmental perturbations may disproportionately affect ecosystems composed primarily of annuals or rstrategist species in general, particularly if landscapes continue to become more and more fragmented.
Pollution	2	Communities may be in close proximity to areas that are commonly quite polluted. Farm fields and pine plantations are regularly sprayed with biocides or fertilizers; powerline rights-of-way are now routinely sprayed with herbicides to keep them open; roadside rights-of-way are subject to pollutant laden runoff from the road surfaces as well as application of salt and other chemicals used to prevent icing in the winter; ruderal areas located near industrial areas are subject to both air- and waterborne pollutants emanating from the industrial plants. All of these pollutants can play a major role determining species viability within the semi-natural habitats used by this group.
Invasive Species	2	Two species that are likely to spread into new areas, particularly at higher elevations due to increased temperatures, are Kudzu and Fire Ants. Both of these exotic species have strong impacts on early successional and other ruderal habitats. Along with changes in agricultural practices, loss of some habitat patches or connections between them may be attributable to the smothering invasion of kudzu.
Climate Change	3	Impacts from land use changes are likely to accelerate at least indirectly due to climate change, with more demand for biofuels or other forms of energy production utilizing “waste grounds.” Like other native ecosystems, early successional habitats are also likely to be affected by increased temperatures, prolonged droughts, more frequent fires and storms, and especially invasion of exotic species.

noted in this group of species is likely due to decreased connectivity between habitat patches, in addition to the decreased extent of these habitats overall.

Disturbed and artificially created/maintained habitats are particularly susceptible to invasion by exotic species, which in some cases can have significant impacts on the native species associated with early successional habitats. While most compositional changes are likely to have mixed effects, invasion by some exotic species can produce severe impacts, greatly reducing the diversity of both animal and plant communities. The Appalachian Bewick's Wren may have been extirpated from North Carolina due to competition with exotic house sparrows and European Starlings, along with brood parasitism by Brownheaded Cowbirds, an invasive species in this area that arrived from the Great Plains (Potter et al. 2006).

Wetland Communities. With stable Beaver populations, Beaver ponds can be maintained for decades. Beaver ponds are a natural community, but result from modification of other community types. With or without climate change, Beaver pond ecosystems are likely to further spread across the state, recreating habitat conditions that existed prior to the great loss of Beavers and their associated species that began with European settlement of North America. This spread will likely have a positive effect on successional wetland inhabitants. The main limiting factor for this reoccupation is human tolerance for Beaver activities and competition with humans for use of bottomlands. A reduction in the number of Beaver ponds will place more importance on man-made ponds as the primary habitat for many lentic aquatic species.

Changes in insect species composition, especially among herbivorous groups, are likely to occur due to changes in plant composition as well as the direct effects of climate change on the insects themselves. Eight very rare species associated with this habitat group are entirely confined to these habitats in North Carolina, including the federally endangered Saint Francis' Satyr. Vertebrate composition is less likely to change if habitat structure remains fairly constant.

While often small in size, cumulatively successional wetland habitats provide critical breeding habitat for many species. Wetland habitats are especially important as breeding sites for amphibian species. Small wetlands can also be important breeding habitat for crayfishes. Wading birds, waterfowl, and songbirds may also use small wetland communities for nesting and feeding areas. Dead trees in Beaver ponds are important foraging and nesting habitat for woodpeckers, such as the Red-headed Woodpecker, and for Wood Duck nesting.

Freshwater wetlands near coastal communities provide an important source of fresh drinking water for wildlife, which will become more important in areas subject to saltwater intrusion. Depending on geographic siting in the landscape, successional wetlands may also provide connectivity between adjacent upland habitats.

Nutria are considered a serious pest species in the United States because they eat a variety of wetland and agricultural plants and their burrowing damages streambank, impoundments, and drainage systems. As warming trends increase, the range of Nutria, a nonnative and often invasive mammal, is likely to expand and populations currently limited by intolerance to cold winters will quickly expand.

4.4.17.6 Recommendations

Loss of habitat and fragmentation of landscapes are the most significant threats to this ecosystem group. Protection of agricultural reserves that maintain traditional farming practices offers the best hope for protecting areas still supporting high-quality examples of this habitat group, including populations of its rarer species. Support for traditional or environmentally sustainable agricultural and silvicultural methods will help maintain this ecosystem group. Maintaining habitat connectivity across the landscape is also critical, both to maintain the resilience of these ecosystems in face of environmental perturbation and to allow shifts in range and species composition to take place.

Surveys. Distributional and status surveys need to focus on species believed to be declining or mainly dependent on at-risk or sensitive natural communities.

- Conduct surveys for species associated with successional habitats, including species for which current distribution information is already available or for species that are considered common (e.g., Eastern Meadowlark, Blue Grosbeak, Eastern Cottontail).

- Continue surveys for all amphibian species associated with small wetland communities, but especially the Mole Salamander, Eastern Tiger Salamander, Dwarf Salamander, and Four-toed Salamander.

- Gather better information about the status and distribution of more common species associated with Piedmont wetland habitats (e.g., the Three-lined Salamander, Common Ribbonsnake).

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. These efforts will inform future decisions on how to manage species and their habitats. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Develop long-term monitoring strategies to document population trends, from which conservation strategies can be specifically designed to target those species.

- Expand and/or target monitoring systems to assess current population status and trend information for all wildlife species associated with this habitat.

- Monitor amphibian populations to detect incidence of fungal and viral infections (e.g., iridoviruses, chytridiomycosis).
- Investigate Nutria population densities, population growth rates, dispersal range, and extent of property damage from burrowing and herbivory.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Research and identify important wildlife crossing areas; evaluate connectivity issues between intact and fragmented habitats used by priority species; work with partners to improve crossing and connectivity.
- Focus habitat use studies on bats and small mammals to clarify how small mammals and bats use early succession habitats.
- Study the efficacy and practicality of toad tunnels and other wildlife crossings that allow passage under roadways and help maintain connectivity between wetland metapopulations.
- Determine minimum upland buffers required to sustain at-risk amphibian populations.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Maintain and restore connections between habitat blocks, not only to allow adjustments in range in response to climate change, but to maintain genetic connectivity, population resilience, and adaptability more generally.
- Develop transportation facilities that utilize longer bridges at streams and wetlands to minimize impacts (and thereby reduce mitigation requirements) and provide crossing options for wildlife that often travel riparian corridors. Wildlife underpasses should be constructed for all new highway projects, as these reduce wildlife–vehicle collisions, conserve important travel corridors, and provide linkages for bear populations and many other wildlife species.

- Limit the development of roads or other infrastructure within large unfragmented blocks, as this would promote the development of denser human settlement or create connectivity barriers through fragmentation.
- Work cooperatively with other agencies to define sustainable forestry criteria for biomass production.
- Allow Beaver pond complexes to develop in natural areas where direct impacts to rare species are not at issue.
- Work with partners to develop property tax incentives to mitigate damages suffered by landowners.
- Explore strategies to promote techniques for managing Beaver damage that minimize the loss of quantity and quality of Beaver ponds.
- Explore management strategies to eradicate undesirable species, such as bullfrogs, from wetlands.
- Maintain sufficient surrounding habitat for seasonal wetlands in order to support the life history requirements of amphibian and reptile populations. Every effort should be made to maintain continuous gradients between wetland and upland sites; roads, agriculture, or forestry operations between complimentary sites may render them ineffective at supporting amphibian and reptile populations (Bailey et al. 2004).

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Protect existing large blocks of habitat and restore connections between these blocks, as this will not only benefit the species in this group, but will enhance the viability of the state's native biodiversity overall.
- Protect smaller tracts that are situated between blocks so they can function as a corridor between conservation sites.
- In the Coastal Plain, give a high priority to protecting movement corridors that allow inland migration away from inundating areas along the sounds and seacoast.

- Over the state as a whole, give a high priority to restoring connections that are lost due to construction of four-lane highways and other roads that create near-impassible barriers for all animals except those capable of flight.
- Preserve riparian buffers and floodplains, especially where clearcutting near wetlands causes higher solar radiation and an increase in probability of wetlands drying out.
- Place a high priority on protecting wetlands and adjacent uplands through acquisition or easement.

4.4.18 Sparsely Settled Mixed Habitats

4.4.18.1 Ecosystem Description

This community type represents large tracts of open land that have not been developed and may have only periodic encroachment from human activities. It may contain a mixture of community types, where vegetation may be natural or a mixture of planted and natural species. Their lack of habitat specificity makes it difficult to assign these communities to any one ecosystem group, all of which represent distinguishable habitat categories. These landscapes often serve as movement corridors for wide-ranging animal species, particularly carnivores near the top of the food web. These species often use a wide variety of habitat types in their pursuit of food, mates, and other resources.

4.4.18.2 Location of Habitat

Sparsely settled mixed habitats occur statewide but are more characteristic of the lower Coastal Plain and the Mountains, particularly in areas which have relatively low human populations. Within the lower Coastal Plain, the largest blocks are on the Albemarle–Pamlico Peninsula, and in the Mountains within national forests.

4.4.18.3 Problems Affecting Habitats

Development and inundation can be expected to reduce availability of large blocks of undisturbed or unfragmented habitat. This trend will continue so long as the human population continues to grow and new ways are found to exploit even the most marginal of lands for human uses.

Sea level rise is likely to affect large areas of the easternmost (outer) Coastal Plain where many important wildlife refuges are located. Inundation of wildlife refuges will result in dispersal inland to Piedmont areas. Movement inland can be expected, but there are far fewer potential refuge areas in the inner Coastal Plain and Piedmont to support viable populations of large predators or venomous snakes than there currently are in portions of the outer Coastal Plain. Movement corridors that allow inland migration away from inundating areas along the sounds and seacoast are critical.

Increased temperatures are likely to have only a minimal effect on this group overall, although a northward shift in range can be expected for the Least Weasel, a primarily boreal species, perhaps leading to its extirpation from the Mountains of North Carolina.

4.4.18.4 Climate Change Compared to Other Threats

Climate change will contribute to the loss of the large blocks of habitat or fragmentation that creates barriers between blocks that are critical for the survival of species in this group. Development of habitat has become the limiting factor for priority species utilizing this habitat. Across the state more generally, increased exploitation of wild or semi-wild lands for energy production is likely to be the most important indirect effect of climate change on this group. Table 4.42 summarizes the comparison of climate change with other existing threats.

4.4.18.5 Impacts to Wildlife

Predatory species utilizing this habitat play an important ecological role in all the ecosystems they occupy by regulating the abundance of species lower down in the food chain,

Table 4.42 Comparison of climate change with other threats to sparsely settled mixed habitats

Threat	Rank Order	Comments
Development	1	Development activities such as residential subdivisions, road construction, and retail development have displaced and will continue to displace wildlife and place them in closer contact with humans. Reduction and fragmentation of large areas of open space will continue to accompany the expansion of the human population; climate change is likely to exacerbate these ongoing impacts. Construction of highways and access roads, increases in traffic, and other effects associated with infrastructural or industrial development needed to support new forms of energy extraction will create impacts.
Persecution	1	Direct persecution remains the largest limiting factor on abundance and range of species in this habitat.
Climate Change	2	The most important direct impact of climate change is likely to be the loss of a large number of coastal refuges due to sea level rise.
Land Use Changes	2	Plans to use grasses like Switchgrass and Miscanthus as biofuels may result in these marginal areas being put into short rotation production as the demand for alternative fuels increases. There is evidence that some species, such as Black Bears, are negatively impacted by wind turbine farms due to loss of mast-producing forests (Loder 2008).

particularly herbivorous mammals. Many of these high-level predators are generalists that have declined in both abundance and range due to conflicts with humans, with the majority now considered to be of conservation concern. Although all of the species included within this guild are highly adaptable and make use of a wide range of habitat types, the majority are considered rare or threatened in North Carolina. These include the Red Wolf, Least Weasel, Eastern Diamondback Rattlesnake, Timber Rattlesnake, and Pigmy Rattlesnake.

Others, like the Black Bear and White-tailed Deer, are currently expanding their range across the state and are currently not considered to be of conservation concern. The status of the Long-tailed Weasel is unknown and based on harvest trends, may be declining. Bobcats are common and their populations appear to be stable.

Sea level rise may lead to inundation of large parts of the Coastal Plain, including the Albemarle–Pamlico Peninsula where large reserves have been set aside for Red Wolves, Black Bears, and other wildlife. It is likely several large wildlife refuges clustered around the sounds will be inundated, including Alligator River, Pocosin Lakes, Lake Mattumuskeet, Swanquarter, Cedar Island, and Mackay's Island National Wildlife Refuges, and the North River, Gull Rock, and Goose Creek Game Lands. Loss or even moderate reduction of these refuges is likely to strongly affect the survival of the pack of Red Wolves that has been restored on Albemarle–Pamlico Peninsula, as well as the largest population of Black Bears along the North Carolina coast.

While some movement inland can be expected, there are far fewer potential refuge areas in the Inner Coastal Plain and Piedmont to support viable populations of large predators or venomous snakes than there currently are in portions of the Outer Coastal Plain. Drought and wildfire may cause animals to range further away from more protected areas as they search for food, water, and cover. This can bring them into conflict with people and roads with high-volume traffic that are common conditions in the Piedmont. Residents in the central Piedmont have expressed safety concerns when Black Bears are sighted, and bears have been killed when attempting to cross busy roads and highways, or directly by local law enforcement officials that are not knowledgeable of normal bear behavior.

Black Bears are tied to forested areas, and in the southeastern United States, forest distribution matches the distribution of bears very closely. In many parts of the region, bears are dependent on oak trees for their energy-rich acorns and on a diversity of soft mast species (e.g., blueberries, blackberries). Where oaks are not the dominant species, diversity in forest types and ages can provide mast-producing hardwoods and shrubs. Bears are opportunistic omnivores, but low food supplies and an increase in fragmented habitat may result in increased bear movement into developed areas and leading to human-caused mortalities (e.g., vehicle, depredation).

Increased temperatures may cause some latitudinal shifts in the ranges occupied by members of this group, but the effects are likely to be mixed. Least Weasels are probably the only species likely to shift its range as a consequence of increased warming. In the Mountains, they may retreat toward the north, becoming less common or even potentially extirpated from the state. In the Coastal Plain, Eastern Diamond-backed Rattlesnakes are currently at the very northern edge of their range and very rare in the state. With warming temperatures there is the potential they will increase in abundance. However, that potential could very well be offset by increased development and fragmentation, as well as persecution.

4.4.18.6 Recommendations

Conflicts with humans have resulted in the restriction of these species to large blocks of mixed habitat where human density and intrusion are minimal. Even Black Bears, which in some areas have adapted to human presence as garbage raiders, are highly unlikely to persist without these large, sparsely settled blocks of habitat. These species require large blocks of habitat where density of human settlement or intensity of human intrusion is relatively low. More than any other, this group requires landscape-level conservation, particularly the protection of large areas of habitat—natural or mixed—from increased density of human settlement.

Surveys. Distributional and status surveys need to focus on species that utilize this community.

- Conduct surveys for species for which current distribution information is already available or for species that are considered common or invasive (e.g., Gray Fox, Raccoon, Coyote).

- Develop long-term monitoring strategies to document population trends, from which conservation strategies can be specifically designed to target those species (e.g., Coyote).

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Research and identify important wildlife crossing areas; evaluate connectivity issues between intact and fragmented habitats used by priority species; work with partners to improve crossing and connectivity.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural

resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Maintain and restore connections between habitat blocks, not only to allow adjustments in range in response to climate change, but to maintain genetic connectivity, population resilience and adaptability more generally.
- Transportation facilities that utilize longer bridges at streams and wetlands not only minimize impacts (and thereby reduce mitigation requirements) but also provide crossing options for wildlife that often travel riparian corridors. Wildlife underpasses should be constructed for all new highway projects, as these reduce wildlife-vehicle collisions, conserve important travel corridors, and provide linkages for bear populations and many other wildlife species.
- Limit the development of roads or other infrastructure within large unfragmented blocks, as this would promote the development of denser human settlement or create connectivity barriers through fragmentation.
- Work cooperatively with other agencies to define sustainable forestry criteria for biomass production.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships utilized to the fullest extent in order to high-quality resources. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Protect existing large blocks of habitat and restoreconnections between these blocks in order to benefit the species in this group and to enhance the viability of the state's native biodiversity overall.
- Protect smaller tracts that are situated between blocks so they can function as a corridor between conservation sites.
- In the Coastal Plain, give a high priority to protecting movement corridors that allow inland migration away from inundating areas along the sounds and seacoast.
- Over the state as a whole, give a high priority to restoring connections that are lost due to construction of four-lane highways and other roads that create near-impassible barriers for all animals except those capable of flight.

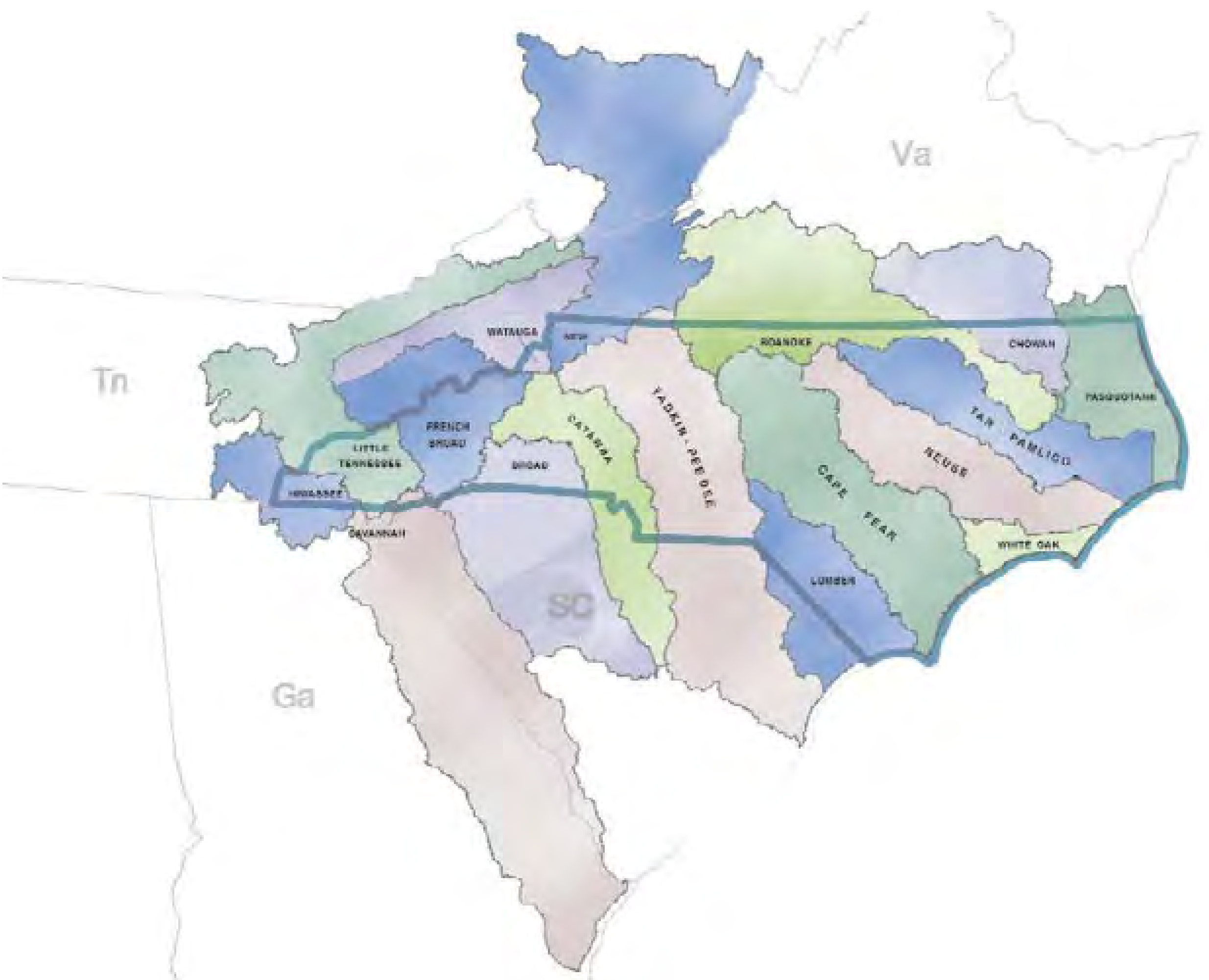
4.5 River Basins

4.5.1 Introduction

In an assessment of southeastern states, North Carolina ranked third highest in overall diversity of stream types (Warren et al. 1997).The richness of North Carolina's aquatic fauna is directly related to the geomorphology of the state, which defines the major drainage divisions and the diversity of habitats within them. Watersheds of large rivers are commonly referred to as basins (Griffith et al. 1999) and North Carolina uses the basin concept as a spatial framework for assessment and management of drainage systems across the state.

Figure 4.6 provides a map depicting the boundaries of the 17 major river basins in North Carolina as designated by the NC Department of Environment and Natural Resources (NCDENR). While 11 of the river basins have headwaters that begin in North Carolina, only four basins are contained entirely within the state (Cape Fear, Neuse, Tar–Pamlico, White

Figure 4.6 North Carolina's river basin boundaries



Oak). The other river basins have waters that drain across adjacent states (Georgia, South Carolina, Tennessee, and Virginia). Information about the river basins is available online at the NCDENR Division of Water Resources Basin Planning Branch web page http://portal.ncdenr.org/web/wq/ps/bpu.

Five western basins in the state are part of the Interior Basin and drain to the Mississippi River and the Gulf of Mexico (Hiwassee, Little Tennessee, French Broad, Watauga, and New). North Carolina boundaries for these five river basins, along with the Savannah River Basin, have boundaries entirely within the Mountain ecoregion, which dominates the western third of the state. Generally, streams in the Mountain ecoregion are relatively high gradient with cool waters, have boulder and cobble-gravel bottoms, and are of low to moderate fertility. Larger streams and rivers have historically supported exceptionally diverse warmwater communities.

The other 12 basins of the state are part of the Atlantic Slope and flow to the Atlantic Ocean. The headwaters of the Broad, Catawba, and Yadkin–Pee Dee River Basins drain the eastern slopes of the Mountains. These river systems drain toward the ocean through the rolling topography of the Piedmont, where all but three of the remaining river basins originate. The Piedmont is a mosaic of broad valleys interspersed with highlands of varying topography and geology. Streams in the Piedmont are generally warmwater systems, have cobble-gravel and sand bottoms, and are of intermediate gradient and fertility.

The Fall Line marks a change in topography from the Piedmont to the flat terrain of the Coastal Plain. The North Carolina basins of the White Oak, Chowan, and Pasquotank rivers are entirely within the Coastal Plain ecoregion and are characterized by low gradient warmwater streams with sand and mud bottoms and high fertility. Natural lakes and extensive wetlands are important aquatic habitats found only in North Carolina's Coastal Plain ecoregion.

A method developed by the US Geological Survey (USGS) spatially organizes drainage areas (DAs) by dividing watersheds into successively smaller hydrologic units based on four levels: regions, subregions, accounting units, and cataloging units (Seaber et al. 1987). The hydrologic units are arranged or nested within each other, from the largest geographic area (regions) to the smallest geographic area (cataloging units). Regional hydrologic units are identified by a unique two-digit hydrologic unit code (HUC) but smaller units may represent the most useful planning unit. The HUCs and associated maps have undergone extensive review by principle federal, regional, and state water-resource agencies and are widely accepted for use in planning and data sharing (Seaber et al. 1987). In North Carolina, 12-digit HUCs are commonly used for sharing aquatic resource data.

Surface water classifications are another tool used in North Carolina to manage and protect state waters. The NC Division of Water Resources (NCDWR) assigns primary classifications to freshwaters to designate the highest and best uses (e.g., drinking water supplies, recreation) for conservation within the surface waters. Each classification has an associated set of water quality standards to protect those uses. All waters must at least meet the standards for Class C (fishable/swimmable) waters. The other primary classifications provide additional levels of protection for water contact recreation (Class B) and drinking water (Water Supply Classes I through V). Streams, rivers, and lakes may have several classifications applied to the same area because they protect different uses or special characteristics of the waterbody (NCDWR 2014c).

Water classification data are available from the National Hydrography Dataset (NHD), a database that interconnects and uniquely identifies the millions of stream segments or reaches that comprise the surface water drainage systems in the United States. The NHD provides a national framework that allows information to be linked by stream reach address to an organization thereby allowing water quality data to be shared with other organizations, analyzed using a Geographic Information System (GIS), and easily integrated into many different types of applications to the benefit of all (EPA 2014b). Datasets containing water classification information is available online from http://www.horizon-systems.com/nhdplus/NHDPlusV2_data.php.

4.5.2 Aquatic Biodiversity and Imperilment

The southeast region has the highest aquatic species diversity in the entire United States (Burr and Mayden 1992; Taylor et al. 1996; Warren et al. 2000; Williams et al. 1993). Southeastern fishes make up two-thirds of US fauna, and nearly half of the North American fish fauna (Burr and Mayden 1992). Molluscan diversity in the region is globally unparalleled, with 91% of all US mussel species found in the southeast (Neves et al. 1997). Crayfish diversity and global importance in the region rivals that of mollusks (Taylor et al. 1996), and crayfish in the southeast comprise 95% of the total species found in all of North America (Butler 2002a). North Carolina freshwaters support a significant proportion of that diversity with at least 210 freshwater fish, 125 mollusk, and 45 crayfish species native to the state.

Unfortunately, patterns of imperilment for aquatic species are similar amongst taxonomic groups. Collen et al. (2014) reports almost one in three freshwater species is threatened with extinction worldwide which, in comparison, is proportionally greater than the risk of extinction for terrestrial species (Burkhead 2012). More than two-thirds of the nation's freshwater mussel and crayfish species are extinct, imperiled, or vulnerable (Williams et al. 1993; Neves et al. 1997; Master et al. 1998). The majority of these at-risk species are native to the southeast.

- North Carolina ranks third among southeastern states in number and percentage of imperiled fishes (Warren et al. 1997).

- Freshwater mollusks are suffering even greater declines, with numerous mussel and aquatic snail species that formerly occurred in the southeast now presumed extinct (Neves et al. 1997).

- Among crustaceans listed as endangered or threatened in the United States, more than half are from the southeast (Schuster 1997).

- Twelve species of North Carolina crayfish are listed as species of concern or rare in the state, with their small native range the primary factor in their vulnerability to habitat loss and competition (Clamp 1999; Taylor et al. 1996). Threats specific to crayfish include pollution and impoundment, but competition with nonindigenous species is also a primary threat to many species (Taylor et al. 1996).

National and regional causes of declines among all aquatic taxa are widely attributed to habitat destruction and degradation and the introduction of nonnative species (Williams et al. 1993; Taylor et al. 1996; Etnier 1997; Warren et al. 1997; Collen et al. 2014). The medium-sized rivers and creeks that provide important habitat for many aquatic species are frequently impounded and substrates have been altered by erosion and sedimentation. Habitat alteration from nonpoint source pollution and flow alteration (i.e., impoundments) is the primary cause of population declines for a large percentage of southeastern fishes considered imperiled (Etnier 1997; Collen et al. 2014). Not surprisingly, nonpoint source pollution and the effects of dams and impoundments are also the leading historic and current threats to freshwater mollusks (Bogan 1993; Neves et al. 1997; Richter et al. 1997). The complex life cycles and habitat requirements of mussels make them especially vulnerable to these perturbations (Adams et al. 1990; Bogan 1993; Neves et al. 1997).

In North Carolina, threats to biodiversity are similar to those listed above and include point and nonpoint source pollution, hydrologic alteration, physical habitat manipulation, and pollution. In recent decades, water quality has improved in many watersheds that were historically polluted primarily by point source discharges; however, overall habitat degradation continues to threaten the health of aquatic communities. Increased development and urbanization, poorly managed crop and animal agriculture, and mining have impacted aquatic systems with point and nonpoint source inputs. Impoundments on major rivers and tributaries drastically alter the hydrologic regime of many North Carolina waterways and result in habitat fragmentation, blockage of fish migration routes, and physical habitat alterations.

The US Environmental Protection Agency (EPA) reports that North Carolina contains approximately 37,662 stream/river miles; 311,236 acres of lakes and impoundments; and 3,121 square miles of coastal bays (EPA 2013a). Information summarized from a EPA Clean Watershed Needs Survey, NPDES permits, and water quality assessments indicates more than half of the rivers are rated as 'impaired' because they are not meeting biological criteria or due to impaired aquatic communities. The EPA reports more than half of the lakes and reservoirs in the state are impaired due to mercury contamination (EPA 2013a). The NC Division of Water Resources (NCDWR) has rated all waters in the state as impaired based on a statewide fish consumption advisory issued by the NC Division of Public Health (NCDPH) for mercury contamination (NCDPH 2014).

4.5.3 Aquatic Conservation Priorities, Strategies, and Recommendations

There has been increased attention focused on analysis of aquatic biodiversity, patterns of imperilment, and threats to distill priorities for proactive management and/or conservation triage. A few efforts have gone beyond (or bypassed) identifying specific priorities to propose strategies that address long-term aquatic conservation needs and actions to address these priorities. These efforts were outlined in the 2005 WAP (NCWRC 2005). To the greatest extent possible and where applicable, this guidance, as well as more recent efforts, have been incorporated into this Plan.

The following sections outline aquatic conservation priorities, strategies, and recommendations that are applicable throughout North Carolina. The remaining portions of this Chapter (Sections 4.5.4 through 4.5.20) describe the 17 river basins, which are organized alphabetically. These descriptions provide a more detailed view of the threats, needs, and conservation priorities within each basin. Priority species are identified for each basin (see Appendix H); however, a complete list of all priority species can be found in Appendix G.

4.5.3.1 Aquatic Conservation Priorities

Conservation priorities have been identified for each river basin at the cataloging unit or stream reach scale and were categorized using two tiers to indicate relative importance when considering the limited resources available for conservation initiatives. The recommendations were developed by Commission biologists through review of their field data as well as data from several agencies and research organizations. The review considered a combination of factors such as the presence of federal- or state-listed species; distribution of priority species; high species diversity; unique habitats, or high-quality habitats in the subbasin; and the importance of the watershed to downstream populations.

Priority areas identified in this Chapter are represented by 12-digit hydrologic unit code (HUC) watershed boundaries and 1-km riparian corridors and characterized as Tier 1 (highest priority) and Tier 2 (high priority) recommendations for conservation. Figures depicting the locations of priority areas are provided in each river basin description. In addition to recommendations provided for each river basin, the following general recommendations are applicable statewide in all river basins. Appendix J provides a list of all

12-digit HUC priorities statewide; this list is available for download as an Excel file from the NCWRC web page: http://www.ncwildlife.org/plan.

4.5.3.2 Conservation Strategies

Historically, aquatic conservation and management strategies have typically focused on a few commercially or recreationally significant game fish species, with stock enhancement as a primary goal. The passage of the 1973 Endangered Species Act and 1972 Clean Water Act (with amendments) stressed ecosystem protection and allowed for focused attention on all species and their habitats. Ecosystem management is likely the most effective strategy for conserving rare aquatic species because it factors in ecological relationships, land-use patterns, and threats to habitat and water quality. It is a complicated and often costly approach and relies heavily on cooperation among federal and state agencies, local governments, private organizations, and individual citizens. However, its holistic approach can benefit all species within the watershed.

The US Fish and Wildlife Service (USFWS) has led in the development of detailed conservation strategies for mussels in the United States (Biggins et al. 1997) and fishes in the southeast (Bibb et al. 2002). Both of these important documents identify specific goals and detailed strategies for achieving them. Jenkinson and Todd (1997) provided a historical perspective of mollusk management in the United States and propose general strategic guidance for habitat protection, population enhancement, harvest controls, public appreciation, and invasive species control and prevention. Some region-scale strategies have recently been drafted and are identified in the applicable river basin descriptions. Conservation efforts have only recently been focused on crayfish. Taylor et al. (2007) identify the present state of crayfish management (and crustaceans in general) and the challenges that face developing adequate management plans.

Surface water classifications are one tool that state and federal agencies use to manage and protect streams, rivers, lakes, and other surface waters in North Carolina. Classifications and their associated protection rules may be designed to protect water quality, fish and wildlife, or other special characteristics. Each classification has associated standards that are used to determine if the designated uses are being protected. The NC Division of Water Resources (NCDWR) has assigned some waterbodies in the state supplemental classifications. Some examples include:

- High Quality Waters (HQW) or Outstanding Resource Waters (ORW) designation when they either have excellent water quality or they are a significant resource to humans or wildlife (NCDWR 2015d). The requirements to be classified as ORWs are more stringent than those for HQWs and in some circumstances, the unique characteristics of the water and resource require that a specialized management strategy be developed (NCDWQ 2011c; NCDWR 2015a, 2015d).

- NCDWR's trout waters (Tr) designation protects freshwaters for natural propagation of trout and survival of stocked trout on a year-round basis. Trout water designations are used only in the Mountain ecoregion.

In addition to the best-use classifications, NCDWR also monitors waters of the state to determine if they are supporting their use classification(s) and assigned use-support ratings. These ratings are published in the most recent 303(d) impaired waterbodies list (EPA 2014a; NCDWR 2015a).

Another conservation strategy is the listing of species for federal protection under the Endangered Species Act (ESA) and for state protection under North Carolina General Statutes. Chapter 3 Species, Section 3.1.1 provides specific information about regulatory protections. Tables provided in each river basin description (Sections 4.5.4 through 4.5.20) provide the listing status of aquatic species identified as Species of Greatest Conservation Need (SGCN). Table 4.43 provides a summary of the listing status designations.

Table 4.43 Federal and state listing status abbreviations

Federal Listing Status		State Listing Status	
E	Endangered; a taxon which is in danger of extinction throughout all or a significant portion of its range.	E	Endangered; any native or once-native species of wild animal whose continued existence as a viable component of the state's fauna is determined to be in jeopardy or listed as a federal endangered species.
T	Threatened; a taxon which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.	T	Threatened; any native or once-native species of wild animal which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range or listed as a federal threatened species.
C	Candidate; taxa for which USFWS has on file enough substantial information on biological vulnerability and threat(s) to support proposals to list them as endangered or threatened.	SC	Special Concern; any species of wild animal native or once-native to North Carolina which is determined to require monitoring but which may be taken under regulations adopted under state laws.
FSC	Federal Species of Concern; Those species that appear to be in decline or otherwise in need of conservation and are under consideration for listing or for which there is insufficient information to support listing at this time. Subsumed under the term 'FSC' are all species petitioned by outside parties and other selected focal species identified in USFWS strategic plans, State Wildlife Action Plans, or Natural Heritage Program Lists.		

4.5.3.3 Recommendations

While much progress has been made toward understanding basic distribution of many priority species, especially fishes, information is still lacking on the distribution of some species, and population strength and trend data are rare. These gaps are especially pronounced among mollusks and crustaceans. While considerable knowledge gaps exist for freshwater mussels, they are even greater for snails and pea clams. Likewise, information vital for effective management of crayfish is insufficient and such information for microcrustaceans (e.g., water fleas, seed shrimp, scuds) is practically nonexistent. Performing extensive field surveys and collecting voucher specimens are important steps in developing conservation measures for aquatic species.

Much of the aquatic insect data tracked by the NC Natural Heritage Program (NCNHP) is provided by the Biological Monitoring group of the NC Division of Water Resources (formerly as Division of Water Quality). However, there is no clear jurisdiction over most of these taxa, and there is a scarcity of biologists focused on these groups. Knowledge levels and data availability for insects, terrestrial gastropods, and arachnids are the lowest of any animal groups in the state. These taxa are an integral part of the ecosystems they share with other invertebrate and vertebrate species. Opportunities to expand our knowledge and understanding of these groups should be taken when possible, and the establishment of habitat-based projects that are mutually beneficial to these groups and to higher taxa should be a focus.

The following recommendations should be considered appropriate to implement statewide and where appropriate in all river basins.

Surveys. General surveys are needed to complete primary distributional status for SGCN and other priority species.

- Complete distribution and status surveys for aquatic snails, crayfish, mussels, fish, and nonnative species.
- Coordinate sampling with other resource management groups.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Conduct long-term monitoring to assess performance of specific conservation actions: stream restoration projects; species restoration projects; improvements in flow regions below dams; improvements in best management practices (BMPs).
- Assess nonnative species impacts and monitor populations of potentially injurious nonnative species and their impacts on priority species.
- Establish protocols, schedules, and sites for long-term population monitoring.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Investigate potential for augmentation or restoration of priority species populations in restored or improved habitats.
- Resolve taxonomic problems and develop species descriptions (if required).
- Review available information and support life history investigations where lacking.
- Support investigations into impacts from habitat fragmentation, especially those due to impoundments or other anthropogenic factors.
- Focus analysis and synthesis of inventory and monitoring data and reporting to inform decision making pertaining to initial species listing and status revision.
- Investigate species vulnerability to impacts from invasive and nonnative species (e.g., Asian Clam) and exposure to chemicals (e.g., endocrine-disrupting compounds) and other pollutants.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital.

- Expand aquatic species restoration efforts through increased capacity for captive culture of priority species.

- Eradicate or control invasive and injurious nonnative species within lentic and lotic systems.
- Support county soil and water conservation measures such as BMP recommendations to address sediment and erosion related to agricultural activities.
- Work through the Federal Energy Regulatory Commission (FERC) relicensing process and other opportunities to mitigate negative impacts from hydropower development and support mitigation and restoration efforts.
- Increase stormwater management, erosion control, and education along with associated inspections of all sites with potential for erosion.
- Evaluate regulatory issues and develop rules that address water quality issues and other threats to priority species and habitats.
- Work through site-specific management plans to protect and conserve waters containing federally listed species.
- Support implementation of low-impact development and better stormwater management through program coordination, cooperative projects, and technical guidance.
- Support clean-up efforts and stricter regulation of Confined Animal Feeding Operations (CAFOs) in addition to promoting best management practices (BMPs) and improvements for animal waste treatment.
- Identify specific priority areas for habitat conservation and restoration. Criteria include areas with high species diversity, rare species, and endemic species; specific areas that are critical to the survival of priority species (e.g., particular streams or spawning sites); and areas recognized by previous national and/or regional prioritization efforts.
- Support incentive and information programs that help reduce sedimentation and erosion (e.g., fencing livestock from streams, improve tilling practices), minimize pesticide and herbicide use, modernize wastewater treatment facilities, and so forth.
- Prioritize education measures to prevent the introduction or spread of invasive nonnative species, particularly crayfishes, Zebra Mussels, and land-locked river herring species (e.g., Blueback Herring, Alewife), as well as nonnative and invasive aquatic and riparian plants.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Support the strategic planning efforts of partner agencies, local governments, and other conservation organizations (USFWS 2014).
- Support and implement comprehensive land-use planning that reduces secondary or cumulative impactsupon water quality and natural resources.
- Develop and support programs that provide technical guidance and assistance to property owners and businesses on how they can reduce impacts and achieve conservation goals.
- Develop and support education and outreach programs, and distribute materials, deliver presentations, and participate in activities.
- Incorporate aquatic priorities into the NC Division of Mitigation Services (formerly NC Ecosystem Enhancement Program [NCEEP]) Watershed Enhancement Program prioritization process, into game lands management, and into game lands acquisitions.
- Support conservation and restoration of streams and riparian zones in priority areas (acquisition, easements, and buffers).
- Support the development and application of an aquatic nuisance species management plan with other agencies/groups.
- Guide academic research projects to help achieve specific conservation goals and objectives.
- Support water quality rules and watershed designations that conserve habitats for priority aquatic species. Outstanding Resource Water and High-Quality Water designations should be supported wherever the criteria are met, especially in watersheds that support priority species.
- Support local and regional land-use planning efforts to affect water quality and habitat conservation, establish riparian buffers along streams, implement low-impact development, and improve stormwater management (e.g., secondary and cumulative impacts). Support and utilize species-listing processes and associated programs to conserve imperiled species and their habitats. When warranted, make recommendations for state listing to the Commission's Nongame Wildlife Advisory Committee.

- Develop and disseminate news and educational print and electronic media. Products could include stand-alone documents, press releases, newspaper and magazine articles, Internet sites, and displays. Improve and maintain existing web resources to provide information about aquatic species, habitats, and conservation priorities.

- Continue to seek opportunities for direct outreach in all river basins.

4.5.4 Broad River Basin

4.5.4.1 River Basin Description

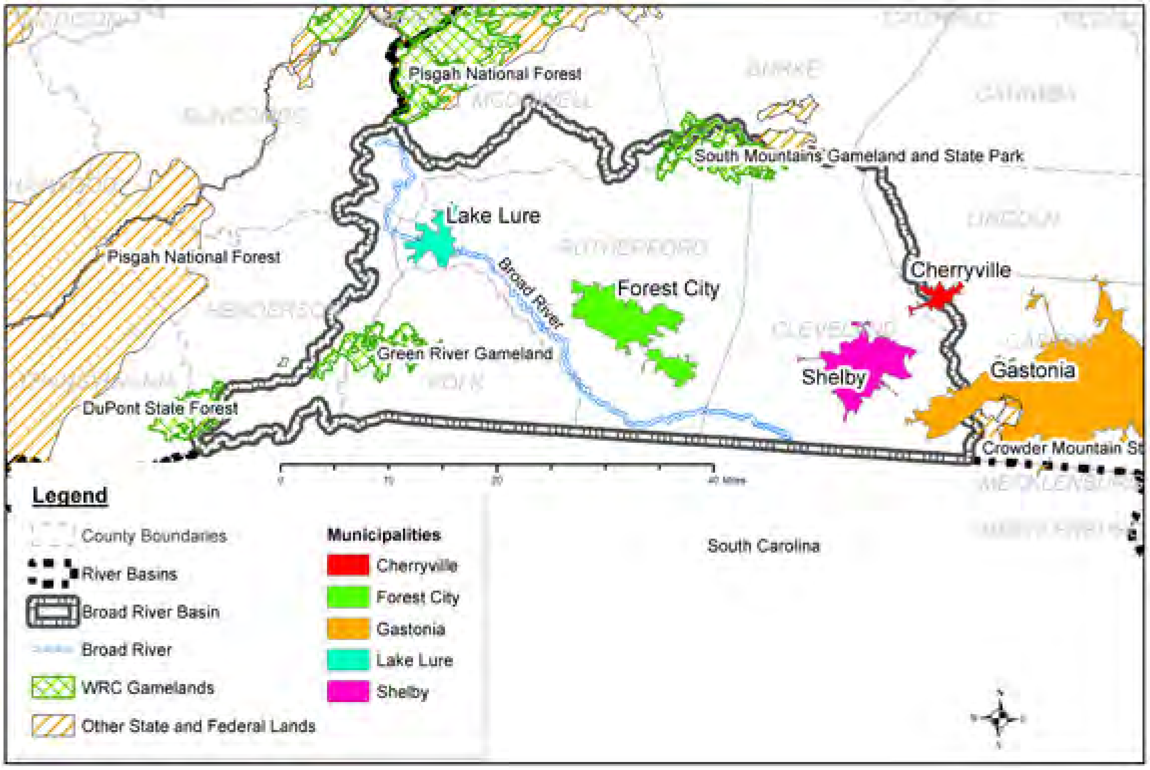
The Broad River Basin originates in North Carolina and flows into South Carolina where it is part of the Edisto-Santee River Basin. The western part of the basin includes headwaters and major tributaries that begin in the Mountain ecoregion and flow southeastward through the foothills to form the Green and Broad Rivers. In the central part of the basin, the First Broad and Second Broad Rivers drain from the easternmost part of the Mountains and flow south across the foothills and Piedmont to merge with the lower Broad River before it crosses into South Carolina. The Broad River merges with the Saluda River near Columbia, South Carolina to form the Congaree River, which flows into Lake Marion and eventually into the Atlantic Ocean. The North Carolina part of the basin covers about 1,513 square miles (28% of the entire watershed) with nearly 3,756 miles of freshwater streams and 3,159 acres of lakes (NCDWR 2015j).

Nearly 73% of the land in the basin is covered by forest or shrubland, about 22% is agricultural lands, and 3.5% is urban or developed land (NCGAP 2009). The Commission manages nearly 36,000 acres of game lands in the Broad River Basin area, including parts of the South Mountains Game Land and Green River Game Land. Crowders Mountain, Chimney Rock State Park, and Hickory Nut Gorge and Hickory Nut Falls are well known state park destinations. The North Carolina Natural Heritage Program (NCNHP) has identified numerous Significant Natural Heritage Areas, Dedicated Nature Preserves, and Managed Areas in the basin that represent exceptionally rare natural communities and features that have a very high need for conservation. Many of these locations are actively managed for biodiversity through disturbance that mimics natural processes.

Overall, stream gradients in the basin decrease as the topography changes from the Mountains to the foothills and into the rolling landscape of the Piedmont. Soils in the Piedmont generally contain greater proportions of sand and clay and have higher erosion potential than those in the upper portion of the basin. Stream habitats in the lower basin are generally dominated by runs and pools with high proportions of sandy and silty substrates. This geographic and geologic change provides a variety of habitats for both rare and common aquatic species, but the higher erosion potential can result in greater impacts from excess sediment loading from disturbed areas.

The Broad River Basin is located along the boundary with South Carolina and encompasses all or part of 10 counties: Buncombe, Burke, Cleveland, Gaston, Henderson, Lincoln, McDowell, Polk, Rutherford, and Transylvania. Municipalities in the basin range in population size from about 200 to 21,000 people and much of the population can be found around the towns of Spindale, Rutherfordton, Forest City, and the City of Shelby (NCDWQ 2008a). Figure 4.7 depicts the geographic location of the Broad River Basin.

Figure 4.7 Location of the Broad River Basin



4.5.4.2 Aquatic Resource Conditions

Surface waters of the state are assigned a classification that carries standards for protecting the best intended uses of that water. There are more than 1,878 miles of freshwater streams in the basin that have been classified by NCDWR for best uses (NCDWR 2015a). Classification categories include aquatic life, recreation, fish consumption, and water supply. Overall, more than 34% of the monitored streams that have data available support intended uses; however, the lack of data for more than half the basin provides an unclear assessment of overall water quality. It is important to note that all waters in the state are rated as impaired based on a state-wide fish consumption advisory for mercury contamination.

Some waterbodies in the basin have supplemental classifications as High-Quality Waters (HQW) or Outstanding Resource Waters (ORW) because they either have excellent water quality or they are a significant resource to humans or wildlife (NCDWR 2014c). The requirements for classification as an ORW are more stringent than those for an HQW and in some circumstances, the unique characteristics of the water and resource require that a specialized management strategy be developed (NCDWQ 2011c; NCDWR 2015a, 2015d). There are two HQW Special Management Strategy Areas in the eastern corner of the basin (Henderson County): Green River (12,269 acres) and Lake Montonia (15 acres) (NCDWR 2015c). These areas require site-specific provisions to protect resource values (e.g., no new discharges or expansion of existing discharges) as described in NC Administrative codes (see 15A NCAC 02B.0225).

Table 4.44 provides information on water quality classifications and use support ratings in the basin.

There are about 515 miles of streams in the Broad River Basin designated as trout (Tr) waters. This is not the same as the Commission's designated public Mountain Trout Waters, which is used to designate waters that support trout and are open to public fishing. In addition to the best use classifications, NCDWR also monitors state waters to determine if they are supporting their use classification(s) and assign use supporting ratings. These ratings are published in the most recent 303(d) impaired waterbodies list (NCDWR 2014a, 2015a).

4.5.4.3 Aquatic Species

There are eight SGCN in the basin: two crayfishes and seven freshwater fishes. Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN associated with aquatic communities found in this river basin. Table 4.45 identifies the SGCN found in the Broad River Basin.

4.5.4.4 Threats Affecting Aquatic Species

Water quality problems are attributable to both point and nonpoint sources. Point sources are primarily wastewater treatment plants and industrial discharges. Both municipal wastewater treatment plants and industrial sources discharge colored effluents to streams

Table 4.44 Water quality classification and rating information for the Broad River Basin

Classifications	Freshwater Miles	Percent (Total Waters)	Freshwater Acres	Percent (Total Waters)
Total Basin Waters*	3,756	—	3,159	—
HQW	65	<1	—	—
ORW	22	<1	15	<1
Use Ratings	**Freshwater Miles**	**Percent (Total Waters)**	**Freshwater Acres**	**Percent (Total Waters)**
Total Named Waters	1,510	—	1,011	—
Supporting	555	37	1,011	100
Impaired	24	<1	—	—
Not Rated	21	<1	—	—
No Data	910	61	—	—

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

Table 4.45 SGCN in the Broad River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
CRAYFISH	*Cambarus lenati*	Broad River Stream Crayfish	—/SC
	Cambarus spicatus	Broad River Spiny Crayfish	FSC/SC
FISH	*Ameiurus brunneus*	Snail Bullhead	—
	Ameiurus platycephalus	Flat Bullhead	—
	Carpiodes sp. cf. cyprinus	a carpsucker	—
	Etheostoma thalassinum	Seagreen Darter	—
	Moxostoma pappillosum	V-lip Redhorse	—
	Salvelinus fontinalis	Brook Trout (native)	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

in the basin, especially in the Second Broad River watershed. The impacts of these effluents at permitted levels are generally regarded as minimal, but effects on native aquatic communities from other solutes in these and other discharges are unclear. Problems with meeting permitted discharge limits have occurred at several wastewater treatment plants in the basin (NCDWQ 2008a).

Most water quality problems that result in impaired ratings due to failure to meet water quality standards can be attributed to nonpoint source pollution. Sedimentation is the main water quality issue and stream sedimentation is severe across the Piedmont portion of the basin. Standards have been exceeded for turbidity in several stream segments in the basin (NCDWQ 2008a). Other sources of nonpoint pollution include lawns, golf courses, and impervious surfaces.

Poorly managed pasture lands contribute substantially to overall soil and streambank erosion. Often, riparian vegetation is minimal or nonexistent and cattle have unlimited direct access to streams which contributes to habitat degradation. Overall lack of riparian vegetation is a widespread problem throughout the basin. Major causes of sedimentation in the basin are land clearing activities (e.g., construction, row crop agriculture, timber harvest, and mining), streambank erosion, and runoff from unpaved rural roads and eroding road grades (NCDWQ 2003, 2008a).

Hydraulic and hydrologic alterations to streams, through accelerated streambank erosion and channel instability, contribute both directly and indirectly to habitat degradation. Streams have been channelized in both rural and developed areas in the basin. Development and urbanization also increase impervious surfaces and often produce drainage patterns and structures that speed the runoff of rainwater and alter hydrograph curves. Property along the Broad River and Lake Lure is being developed for second homes, vacation lodges, and recreational facilities such as golf courses and horse farms. Hydrologic alteration can cause flash flooding which further accelerates streambank erosion and channel degradation.

There are significant impacts to native aquatic communities in the Broad River Basin from impoundments; however, they are not as widespread as in some of the other basins in the Mountain ecoregion (e.g., Hiwassee, Little Tennessee, and Catawba). Lake Lure, Kings Mountain, and Lake Adger impoundments appear to have the greatest impact on aquatic resources. Impacts include thermal and hydrologic alteration to tailwaters, water quality and quantity issues associated with nonexistent or inadequate flow, direct effects of impoundment, fragmentation of upstream populations, and loss of genetic diversity caused by barriers between populations.

Several existing impoundments are used for water supply and new impoundments are proposed within the basin for the same reason. As human population increases in the region, water supply is an increasing burden on surface waters. Water withdrawals, impoundments, and interbasin water transfers can significantly alter habitats for native aquatic species.

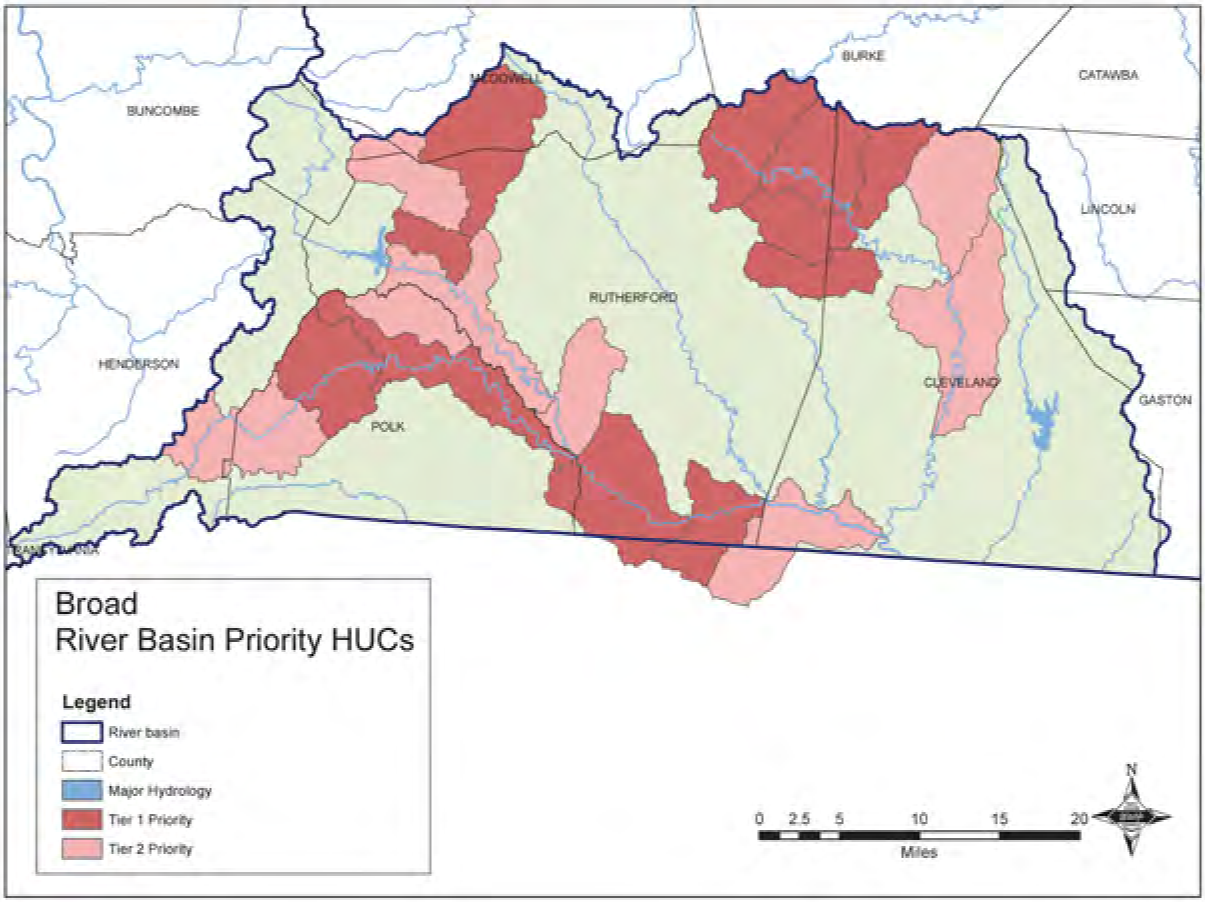
Nonnative species in the Broad River Basin include the Rusty Crayfish, Asian Clam, Common Carp, Channel Catfish, Smallmouth Bass, Muskellunge, Rainbow and Brown trout, and Warpaint Shiner. Some reservoirs have landlocked populations of introduced Blueback Herring and Alewife, anadromous species that normally migrate between fresh and coastal waters in areas where they are native. The Saffron Shiner is native to other river basins in the state, but has been introduced and occurs as a nonnative species in the Broad River Basin.

Nonnative vegetation can also negatively impact native aquatic communities. This includes both aquatic and riparian plant species and nonnative plant pathogens that can alter riparian vegetation and affect aquatic habitats (e.g., Hemlock Wooly Adelgid). Presently, specific impacts from nonnative species in the Broad River Basin are unclear and more information is needed to inform appropriate management actions.

4.5.4.5 Recommendations

Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priority watersheds identified in the Broad River Basin are shown in Figure 4.8 and a list of the priority 12-digit HUCs is included in Appendix J.

Figure 4.8 **Location of priority watersheds in the Broad River Basin**



Basin Specific Recommendations

Surveys. General surveys are needed to complete primary distributional status for SGCN and other priority species (see Appendix G).

- Aquatic Snails—inventory primary distribution; determine potential habitats and distribution surveys for hydrobiids.
- Crayfishes—complete primary inventories and determine status of endemic species.
- Mussels—complete primary inventories.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities, and invasive species. These efforts will inform species and habitat management decisions. While long-term monitoring sites have been established and baseline data gathered in most areas of the basin for fishes and crayfishes, a comprehensive approach to long-term monitoring is still lacking for mussels. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Resolve taxonomic problems and species descriptions (if required) for mussels in the genera *Elliptio* and *Strophitus*, and putative undescribed crayfishes in the basin.
- Investigate impacts from habitat fragmentation and invasive species in the basin.
- Investigate aquatic community response to stream restoration projects in priority areas.
- Support research to improve habitat conditions in regulated rivers.

In addition to the SGCN species found in the basin (see Table 4.45), a list of knowledge-gap priority species is provided in Table 4.46.

Table 4.46 Knowledge-gap priority species in the Broad River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
CRAYFISH	*Cambarus howardi*	Chattahoochee Crayfish	—
	Cambarus johni	Carolina Foothills Crayfish	—
FISH	*Cyprinella labrosa*	Thicklip Chub	—
	Cyprinella zanema	Santee Chub	—
	Notropis rubricroceus	Saffron Shiner [Nonnative in this basin]	—
MUSSEL	*Corbicula fluminea*	Asian Clam [Exotic]	—
	Elliptio icterina	Variable Spike	—
	Pyganodon cataracta	Eastern Floater	—
	Strophitus undulatus	Creeper	—/T
	Utterbackia imbecillis	Paper Pondshell	—

* See Table 4.3 in Section 4.5.3.2 for abbreviations.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital. Specific issues in this basin include high rates of erosion and sedimentation, secondary and cumulative impacts upon water quality, riparian vegetation restoration and conservation, water supply watershed protection, and protection of headwaters.

- Incorporate management goals for aquatic community conservation and focus on restoration and enhancement of critical habitats and communities for Green River and South Mountain Game Lands.

- Reintroduce extirpated freshwater mussel and fish species in restored or improved habitats as opportunities become available.

- Prioritize education and other measures to prevent the introduction or spread of invasive nonnative crayfishes.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to conserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- NC Division of Mitigation Services (NCDMS) has developed River Basin Restoration Priorities (RBRP) for the Broad River Basin and Local Watershed Plans (LWP) for the Catheys and Cove Creek watersheds (NCEEP 2009a).

4.5.5 Cape Fear River Basin

4.5.5.1 River Basin Description

The Cape Fear River Basin is the largest river basin in North Carolina and is contained entirely within the state. The Cape Fear River flows southeast through the Piedmont ecoregion into the Coastal Plain before reaching the city of Wilmington and draining into the Atlantic Ocean. The basin covers about 9,164 square miles and has 21,300 miles of freshwater streams, 31,135 acres of freshwater lakes and reservoirs, 31,753 acres of estuarine habitat, and 47 miles of Atlantic coastline (NCDWQ 2005; NCDWR 2015j). Major drainages in the basin include the Haw River, Deep River, Northeast Cape Fear River, Black River, and the Cape Fear River.

The Cape Fear River Basin can be characterized by three general regions: the Upper Cape Fear, including the headwaters in the Piedmont; the Middle Cape Fear, including the fall line and the Sandhills; and the Lower Cape Fear, which includes the coastal region with blackwater streams and swamps. The headwaters include the Deep River, originating near High Point, and the Haw River, originating north of Greensboro, which join to form the Cape Fear River just downstream of the B. Everett Jordan Reservoir dam. Much of the headwater area is located in and flows through highly urbanized areas, which significantly impacts water quality in the basin. Blackwater streams and rivers in the lower Cape Fear include the South River, Black River, and the Northeast Cape Fear River. Species found in the Sandhills and Coastal Plain have a high rate of endemism due to unique habitats in those ecoregions.

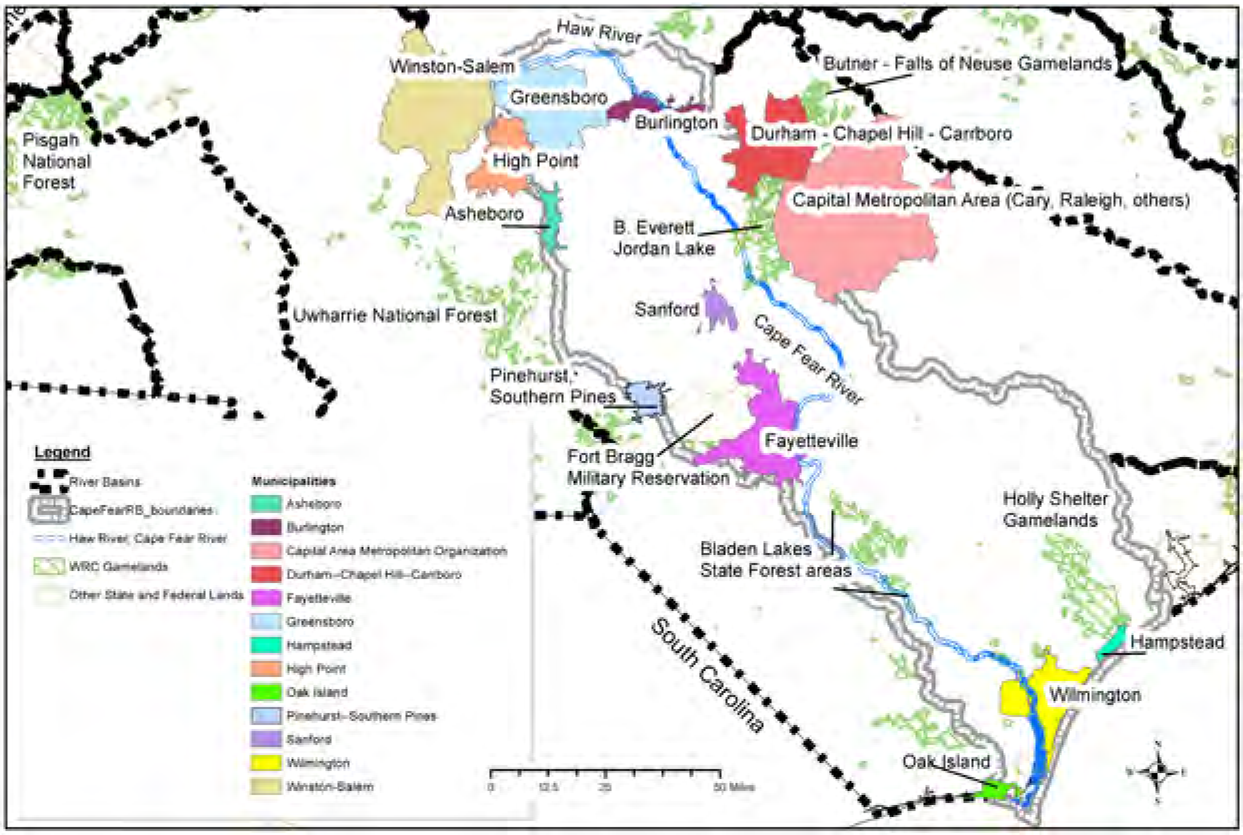
Land use in the basin is 42% forested, 18% wetland, 12% urban or developed, 6% grassland, and 21% agricultural (MRLC 2011; Jin et al. 2013). Public lands include approximately 234,381 acres of state and federal lands. Significant public lands include the B. Everett Jordan Reservoir, Bladen Lakes State Park, and numerous game lands managed by the NC Wildlife Resources Commission (NCWRC). The estimated 2010 human population was 2,072,304, which represents about 22% of the state's total population (USCB 2010; NCDWR 2015j).

The basin encompasses all or part of 26 counties and includes 115 municipalities of varying population sizes. Sizable cities located in this basin include Durham, Greensboro, High Point, Fayetteville, and Wilmington. Figure 4.9 depicts the geographic location of the basin.

4.5.5.2 Aquatic Resource Conditions

Segments of Black River, Deep River, Little River, South River, and several freshwater streams and lakes have supplemental classifications as High-Quality Waters (HQW) or Outstanding Resource Waters (ORW) because they either have excellent water quality or they are a significant resource to humans and/or wildlife (NCDWR 2015d).The Cape Fear River near the Lilliput Creek, Walden Creek, and Snow's Cut confluences, Buzzard Bay, Muddy

Figure 4.9 **Location of the Cape Fear River Basin**



Slough, and other coastal tributaries, and coastal estuarine waters associated with the Intracoastal Waterway also carry an HWQ or ORW classification (NCDWR 2015a).

Table 4.47 provides information on water quality classifications and use support ratings in the basin.

There are HQW and ORW Special Management Strategy Areas in the basin for the Northeast Cape Fear River, Deep River, Little River, Black and South River Area, Topsail and Middle Sound Area, Masonboro Sound Area, and six additional areas totaling 124,355 ORW acres and 152,786 HQW acres (NCDWR 2015c). These areas require site-specific provisions to protect resource values (e.g., no new discharges or expansion of existing discharges) (see 15A NCAC 02B.0225).

There are 1,829 miles and 18,584 acres of freshwaters considered to be nutrient-sensitive waters (NSW) in the Cape Fear River Basin (NCDWR 2015a). The NSW classification applies to all waters in the Haw River and Jordan Reservoir watersheds, and is intended for those that need additional nutrient management because of greater vulnerability to excessive aquatic vegetation growth (NCDWQ 2005).

Table 4.47 Water quality classification and rating information for the Cape Fear River Basin

Classifications	Freshwater Miles	Percent (Basin Waters)	Freshwater Acres	Percent (Basin Waters)	Coastal Acres	Percent (Basin Waters)
Total Basin Waters*	10,828	—	68,884	—	23,942	—
HQW	163	<1	262	<1	—	—
ORW	129	<1	3,623	5	—	—
Use Ratings	**Freshwater Miles**	**Percent (Monitored Waters)**	**Freshwater Acres**	**Percent (Monitored Waters)**	**Coastal Acres**	**Percent (Monitored Waters)**
Total Named Waters	6,586	—	34,780	—	23,942	—
Supporting	1,911	29	20,319	58	6,236	26
Impaired	445	<1	7,929	23	17,008	71
Not Rated	198	<1	—	—	—	—
No Data	4,032	62	6,532	19	698	<1

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

4.5.5.3 Aquatic Species

There are 35 SGCN in the basin: two aquatic snails, two crayfish, 18 freshwater or anadromous fishes, and 13 mussels. Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN associated with aquatic communities found in this river basin. Table 4.48 identifies the SGCN found in the Cape Fear River Basin.

4.5.5.4 Threats Affecting Aquatic Species

The Cape Fear River Basin contains multiple areas of high human population density and the most populated areas are located in the Piedmont municipal regions referred to as the Triad and the Triangle (NCDWQ 2005). The Triad is the area encompassing Winston-Salem, Greensboro, and Highpoint, and the Triangle is the area anchored by Raleigh, Durham, and Chapel Hill. All of the major urban centers in the basin are experiencing fast growth rates. As counties in the upper basin and those along the coast experience high population growth, current capacities for drinking water and wastewater treatment will experience increased demands for service that could require a corresponding increase in utility construction, water withdrawals, and treatment discharges. Comparison of water supply demand projections for municipalities in the basin with percent of projected water supply available for the 2040 planning period indicates demand from growth will utilize from 50% to 99% of available water supplies in the basin (NCDWR 2014b).

TABLE 4.48 SGCN in the Cape Fear River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
AQ SNAIL	*Helisoma eucosmium*	Greenfield Rams-horn	—
	Planorbella magnifica	Magnificent Rams-horn	C/E
CRAYFISH	*Cambarus catagius*	Greensboro Burrowing Crayfish	—/SC
	Procambarus ancylus	Coastal Plain Crayfish	—
FISH	*Acipenser brevirostrum*	Shortnose Sturgeon	E/E
	Acipenser oxyrinchus	Atlantic Sturgeon	E/E
	Ameiurus brunneus	Snail Bullhead	—
	Ameiurus platycephalus	Flat Bullhead	—
	Carpiodes sp. cf. velifer	Atlantic Highfin Carpsucker	—/SC
	Cyprinella sp. cf. zanema	Thinlip Chub	—/SC
	Elassoma evergladei	Everglades Pygmy Sunfish	—
	Enneacanthus chaetodon	Blackbanded Sunfish	—
	Enneacanthus obesus	Banded Sunfish	—
	Etheostoma collis	Carolina Darter	FSC/SC
	Heterandria formosa	Least Killifish	—/SC
	Moxostoma pappillosum	V-lip Redhorse	—
	Moxostoma sp. 1 [sp. carolina]	Carolina Redhorse	FSC/T
	Notropis chalybaeus	Ironcolor Shiner	—
	Notropis mekistocholas	Cape Fear Shiner	E/E
	Noturus sp. 2 [cf. leptacanthus]	Broadtail Madtom	FSC/SC
	Semotilus lumbee	Sandhills Chub	FSC/SC
MUSSEL	*Alasmidonta undulata*	Triangle Floater	—/T
	Alasmidonta varicosa	Brook Floater	FSC/E
	Anodonta couperiana	Barrel Floater	—/E
	Elliptio marsupiobesa	Cape Fear Spike	—/SC
	Fusconaia masoni	Atlantic Pigtoe	FSC/E
	Lampsilis cariosa	Yellow Lampmussel	FSC/E
	Lampsilis sp. 2	Chameleon Lampmussel	—
	Lasmigona subviridis	Green Floater	FSC/E
	Toxolasma pullus	Savannah Lilliput	FSC/E
	Villosa constricta	Notched Rainbow	—/SC
	Villosa delumbis	Eastern Creekshell	—
	Villosa vaughaniana	Carolina Creekshell	FSC/E

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

The basin has numerous Confined Animal Feeding Operations (CAFOs), primarily swine production, with 1,349 facilities and 2,179 associated waste lagoons (NCDWR 2015f). These facilities, as well as several other impact factors in the basin, result in waters being rated as impaired, due to fecal coliform and *enterococcus* bacterial contamination, ammonia, chlorides, habitat degradation, chlorophyll *a*, low dissolved oxygen (DO), turbidity, nutrients, elevated heavy metal or cyanide levels, and other point and nonpoint pollutants (NCDWQ 2005). While any one source may only create local impacts, the cumulative effects from multiple sources and impacts occurring throughout the basin have had a severe and long-lasting impact. Sedimentation from agriculture, forestry, and construction practices and stormwater discharge are major issues in the basin.

According to an NC Department of Energy, Mineral, and Land Resources dam inventory (2014) there are at least 1,290 impoundments in the basin. The mainstem of the Cape Fear is interrupted by three locks and dams in the middle and lower portions of the river. The upper Cape Fear River has large barriers at Buckhorn Dam and Jordan Dam. There are also numerous smaller dams on the tributaries to the Cape Fear. The consequences of these impoundments include blocked migration routes for diadromous and resident native species, reduced recolonization and dispersal potential for multiple aquatic taxa, and unnatural flow regimes below managed dams (Williams et al. 1993; Etnier 1997; Neves et al. 1997; Warren et al. 2000; NCWRC 2005).

Invasive species (e.g., Flathead Catfish, Blue Catfish, Red Swamp Crayfish) are established in the Cape Fear River Basin and continue to negatively impact native species populations (Fuller et al. 1999; Cooper 2005) via predation and competition. The Striped Shiner is native to other river basins in the state, but has been introduced and occurs as a nonnative species in the Cape Fear River Basin.

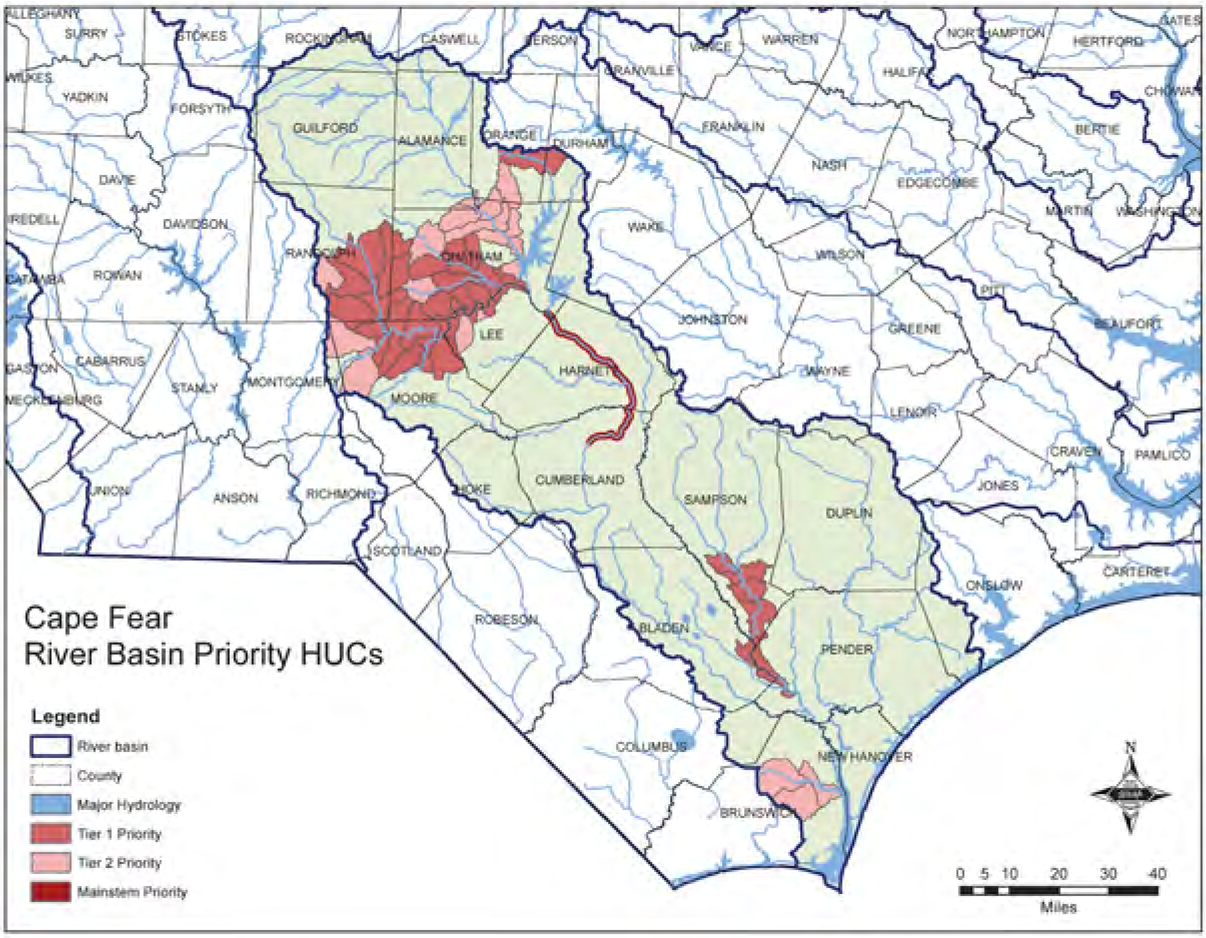
4.5.5.5 Recommendations

Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priority watersheds identified in the Cape Fear River Basin are shown in Figure 4.10 and a list of the priority 12-digit HUCs is included in Appendix J.

Basin Specific Recommendations

Surveys. Surveys need to focus on aquatic snails, crayfish, mussels, and fish believed to be declining or dependent on at-risk or sensitive communities (NCWRC 2005). Conduct distribution and status surveys for priority species (see Table 4.49) such as the Ironcolor Shiner, Carolina Redhorse, and Atlantic Pigtoe.

Figure 4.10 **Location of priority HUC12 watersheds in the Cape Fear River Basin**



Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters. Studies should include identification of population trends, as well as assessment of conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions

for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Support species descriptions for undescribed taxa (e.g., Carolina Redhorse).
- Determine the vulnerability of species across all taxa groups to emerging threats such as endocrine-disrupting chemicals (EDCs) and other compounds that are present in many of our waterways.
- Identify limiting factors of declining species (e.g., Ironcolor Shiner).

In addition to the SGCN species found in the basin (see Table 4.48), a list of knowledge-gap priority species is provided in Table 4.49.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. General needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and

Table 4.49 Knowledge-gap priority species in the Cape Fear River Basin.

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
AQ SNAIL	*Cipangopaludina japonica*	Japanese Mysterysnail [Exotic]	—
CRAYFISH	*Cambarus davidi*	Carolina Ladle Crayfish	—
	Cambarus hystricosus	Sandhills Spiny Crayfish	—
	Procambarus pearsei	Carolina Sandhills Crayfish	—
	Procambarus plumimanus	Croatan Crayfish	—
FISH	*Chrosomus oreas*	Mountain Redbelly Dace	—
	Fundulus diaphanus	Banded Killifish	—
	Lepisosteus osseus	Longnose Gar	—
	Petromyzon marinus	Sea Lamprey	—
MUSSEL	*Corbicula fluminea*	Asian Clam [Exotic]	—
	Elliptio icterina	Variable Spike	—
	Elliptio roanokensis	Roanoke Slabshell	—/T
	Lampsilis radiata	Eastern Lampmussel	—/T
	Ligumia nasuta	Eastern Pondmussel	—/T
	Pyganodon cataracta	Eastern Floater	—
	Pyganodon grandis	Giant Floater	—
	Strophitus undulatus	Creeper	—/T
	Uniomerus carolinianus	Florida Pondhorn	—
	Utterbackia imbecillis	Paper Pondshell	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

regulation and prevention of the introduction and spread of exotic or invasive species are vital.

- Promote programs to upgrade/increase compliance at wastewater treatment facilities and CAFOs.
- Provide support for land conservation, particularly in riparian areas (acquisition, easements, etc.).
- Support well-planned stream restoration work in collaboration with other organizations.
- Support dam removal where appropriate.
- Reintroduce or augment rare mollusk and fish species populations in areas where water quality and stream habitats have recovered sufficiently to support them.
- Continue to identify areas critical to aquatic ecosystem health that can be conserved or restored.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Guide academic research projects to help achieve specific conservation goals and objectives.
- Support the application of an aquatic nuisance species management plan with other agencies/groups.
- Address secondary and cumulative impacts upon water quality, buffer ordinances, water supply watershed protection, headwaters protection, etc. (NCDWQ 2005; NCWRC 2002).
- Work with and promote existing programs that help farmers reduce sedimentation/erosion (e.g., install fences to keep livestock out of streams and improve tilling practices) as well as reduce pesticide and herbicide use.

4.5.6 Catawba River Basin

4.5.6.1 River Basin Description

The Catawba River Basin is located in the south central portion of western North Carolina in the Mountain and Piedmont ecoregions. Headwaters begin in the western side of McDowell County and flow eastward into the Piedmont before turning southeast and flow ing toward the North Carolina/South Carolina border. The basin covers approximately 3,285 square miles and has more than 7,940 miles of freshwater streams. The Linville River, one of only four rivers in the state designated as a Natural and Scenic River, is located in the Catawba River Basin (National Wild and Scenic Rivers System, n.d.). The Linville River flows through the Pisgah National Forest Wilderness area and into Lake James. Practically all of the Catawba River from Lake James south is impounded by a chain of dams before entering South Carolina.

This basin, along with the Broad River Basin, forms the headwaters of the Santee-Cooper River system which flows through South Carolina to the Atlantic Ocean. There are three major river drainages in the basin:

- Upper Catawba: major tributaries include Catawba River headwaters, Linville River, North Muddy Creek, Warrior Fork, Johns River, Silver Creek, Lower Creek, Little River, Gunpowder Creek, Muddy Fork, Dutchman's Creek, and Crowders Creek.
- Lower Catawba: major tributaries include Twelve Mile Creek, Six Mile Creek, Waxhaw Branch, Irwin Creek, McAlpine Creek, and Sugar Creek.
- South Fork Catawba: major tributaries include Henry Fork, Jacob Fork, Clark Creek, and Long Creek.

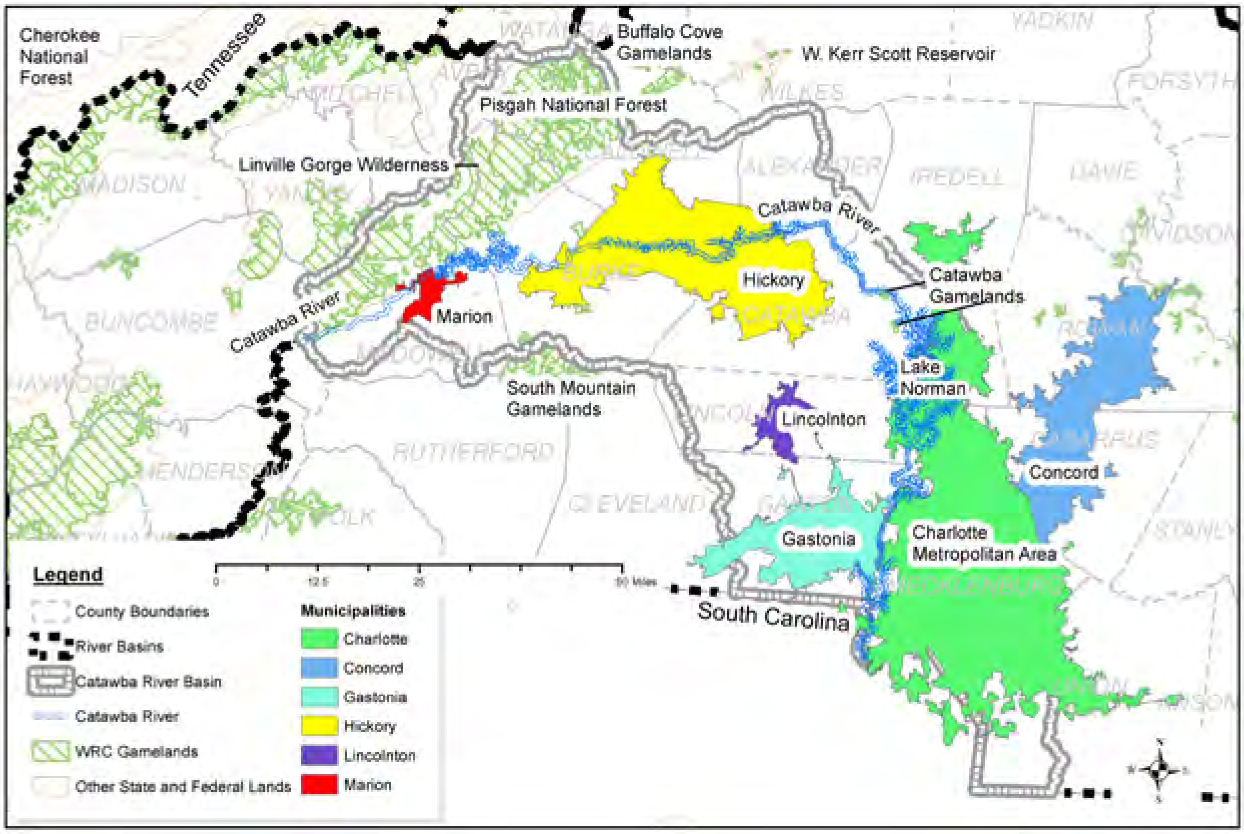
Based on 2011 National Land Cover Dataset information land use in the basin was estimated to be 54% forested, 23% urban or developed, 16% agricultural, 3% grassland, and less than 1% wetland (MRLC 2011; Jin et al. 2013).

The Catawba River Basin encompasses all or portions of 11 counties and 61 municipalities, including the largest municipality in the state (Charlotte). Other large municipalities include Gastonia, Hickory, Huntersville, Lenoir, Mooresville, and Morganton. Figure 4.11 depicts the geographic location of the basin.

4.5.6.2 Aquatic Resource Conditions

There are 3,100 miles of freshwater streams and 54,363 acres of lake and reservoir waters in the basin that have been classified by NCDWR for best uses. There are 11 HQW (108,638 acres) and 7 ORW (107,910 acres) Special Management Strategy Areas in the basin (NCDWR

FIGURE 4.11 **Location of the Catawba River Basin**



2015c). Notable areas include Armstrong Creek, Wilson Creek area, Linville River, Henry and Jacobs Fork areas, and Upper and Steele Creek areas. These areas require site-specific provisions to protect resource values (no new discharges or expansion of existing discharges) (see 15A NCAC 02B.0225).

Table 4.50 provides information on water quality classifications and use-support ratings in the basin.

Another supplemental classification is NCDWR's trout water (Tr) designation which protects freshwaters for natural propagation of trout and survival of stocked trout on a year-round basis. There are about 632 miles of streams in the Catawba River Basin designated as trout waters. This is not the same as the Commission's designated public Mountain Trout Waters, which is used to designate waters that support trout and are open to public fishing. These waters are classified for NCWRC management purposes as either hatchery-supported (periodically stocked with trout) or wild trout waters (high-quality waters that sustain trout populations by natural reproduction).

Table 4.50 Water quality classification and rating information for the Catawba River Basin

Classifications	Freshwater Miles	Percent (Total Waters)	Freshwater Acres	Percent (Total Waters)
Total Basin Waters*	7,941	—	57,063	—
HQW	327	4	21	<1
ORW	256	3	5	<1
Use Ratings	**Freshwater Miles**	**Percent (Total Waters)**	**Freshwater Acres**	**Percent (Total Waters)**
Total Named Waters	3,114	-	54,363	—
Supporting	848	27	11,999	22
Impaired	364	12	39,830	73
Not Rated	19	<1	—	—
No Data	1,883	60	2,535	<1

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

4.5.6.3 Aquatic Species

Table 4.51 identifies SGCN found in the Catawba River Basin. There are 15 SGCN in the basin: two crayfish species, eight freshwater or anadromous fish species, and five freshwater mussel species. Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN associated with aquatic communities found in this river basin.

4.5.6.4 Threats Affecting Aquatic Species

Impoundment is a major factor in the loss and degradation of habitat for priority aquatic species in the Catawba basin. All but the upper headwater reaches of the Catawba River (upstream from Lake James) are either impounded or regulated by hydropower projects (Duke Energy). Coldwater releases degrade the Lake James tailwater for many native species and it is presently managed as a stocked trout fishery. Migration of anadromous and potamodromous fishes are severely limited, if not altogether prevented by dams. The few remaining free-flowing, cool- or warmwater high-quality habitats in larger tributary streams are isolated and fragmented by the impoundment effects on the mainstem Catawba River. The total effect of this habitat fragmentation on priority species populations in not entirely clear; however, some impacts are evident. Habitats may be recovering in some streams where species were extirpated by past habitat loss. Potential recolonization of these recovering habitats may be impossible due to barriers created by dams, impoundments, and/or intervening habitat made unsuitable by other factors.

Table 4.51 SGCN in the Catawba River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
CRAYFISH	*Cambarus aldermanorum*	Needlenose Crayfish	—
	Cambarus eeseeohensis	Grandfather Mountain Crayfish	FSC/—
FISH	*Ameiurus brunneus*	Snail Bullhead	—
	Ameiurus platycephalus	Flat Bullhead	—
	Carpiodes sp. cf. cyprinus	a carpsucker	—
	Etheostoma collis	Carolina Darter	FSC/—
	Etheostoma thalassinum	Seagreen Darter	—
	Moxostoma pappillosum	V-lip Redhorse	—
	Salvelinus fontinalis	Brook Trout (Native)	—
MUSSEL	*Alasmidonta varicosa*	Brook Floater	—/E
	Lasmigona decorata	Carolina Heelsplitter	E/E
	Villosa constricta	Notched Rainbow	—/SC
	Villosa delumbis	Eastern Creekshell	—
	Villosa vaughaniana	Carolina Creekshell	FSC/E

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

With the exception of streams located on public lands, streams within the basin are degraded or threatened by a number of factors, including sedimentation, loss of riparian woody vegetation, water withdrawals, channelization and/or relocation, point source pollution, and nutrient loading. Ground disturbance from development activities and poorly managed agriculture are the primary sources of erosion, sedimentation, and nutrient enrichment. Point sources of pollution include wastewater treatment plants and permitted industrial discharges (much of the basin flows through highly urbanized areas). Alterations to stream channels, increased impervious surfaces (resulting in increased flashiness), and loss of riparian vegetation contribute to stream channel and bank erosion, which in turn contribute to sedimentation and other physical habitat degradation.

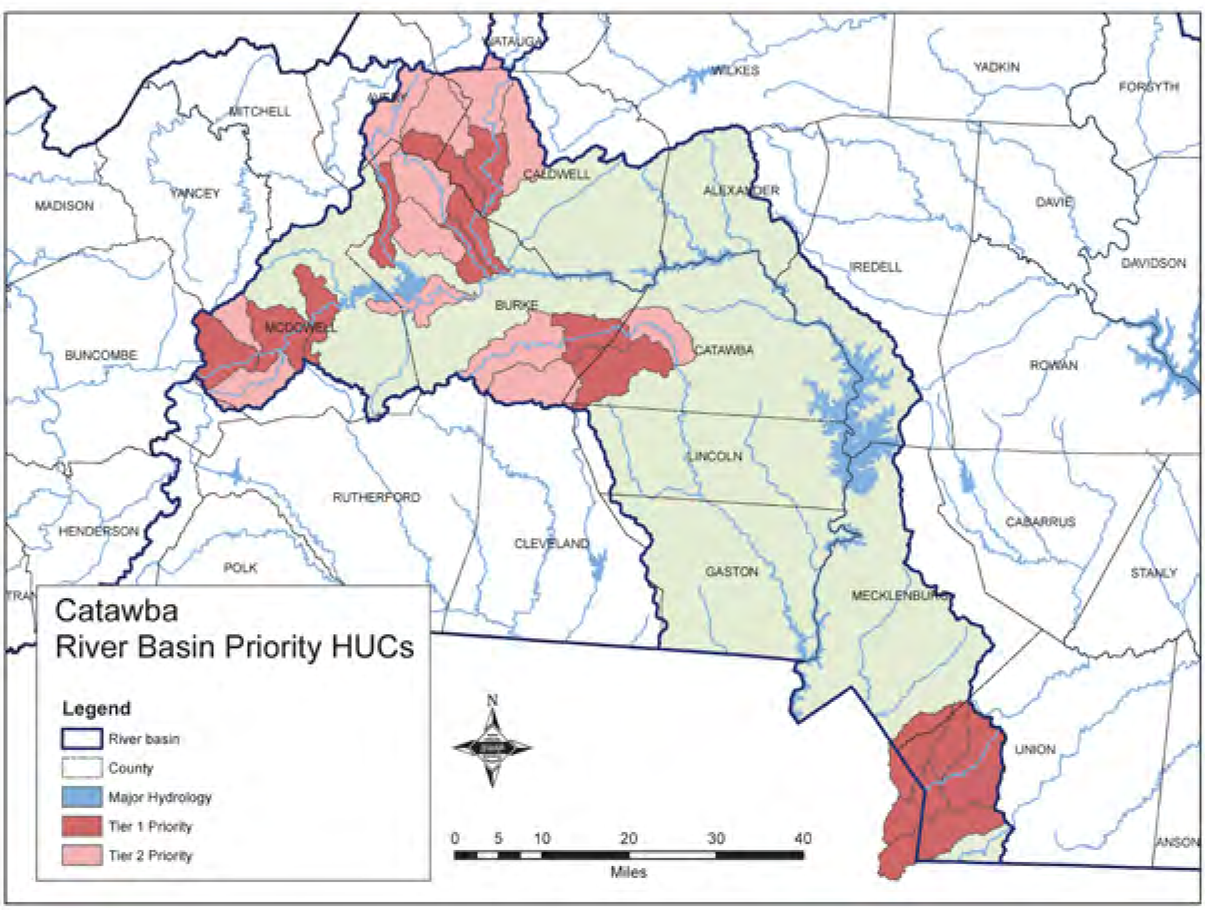
Several existing impoundments are used for water supply and new impoundments are being proposed within the basin for that purpose. As human population increases, water supply is an increasing burden on surface waters. Water withdrawals, impoundments, and interbasin water transfers can significantly alter habitats for native aquatic species. This is an emerging problem that will likely increase in importance in the near future.

Nonnative species known in the basin include Asian Clams, Virile Crayfish, Japanese Mystery Snail, Grass Carp, Blue, Channel, and Flathead catfishes, Smallmouth Bass, Muskellunge, White Bass, Yellow Bass, Rainbow and Brown trout, and even the exotic Northern Snakehead. Land-locked Blueback Herring, Alewife, and White Perch are known in several impoundments. In fact, over 33 exotic fish species have been identified in the basin (NCWRC 2005). Nonnative vegetation can also negatively impact native aquatic animal communities. This includes both aquatic and riparian plant species and nonnative plant pathogens that can alter riparian vegetation (e.g., Hemlock Wooly Adelgid). Nonnative aquatic plants are also present in the Catawba River Basin and are a known nuisance, especially in reservoirs. Specific impacts in the Catawba River Basin from these and other introduced species are unclear.

4.5.6.5 Recommendations

Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priority watersheds identified in the Catawba River Basin are shown in Figure 4.12 and a list of the priority 12-digit HUCs is included inAppendix J.

FIGURE 4.12 Location of priority watersheds in the Catawba River Basin



Basin Specific Recommendations

Surveys. General distribution of most priority species is known; however, surveys are needed to complete distributional status for some priority and invasive species (see Table 4.51).

- Aquatic Snails—inventory primary distribution; determine potential habitats and distribution surveys for hydrobiids.
- Crayfishes—complete primary inventories and determine status of endemic and non-native species.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities and invasive species. These efforts will inform species and habitat management decisions. While long-term monitoring sites have been established and baseline data gathered in most areas of the basin for fishes and crayfishes, a comprehensive approach to long-term monitoring is still lacking for mussels. Project-specific monitoring for species restoration in the South Fork Catawba River system and other conservation actions are also needed. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Resolve taxonomic problems and species descriptions (if required) for mussels in the genera *Elliptio* and *Strophitus*, and putative undescribed crayfishes in the basin.
- Investigate the impact of habitat fragmentation and invasive species on the basin.
- Investigate aquatic community response to stream restoration projects in priority areas.
- Investigate potential for reintroduction of priority species.
- Support research to improve habitat conditions in regulated rivers.

In addition to the SGCN species found in the basin (see Table 4.51), a list of knowledge-gap priority species is provided in Table 4.52.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital. Specific issues in this basin include high rates of erosion and sedimentation, secondary and cumulative impacts upon water quality, riparian vegetation restoration and conservation, water supply watershed protection, and headwaters protection.

- Incorporate management goals for aquatic community conservation and enhancement planning for Johns River and South Mountain Game Lands.
- Continue reintroduction of extirpated mussel species in the South Fork Catawba River system and investigate restoration in other restored or improved habitats as opportunities become available.
- Prioritize education and other measures to prevent the introduction or spread of invasive nonnative crayfishes

Table 4.52 Knowledge-gap priority species in the Catawba River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
AQ SNAIL	*Cipangopaludina japonica*	Japanese Mystery Snail [Exotic]	—
CRAYFISH	*Cambarus howardi*	Chattahoochee Crayfish	—
	Cambarus johni	Carolina Foothills Crayfish	—
FISH	*Chrosomus oreas*	Mountain Redbelly Dace [Nonnative in this basin]	—
	Cyprinella labrosa	Thicklip Chub	—
	Cyprinella zanema	Santee Chub	—
	Notropis rubricroceus	Saffron Shiner [Nonnative in this basin]	—
	Notropis telescopus	Telescope Shiner [Nonnative in this basin]	—
MUSSEL	*Corbicula fluminea*	Asian Clam [Exotic]	—
	Elliptio icterina	Variable Spike	—
	Pyganodon cataracta	Eastern Floater	—
	Strophitus undulatus	Creeper	—/T
	Uniomerus carolinianus	Florida Pondhorn	—
	Utterbackia imbecillis	Paper Pondshell	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Support NCDMS Watershed Restoration Plans (WRPs) (see NCEEP 2004) and priorities (see NCEEP 2007a) for the entire basin and Local Watershed Plans (LWPs) and Project Atlases for five smaller units (see MACTEC, NCEEP, and WPCG 2006). Available online: http://portal.ncdenr.org/web/wq/ps/bpu/watershed-plan-map and http://portal.ncdenr.org/web/eep/rbrps/catawba.

- The NCDWR has prepared a Catawba River Basin Water Resources Plan to "determine the water capacity of the Catawba River to serve future populations and at the same time to identify any potential trouble-spots or conflicts related to water supply and its demand" (NCDWR 2007). The Catawba-Wateree Basin Advisory Commission helps administer water issues in the basin and is a source for much information associated with those issues. Available online: http://www.ncwater.org/files/publications/Final_Draft_Catawba_River_Basin_Plan_2007.pdf and http://portal.ncdenr.org/web/wq/river-basin-avdisory-commission/catawbarbac.

- The Catawba River District Partners, the Catawba and Foothills land conservancies, Catawba Riverkeeper, and many other non-governmental organizations (NGOs) are active in the basin and are potential partners. See NCDWR Basinwide Plan for more information (available online: http://portal.ncdenr.org/web/wq/ps/bpu/basin/catawba).

4.5.7 Chowan River Basin

4.5.7.1 River Basin Description

The Chowan River is formed at the confluence of the Nottoway and Blackwater rivers near the border of Virginia and North Carolina, and it is approximately 50 miles long. The North Carolina portion of the basin is composed of two major drainages: Chowan River and Meherrin River. Major tributaries to the Chowan River include the Meherrin River, Potecasi Creek, Wiccacon River, Bennetts Creek, Indian Creek, and Rockyhock Creek. The Chowan River Basin is part of the Albemarle–Pamlico Estuarine system, the second largest estuarine system in the United States.

The headwaters of the Chowan River begin in the Coastal Plain ecoregion of Virginia, where 75% of the basin is located. The basin enters North Carolina in the northeastern portion of the state. Along with the Roanoke River, the Chowan supplies most of the fresh water supply to the Albemarle Sound. Fishes move between the Chowan, Roanoke and Pasquotank River basins freely as a result of the common connection with the sound (NCDWQ 2007a). As the twelfth largest river basin in the state, the Chowan River Basin is one of the smaller basins with a watershed of 1,298 square miles in the state. The basin contains about 1,124 miles of freshwater streams, 1,787 acres of lakes and impoundments, and 16,500 acres of estuarine waters (NCDWQ 2007a; NCDWR 2015a).

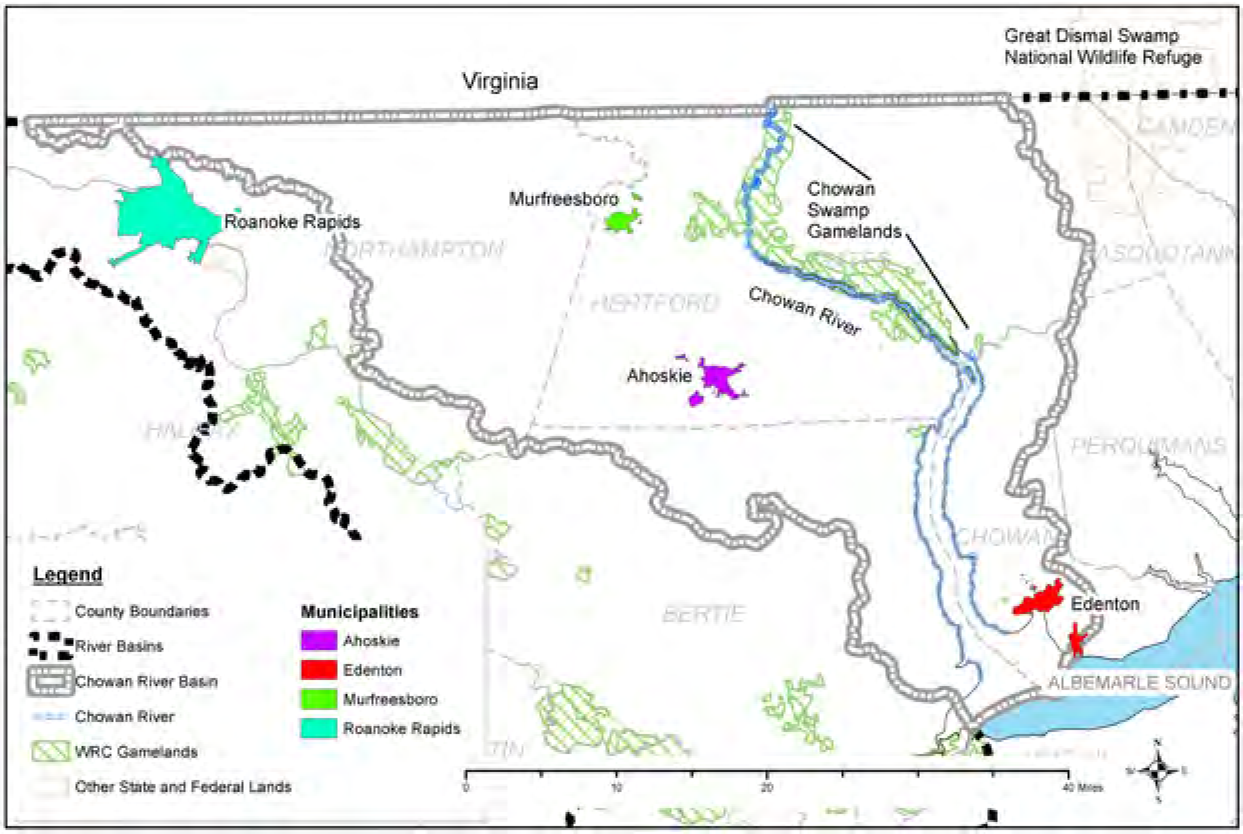
Land use in the basin is 40% forested, 27% agricultural, 20% wetland, 4% grassland, and 6% urban or developed (NCDWR 2015b). Land in this area is very flat and the geology consists of alternating layers of sand, silt, clay and limestone. Low flow over the warmest months of the year limits the ability of streams to maintain high DO levels. The region has slow natural drainage. Many streams are swamp systems, and many man-made ditches have been installed to accommodate drainage for agriculture (NCDWQ 2007a, 2011b). Stream swamp systems periodically have no visible flow or low flow, usually during the summer, but flowing water should be present in swamp streams during the winter.

The North Carolina portion of the basin includes all or part of five counties: Northampton, Hertford, Gates, Bertie and Chowan. There are 19 municipalities in the basin and the largest are Edenton, Ahoskie, and Murfreesboro. Human population density is about 44 persons per square mile based on an estimated population size of 61,034 people, which is less than 1% of North Carolina's total population (NCDWQ 2007a, 2009; USCB 2012). Figure 4.13 depicts the geographic location of the basin.

4.5.7.2 Aquatic Resource Conditions

Approximately 100 miles of the Chowan River are considered an Aquatic Significant Natural Heritage Area by the NCNHP. The Chowan River receives this designation because of the diversity of its freshwater mussel populations, many of which are rare and

FIGURE 4.13 Location of the Chowan River Basin



vulnerable. The Chowan River Basin was the first waterbody in the state to be designated NSW. This designation protects areas with water quality problems associated with excessive plant growth resulting from nutrient enrichment, likely from nonpoint sources (fertilizer in runoff from agriculture and waste from confined animal operations), and nuisance algae blooms associated with excess nutrient loads. Nearly all of the 16,500 acres of estuarine waters in the basin are ranked by NCDWR as supporting aquatic life.

Table 4.53 provides information on water quality classifications and use support ratings in the basin.

The entire area of the Albemarle Sound is rated impaired (i.e., exceeding criteria) due to a dioxin fish consumption advisory issued by the NC Division of Public Health (NCDPH 2014). Other factors that contribute to impaired ratings include fecal coliform and *enterroccus* bacteria contamination from confined animal operations and agricultural activities (NCDWQ 2007a).

There are no major reservoirs in the North Carolina portion of the basin but the NC Division of Energy, Mineral, and Land Resources dam inventory (NCDEMLR 2014) reports there

Table 4.53 Water quality classification and rating information for the Chowan River Basin

Classifications	Freshwater Miles	Percent (Basin Waters)	Freshwater Acres	Percent (Basin Waters)	Coastal Acres	Percent (Basin Waters)
Total Basin Waters*	2,338	—	1,787	—	16,500	—
HQW	—	—	—	—	—	—
ORW	—	—	—	—	—	—
Use Ratings	**Freshwater Miles**	**Percent (Monitored Waters)**	**Freshwater Acres**	**Percent (Monitored Waters)**	**Coastal Acres**	**Percent (Monitored Waters)**
Total Named Waters	799		—	—	—	—
Supporting	222	28	—	—	—	—
Impaired	55	7	—	—	—	—
Not Rated	40	5	—	—	—	—
No Data	482	60	—	—	—	—

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

are 22 impoundments of varying sizes in the basin. Most were built to provide recreation or irrigation waters and some were constructed as millponds.

4.5.7.3 Aquatic Species

There are 12 SGCN in the basin: one crayfish, eight fishes, and three mussel species. Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN associated with aquatic communities found in this river basin. Table 4.54 identifies the SGCN found in the Chowan River Basin.

4.5.7.4 Threats Affecting Aquatic Species

Invasive species (e.g., Asian Clam, Red Swamp Crawfish, Channel Catfish) have become established in the Chowan River Basin and continue to negatively impact native species populations.

In the Chowan River Basin, elevated mercury levels have been measured in long-lived piscivorous (fish-eating) predator fish. The NCDHHS, Division of Public Health has posted a fish consumption advisory for the Chowan River Basin that includes all Largemouth Bass, Black Crappie, Catfish, Chain Pickerel, and Warmouth; Yellow Perch, and Bowfin (or Blackfish) caught east of I-85; and for Black Crappie caught south and east of I-95 for mercury contamination (NCDWQ 2011a). Other fish consumption advisories in the basin include

Table 4.54 SGCN in the Chowan River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
CRAYFISH	*Orconectes virginiensis*	Chowanoke Crayfish	FSC/SC
FISH	*Acipenser brevirostrum*	Shortnose Sturgeon	E/E
	Acipenser oxyrinchus	Atlantic Sturgeon	E/E
	Ameiurus platycephalus	Flat Bullhead	—
	Enneacanthus chaetodon	Blackbanded Sunfish	—
	Enneacanthus obesus	Banded Sunfish	—
	Moxostoma pappillosum	V-lip Redhorse	—
	Notropis bifrenatus	Bridle Shiner	FSC/E
	Notropis chalybaeus	Ironcolor Shiner	—
MUSSEL	*Alasmidonta undulata*	Triangle Floater	—/T
	Anodonta implicata	Alewife Floater	—/T
	Lampsilis cariosa	Yellow Lampmussel	FSC/E

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

an advisory for dioxin contamination for Catfish and Carp caught in the Albemarle Sound (NCDPH 2014). Historically, dioxin, a by-product of paper mill bleaching practices, degraded water quality and negatively affected aquatic biota. However, new bleaching technologies have reduced contaminates from paper plant wastewater that enter the basin (NCOEE 2015).

There are 51 permitted CAFOs in the Chowan River Basin with 100 waste lagoons associated with the facilities. Waste from these sites contains high levels of nutrients (e.g., nitrogen and phosphorus) in addition to fecal coliform bacteria and any chemical compounds, such as antibiotics or hormone products used in commercial feeding operations (NCDWR 2015b). Animal-waste lagoons and spray fields that discharge near or into aquatic environments through runoff, percolation into groundwater, and volatilization of ammonia and the release of bacterial contamination can significantly degrade water quality and endanger human and animal health (Mallin 2003; Mallin and Cahoon 2003).

Chronic episodes of hypoxia exist in the Chowan River and its tributaries in most years during seasonally hot weather. Dissolved oxygen levels frequently fall below 3.0 mg/l, which negatively affects aquatic biota. Cyclonic events and their accompanying rainfall, storm surge, inundation, and flushing of bottomland swamp habitats have occurred repeatedly within the basin since 1995. These tropical events exacerbate an already fragile summer ecosystem, which leads to lower DO levels that can produce major fish kills within the basin (NCDWQ 2007a). Soil erosion and runoff of fertilizer and animal waste caused by farming has been a concern within the basin. However, farmers have taken positive steps to reduce runoff effects which have resulted in 123,244 fewer tons of eroding soils each year (NCOEE 2015).

There are no interbasin transfers between the Chowan and other river basins. Water withdrawals occur primarily for agricultural purposes (NCDWQ 2007a). Nonpoint pollution sources that degrade water quality include agriculture, animal operations, urban development, forestry operations, stormwater discharge, rural residential development, hydrologic modifications, and septic systems. Point pollution sources in the basin may include municipality wastewater treatment plants, industrial facilities, and urban and industrial stormwater systems.

Two of the five counties in the basin are expected to experience growth rates in excess of 10% by 2020. As the counties in the Chowan River Basin continue to grow along the inner waterways there will likely be a loss of natural areas and an increase in the amount of impervious surface associated with new homes and businesses (NCDWQ 2007a).

Sea level rise has the potential to dramatically alter North Carolina's coast and estuary systems. Coastal infrastructure, residential properties and industry are threatened and water quality conditions will change (NCDWQ 2007a).

4.5.7.5 Recommendations

Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priorities identified in the Chowan River Basin are shown in Figure 4.14 and a list of the priority 12-digit HUCs is included in Appendix J.

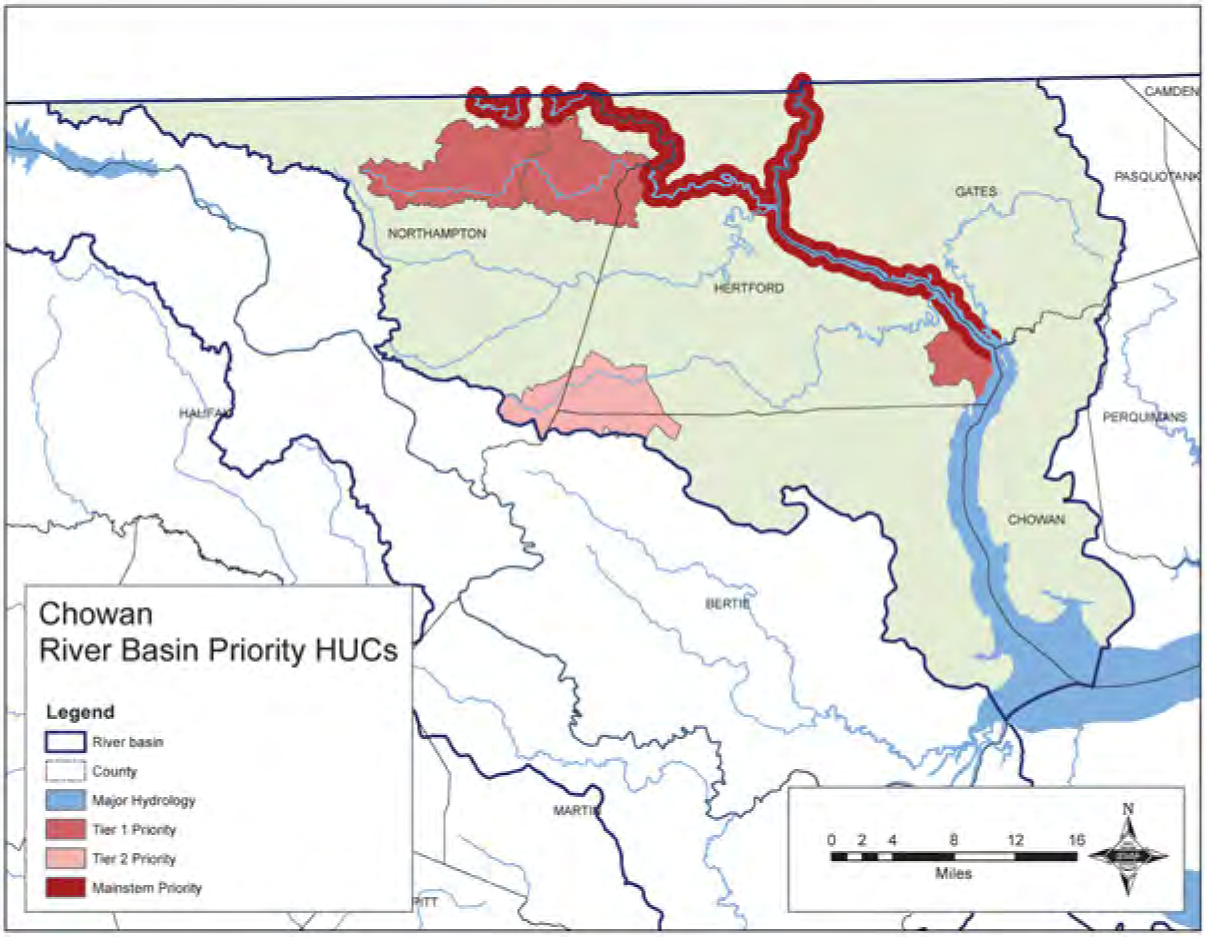
Basin Specific Recommendations

Surveys. General surveys are needed to complete primary distributional status for SGCN and other priority species (see Appendix G).

- Aquatic Snails—conduct baseline distribution surveys for all species.
- Crayfish—conduct a baseline distribution survey for *Cambarus sp. C*.
- Fishes—determine distribution of priority species (e.g., Bridle Shiner, Blackbanded Sunfish, and V-lip Redhorse).
- Mussels—determine distribution of priority species (e.g., Yellow Lampmussel, Alewife Floater, and Eastern Pondmussel).

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to a changing climate. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform future decisions on how to manage

FIGURE 4.14 **Location of priority watersheds in the Chowan River Basin**



species and their habitats. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Identify long-term monitoring sites and develop monitoring protocols for priority species (e.g., Ironcolor Shiner, Triangle Floater, and Chowanoke Crayfish).

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic or evolutionary status of locally variable forms are needed.

- Study habitat use and life-history characteristics of priority species (e.g., Atlantic Sturgeon, Chowanoke Crayfish, and V-lip Redhorse)
- Determine impacts of nonnative species on priority species.
- Support taxonomic research for priority species (e.g., Lake Phelps Killifish and *Cambarus sp. C*).
- Support genetics research that informs augmentation policy.
- Support development of captive propagation techniques for priority species (e.g., Bridle Shiner, Banded Sunfish, and Alewife Floater)

In addition to the SGCN species found in the basin (see Table 4.54), a list of knowledge-gap priority species is provided in Table 4.55.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats.

- Support efforts to restore the native aquatic community (e.g., reintroduction or augmentation).

Table 4.55 Knowledge-gap priority species in the Chowan River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
FISH	*Etheostoma vitreum*	Glassy Darter	—
	Fundulus diaphanus	Banded Killifish	—
	Lepisosteus osseus	Longnose Gar	—
	Percina roanoka	Roanoke Darter	—
	Petromyzon marinus	Sea Lamprey	—
MUSSEL	*Corbicula fluminea*	Asian Clam [Exotic]	—
	Elliptio fisheriana	Northern Lance	—
	Elliptio icterina	Variable Spike	—
	Lampsilis radiata	Eastern Lampmussel	—/T
	Ligumia nasuta	Eastern Pondmussel	—/T
	Pyganodon cataracta	Eastern Floater	—
	Uniomerus carolinianus	Florida Pondhorn	—
	Utterbackia imbecillis	Paper Pondshell	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

- Support acquisition of land that is adjacent to current conservation holdings or priority watersheds.
- Support other regulatory agencies to minimize impacts on species and habitats.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Support the implementation of the Coastal Habitat Protection Plan at all levels of government and amongst citizens (NCDWQ 2007a).
- Continue collaborative efforts between natural resource agencies within North Carolina and Virginia to improve adaptive management and policies on a watershed ecosystem scale (NCDWQ 2007a).
- Support restoration projects, potential renovation of Dillard's Millpond.
- Protect SAV in coastal areas (collaborate with Coastal NC SAV Coalition).

4.5.8 French Broad River Basin

4.5.8.1 River Basin Description

The French Broad River Basin in North Carolina encompasses 2,830 square miles, including 4,136 stream miles, and is entirely within the Mountain ecoregion. The headwaters are entirely within North Carolina. The basin drains from the north and western slopes of the Black Mountains, the highest range in the eastern United States. The upper mainstem French Broad River system drains from the high mountains of the Blue Ridge and flows through the broad, flat valley of the Asheville Basin.

The French Broad River Basin in North Carolina is composed of three major subbasins, each of which individually flow northwest into Tennessee: French Broad River, Pigeon River, and Nolichucky River.

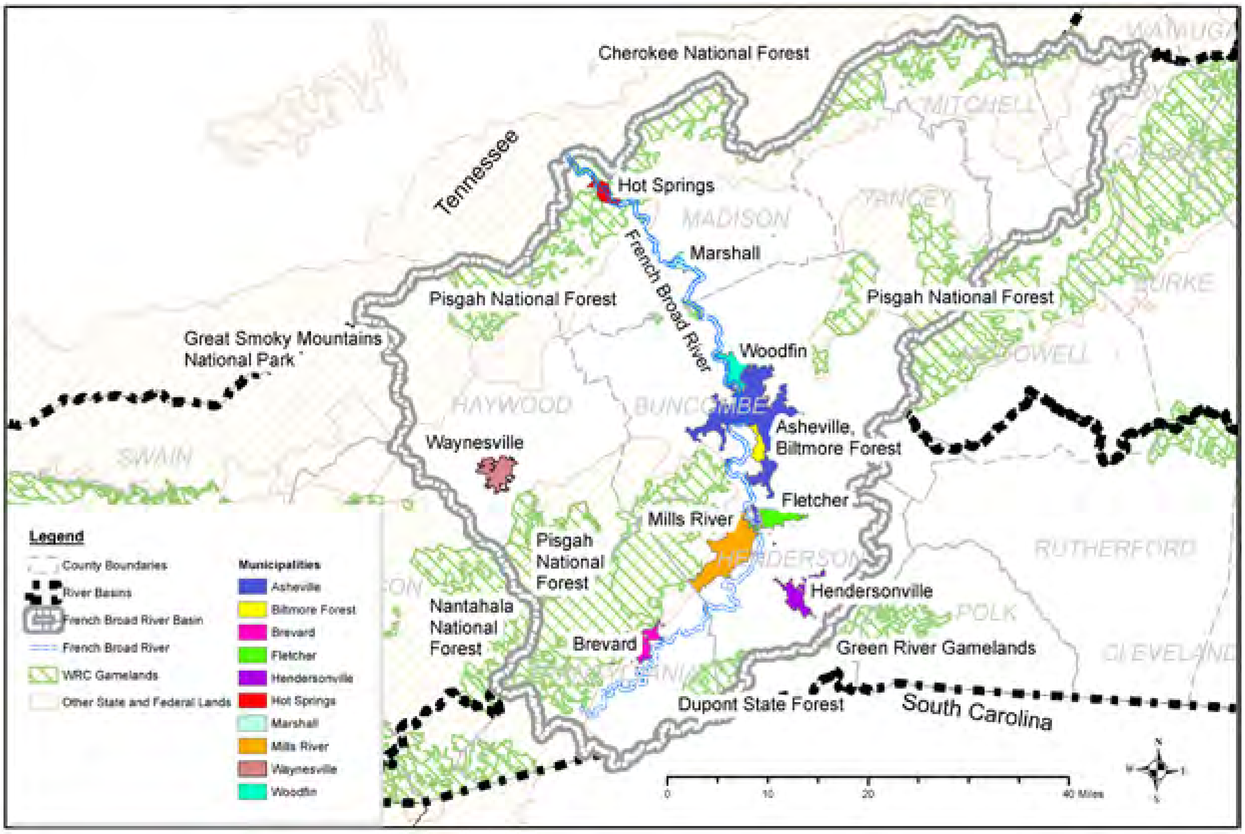
- Within the Asheville Basin, the French Broad and tributaries are relatively low gradient and share many habitat characteristics with streams in more lowland areas. Consequently, a number of aquatic species more typical of the Valley and Ridge, Piedmont, and even Coastal Plain are known from this part of the French Broad and nowhere else in the Blue Ridge Mountains. Near the city of Asheville, the French Broad flows out of the Asheville Basin and descends a relatively steep, narrow gorge before entering Tennessee. There are no major dams and reservoirs on the mainstem French Broad in North Carolina; however, there are three run-of-river impoundments with small detention pools (Craggy, Capitola, and Redmon). There are multiple small dams and impoundments on larger tributaries (e.g., Lake Julian, Beetree Reservoir, Enka Lake) and many more on smaller streams, especially in the upper portion of the watershed in Henderson and Transylvania counties.

- The topography of the Pigeon River watershed is similar, with high-gradient headwaters, a relatively flat midsection, and a steep gorge near the Tennessee border. Dams and impoundments in the Pigeon River subbasin include Walters Dam/Waterville Lake (with a 12-mile bypassed reach downstream), Lake Junaluska, Allen Creek Reservoir, and Lake Logan.

- The midSection of the Nolichucky River watershed lacks substantial flat areas and remains more high gradient and gorge-like throughout its length in North Carolina. While there are a few small impoundments on minor tributaries, there are no dams on the Nolichucky River and its major tributaries.

Approximately 77% of the basin is forested, 11% is agriculture, 11% is considered developed, 1% is grassland, and less than 1% is wetlands (MRLC 2011; Jin et al. 2013). Much of the forested land is at the higher elevations and lies within the boundaries of Pisgah National Forest, Blue Ridge Parkway, and a portion within the Great Smoky Mountains National Park. Most

Figure 4.15 Location of the French Broad River Basin



agricultural and developed lands are concentrated within the river valleys, though residential development is occurring on increasingly steeper slopes.

The basin contains all or portions of eight counties (Avery, Buncombe, Haywood, Henderson, Madison, Mitchell, Transylvania, and Yancey), and all or portions of 27 municipalities, including Asheville, Brevard, Hot Springs, and Waynesville. Figure 4.15 depicts the geographic location of the basin.

4.5.8.2 Aquatic Resource Conditions

Water quality is generally good for areas where data are available; however, there are problems (described below) in parts of the basin, and the lack of data for nearly half the basin provides an unclear assessment of overall water quality. It is important to note that all waters in the state are rated as impaired based on a state-wide fish consumption advisory for mercury contamination. There are more than 4,700 miles of freshwater streams in the basin that have been classified by NCDWR for best uses (NCDWR 2015d). Table 4.56 provides information on water quality classifications and use-support ratings in the basin.

Table 4.56 Water quality classification and rating information for the French Broad River Basin

Classifications	Freshwater Miles	Percent (Basin Waters)	Freshwater Acres	Percent (Basin Waters)
Total Basin Waters*	8,390	—	1,946	—
HQW	698	8	377	19
ORW	657	8	0	0
Use Ratings	**Freshwater Miles**	**Percent (Monitored Waters)**	**Freshwater Acres**	**Percent (Monitored Waters)**
Total Named Waters	3,995	—	2,032	—
Supporting	908	23	1,645	81
Impaired	252	6	—	—
Not Rated	35	<1	—	—
No Data	2,801	70	387	19

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

North Carolina Division of Water Resources' trout water designation (Tr) is a supplemental classification that protects freshwaters for natural propagation of trout and survival of stocked trout on a year-round basis. There are about 2,545 miles of streams in the French Broad River Basin designated as trout waters. This is not the same as the Commission's designated public Mountain Trout Waters, which is used to designate waters that support trout and are open to public fishing.

There are a total of 50,117 acres of HQW Special Management Strategy Areas (SMSAs) in the basin: the East Fork and West Fork of the French Broad River; Crab, Williamson, Laurel, and Catheys creeks; and Rocky, Rockbrook Camp, and Keystone Camp branches (NCDWR 2015c). There are 231,580 acres of ORW SMSAs for Big Laurel and Spring creeks, South Toe River and Tributaries Area, Cataloochee Creek Area, South Fork Mills River, and Rough Creek Area. There are also 163,614 acres of HQW SMSAs that span the Little Tennessee and French Broad River Basins. The SMSAs require site-specific provisions to protect resource values (e.g., no new discharges or expansion of existing discharges) (see 15A NCAC 02B.0225).

4.5.8.3 Aquatic Species

There are 26 SCGN in the basin: 2 amphibian species, 1 crayfish, 19 freshwater fishes, and 4 freshwater mussel species. Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN associated with aquatic communities found in this river basin. Table 4.57 identifies the SGCN found in the French Broad River Basin.

Table 4.57 SGCN in the French Broad River Basin

Taxa Group	Scientific Name	Common Name	Federal/State Status*
AMPHIBIAN	*Cryptobranchus alleganiensis allaganiensis*	Eastern Hellbender	FSC/SC
	Eurycea junaluska	Junaluska Salamander	FSC/T
CRAYFISH	*Cambarus reburrus*	French Broad River Crayfish	FSC/—
FISH	*Aplodinotus grunniens*	Freshwater Drum	—/SC
	Carpiodes carpio	River Carpsucker	—/SC
	Carpiodes cyprinus	Quillback	—
	Cottus carolinae	Banded Sculpin	—/T
	Erimystax insignis eristigma	Southern Blotched Chub	FSC/—
	Etheostoma acuticeps	Sharphead Darter	FSC/T
	Etheostoma simoterum	Tennessee Snubnose Darter	—/SC
	Hiodon tergisus	Mooneye	—/SC
	Lampetra appendix	American Brook Lamprey	—
	Moxostoma breviceps	Smallmouth Redhorse	—
	Moxostoma carinatum	River Redhorse	—
	Noturus eleutherus	Mountain Madtom	—/SC
	Noturus flavus	Stonecat	—/E
	Percina burtoni	Blotchside Logperch	FSC/E
	Percina caprodes	Logperch	—/T
	Percina squamata	Olive Darter	FSC/SC
	Salvelinus fontinalis	Brook Trout (Native)	—
MUSSEL	*Alasmidonta raveneliana*	Appalachian Elktoe	E/E
	Alasmidonta viridis	Slippershell Mussel	—/E
	Fusconaia subrotunda	Longsolid	FSC/—
	Pleurobema oviforme	Tennessee Clubshell	FSC/E

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

4.5.8.4 Threats Affecting Aquatic Species

Habitat degradation resulting from nonpoint source pollution is the most widespread problem throughout the basin. Nutrient enrichment was identified as a greater problem in the French Broad River Basin than in any other interior basin drainage in the region (Hampson et al. 2000). Highway construction and its associated indirect and secondary impacts are also significant concerns in many parts of the basin.

Development, urbanization, and agriculture are significant sources of nonpoint source pollution and sedimentation. Poorly managed development on steep slopes and within riparian areas along tributaries apparently contributes much of the sedimentation from development activities. Threats from hydrologic modifications resulting from increased urbanization (i.e., increased impervious surfaces, flood plain development and filling, stream channel alterations) seem to be increasing throughout the basin, with some areas experiencing greater impacts than others.

Habitat degradation from point sources of pollution, though not as widespread as nonpoint sources, is still a significant problem in portions of the basin. Compared to other basins in the region (e.g., Hiwassee, Little Tennessee, and Catawba), impacts from impoundments are relatively minor in the French Broad River Basin; however, these impacts are an issue for portions of the basin.

Problems associated with nonnative and invasive species are unclear at present; however, the native Long-Ear Sunfish has apparently been displaced entirely throughout the basin by the nonnative Redbreast Sunfish. The White River Crayfish, White Catfish, Flat Bullhead and Snail Bullhead (all native to the Atlantic Slope) are established in the basin. The Red Swamp Crawfish, a native of the lower Mississippi and Gulf Coast drainages, has apparently become established recently in the upper French Broad River subbasin, and could threaten the endemic French Broad Crayfish. The Asian Clam is known to exist in the French Broad River subbasin, but its extent throughout the basin is not fully documented. The invasive Japanese Knotweed is widespread and expanding in riparian areas throughout the basin.

Habitat for priority aquatic species in the French Broad River subbasin is affected by impacts related to development and urbanization, agriculture, and point sources. Sedimentation and turbidity are more or less chronic problems in most of the larger streams in the lower elevations of the Asheville watershed and surrounding area, including the mainstem French Broad River. Point source pollution, including both present problems and residual effects from much more severe pollution of the past, contributes significantly to habitat degradation and the extirpation of priority species. However, aquatic habitats overall have improved substantially over the past 40 years.

Very few high-quality habitats for cool- and warmwater priority species in medium to large streams have remained intact through the 20th century. The mainstem French Broad River and tributaries from the confluence of the Davidson River downstream to the Tennessee border have lost a substantial portion of their aquatic species. Habitat continues to remain unsuitable for some of these species; however, recovery of some species may be possible. The Upper French Broad River, Little River, Mills River, and Ivy River have been the primary refuges for most of the priority species that are still extant in this subbasin. However, increased development and chance events are ever-present threats in such fragmented refugia.

High-quality habitat for priority mussels in the Little River is limited to a short reach between Cascade Lake and the confluence of Crab Creek, where sedimentation from agriculture and development in the watershed degrades habitat. Runoff from large-scale agriculture and development, and riparian degradation and bank erosion threaten the lower Mills River.

Dams on the mainstem French Broad River are run-of-river and appear to have fewer negative impacts than peaking operation and reservoir impoundment. Barrier effects and population fragmentation (or at least the isolation of upstream populations) impact extant riverine fishes (especially potamadromous species) and the potential for restoration of extirpated species (e.g., Lake Sturgeon, Sauger).

The Pigeon River has experienced significant degradation from point source pollution and impoundment, as well as nonpoint sources. A paper mill at Canton (Blue Ridge Paper Products, formerly Champion Paper) discharged toxic wastes directly into the Pigeon River for several decades. Many priority species were eliminated from the mainstem Pigeon River by this pollution. Improvements in wastewater treatment that began in the early 1990s have improved habitat conditions and prospects for recovery of many native species are good. Improvements in the paper mill's impacts to the reservoir must meet certain thresholds defined by chemical and biological criteria before water can be released.

The most significant impacts from impoundment in the French Broad River Basin are at the Walters Dam (Progress Energy) and bypass reach on the Pigeon River. Approximately 5 miles of the river is impounded in Walters Reservoir, and the river 12 miles downstream from Walters Dam is dewatered (except for some leakage at the dam and tributary inflow) by bypassing water from the reservoir through a penstock to a powerhouse near the Tennessee state line. Restoration of minimum flows to the bypassed reach is tied to improvements in upstream water quality (per FERC, Article 414).

The Pigeon River and short reaches of the East Fork and West Fork of the Pigeon, upstream from Canton, have remained a relatively high-quality cool- and warmwater habitat that has provided refuge for most of the priority species that are still extant in the subbasin. Increasing development could potentially degrade this important habitat. Other tributaries, such as Jonathans Creek, Richland Creek, Fines Creek, and Crabtree Creek are variously degraded by nonpoint source pollution that comes primarily from poorly managed agriculture and increasing development.

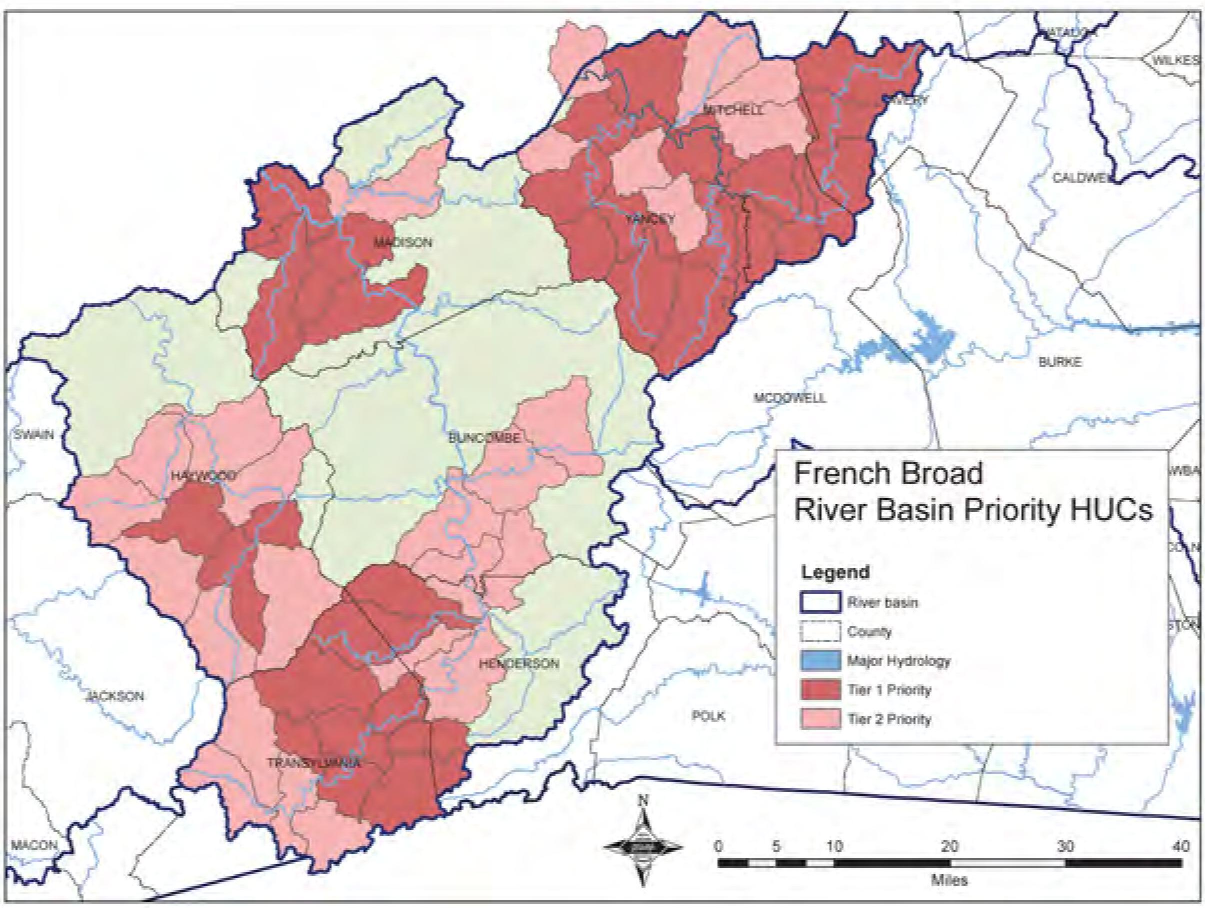
Historically, sedimentation and pollution from several mining operations throughout the Nolichucky River subbasin (primarily in the North Toe watershed) significantly degraded cool- and warmwater habitats. Encouragingly, improvements that began in the 1970s have helped reduce these impacts. Habitat in the North Toe River between Spruce Pine and the South Toe River confluence continues to be degraded, apparently from discharges and runoff from mining operations and the town of Spruce Pine. Floodplain gravel mining in the Cane River watershed poses a potential threat to long-term channel stability and habitat quality.

The failure of the Burnsville wastewater treatment plant in 2008 had serious impacts on the Cane River, with most of the Appalachian Elktoe population eliminated; however, major renovations and improvements at the treatment plant have restored water quality conditions. Development is increasing throughout much of this subbasin and erosion and sedimentation may also be on the rise.

4.5.8.5 Recommendations

Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priorities identified in the French Broad River Basin are shown in Figure 4.16 and a list of the priority 12-digit HUCs is included in Appendix J.

Figure 4.16 Location of priority watersheds in the French Broad River Basin



Basin Specific Recommendations

Surveys. Primary distributional surveys for most priority species have been completed; however, more detailed data are needed.

- Snails—inventory primary distribution; determine potential habitats and distribution surveys for hydrobiids.
- Crayfishes—complete primary inventories and determine status of endemic species.
- Survey seasonal occurrence of potamodromous, or migratory riverine fishes in the lower reaches of French Broad, Pigeon, and Nolichucky rivers.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters. Studies should include identification of population trends, as well as assessment of impacts from conservation and development activities and invasive species. These efforts will inform species and habitat management decisions. Long-term monitoring sites have been established and baseline data gathered in most areas of the basin for fishes, crayfishes, and mussels, and monitoring strategies have been developed for many priority species, including Appalachian Elktoe. Periodic sampling of species and habitat condition should continue and be guided by potential for change. More frequent monitoring may be required for specific project assessment.

- Conduct special purpose monitoring to assess performance of specific conservation actions, such as Pigeon River species restoration and Appalachian Elktoe restoration in Cane River.
- Monitor distribution and status of nonnative species (e.g., nonnative catfishes and crayfishes).

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Long-term habitat improvement trends in the basin may present more opportunities for reintroduction of native species. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Support research projects on improving the success and efficiency of Pigeon River species restoration projects and other species restoration projects in the basin.

- Investigate impacts from development, habitat fragmentation, point and nonpoint source pollution, and invasive species in the basin. Vulnerable species include French Broad Crayfish, Appalachian Elktoe, and native catfishes.

- Explore further opportunities for species restoration, especially extirpated priority species. Determine measurable habitat requirements and assess basin conditions for potential reintroduction opportunities (e.g., Lake Sturgeon, priority mollusks).

In addition to the SGCN species found in the basin (see Table 4.57), a list of knowledge-gap priority species is provided in Table 4.58.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations

Table 4.58 Knowledge-gap priority species in the French Broad River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
FISH	*Cyprinella spiloptera*	Spotfin Shiner	—
	Etheostoma chlorobranchium	Greenfin Darter	—
	Etheostoma gutselli	Tuckasegee Darter	—
	Etheostoma rufilineatum	Redline Darter	—
	Etheostoma swannanoa	Swannanoa Darter	—
	Hybopsis amblops	Bigeye Chub	—
	Ichthyomyzon bdellium	Ohio Lamprey	—
	Ichthyomyzon greeleyi	Mountain Brook Lamprey	—
	Ictiobus niger	Black Buffalo	—
	Lepisosteus osseus	Longnose Gar	—
	Luxilus chrysocephalus	Striped Shiner	—/SC
	Notropis micropteryx	Highland Shiner	—
	Notropis photogenis	Silver Shiner	—
	Notropis rubricroceus	Saffron Shiner	—
	Notropis telescopus	Telescope Shiner	—
	Notropis volucellus	Mimic Shiner	—
	Percina aurantiaca	Tangerine Darter	—
	Percina evides	Gilt Darter	—
	Phenacobius crassilabrum	Fatlips Minnow	—
	Pimephales notatus	Bluntnose Minnow	—
	Sander canadensis	Sauger	—
MUSSEL	*Corbicula fluminea*	Asian Clam [Exotic]	—
	Strophitus undulatus	Creeper	—/T
	Utterbackia imbecillis	Paper Pondshell	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital. Specific issues in this basin include high rates of development and associated erosion and sedimentation, secondary and cumulative impacts upon water quality, riparian vegetation restoration and conservation, point sources of pollution, water supply watershed protection, and headwaters protection.

- Support conservation and restoration of streams and riparian zones in priority areas.
- Incorporate management goals for aquatic community conservation and enhancement planning for Sandymush and Cold Mountain Game Lands.
- Continue current species restoration efforts in the Pigeon River and reintroduce extirpated species in restored or improved habitats as opportunity allows.
- Continue restoration and augmentation of Appalachian Elktoe in the Cane River.
- Prioritize education and other measures to prevent the introduction or spread of invasive nonnative species, especially crayfishes.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience. Many overlapping priorities and common objectives, readily available support, and many willing partners provide abundant opportunities in the French Broad River Basin. See NCDWR Basin Plan, Chapters 9 and 10, for more information: http://portal.ncdenr.org/web/wq/ps/bpu/basin/frenchbroad/2011.

- Support NCDMS's Watershed Restoration Plan (WRP) and River Basin Restoration Priorities (RBRP) for the French Broad River Basin, and several Local Watershed Plans (LWP) and Project Atlases, including Mud Creek, Bald Creek, South Hominy Creek subbasins (NCWRP 2001b; NCEEP 2003, 2005, 2006). Available online: http://portal.ncdenr.org/web/eep/rbrps/french-broad.
- Work with multiple agency and non-governmental partners and potential partners to share common goals and objectives, and take advantage of the many opportunities for cooperation throughout the basin. These partners include: USFWS, NCDWR, Haywood Waterways Association, North Toe Partnership and Toe River Watch, RiverLink, French Broad Riverkeeper, The Pigeon River Fund, and many others.

- Partner with Soil and Water Conservation District and NRCS programs, such as the Agriculture Cost Share Program, as they are also effective partners for conservation in priority areas.

- Continue successful restoration partnerships in the Pigeon River and Richland Creek to restore habitats and species.

- Continue work with Duke Energy, FERC, French Broad EMC, resource agencies, and other cooperators to fulfill relicense settlement agreements and other mitigation for hydropower impacts from Little Tennessee River Basin projects.

4.5.9 Hiwassee River Basin

4.5.9.1 River Basin Description

The Hiwassee River is part of the Mississippi River System, with headwaters that begin in Georgia. The Hiwassee River flows generally to the northwest through North Carolina and into Tennessee, where it joins the Tennessee River. The North Carolina portion of the basin is located entirely within the Mountain ecoregion. Major tributaries in the basin include the Valley River, Nottely River, Tusquitee Creek, and Brasstown Creek. There are approximately 2,068 miles of freshwater streams and 10,583 acres of impoundments and reservoirs in the basin (NCDWR 2015j; USGS n.d.).

The Valley River and Brasstown Creek are the largest streams that are not impounded in the North Carolina portion of the basin. The main stem Hiwassee and Nottely Rivers are regulated by the Tennessee Valley Authority (TVA) for the production of hydroelectric power, with three large impoundments that form the Chatuge, Hiwassee, and Apalachia reservoirs.

- Chatuge Reservoir straddles the North Carolina/Georgia line and impounds the Hiwassee River. The North Carolina portion of the lake is situated in the southwestern portion of the state in Clay County. It provides flood damage reduction, hydroelectric power generation, augmentation of water flows for navigation downstream, and numerous recreational opportunities (TVA 2015). The shoreline is surrounded by development and its proximity to four major cities in four different states likely contributes to its popularity for vacation homes.

- Hiwassee Reservoir impounds the Hiwassee River to create a 22-mile long reservoir in Cherokee County, NC. The reservoir provides hydroelectric power generation and flood damage reduction, as well as several recreational facilities for camping, fishing, and boating (TVA n.d.).

- Apalachia Reservoir is downstream from Hiwassee Reservoir and the powerhouse is operated as run-of-river (little or no water storage provided). Most flow from the dam is diverted through a pipeline from the dam to the Apalachia Powerhouse 8.3 miles downstream in Tennessee before it is returned to the river channel. Minimum flows are released from the dam to the channel downstream, which crosses the state line less than a mile from the dam. The reservoir has very little private shoreline development and no commercial recreational facilities (TVA n.d.).

The Hiwassee River Basin covers approximately 644 square miles, making it one of the smaller basins in the state. Based on 2011 National Land Cover Dataset information, land use in the basin was estimated to be 85% forested, 7% urban or developed, 5% agricultural, 2% grassland, and less than 1% wetland (MRLC 2011). The Nantahala National Forest covers nearly half of the basin and there are substantial private holdings in the middle and higher elevations. Small portions of Eastern Band of Cherokee Indian tribal lands are located within the basin (primarily within the Hanging Dog Creek watershed).

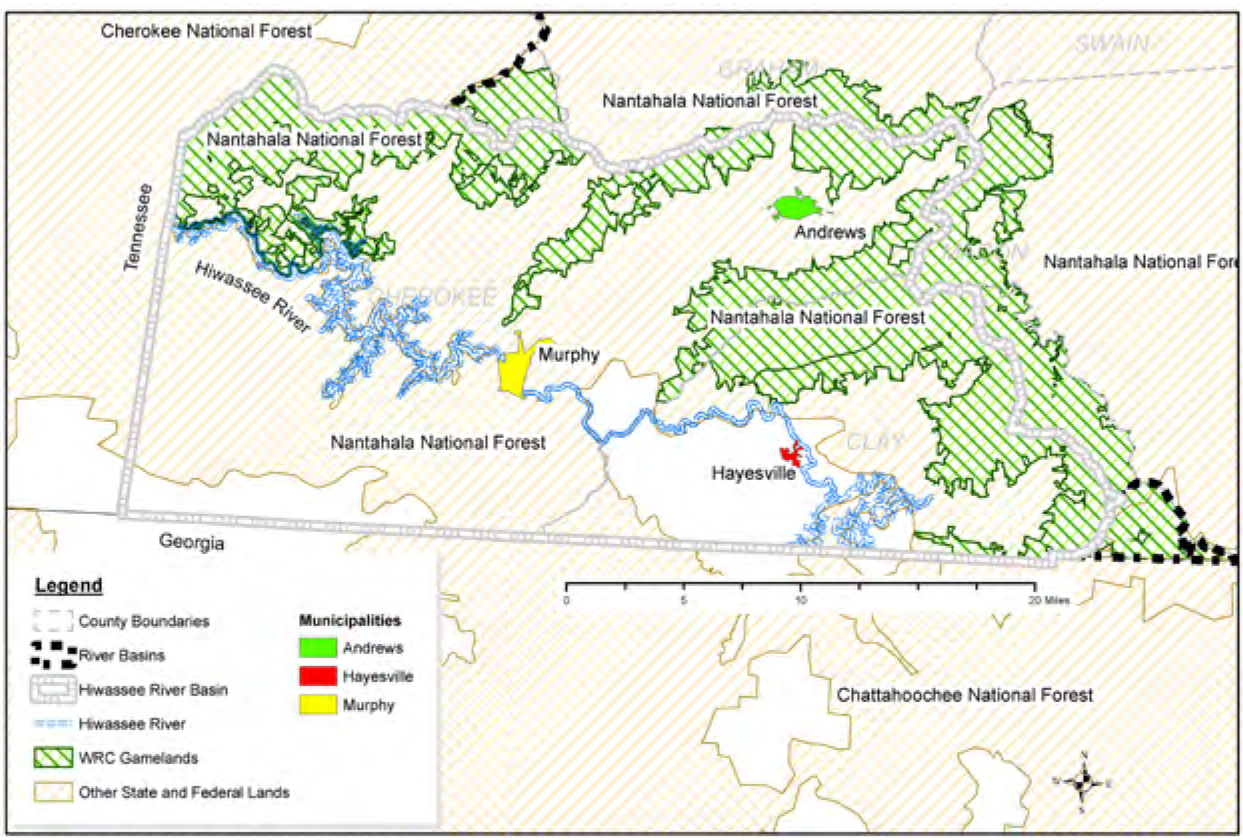
The Hiwassee River Basin encompasses all or portions of two counties (Cherokee and Clay) and three municipalities (Andrews, Hayesville, and Murphy). Figure 4.17 depicts the geographic location of the basin.

4.5.9.2 Aquatic Resource Conditions

Surface waters of the state are assigned a classification that carries standards for protection of the best uses of that water. Classification categories include aquatic life, recreation, fish consumption, and water supply. There are 1,277 miles of freshwater streams in the basin that have been classified by NCDWR for best intended uses. It is important to note that all waters in the state are rated as impaired based on a state-wide fish consumption advisory for mercury contamination.

Some waterbodies in the basin have supplemental classifications as High Quality Waters (HQW) or Outstanding Resource Waters (ORW) because they either have excellent water

Figure 4.17 Location of the Hiwassee River Basin



quality or they are a significant resource to humans or wildlife (NCDWQ 2015d). There are ORW Special Management Strategy Areas in the basin for Britton Creek (425 acres); Fires Creek area (14,858 acres); Gipp Creek area (1,693 acres); and Tusquitee Creek area (19,561 acres) (NCDWR 2015c). These areas require site-specific provisions to protect resources (e.g., no new discharges or expansion of existing discharges) (see 15A NCAC 02B.0225). Detailed information on water quality parameters in the Hiwassee River Basin is available online from NCDWR Basin Planning Branch (http://portal.ncdenr.org/web/wq/ps/bpu). Table 4.59 provides summary information on water quality classifications and use-support ratings in the basin.

Another supplemental classification is NCDWR's trout water designation (Tr), which protects freshwaters for natural propagation of trout and survival of stocked trout on a year-round basis. There are about 306 stream miles in the Hiwassee River Basin designated as trout waters. This is not the same as the Commission's designated public Mountain Trout Waters, which is used to designate waters that are open to public trout fishing.

4.5.9.3 Aquatic Species

There are 24 SGCN in the basin: 2 aquatic amphibian species; 2 aquatic snail species; 5 crayfish species; 10 freshwater fish species; and 5 freshwater mussel species. Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN associated with aquatic communities found in this river basin. Table 4.60 identifies SGCN found in the Hiwassee River Basin.

Table 4.59 Water quality classification and rating information for the Hiwassee River Basin

Classifications	Freshwater Miles	Percent (Basin Waters)	Freshwater Acres	Percent (Basin Waters)
Total Basin Waters*	2,068	—	10,583	—
Classified Waters	1,277	62	9,742	92
HQW	71	3	—	—
ORW	55	3	—	—
Use Ratings	**Freshwater Miles**	**Percent (Basin Waters)**	**Freshwater Acres**	**Percent (Basin Waters)**
Total Named Waters	934	—	10,357	—
Supporting	185	20	10,315	99
Impaired	44	5	—	—
Not Rated	13	1	—	—
No Data	692	74	42	<1

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

A USFWS assessment of imperiled fishes of the southern Appalachian ecosystem notes the Hiwassee River is one of the highest priority stream systems in the ecosystem (Butler 2002b). Five highly imperiled taxa were identified for the river system; of these taxa, four are found in North Carolina. The report identified five additional imperiled fishes occurring in the Hiwassee River Basin in North Carolina. The imperiled species identified in the report that can be found in North Carolina are as follows:

- Sicklefin Redhorse—occurs in clean streams with little sedimentation, generally in swift water over rocky substrata.
- Greenside Darter—occurs in swift riffles with boulders and rubble.
- Redline Darter—occurs in swift, shallow, rocky riffles in clear streams.
- Olive Darter—occurs in fast boulder and bedrock chutes.
- Smoky Dace—occurs in sand and rock pools of small montane streams.

Table 4.60 SGCN in the Hiwassee River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
AMPHIBIAN	*Cryptobranchus alleganiensis allaganiensis*	Eastern Hellbender	FSC/SC
	Eurycea junaluska	Junaluska Salamander	FSC/T
AQ SNAIL	*Elimia christyi*	Christy's Elimia	FSC/E
	Leptoxis virgata	Smooth Mudalia	FSC/—
CRAYFISH	*Cambarus acanthura*	Thornytail Crayfish	—
	Cambarus brimleyorum	Valley River Crayfish	—
	Cambarus carolinus	Red Burrowing Crayfish	—
	Cambarus nodosus	Knotty Burrowing Crayfish	—
	Cambarus parrishi	Hiwassee Headwater Crayfish	FSC/SC
FISH	*Clinostomus sp. 1*	Smoky Dace	FSC/SC
	Cottus carolinae	Banded Sculpin	—/T
	Erimystax insignis eristigma	Southern Blotched Chub	FSC/—
	Moxostoma breviceps	Smallmouth Redhorse	—
	Moxostoma carinatum	River Redhorse	—
	Moxostoma sp 2	Sicklefin Redhorse	C/T
	Salvelinus fontinalis	Brook Trout (Native)	—
MUSSEL	*Elliptio dilatata*	Spike	—
	Fusconaia subrotunda	Longsolid	FSC/—
	Pleurobema oviforme	Tennessee Clubshell	FSC/E
	Pleuronaia barnesiana	Tennessee Pigtoe	FSC/E
	Villosa iris	Rainbow	—/SC

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

4.5.9.4 Threats Affecting Aquatic Species

Nonpoint source pollution and altered hydrologic regimes are primary impacts on native aquatic communities and their habitats in the Hiwassee basin. Human population growth, and associated residential and commercial development, is one of the most important issues in the basin. Development on steep slopes, increased impervious surfaces, contribute to increased erosion and sedimentation, as well as increased wastewater and runoff of contaminants, which negatively impacts water quality, hydrology, and aquatic habitat (NCDWQ 2012b). Development is likely to increase substantially in the basin in the coming years.

Including the seven impoundments regulated under FERC licensing or operated by TVA in the basin, an NCDENR dam inventory (NCDEMLR 2014) indicates there are at least 52 impoundments in the basin. Fifty-seven miles of historically free-flowing riverine habitats are now either seasonally or permanently flooded by Chatuge, Mission, Hiwassee, and Appalachia dams and reservoirs, or are indirectly affected by impoundment. The unimpounded reaches of the Nottely and Hiwassee rivers, downstream from dams, are affected by coldwater releases, altered hydrologic regimes, and periodic low levels of DO due to hypolimnetic and peaking power production releases from Chatuge and Nottely dams. Impoundment and thermal alteration may further affect native species by fragmenting available suitable habitat and isolating historically contiguous populations in tributaries.

The NCDWR also monitors state waters to determine if they are supporting their use classification(s) and assigned use-support ratings. The NCDWR reports Lake Chatuge has been consistently oligotrophic (offering little to sustain life) since monitoring first began (2012b) and ecological health has been rated primarily as either poor or at the low end of the fair range in most years (TVA n.d.). Periodic higher ecology health ratings have been associated with improved chlorophyll levels, higher levels of DO, timing and amount of rainfall, and changes to runoff and contaminants in sediment (TVA n.d.). The Hiwassee River Watershed Coalition and TVA developed the Lake Chatuge Watershed Action Plan (HRWC 2007) to serve as a restoration guide for returning the lake to good ecological health.

Nonnative species also pose potential threats to native aquatic species in the Hiwassee River Basin. The Blueback Herring, Asian Clam, Striped Bass, Snail Bullhead, Rainbow Trout, Brown Trout, and Rusty Crayfish are established in the basin. Blueback Herring appear to be having an impact on game species (i.e., Walleye) in the Hiwassee Reservoir and Hiwassee River, but impacts to nongame species are unknown at present. Specific impacts from Asian Clam and introduced game fishes are also unclear. Other potential problems are indirect effects from invasive plant species and exotic pathogens that can significantly alter riparian vegetation (e.g., Japanese Knotweed, Hemlock Wooly Adelgid).

4.5.9.5 Recommendations

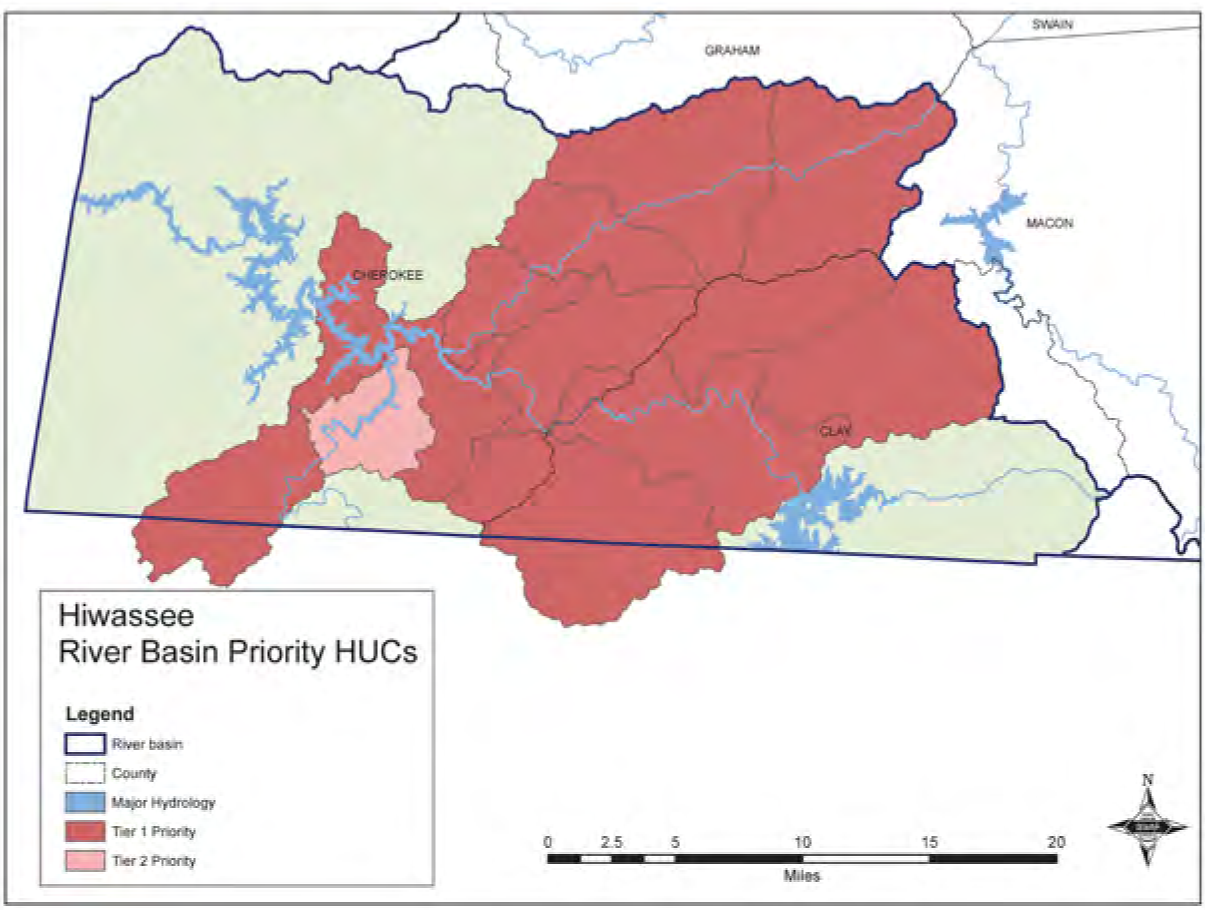
Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priorities identified in the Hiwassee River Basin are shown in Figure 4.18 and a list of the priority 12-digit HUCs is included in Appendix J.

Basin Specific Recommendations

Surveys. General surveys are needed to complete primary distributional status for SGCN and other priority species (see Table 4.60).

- Sicklefin Redhorse—complete distribution surveys and support completion of life history studies; identify important spawning areas.
- Aquatic snails—inventory primary distribution; determine potential habitats and distribution surveys for hydrobiids.
- Determine distribution of nonnative species (e.g., Blueback Herring).

FIGURE 4.18 Location of priority watersheds in the Hiwassee River Basin



Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Create additional ambient monitoring stations or sediment monitoring stations in the basin, especially on Tusquitee Creek (NCDWQ 2012b).
- Conduct long-term monitoring to identify population trends for Sicklefin Redhorse, Blotched Chub, and Christy's Elimia.
- Monitor Blueback Herring populations to assess impacts on priority species.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Resolve the taxonomy of mussels in the genera *Villosa, Pleurobema,* and *Fusconaia*, and create species descriptions for Smoky Dace and Sicklefin Redhorse.
- Study early life history, propagation and culture, movement, and habitat use of Sicklefin Redhorse.
- Conduct research to improve habitat conditions in regulated reaches of the Hiwassee and Nottely rivers.
- Investigate aquatic community response to restoration projects in priority areas.
- Identify impacts of nonnative species on priority species and habitats (e.g., Blueback Herring).

In addition to the SGCN species found in the basin (see Table 4.60), a list of knowledge-gap priority species is provided in Table 4.61.

Table 4.61 Knowledge-gap priority species in the Hiwassee River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
FISH	*Cyprinella spiloptera*	Spotfin Shiner	—
	Etheostoma rufilineatum	Redline Darter	—
	Gambusia affinis	Western Mosquitofish [Nonnative in this basin]	—
	Hybopsis amblops	Bigeye Chub	—
	Ichthyomyzon greeleyi	Mountain Brook Lamprey	—
	Luxilus chrysocephalus	Striped Shiner	—/SC
	Notropis micropteryx	Highland Shiner	—
	Notropis photogenis	Silver Shiner	—
	Notropis telescopus	Telescope Shiner	—
	Percina aurantiaca	Tangerine Darter	—
	Percina evides	Gilt Darter	—
	Pimephales notatus	Bluntnose Minnow	—
MUSSEL	*Corbicula fluminea*	Asian Clam [Exotic]	—
	Utterbackia imbecillis	Paper Pondshell	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital. Specific issues in this basin include secondary and cumulative impacts upon water quality, riparian vegetation and stream bank restoration and conservation, mitigation of hydropower development impacts, and species restoration opportunities.

- Support conservation and restoration of streams and native riparian vegetation in priority areas, especially in the Valley River, Brasstown Creek, and the Peachtree-Martins Creek watersheds.
- Enforce erosion control and site-specific stormwater control requirements in order to protect water quality where development is occurring in watersheds with ORW, HQW, and Tr waters, especially Fires Creek and Tusquitee Creek, and the Sweetwater Creek watershed (NCDWQ 2012b).
- Investigate the potential for restoring Christy's Elimia, Sicklefin Redhorse, and priority mussel species in restored or improved habitats.

- Prioritize education and other measures to prevent the introduction or spread of invasive nonnative species, particularly crayfishes, Zebra Mussels, and land-locked river herring species (e.g., Blueback Herring, Alewife), as well as nonnative and invasive aquatic and riparian plants.

- The NCDMS (or NCEEP) has identified targeted local watersheds as restoration priorities in most river basins using 14-digit HUCs. Information about these priorities in the Hiwassee River Basin is available online: http://portal.ncdenr.org/web/eep/rbrps/hiwassee.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Continue to cooperate with the Hiwassee River Watershed Coalition, resource agencies, and other partners to implement watershed restoration efforts outlined in the Restoration Plan for the Hiwassee River Basin (NCWRP 2001c; NCEEP 2008a), and the Peachtree-Martins Creek Local Watershed Plan (NCEEP 2007b).

- Partner with Soil and Water Conservation District programs, such as the Agriculture Cost Share Program, as they are also effective partners for conservation in priority areas. They can provide technical guidance and assistance to agricultural landowners for planting and maintaining native woody species where fields (e.g., crops, hay, pasture) border riparian corridors (e.g., the Brasstown Creek and Valley River drainage areas) (NCDWQ 2012b).

- Establish programs to assist homeowners who have failed to replace septic systems with a new treatment system (a septic tank, dual or recirculation sand filters, disinfection, and step aeration) (NCDWQ 2012b).

- Support watershed restoration and action plans developed for the Valley River and Lake Chatuge (HRWC 2007).

- Cooperate with the USFWS to evaluate the status of Sicklefin Redhorse as a candidate for federal listing as threatened or endangered, and explore opportunities for Candidate Conservation Agreements.

4.5.10 Little Tennessee River Basin

4.5.10.1 River Basin Description

The Little Tennessee River Basin drains part of southwestern North Carolina in Graham, Macon, Swain, Jackson, and Clay counties in the Mountain ecoregion. The headwaters of the Little Tennessee River are in northeastern Georgia, where it flows for seven miles before entering North Carolina. The mainstem Little Tennessee River flows 125 miles through North Carolina before entering Tennessee where it joins the Tennessee River. It is part of the Tennessee/Ohio/Mississippi river system.

The basin covers 1,797 square miles in North Carolina and has 2,565 stream miles and 21,158 acres of impoundments. Major tributaries include the Cullasaja, Nantahala, Tuckasegee, Oconaluftee, and Cheoah rivers. Impoundments include Fontana, Nantahala, Calderwood, Cheoah, Santeetlah, Glenville, Bear Creek, Cedar Cliff, Wolf Creek, Tanasee Creek, Ela, Emory, and Sequoyah. Land use in the basin is about 90% forested, 5% urban or developed, 3% agricultural, and less than 1% each of grassland and wetland (MRLC 2011; Jin et al. 2013).

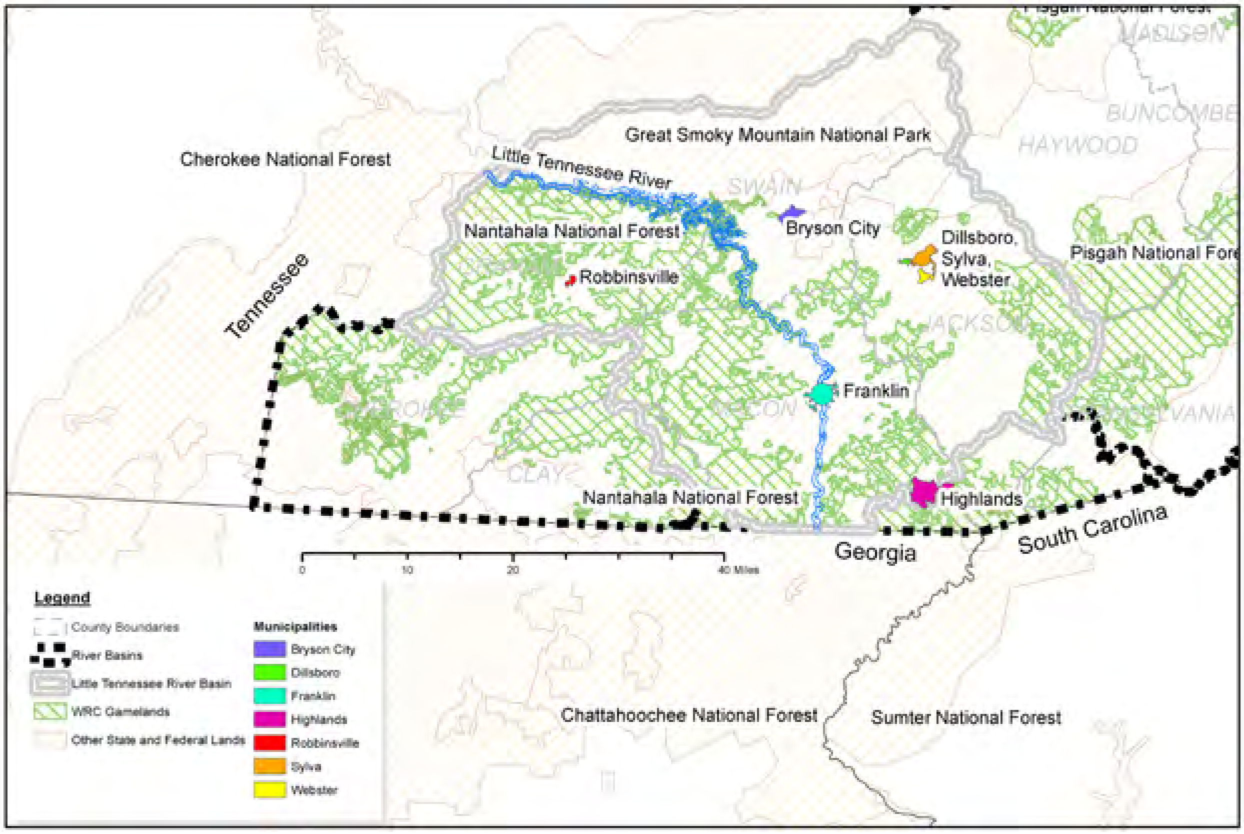
Land ownership in the basin is more than 50% publicly owned, with much of that lying within the boundaries of the Great Smoky Mountains National Park and Nantahala National Forest. The Needmore Game Land (about 4,600 acres) is a recently acquired tract along the Little Tennessee River in Macon and Swain counties and is managed by the NCWRC. The Qualla Boundary Cherokee Indian Reservation covers portions of the Oconaluftee and Tuckasegee watersheds. Much of the higher elevations are within the National Forest and National Park; however, development on private holdings in higher elevations has increased in recent years. Development is presently greatest in the valleys and along the major waterways.

The Little Tennessee River Basin encompasses all or portions of six counties and nine municipalities. Sizeable municipalities in this basin include Bryson City, Franklin, Highlands, and Sylva (Figure 4.19).

4.5.10.2 Aquatic Resource Conditions

There are more than 3,200 miles of freshwater streams in the basin that have been classified by NCDWR for best uses (NCDWQ 2012c). Water quality is generally good for areas where data are available; however, there are problems in parts of the basin (described below), and the lack of data for nearly half the basin provides an unclear assessment of overall water quality. It is important to note that all waters in the state are rated as impaired based on a state-wide fish consumption advisory for mercury contamination. In addition to the best-use classifications, NCDWR also monitors waters of the state to determine if they are

FIGURE 4.19 Location of the Little Tennessee River Basin



supporting their use classification(s) and assigned use-support ratings. These ratings are published in the most recent 303(d) impaired waterbodies list (NCDWQ 2007b, 2012c).

The upper headwaters of the East Fork Tuckasegee and Nantahala rivers are designated ORW and multiple higher elevation streams are designated HQW (NCDWR 2015a).There are ORW and HQW Special Management Strategy Areas in the basin for the Upper Nantahala River Area (34,397 acres), Tuckaseegee River Area (7,255 acres), North Shore Fontana Lake Area (83,016 acres), Snowbird Creek (10,719 acres), Slickrock Creek (6,648 acres), Flat Creek (2,671 acres), and Oconaluftee River (586 acres) (NCDWR 2015c). These areas require site-specific provisions to protect resource values (e.g., no new discharges or expansion of existing discharges) (see 15A NCAC 02B.0225).

Table 4.62 provides information on water quality classifications and use support ratings in the basin.

The basin contains some of the highest quality waters in the state, with many high elevation trout streams supporting native Brook Trout. There are approximately 1,727 miles of NCDWR designated trout waters (Tr) in the basin (NCDWR 2015a). This is not the same as the

Table 4.62 Water quality classification and rating information for the Little Tennessee River Basin

Classifications	Freshwater Miles	Percent (Basin Waters)	Freshwater Acres	Percent (Basin Waters)
Total Basin Waters*	4,647	—	15,307	—
HQW	442	10	1,389	9
ORW	302	7	756	5
Use Ratings	**Freshwater Miles**	**Percent (Monitored Waters)**	**Freshwater Acres**	**Percent (Monitored Waters)**
Total Named Waters	2,503	—	14,171	—
Supporting	436	17	12,370	87
Impaired	72	3	171	1
Not Rated	23	<1	—	—
No Data	1,973	79	1,630	12

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

Commission's designated public Mountain Trout Waters, which is used to designate waters that are open to public trout fishing.

The 24 mile-long reach of the Little Tennessee River between Franklin and Fontana Reservoir supports the greatest diversity and abundance of native aquatic species in the region. Strong populations of Spotfin Chub, Sicklefin Redhorse, and many other priority species generally thrive in the high quality habitat conditions. However, some historically abundant mussels, including Appalachian Elktoe, have declined precipitously throughout the reach. Good habitat conditions and native aquatic communities, including many priority species, also exist in the lower Tuckasegee River.

4.5.10.3 Aquatic Species

There are 19 SGCN priority species in the basin: four crayfish species, nine freshwater fish species, and six freshwater mussel species. Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN associated with aquatic communities found in this river basin. Table 4.63 identifies SGCN found in the Little Tennessee River Basin.

4.5.10.4 Threats Affecting Aquatic Species

The major problems affecting species and habitats in the Little Tennessee River Basin are impoundments (dams) and their associated impacts, and excess erosion and stream sedimentation. Of the entire 144 miles of the mainstem Little Tennessee River (in Georgia,

Table 4.63 SGCN in the Little Tennessee River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
CRAYFISH	*Cambarus carolinus*	Red Burrowing Crayfish	—
	Cambarus georgiae	Little Tennessee Crayfish	FSC/SC
	Cambarus reburrus	French Broad River Crayfish	FSC/—
	Cambarus tuckasegee	Tuckaseegee Stream Crayfish	—
FISH	*Clinostomus sp. 1*	Smoky Dace	FSC/SC
	Erimonax monachus	Spotfin Chub	T/T
	Etheostoma vulneratum	Wounded Darter	FSC/SC
	Moxostoma breviceps	Smallmouth Redhorse	—
	Moxostoma carinatum	River Redhorse	—
	Moxostoma sp 2	Sicklefin Redhorse	C/T
	Noturus flavus	Stonecat	—/E
	Percina squamata	Olive Darter	FSC/SC
	Salvelinus fontinalis	Brook Trout (native)	—
MUSSEL	*Alasmidonta raveneliana*	Appalachian Elktoe	E/E
	Alasmidonta viridis	Slippershell Mussel	—/E
	Elliptio dilatata	Spike	—/SC
	Pegias fabula	Littlewing Pearlymussel	E/E
	Pleurobema oviforme	Tennessee Clubshell	FSC/E
	Villosa iris	Rainbow	—/SC

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

North Carolina, and Tennessee), only 47 miles in Georgia and North Carolina remain unimpounded. Habitat alteration from impoundment, coldwater releases, and peaking flow regulation from dams also substantially impair and limit native aquatic communities in the upper Tuckasegee, Nantahala, and Cheoah river systems. Populations of aquatic animals are also fragmented and isolated by dams and other barriers throughout the basin.

Potentially high-quality habitats are further degraded from nonpoint source pollution, primarily from erosion and sedimentation from disturbance related to development and agriculture. Water and habitat quality upstream from Lake Emory at Franklin (upper Little Tennessee River, Cullasaja River, Cartoogechaye Creek, and tributaries) varies considerably (LTLT 2011; NCDWQ 2012c for further information). Instream habitat conditions in the upper Little Tennessee River are impaired by excessive sedimentation. Habitat for sensitive aquatic species within this reach is presently marginal to totally lacking. Portions of the Cullasaja River and Cartoogechaye Creek are presently in relatively good shape. While some tributaries in this area contribute significantly, substantial amounts of sediment result from bank erosion along the upper Little Tennessee mainstem. Erosion and sedimentation are also problems in the Tuckasegee River watershed, especially in the larger tributaries between Cullowhee and Bryson City (Savannah and Scott creeks).

Invasive, nonnative species are a potential problem. The Yellowfin Shiner has apparently been introduced to the upper Little Tennessee River and is expanding downstream from Franklin. Other nonnative fish species (e.g., Flat Bullhead, Bluehead Chub, and Yellow Perch) also inhabit portions of the basin. The Asian Clam is established in the Little Tennessee and Tuckasegee rivers. Chinese Mystery Snails have been found in Cowee Creek and Little Tennessee River. The Rusty Crayfish was previously thought to be established in the basin (Cooper 2005; Simmons and Fraley 2010), but recent molecular studies have identified these nonnatives as Kentucky River Crayfish (Kessler et al., forthcoming). Zebra Mussels are not yet known to be established in North Carolina waters, but are known to exist in the Tellico Reservoir (Little Tennessee River) downstream, in Tennessee.

Nonnative vegetation can also negatively impact native aquatic animal communities. This includes both nonnative aquatic and riparian plant species and nonnative plant pathogens that can alter riparian vegetation and affect aquatic habitats (e.g., Hemlock Wooly Adelgid). Monoecious Hydrilla has invaded the Santeetlah Reservoir, Cheoah River, and Little Tennessee River since 2005.

4.5.10.5 Recommendations

Conservation priorities that apply statewide to all river basins are presented.3.3. Priorities identified in the Little Tennessee River Basin are shown in Figure 4.20 and a list of the priority 12-digit HUCs is included in Appendix J.

Basin Specific Recommendations

Surveys. General surveys are needed to complete primary distributional status for SGCN and other priority species General surveys are still needed to complete distributional status for some priority species (see Table 4.63).

- Snails—complete primary distribution inventories; determine potential habitats and distribution surveys for hydrobiids.
- Sicklefin Redhorse—identify important spawning areas and early juvenile habitats.
- Smoky Dace—complete primary distribution inventories.

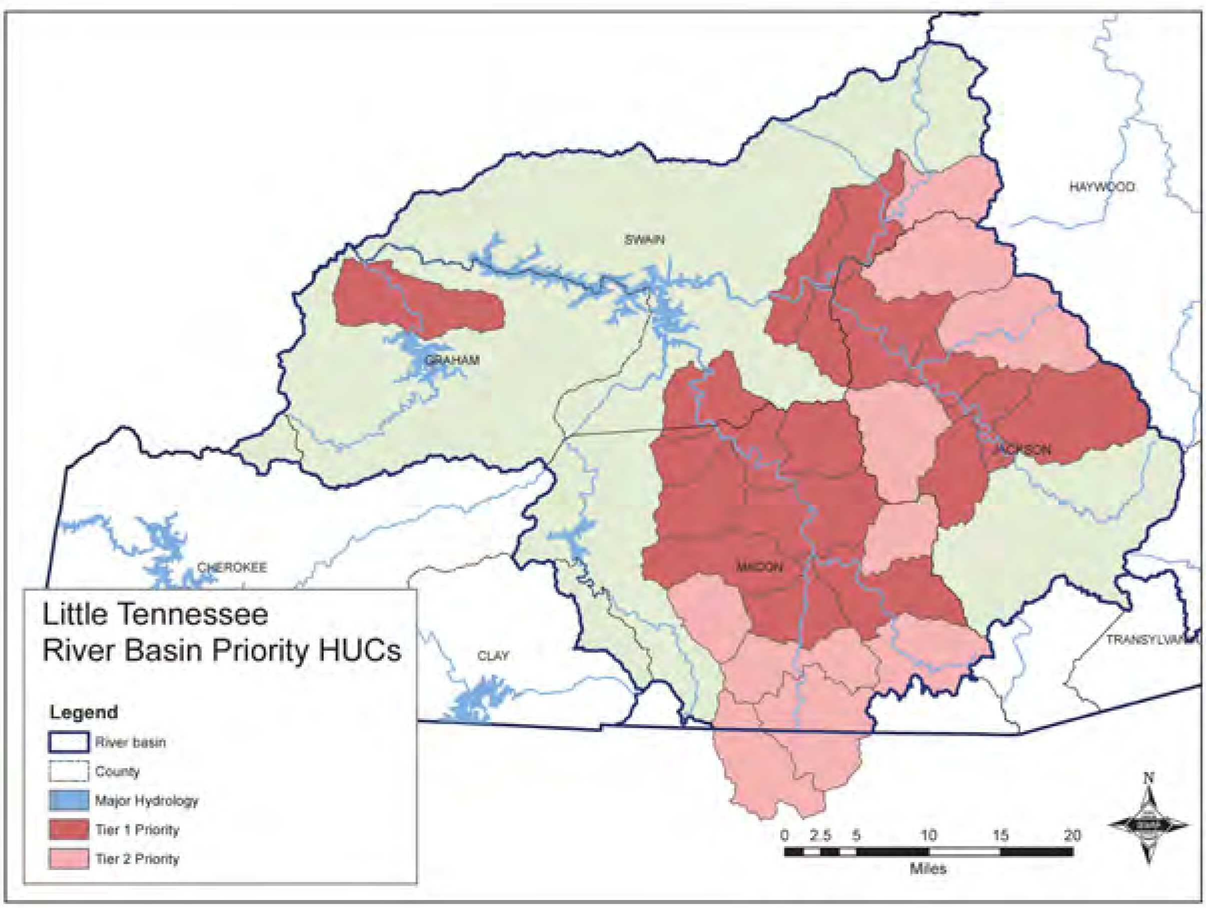
Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters.

Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Several long-term monitoring strategies are in place for priority areas and species, including Spotfin Chub and Appalachian Elktoe. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Monitor distribution and status of nonnative species (e.g., Yellowfin Shiner, Chinese Mystery Snail, Kentucky River Crayfish).
- Continue periodic monitoring of priority areas and species.
- Continue monitoring aquatic community response to remediation of hydropower impacts and species restoration in Cheoah River.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics,

FIGURE 4.20 Location of priority watersheds in the Little Tennessee River Basin



feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Resolve the taxonomy of mussels in the genus *Villosa* and species descriptions for Smoky Dace and Sicklefin Redhorse.
- Study the early life history, propagation and culture, movement, and habitat use of Sicklefin Redhorse.
- Continue research into potential causes for the decline of Appalachian Elktoe and Slippershell in the Little Tennessee River.
- Research to improve habitat conditions in regulated reaches of the Cheoah, Nantahala, and Tuckasegee rivers.
- Investigate aquatic community response to restoration projects in priority areas.
- Identify impacts of nonnative species on priority species and habitats (e.g., Asian Clam, Kentucky River Crayfish, Hydrilla).

In addition to the SGCN species found in the basin (see Table 4.63), a list of knowledge-gap priority species is provided in Table 4.64.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital. Specific issues in this basin include secondary and cumulative impacts upon water quality, riparian vegetation and stream bank restoration and conservation, mitigation of hydropower development impacts, and species restoration opportunities.

- Support conservation and restoration of streams and riparian zones in priority areas.
- Incorporate management goals for aquatic community conservation and enhancement planning and new land acquisitions for Needmore Game Lands.
- Continue reintroduction of extirpated priority and other species in the Cheoah River and other restored or improved habitats as opportunity allows.

Table 4.64 Knowledge-gap priority species in the Little Tennessee River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
FISH	*Ameiurus platycephalus*	Flat Bullhead [Nonnative in this basin]	—
	Etheostoma gutselli	Tuckasegee Darter	—
	Ichthyomyzon greeleyi	Mountain Brook Lamprey	—
	Notropis lutipinnis	Yellowfin Shiner [Nonnative in this basin]	—/SC
	Notropis micropteryx	Highland Shiner	—
	Notropis photogenis	Silver Shiner	—
	Notropis telescopus	Telescope Shiner	—
	Percina aurantiaca	Tangerine Darter	—
	Percina evides	Gilt Darter	—
	Phenacobius crassilabrum	Fatlips Minnow	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

- Continue restoration and augmentation of Sicklefin Redhorse, and evaluate potential for the restoration of other target priority species in the upper Tuckasegee, Little Tennessee, and Oconaluftee rivers.

- Prioritize education and other measures to prevent the introduction or spread of invasive nonnative species, particularly crayfishes, Zebra Mussels, and land-locked river herring species (e.g., Blueback Herring, Alewife).

Conservation Programs and Partnerships. Conservation programs, incentives and partnerships should be utilized to the extent possible to conserve high quality resources and important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience. Many overlapping priorities and common objectives, the relative availability of funding and support, and many willing partners provide abundant opportunities in the Little Tennessee River Basin.

- Support NCDMS's Watershed Restoration Plan (WRP) and River Basin Restoration Priorities (RBRP) for the Little Tennessee River Basin and Local Watershed Plans (LWPs) and a Project Atlas for the Franklin to Fontana Reservoir reach (NCWRP 2002a; NCEEP 2008b, 2011).

- Work with the Partnership for the Little Tennessee (PLT), a consortium of state and federal resource management agencies, Land Trust for the Little Tennessee River, Watershed Association for the Tuckasegee River, and other stakeholders that identify and address issues common across the watershed in North Carolina. Current projects include finding solutions for construction contractor training in erosion prevention BMPs.

- Partner with Soil and Water Conservation District programs, such as the Agriculture Cost Share Program, as they are also effective partner programs for conservation in priority areas.

- Continue working with Duke Energy, Brookfield Energy, FERC, and other resource agencies and cooperators to fulfill relicense settlement agreements and other mitigation for hydropower impacts from Little Tennessee Basin projects.

- Investigate, implement, and support (as appropriate) programs that are directed at candidate or listed species recovery (e.g., Candidate Conservation Agreements, Habitat Conservation Planning, Safe Harbor agreements).

- The entire Little Tennessee River Basin across North Carolina, Georgia, and Tennessee state boundaries has been designated a Native Fish Conservation Area by the Fisheries Conservation Foundation, and an interstate and multi-partner steering committee with topical work groups has been established to identify and cooperatively address basinwide issues. More information is available online: http://www.fishconserve.org/2013/01/31/native-fish-conservation-areas-nfcas/ and http://www.fishconserve.org/2013/06/03/rivers-of-success-campaign-native-fish-conservation-areas/.

4.5.11 Lumber River Basin

4.5.11.1 River Basin Description

The Lumber River Basin is located in the southeastern corner of North Carolina and the northeastern corner of South Carolina. The headwaters of the Lumber River originate in the Sandhills ecoregion (a notable center of species endemism) in the northwest corner of the basin. The remaining portion of the basin occurs in the Coastal Plain ecoregion. The basin covers approximately 3,329 square miles, making it the seventh largest river basin, and has nearly 26 miles of Atlantic coast line. There are approximately 2,222 miles of freshwater streams, 9,865 acres of freshwater lakes, and 4,680 acres of estuarine or saline waterbodies. All but two rivers in the basin flow into the Great Pee Dee River in South Carolina: the Shallotte and Lockwoods Folly rivers drain directly to the Atlantic Ocean. A total of 115 miles have been designated as State Natural and Scenic Water and 81 miles have been designated as National Wildlife and Scenic Water (NCEEP 2008c; NCGS n.d.; NWSRS n.d.).

Waterbodies in the Sandhills ecoregion are typified by flowing sand-bottomed streams, with acidic water, and are primarily located in the northwestern one-third of the basin. Soils in the Sandhills are well drained and provide a reliable source of groundwater recharge to the streams that run through this part of the basin. Coastal Plain waterbodies are typically meandering and have low flow conditions that contribute to the basin being dominated by blackwater systems. Streams are often braided systems, have wide floodplains, and have natural communities that are often hardwood bottomlands or pocosin wetlands (NCDWQ 2010; NCDWR 2010). Natural Carolina bays can be found throughout much of the basin, with smaller bays that are often ephemeral and ideal habitat for amphibians.

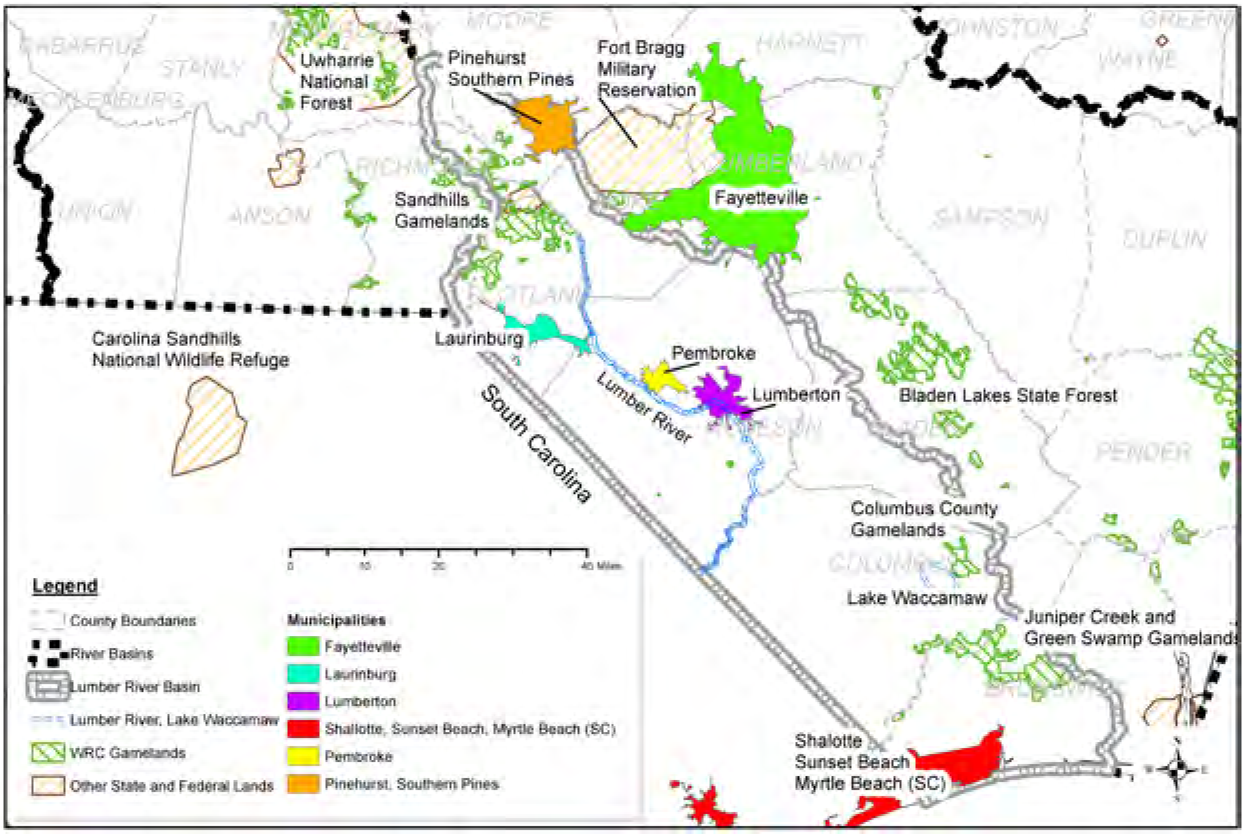
Based on the 2011 National Land Cover Dataset, land use in the basin was estimated to be 29% forested, 2% grassland, 26% agricultural, 32% wetland, and 7.3% urban or developed (NLCD 2011). There are six game lands in the basin covering 109,134 acres, including a portion of the Green Swamp Game Lands. Rapid population growth in the upper end of the basin (Moore and Hoke counties) is associated with recreation activities (golf communities) and Department of Defense (DOD) facilities, while growth along the coast (Brunswick County) is associated with development for tourism. This growth contrasts with other areas in the basin where growth rates are much lower (NCDWR 2010).

The Lumber River Basin encompasses all or portions of 10 counties and 51 municipalities. Sizeable municipalities in this basin include Aberdeen, Boiling Spring Lakes, Laurinburg, Lumberton, Pinehurst, Shallotte, and Southern Pines (Figure 4.21).

4.5.10.2 Aquatic Resource Conditions

Segments of the Lumber River, Naked Creek, Drowning Creek, and Lake Waccamaw have supplemental classifications as High-Quality Waters (HQW) or Outstanding Resource

Figure 4.21 Location of the Lumber River Basin



Waters (ORW) because they either have excellent water quality or they are a significant resource to humans and/or wildlife (NCDWQ 2010). Coastal estuarine waters and waters at the mouth of the Lockwoods Folly and Shallotte rivers and their tributaries carry either an HWQ or ORW classification (NCDWR 2015a).There are ORW Special Management Strategy Areas in the basin for the Lumber River (65,169 acres), Naked Creek (25,189 acres), and Lake Waccamaw (9,760 acres) (NCDWR 2015c). These areas require site-specific provisions to protect resource values (e.g., no new discharges or expansion of existing discharges) (see 15A NCAC 02B.0225).

Table 4.65 provides information on water quality classifications and use support ratings in the basin.

4.5.11.3 Aquatic Species

There are 25 SGCN in the basin: 2 aquatic snail species, 3 crayfishes, 14 freshwater fishes, and 6 freshwater mussel species. Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies

Table 4.65 Water quality classification and rating information for the Lumber River Basin

Classifications	Freshwater Miles	Percent (Total Basin Waters)	Freshwater Acres	Percent (Total Basin Waters)	Estuary Acres	Percent (Total Basin Waters)
Total Basin Waters*	6,316	—	9,987	—	4,680	—
HQW	202	7	164	2	4,493	96
ORW	20	<1	8,840	89	—	—
Use Ratings	**Freshwater Miles**	**Percent (Total Monitored)**	**Freshwater Acres**	**Percent (Total Monitored)**	**Estuary Acres**	**Percent (Total Monitored)**
Total Named Waters	2,220	—	9,130	—	4,499	—
Supporting	595	27	8,936	98	78	2
Impaired	74	3	—	—	4,400	98
Not Rated	61	3	—	—	—	—
No Data	1,490	67	194	2	21	<1

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

SGCN associated with aquatic communities found in this river basin. Table 4.66 identifies the SGCN found in the Lumber River Basin.

4.5.11.4 Threats Affecting Aquatic Species

Impacts affecting species and their habitats within the Lumber River Basin include non-point sources of pollution resulting from inadequate management practices related to agriculture, forestry, construction, and stormwater discharges. Sedimentation due to erosion is one of the major causes of habitat loss in this basin.

In addition, the Lumber River Basin has a dense concentration of swine production facilities. There are 217 permitted Confined Animal Feeding Operations (CAFOs) in the Lumber River Basin with 313 waste lagoons associated with the facilities. Waste from these sites contains high levels of nutrients (e.g., nitrogen and phosphorus) in addition to fecal coliform bacteria and any chemical compounds, such as antibiotics or hormone products used in commercial feeding operations (NCDWR 2015b). Animal-waste lagoons and spray fields that discharge near or into aquatic environments through runoff, percolation into groundwater, and volatilization of ammonia and the release of bacterial contamination can significantly degrade water quality and endanger human and animal health (Mallin 2003; Mallin and Cahoon 2003).

According to an NCDENR dam inventory (NCDEMLR 2014), there are at least 145 impoundments in the basin, most of which are small impoundments. The consequences of these

Table 4.66 SGCN species in the Lumber River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
AQ SNAIL	*Amnicola sp. 1*	Waccamaw Snail	—/SC
	Floridobia [Cincinnaitia] sp.1	Waccamaw Siltsnail	—/SC
CRAYFISH	*Procambarus ancylus*	Coastal Plain Crayfish	—
	Procambarus blandingii	Santee Crayfish	—
	Procambarus braswelli	Waccamaw Crayfish	—/SC
FISH	*Ameiurus brunneus*	Snail Bullhead	—
	Ameiurus platycephalus	Flat Bullhead	—
	Cyprinella sp. cf. zanema	Thinlip Chub	—/SC
	Elassoma boehlkei	Carolina Pygmy Sunfish	FSC/T
	Elassoma evergladei	Everglades Pygmy Sunfish	—
	Enneacanthus chaetodon	Blackbanded Sunfish	—
	Enneacanthus obesus	Banded Sunfish	—
	Etheostoma mariae	Pinewoods Darter	FSC/SC
	Etheostoma perlongum	Waccamaw Darter	FSC/T
	Fundulus waccamensis	Waccamaw Killifish	FSC/SC
	Menidia extensa	Waccamaw Silverside	T/T
	Notropis chalybaeus	Ironcolor Shiner	—
	Noturus sp. 2 [cf. leptacanthus]	Broadtail Madtom	FSC/SC
	Semotilus lumbee	Sandhills Chub	FSC/SC
MUSSEL	*Elliptio marsupiobesa*	Cape Fear Spike	—/SC
	Elliptio waccamawensis	Waccamaw Spike	FSC/E
	Lampsilis cariosa	Yellow Lampmussel	FSC/E
	Lampsilis fullerkati	Waccamaw Fatmucket	FSC/T
	Toxolasma pullus	Savannah Lilliput	FSC/E
	Villosa delumbis	Eastern Creekshell	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

dams include blocked migration routes for diadromous and resident native species, and reduced recolonization and dispersal potential for multiple aquatic taxa (Williams et al. 1993; Etnier 1997; Neves et al. 1997; Warren et al. 2000; NCWRC 2005) Water withdrawals for irrigation and similar uses further change flow patterns and reduce the quality/quantity of available habitat for aquatic species (NCDWQ 2010). Invasive species (e.g., Flathead Catfish and Red Swamp Crayfish) are established in the Lumber River Basin and continue to negatively impact native species populations (Fuller et al. 1999; Cooper 2005) via predation and competition.

4.5.11.5 Recommendations

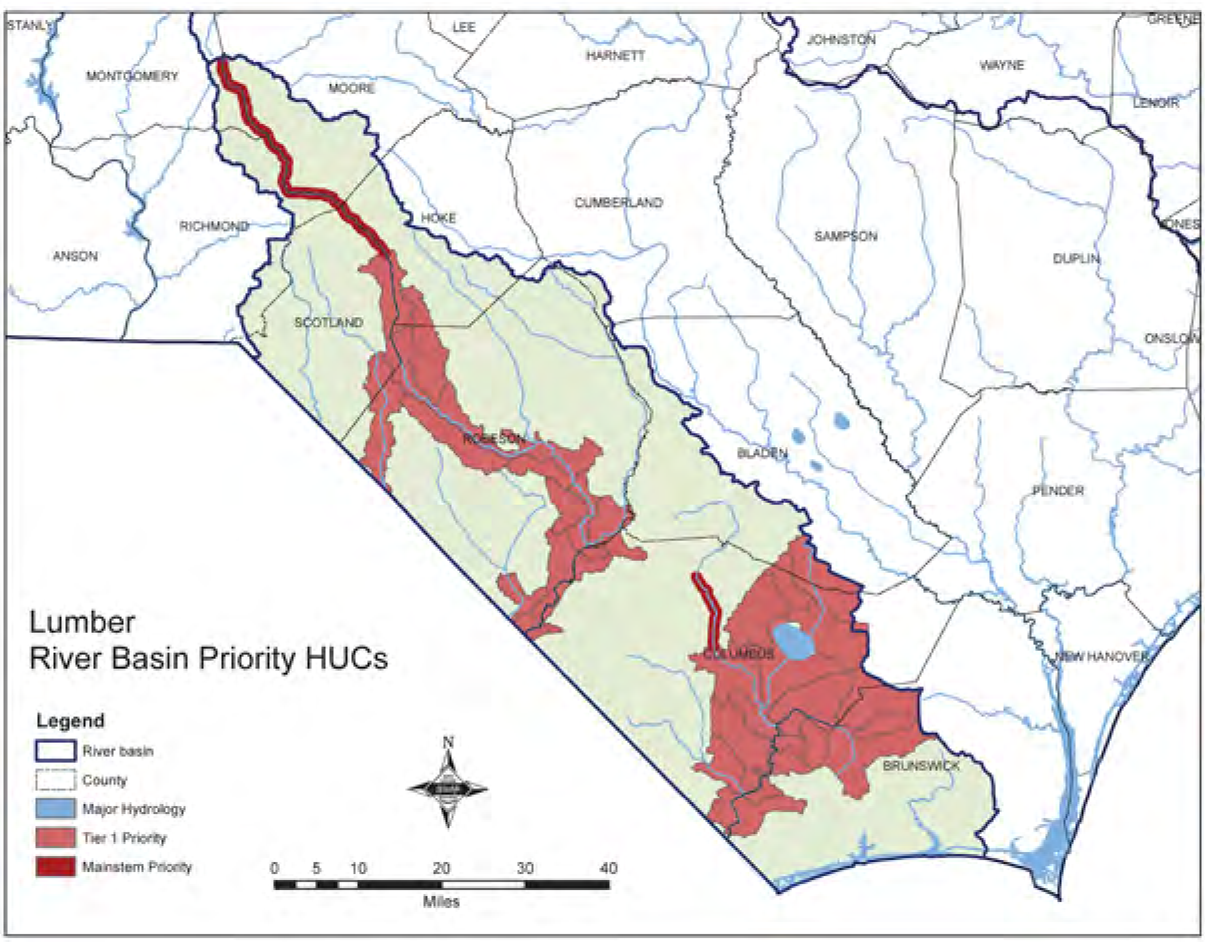
Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priorities identified in the Lumber River Basin are shown in Figure 4.22 and a list of the priority 12-digit HUCs is included in Appendix J.

Basin Specific Recommendations

Surveys. Priorities for distribution and status surveys need to focus on aquatic snails, crayfish, mussels, and fish believed to be declining or dependent on at-risk or sensitive communities (see Table 4.66). Conduct distributional and status surveys on basin-specific priorities such as Pygmy Sunfish species (*Elassoma* spp.), Broadtail Madtom, Sandhills Chub, and Ironcolor Shiner.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters.

Figure 4.22 Location of priority watersheds in the Lumber River Basin



Studies should include identification of population trends, as well as assessment of conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible. Monitor populations of endemic fishes and mussels occurring in Lake Waccamaw to assess the effect of land use changes and practices in the surrounding watershed and the introduction of nonnative plants and animals.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. Studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Support species descriptions for undescribed taxa (e.g., Broadtail Madtom).
- Determine vulnerability of species across all taxa groups to emerging threats such as endocrine-disrupting chemicals (EDCs) and other compounds that are present in many of the waterways of the Lumber River Basin.
- Identify ways to eradicate or reduce the impacts of nonnative species in Lake Waccamaw.

In addition to the SGCN species found in the basin (see Table 4.66), a list of knowledge-gap priority species is provided in Table 4.67.

Management Practices Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. General needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and prevention of the introduction and spread of exotic or invasive species are vital. Specific issues that need to be addressed in this basin include secondary and cumulative impacts upon water quality, buffer ordinances, water supply watershed protection, and protection of headwaters.

- Promote programs to upgrade/increase compliance at wastewater treatment facilities and CAFOs.

Table 4.67 Knowledge-gap priority species in the Lumber River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
CRAYFISH	*Procambarus pearsei*	Carolina Sandhills Crayfish	—
FISH	*Fundulus chrysotus*	Golden Topminnow	—
	Lepisosteus osseus	Longnose Gar	—
MUSSEL	*Corbicula fluminea*	Asian Clam [Exotic]	—
	Elliptio fisheriana	Northern Lance	—
	Elliptio icterina	Variable Spike	—
	Lampsilis radiata	Eastern Lampmussel	—/T
	Pyganodon cataracta	Eastern Floater	—
	Uniomerus carolinianus	Florida Pondhorn	—
	Utterbackia imbecillis	Paper Pondshell	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

- Provide support for land conservation, particularly in riparian areas (acquisition, easements, restoration).
- Support well-planned stream restoration work in collaboration with other organizations.
- Continue to identify areas critical to aquatic ecosystem health that can be conserved or restored.
- Coordinate and provide management guidance on managed properties, such as NCWRC game lands, to maximize effective conservation and restoration activities on these public lands.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to conserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Guide academic research projects to help achieve specific conservation goals and objectives.
- Support the development and application of an aquatic nuisance species management plan with other agencies/groups.

- Address secondary and cumulative impacts upon water quality, buffer ordinances, water supply watershed protection, headwaters protection, etc. (NCDWQ 2010; NCWRC 2002).
- Work with and promote existing programs that help farmers reduce sedimentation/erosion (e.g., install fences to keep livestock out of streams) as well as reduce pesticide and herbicide use.
- Provide landowners, developers, and municipal planners with education and guidance on how to protect aquatic habitats and water quality.

4.5.12 Neuse River Basin

4.5.12.1 River Basin Description

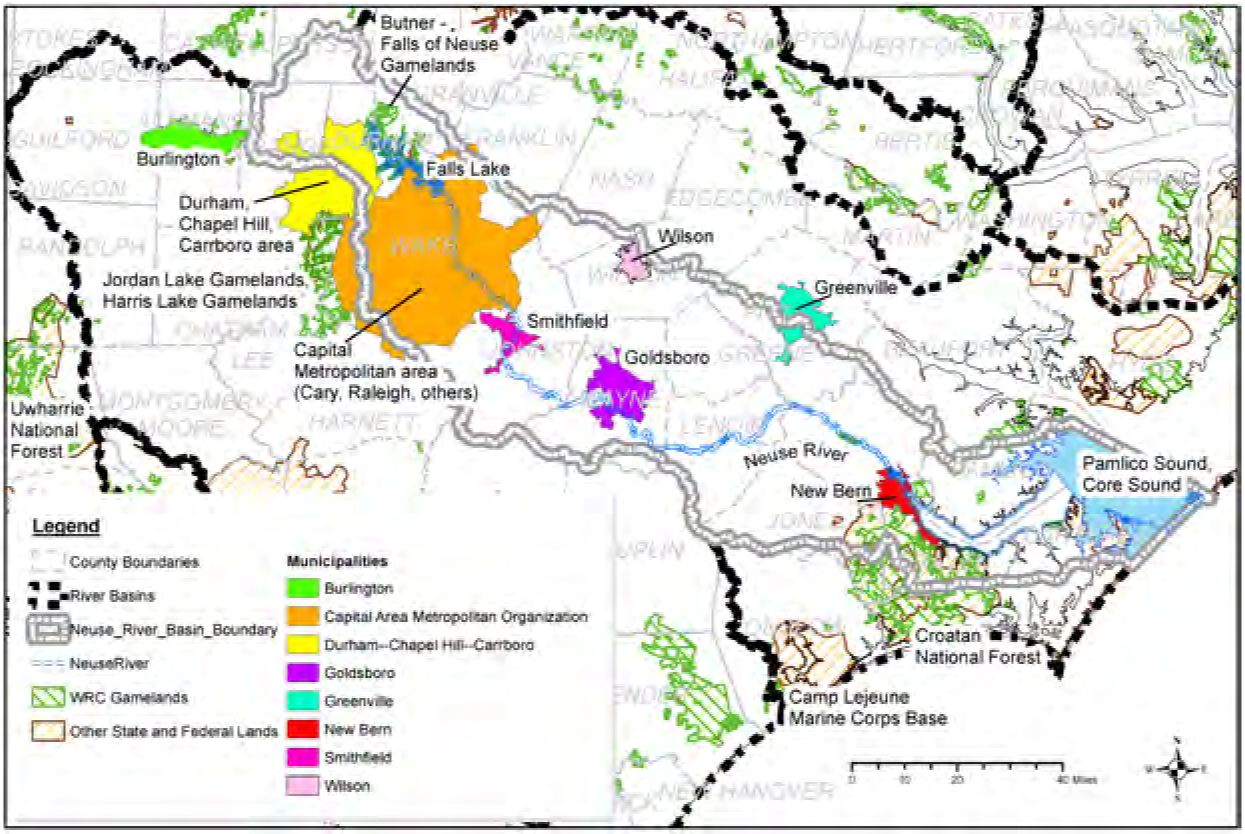
The Neuse River Basin is an Atlantic Slope drainage with headwaters originating in the north-central Piedmont ecoregion in Person and Orange counties. The uppermost 22 miles of the river's main stem is impounded behind Falls of the Neuse Reservoir dam just northeast of the city of Raleigh. Downstream of the dam, the river continues its course for approximately 185 miles southeast past the cities of Raleigh, Smithfield, Goldsboro, and Kinston (NCDWQ 2009, 2012d; NCDWR 2015g). It flows southeast until it reaches tidal waters near Streets Ferry, upstream of New Bern. At New Bern, the river broadens dramatically and turns into a 40-mile long brackish tidal estuary that eventually flows into the Pamlico Sound. The Neuse River Basin is the third-largest basin in North Carolina, covering 6,062 square miles, and is one of only four major river basins whose boundaries are located entirely within the state (NCDWR 2015d, 2015h). There are 3,389 freshwater stream miles, 17,902 acres of freshwater reservoirs and lakes, 143 saltwater stream miles, and 370,779 estuarine/saltwater acres in the basin. Major tributaries in the basin include the Eno, Flat, Little, and Trent rivers and Crabtree, Swift, and Contentnea creeks.

There are two distinct portions of the Neuse River Basin: the upper one-third in the Piedmont and the lower two-thirds in the Coastal Plain. Streams in the Piedmont portion typically are low gradient, with sluggish pools separated by riffles and occasional small rapids. Soils are highly erodible in the Piedmont and are underlain by fractured rock formations that have a limited water storage capacity. This portion of the basin tends to have low summer flows and limited ability to assimilate oxygen-consuming wastes, which contributes to hypoxia. The Coastal Plain portion features slow-moving blackwater streams, low-lying swamps, and productive estuarine waters. The larger waterbodies in the basin are meandering, often lined with swamps and bottomland hardwoods, and often have naturally low DO and pH. Soils are deep sands that have a high groundwater storage capacity. Natural lakes include the remnants of bay lakes in the lower Coastal Plain (NCDWQ 2012a).

There are several areas of rapidly expanding urban land use; however, much of the land use in the basin is agriculture or forest. Protected forested land in the basin includes Eno River State Park and seven game lands covering 236,330 acres (e.g., portions of the Croatan National Forest, Butner–Falls of Neuse, Neuse River) (NCDWQ 2012a). Based on 2011 National Land Cover Dataset information, land use in the basin was estimated to be 29.4% forested, 4.4% grassland, 26.2% agricultural, 19.3% wetland, and 12.4% urban or developed (MRLC 2011; Jin et al. 2013).

The Neuse River Basin encompasses all or portions of 18 counties and 77 municipalities. Large cities located in this basin includes several of the fastest growing urban and suburban areas in the state, Cary, Durham, Goldsboro, Greenville, New Bern, Raleigh, Smithfield, and Wilson. Figure 4.23 depicts the geographic location of the basin.

Figure 4.23 Location of the Neuse River Basin



4.5.12.2 Aquatic Resources

There are about 12,703 miles of streams and rivers, including small intermittent and ephemeral streams, and numerous acres of freshwater and estuarine wetland communities in the basin (NCDWR 2015a). There are 881 stream miles that have supplemental classifications as High Quality Waters (HQW) and about 238 stream miles of Outstanding Resource Waters (ORW) in the basin because they either have excellent water quality or they are a significant resource to humans and/or wildlife (NCDWQ 2011a). This includes freshwater segments of the Neuse, Eno, Little, and South rivers. Coastal estuarine waters of the Intracoastal Waterway, Core and Pamlico Sounds, and their bays carry either a HWQ or ORW classification (NCDWR 2015a). The Neuse River Estuary has approximately 50,852 saltwater acres that are classified as HQW; the Pamlico Sound has over 84,692 saltwater acres classified as HQW; and the West Bay covers more than 16,359 of brackish waters that are classified as HQW. Core Sound has approximately 18,202 saltwater acres classified as ORW.

There are ORW Special Management Strategy Areas in the basin for Deep Creek (23,660 acres) and Core Sound with Pamlico and Back Sound Areas (126,940 acres) (NCDWR 2015c). These areas require site-specific provisions to protect resource values (no new discharges or expansion of existing discharges) (see 15A NCAC 02B.0225).

The Neuse River Estuary is made up of the Pamlico Sound, upper Core Sound, West Bay, and their embayments and tributaries. These waters are all classified as nutrient-sensitive waters (NSW). This classification is intended for waters that need additional nutrient management due to greater vulnerability to excessive aquatic vegetation growth (NCDWR 2015d).

Table 4.68 provides information on water quality classifications and use support ratings in the basin.

4.5.12.3 Aquatic Species

There are 26 priority species in the basin identified as SGCN: 1 is an aquatic snail, 1 is a crayfish, 13 are freshwater fishes, and 11 are freshwater mussels. Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN associated with aquatic communities found in this river basin. Table 4.69 identifies the SGCN found in the Neuse River Basin.

4.5.12.4 Threats Affecting Aquatic Species

It is important to note that all waters in the state are rated as impaired based on a statewide fish consumption advisory for mercury contamination. In the Wake County portion of the basin, Brier Creek, Little Brier Creek, Crabtree Creek, Lake Crabtree, Rocky Branch, Walnut Creek, and the Neuse River (from Crabtree Creek to Auburn-Knightdale Road) all carry

Table 4.68 Water quality classification and rating information for the Neuse River Basin

Classifications	Freshwater Miles	Percent (Basin Waters)	Freshwater Acres	Percent (Basin Waters)	Coastal Acres	Percent (Basin Waters)
Total Basin Waters*	12,703	—	43,232	—	371,531	—
HQW	279	2	989	2	270,415	72
ORW	23	<1	944	2	65,513	18
Use Ratings	**Freshwater Miles**	**Percent (Monitored Waters)**	**Freshwater Acres**	**Percent (Monitored Waters)**	**Coastal Acres**	**Percent (Monitored Waters)**
Total Named Waters	3,410	—	18,323	—	371,531	—
Supporting	993	29	10,950	60	324,952	87
Impaired	441	13	7,113	39	41,934	11
Not Rated	147	4	—	—	—	—
No Data	1,829	54	260	1	4,645	1

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

Table 4.69 SGCN priority species in the Neuse River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
AQ SNAIL	*Somatogyrus virginicus*	Panhandle Pebblesnail	FSC/—
CRAYFISH	*Procambarus medialis*	Pamlico Crayfish	—
FISH	*Acipenser oxyrinchus*	Atlantic Sturgeon	E/E
	Ambloplites cavifrons	Roanoke Bass	FSC/—
	Ameiurus brunneus	Snail Bullhead	—
	Ameiurus platycephalus	Flat Bullhead	—
	Enneacanthus chaetodon	Blackbanded Sunfish	—
	Enneacanthus obesus	Banded Sunfish	—
	Etheostoma collis	Carolina Darter	FSC/SC
	Lampetra aepyptera	Least Brook Lamprey	—/T
	Moxostoma pappillosum	V-lip Redhorse	—
	Notropis bifrenatus	Bridle Shiner	FSC/E
	Notropis chalybaeus	Ironcolor Shiner	—
	Notropis volucellus	Mimic Shiner	—
	Noturus furiosus	Carolina Madtom	FSC/T
MUSSEL	*Alasmidonta heterodon*	Dwarf Wedgemussel	E/E
	Alasmidonta undulata	Triangle Floater	—/T
	Elliptio lanceolata	Yellow Lance	FSC/E
	Elliptio marsupiobesa	Cape Fear Spike	—/SC
	Elliptio steinstansana	Tar River Spinymussel	E/E
	Fusconaia masoni	Atlantic Pigtoe	FSC/E
	Lampsilis cariosa	Yellow Lampmussel	FSC/E
	Lampsilis sp. 2	Chameleon Lampmussel	—
	Lasmigona subviridis	Green Floater	FSC/E
	Villosa constricta	Notched Rainbow	—/SC

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

a health advisory against eating any fish from these waters because of contamination by polychlorinated biphenyls (PCBs) (NCDPH 2014).

In 2007, the Neuse River was listed as one of the most endangered rivers in the United States because of eutrophication caused by high waste loads attributed to development and agriculture (American Rivers 2007; Ferrell et al. 2014). Nonpoint source pollution from agriculture and forestry has degraded aquatic habitats within the basin. For example, animal waste byproducts cause increased levels of nitrates and phosphates, which can lead to excess growth of algae and aquatic plants and to decreased DO levels (especially during summer months) that result in fish kills.

There are 539 permitted CAFOs in the Neuse River Basin with 900 waste lagoons associated with the facilities. Waste from these sites is a source of high levels of nutrients (e.g., nitrogen and phosphorus) (NCDWR 2015b). Animal-waste lagoons and sprayfields that discharge nutrients and bacteria contamination near or into aquatic environments through runoff, percolation into groundwater, and volatilization of ammonia and the release of bacterial contamination can significantly degrade water quality and endanger health (Mallin 2003; Mallin and Cahoon 2003).

According to an NCDENR dam inventory (NCDEMLR 2014), there are at least 654 impoundments in the basin, most of which are mill or farm ponds. Impoundments in the basin have affected aquatic species by physically altering habitat, reducing flows and DO, and causing erosion. Modification of flow regimes by upstream impoundments affects various life history characteristics of downstream migratory fishes and other aquatic fauna by limiting dispersal and recolonization. Additionally, water withdrawals for irrigation reduce the amount of habitat available for aquatic species (NCDWQ 2009).

The upper 22 miles of the Neuse River proper are impounded by the Falls of the Neuse Reservoir dam which was built by the US Army Corps of Engineers to provide drinking water, flood control, and recreation opportunities. Other major reservoirs in the Neuse River Basin include Milburnie Dam, Little River Reservoir, Lake Michie, Lake Orange, Corporation Lake, Lake Ben Johnson, Lake Butner, Lake Rogers, Lake Wheeler, Lake Benson, and Buckhorn Reservoir. A proposal to remove the Milburnie Dam is being evaluated and, if approved, would open 15 miles of the Neuse River and tributaries for migration and spawning of American Shad, Striped Bass, and other anadromous fish as well as restore free-flowing stream habitat for many priority aquatic species (American Rivers 2012).

The Falls of the Neuse Reservoir (Falls Lake) and Lake Johnson are rated as impaired based on turbidity, failure to meet water quality standards for nutrient enrichment, and PCB contamination in fish tissue samples. Eutrophic conditions have been present in Falls Lake since it was impounded in the early 1980s (NCOEE 2007; NCDWQ n.d.; NCDWR 2015b) and high levels of chlorophyll *a*, low DO, turbidity, and contamination are persistent problems. Other examples of impaired impoundments include Big Lake and Reedy Creek Lake in Umstead State Park (Wake County).

Atmospheric deposition of nitrogen from cars and factories can lead to decreased water quality. Large quantities of nutrients, especially nitrogen, from nonpoint sources are considered the greatest threat to water quality of the Neuse River Estuary. There are over 400 point source waste discharge permits for the basin from municipal wastewater treatment plants, industrial facilities, small package treatment plants, and large urban and industrial stormwater. Municipal point source waste pollution also contributes nitrogen, phosphorus, and other contaminants to waters in the basin.

United States Census Bureau (USCB) data shows that five of the fastest-growing cities in the United States are located in the Neuse River Basin. Based on population growth between 2010 and 2014, and in comparison with growth rates in other states, North Carolina was ranked as the fifth fastest growing state in the nation (USCB 2014). Population in the basin is expected to increase by as much as 44% by 2020 and USCB projects that the population in the Neuse River Basin will increase by more than 867,000 people. Projected growth patterns for the Neuse River Basin predict the population will be over two million people by 2020 (USCB 2014; NCDWR 2015a).

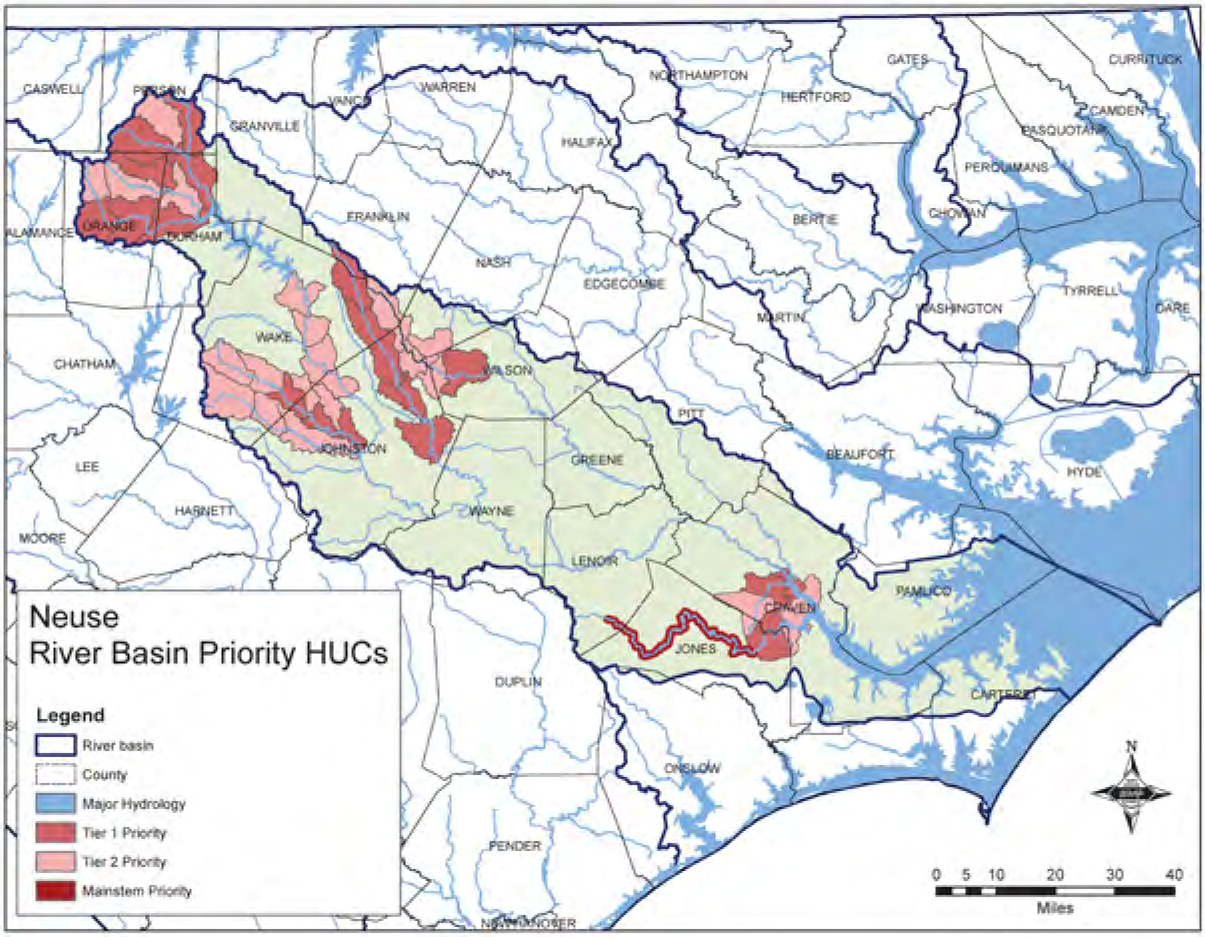
Urban centers in the Piedmont rely on surface water withdrawn from reservoirs or directly from the Neuse River (about two-thirds of the total demand on the basin), while rural areas and communities in the Coastal Plain rely more on groundwater (NCDWR 2015c). As is the case in the Cape Fear River Basin, current drinking water supplies and wastewater treatment capacities may not be sufficient to meet demands caused by population growth, and new infrastructure will be needed to meet these demands. Development and the related need for additional infrastructure will result in increased stresses on already impaired aquatic resources. The loss of natural areas and increase in impervious surfaces that result from rapid population growth cause increased sediment runoff from construction. More homes mean an increase in lawn fertilizer runoff. Heavy metal runoff contributes to elevated mercury levels in fish tissue. These point and nonpoint runoff sources accumulate in the Pamlico Sound, where researchers at the University of North Carolina at Wilmington found one-third of the sediments contaminated with chemicals and toxic metals (Powell 1999).

Hydrilla is found from the headwaters of the Eno River downstream almost to Falls Lake. Lake Orange, Corporation Lake, and both forks of the upper Eno River are infested with this invasive aquatic plant. During the months of June through September/October, Hydrilla is the most evident weed in the Eno River and the population of Hydrilla appears to be growing each year. The problem with Hydrilla is compounded by the fact that the water flow in the river is so low for most of the year, allowing Hydrilla to establish populations in the river that continue to spread. Hydrilla is not often a problem in higher flow rivers. Hydrilla has been identified as one of the biggest threats to the natural resources of Eno River State Park (Nealson 2012).

4.5.12.5 Recommendations

Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priorities identified in the Neuse River Basin are shown in Figure 4.24 and a list of the priority 12-digit HUCs is included in Appendix J.

FIGURE 4.24 Location of priority watersheds in the Neuse River Basin



Basin Specific Recommendations

Surveys. General surveys are needed to complete primary distributional status for SGCN and other priority species (see Table 4.69).

- Fishes—determine distribution and status of priority species, such as Banded Sunfish, Black Banded Sunfish, Bridle Shiner, Carolina Madtom, Ironcolor Shiner, Least Brook Lamprey, Mimic Shiner, and V-lip Redhorse.
- Mussels—determine distribution and status of priority species, especially Atlantic Pigtoe, Eastern Rainbow, Green Floater, Tar River Spinymussel, and Yellow Lance.
- Crayfishes—determine distribution and status of priority species (Carolina Ladle Crayfish, Croatan Crayfish, and Pamlico Crayfish).
- Snails—conduct baseline distribution surveys for all species that occur in the basin.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species.

- Identify long-term monitoring sites and develop monitoring protocols for priority species (e.g., Atlantic Pigtoe, Bridle Shiner, Carolina Madtom, Dwarf Wedgemussel, Green Floater, Ironcolor Shiner, and Yellow Lance).

Research. Research to facilitate appropriate conservation actions includes investigation of habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Study habitat use and life history characteristics of priority species (e.g., Carolina Ladle Crayfish, Green Floater, Least Brook Lamprey, Triangle Floater, and V-lip Redhorse).
- Support taxonomic research for priority species (e.g., *Cambarus sp. C* complex, Chameleon Lampmussel, Eastern Rainbow, Mimic Shiner, Panhandle Pebblesnail, and the mussel genus *Elliptio)*.
- Support development of captive propagation techniques for priority species (e.g., Bridle Shiner, Carolina Madtom, Green Floater, Ironcolor Shiner, and Triangle Floater).
- Support genetics research that informs augmentation policy for priority species (e.g., Atlantic Pigtoe, Bridle Shiner, Carolina Madtom, Chameleon Lampmussel, Green Floater, Ironcolor Shiner, Triangle Floater, and Yellow Lance).
- Determine impacts of nonnative species on priority species (e.g., Japanese Mystery Snail, Red Swamp Crawfish, and Flathead Catfish).

In addition to the SGCN species found in the basin (see Table 4.69), a list of knowledge-gap priority species gaps is provided in Table 4.70.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations

Table 4.70 Knowledge-gap priority species in the Neuse River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
AQ SNAIL	*Cipangopaludina japonica*	Japanese Mystery Snail [Exotic]	—
CRAYFISH	*Cambarus davidi*	Carolina Ladle Crayfish	—
	Procambarus plumimanus	Croatan Crayfish	—
FISH	*Chrosomus oreas*	Mountain Redbelly Dace	—
	Etheostoma vitreum	Glassy Darter	—
	Fundulus diaphanus	Banded Killifish	—
	Lepisosteus osseus	Longnose Gar	—
	Moxostoma cervinum	Blacktip Jumprock	—
	Nocomis raneyi	Bull Chub	—
	Percina nevisense	Chainback Darter	—
	Percina roanoka	Roanoke Darter	—
	Petromyzon marinus	Sea Lamprey	—
MUSSEL	*Corbicula fluminea*	Asian Clam [Exotic]	—
	Elliptio fisheriana	Northern Lance	—
	Elliptio icterina	Variable Spike	—
	Elliptio roanokensis	Roanoke Slabshell	—/T
	Lampsilis radiata	Eastern Lampmussel	—/T
	Pyganodon cataracta	Eastern Floater	—
	Strophitus undulatus	Creeper	—/T
	Taxolasma parvum (parvus)	Lilliput [Exotic]	—
	Uniomerus carolinianus	Florida Pondhorn	—
	Utterbackia imbecillis	Paper Pondshell	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital.

- Support efforts to restore the native aquatic community through reintroduction or augmentation.
- Support acquisition of land that is adjacent to current conservation holdings or priority watersheds.
- Support other regulatory agencies to minimize impacts on species and habitats.
- Where appropriate, support dam removal and habitat restoration.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Guide academic research projects to help achieve specific conservation goals and objectives.
- Support the development and application of an aquatic nuisance species management plan with other agencies/groups.
- Address secondary and cumulative impacts upon water quality (buffer ordinances, water supply watershed protection, headwaters protection).
- Work with and promote existing programs that help farmers reduce sedimentation/erosion (e.g., installing fences to keep livestock out of streams and improving tilling practices), as well as reduce pesticide and herbicide use.
- Support stormwater management and wastewater treatment plant improvements and upgrades.
- Develop and disseminate educational and news print media, including stand-alone documents, press releases, newspaper and magazine articles, and displays.
- Improve and maintain existing web resources (mussel, crayfish, and fish atlases, etc.)
- Continue to seek opportunities for direct outreach throughout the basin.

4.5.13 New River Basin

4.5.13.1 River Basin Description

The New River Basin in North Carolina is located in the northwest corner of the state and is part of the Kanawha/Ohio/Mississippi River system. The basin drains 754 square miles in North Carolina and includes approximately 2,071 stream miles. It is the only interior basin drainage in North Carolina that does not flow into the Tennessee River. The New River Basin is entirely within the Mountain ecoregion and is comprised of three subbasins: the North Fork New River, the South Fork New River, and the Little River.

The length of the basin made up of the 26.5 miles of the lower South Fork New River and the entire North Carolina portion of the New River is designated as both a USA National Wild and Scenic River (NWSRS 2015) and a state Natural and Scenic River (NCDPR 2015). The entire New River was named an American Heritage River (NCPDR 2015) in 1998.

The North Carolina portion of the New River Basin is mountainous and rural. Based on 2011 National Land Cover Dataset information, land use in the basin is 69% forested, 22% agricultural, 7% developed or urban, 1% grassland, and less than 1% wetland (MRLC 2011; Jin et al. 2013). Most land in the basin is privately owned. Public land ownership includes the New River State Park (1,300 acres along the South Fork New River), Mount Jefferson State Natural Area, Elk Knob State Park, five NCWRC game lands covering about 8, 203 acres (including Three Top Mountain, Pond Mountain, and Mitchell River), and relatively small areas within the Blue Ridge Parkway (Blue Ridge National Heritage Area 2015). Recently, the USFWS established the Mountain Bogs National Wildlife Refuge (39 acres) in Ashe County for conservation of Appalachian mountain bog habitats and protection of federal listed endangered and threatened species (USFWS 2013). NCWRC recently established the Watson-Old Man's Bog Tract (about 10 acres) in Alleghany County to protect rare species.

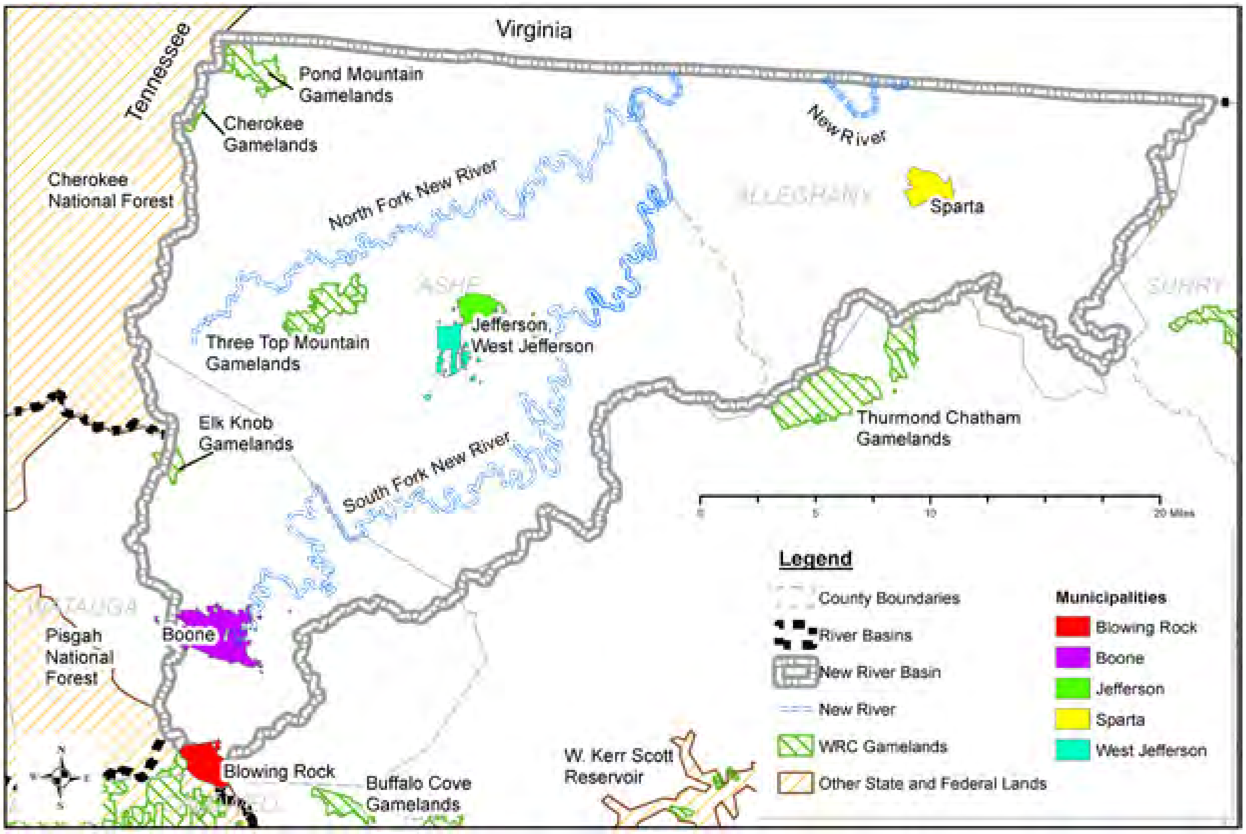
The New River Basin encompasses all or portions of three counties (Ashe, Alleghany, and Watauga) and has six municipalities, with Boone being the largest. Figure 4.25 depicts the geographic location of the basin.

4.5.13.2 Aquatic Resource Conditions

Water quality is generally good in the New River Basin. However, impaired waters within the basin include Naked Creek, Little Buffalo Creek (due to wastewater treatment plant discharge, nonpoint sources-sedimentation), Peak Creek, Ore Knob Branch, and Little Peak Creek (due to acid mine drainage).

The entire Wild and Scenic-designated reach of the New River and South Fork New River reach is classified as Outstanding Resource Waters (ORW). Most of the middle reach of the South Fork New River is designated as High-Quality Waters (HQW), as is the lower Little

Figure 4.25 Location of the New River Basin



River. The requirements for classification as ORW are more stringent than those for HQW and in some circumstances, the unique characteristics of the resources require that a specialized management strategy be developed (NCDWQ 2011c).

There are four HQW (51,463 acres) and six ORW (160,697 acres) Special Management Strategy Areas in the basin for North Fork and South Fork New River areas, Little River, Howard Creek, and Old Field Creek and Call Creek areas (NCDWR 2015c). These areas require site-specific provisions to protect resource values (no new discharges or expansion of existing discharges) (see 15A NCAC 02B.0225).

Table 4.71 provides information on water quality classifications and use support ratings in the basin.

The basin contains some of the highest quality waters in the state, with many high-elevation trout streams supporting native Brook Trout. There are 569 miles of NCDWR-designated trout waters (Tr) in the basin. This is not the same as the Commission's designated public Mountain Trout Waters, which is used to designate waters that are open to public trout fishing.

Table 4.71 Water quality classification and rating information for the New River Basin

Classifications	Freshwater Miles	Percent (Basin Waters)	Freshwater Acres	Percent (Basin Waters)
Total Basin Waters*	2,071	—	239	—
HQW	194	9	—	—
ORW	329	16	—	—
Use Ratings	**Freshwater Miles**	**Percent (Monitored Waters)**	**Freshwater Acres**	**Percent (Monitored Waters)**
Total Named Waters	924	—	—	—
Supporting	440	48	—	—
Impaired	36	4	—	—
Not Rated	4	<1	—	—
No Data	444	48	—	—

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

4.5.13.3 Aquatic Species

There are nine SGCN in the basin: six freshwater fishes and three freshwater mussel species. Appendix G provides a list of SGCN and other priority for which thereknowledge gaps and management concerns. Appendix H identifies SGCN associated with aquatic communities found in this river basin. Table 4.72 identifies the SGCN found in the New River Basin.

4.5.13.4 Threats Affecting Aquatic Species

While water quality is generally good, there are localized problems and general habitat degradation in many cool- and warmwater habitats for priority species throughout the basin. Development and land clearing, poorly managed livestock grazing (which causes runoff and stream bank degradation), unpaved rural roads along streams, and loss of riparian vegetation are some of the primary sources. There are nine permitted CAFOs for cattle in the basin with 12 waste lagoons associated with the facilities. Waste from these sites contains high levels of nutrients (e.g., nitrogen and phosphorus) in addition to fecal coliform bacteria and chemical compounds, such as antibiotics or hormone products used in commercial feeding operations (NCDWR 2015b). Animal-waste lagoons and spray fields that discharge associated wastewater near aquatic environments are a source of contamination from runoff, percolation into groundwater, and volatilization of ammonia and the release of bacterial contamination. These sources can significantly degrade water quality and endanger human and animal health (Mallin 2003; Mallin and Cahoon 2003).

Water quality is variously degraded by acid mine drainage, impacts from urban runoff, and wastewater treatment plant discharge. Erosion and sedimentation have widespread

Table 4.72 SGCN in the New River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
FISH	*Etheostoma kanawhae*	Kanawha Darter	—
	Exoglossum laurae	Tonguetied Minnow	—
	Percina caprodes	Logperch	—/T
	Percina gymnocephala	Appalachia Darter	—
	Percina oxyrhynchus	Sharpnose Darter	—/SC
	Salvelinus fontinalis	Brook Trout (Native)	—
MUSSEL	*Cyclonaias tuberculata*	Purple Wartyback	—/E
	Elliptio dilatata	Spike	—/SC
	Lasmigona subviridis	Green Floater	FSC/E

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

impacts on aquatic habitats. Impacts from sedimentation appear to be quite severe in some localized areas and generally degrade habitats in larger tributaries and in the mainstem New River. Habitats in the same reaches also appear to suffer from over-widened channels with more uniform depth and substrate coarseness. Increasing human population places greater demand on drinking water supplies. Increased water withdrawals from streams, primarily in the upper South Fork New River subbasin, are a potential trend.

Most agriculture and development is concentrated in the valleys with the exception of Christmas tree farms, although development on steeper slopes is increasing. Christmas tree production is a major agricultural enterprise in the basin and large amounts of pesticides and herbicides are used. Impacts from this on aquatic systems are largely unknown.

Impoundment is not a significant issue in the basin. According to an NCDENR dam inventory (NCDEMLR 2014), there are 46 impoundments in the basin. Most are small privately owned lakes used for recreation. There is one run-of-river hydroelectric facility at Sharpe Falls on North Fork New River, and numerous small impoundments on tributaries.

Numerous nonnative aquatic animal species are established in the basin. As identified in previous basin accounts, nonnative vegetation can also negatively impact native aquatic animal communities. This includes both aquatic and riparian plant species and nonnative plant pathogens that can alter riparian vegetation and affect aquatic habitats (e.g., Hemlock Wooly Adelgid). Hydrilla is well established throughout many of the larger streams, especially the South Fork system, and appears to substantially impact instream habitats. Overall, impacts of invasive species on populations of native species are unclear at present, but should be a focus of long-term monitoring and specific investigations.

4.5.13.5 Recommendations

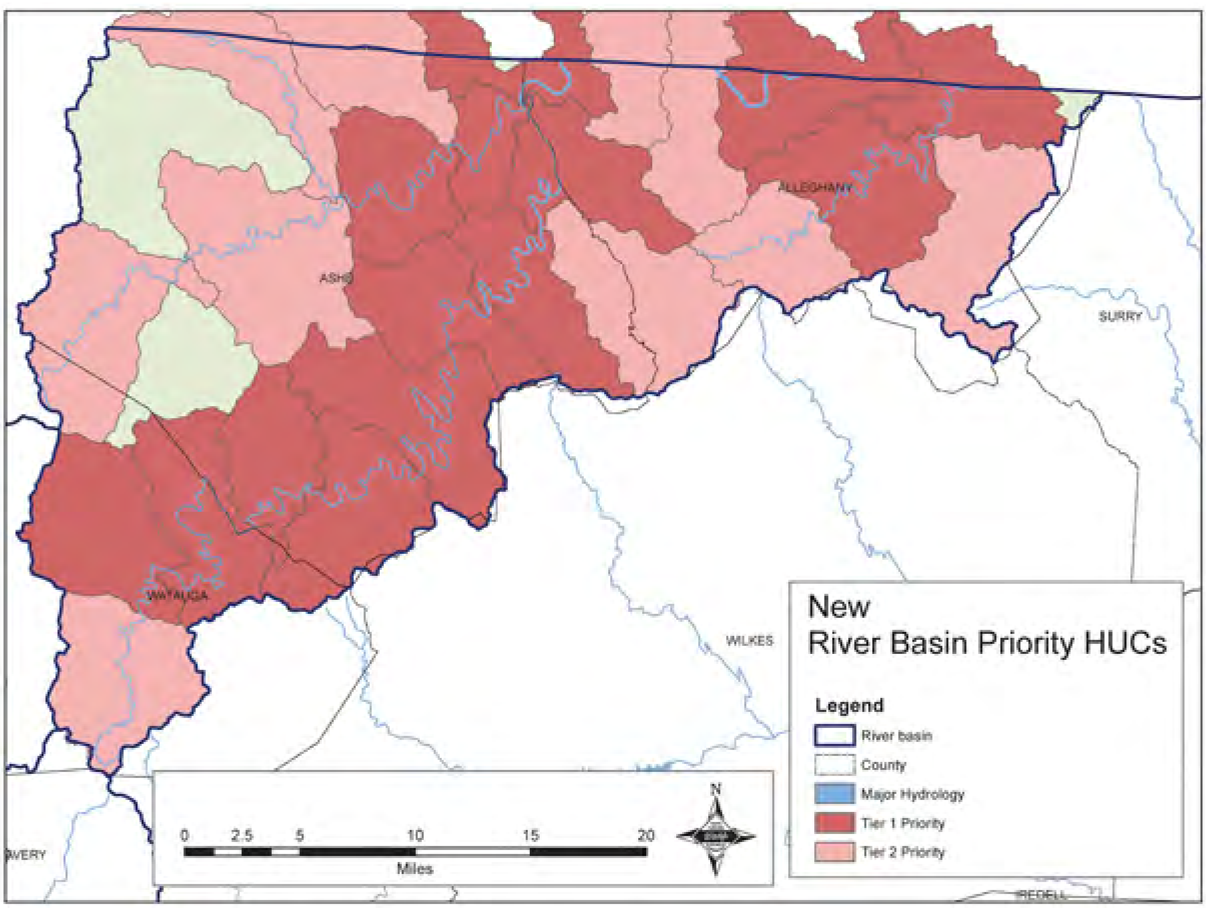
Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priorities identified in the New River Basin are shown in Figure 4.26 and a list of the priority 12-digit HUCs is included in Appendix J.

Basin Specific Recommendations

Surveys. While the general distributions of most SGCN species are known, surveys are still needed to complete primary distributional status for certain SGCN species (see Table 4.71).

- Aquatic Snails—complete primary distribution inventories; determine potential habitats and distribution surveys for hydrobiids.
- Determine distribution of nonnative species in the basin.

FIGURE 4.26 Location of priority watersheds in New River Basin.



Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Baseline data and sites for long-term monitoring of fish, crayfish, and mussels are established and should be monitored periodically. These efforts will inform species and habitat management decisions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Monitor status of nonnative species (e.g., Hydrilla).
- Continue periodic monitoring of priority areas and species.
- Establish baselines and sites for long-term monitoring of snails in the basin.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

In addition to the SGCN species found in the basin (see Table 4.72), a list of knowledge-gap priority species is provided in Table 4.73.

Table 4.73 Knowledge-gap priority species in the New River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
FISH	*Chrosomus oreas*	Mountain Redbelly Dace	—
	Cyprinella spiloptera	Spotfin Shiner	—
	Nocomis platyrhynchus	Bigmouth Chub	—
	Notropis photogenis	Silver Shiner	—
	Notropis rubricroceus	Saffron Shiner	—
	Notropis scabriceps	New River Shiner	—
	Notropis sp. cf. rubellus	Kanawha Rosyface Shiner	—
	Notropis volucellus	Mimic Shiner	—
	Phenacobius teretulus	Kanawha Minnow	FSC/SC
	Pimephales notatus	Bluntnose Minnow	—
MUSSEL	*Corbicula fluminea*	Asian Clam [Exotic]	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital. Specific issues in this basin include secondary and cumulative impacts upon water quality, riparian vegetation and stream bank restoration and conservation, mitigation of hydropower development impacts, and species restoration opportunities.

4.5.14 Pasquotank River Basin

4.5.14.1 River Basin Description

The Pasquotank River Basin is an Atlantic Slope drainage with a small portion of its headwaters in Virginia. The remainder of the basin lies in North Carolina's Coastal Plain and drains into the Albemarle Sound. The Pasquotank River flows as freshwater until tidal influence begins downstream of Elizabeth City. The Pasquotank is the fifth largest river basin in the state (3,366 square miles), and has 107 miles of Atlantic coast line. Major tributaries within the river basin include Alligator River, Perquimans River, Little River, Yeopim River, Scuppernong River, and North River. There are no major reservoirs in the basin.

Based on the 2011 National Land Cover Dataset, land use in the basin was estimated to be 6% forested, 20% agricultural, 33% wetland, 4% urban or developed, and less than 1% grassland (MLCR 2011; Jin et al. 2013). Land in the basin is very flat and geology consists of alternating layers of sand, silt, clay, and limestone. Low flows over the warmest months of the year limits the ability of streams in the basin to maintain high DO levels.

Nearly 22% of the land in the basin is classified as a national wildlife refuge (Alligator River, Currituck, Great Dismal Swamp, Mackay Island, Pea Island, and Pocosin Lakes). Lake Phelps, located in Pettigrew State Park, is the state's second largest natural lake at 16,000 acres. Additionally, the basin contains the 70-mile long Cape Hatteras National Seashore. The basin contains all or portions of 13 NCWRC game lands (including Buckridge, Gull Rock, New Lake, Northwest River Marsh, and Roanoke Island Marshes), representing over 103,838 acres (5% of the basin). These game lands include a black bear sanctuary on North River Game Land and waterfowl impoundments on the North River, Futch, and Lantern Acres game lands.

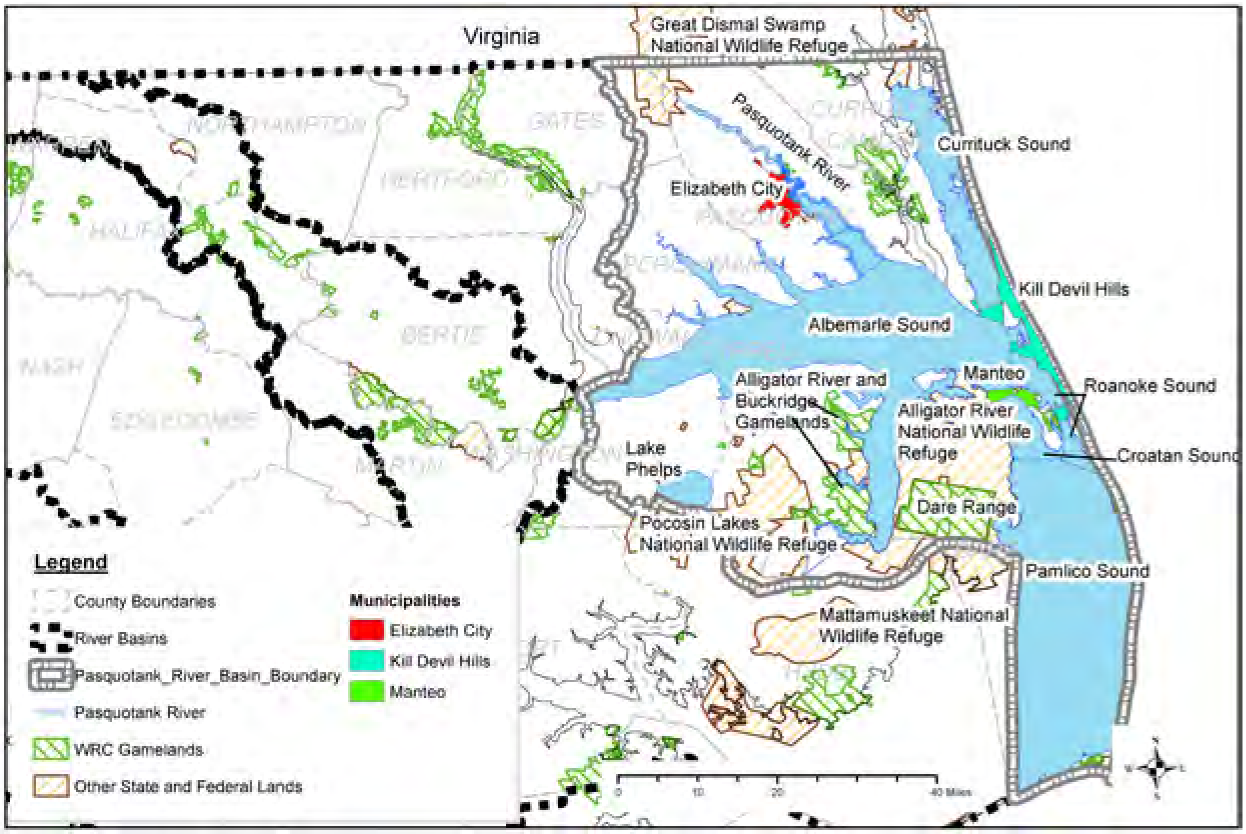
There are 13 municipalities within the 10 counties in the basin. The largest municipalities are Elizabeth City, Manteo, and Kill Devil Hills on the Outer Banks. According to USCB data (2010), the human population is estimated to be 139,127; however, seasonal populations may be higher, as the Outer Banks are a popular vacation destination. Figure 4.27 shows the location of the Pasquotank River Basin.

4.5.14.2 Aquatic Resource Conditions

Waterbodies in the basin exhibit a broad range of conditions, from the brackish waters of the Albemarle Sound to the tidal freshwater marshes of the upper Currituck to the freshwater rivers and streams throughout. Unique in this basin is Phelps Lake, a large shallow natural lake located in Pettigrew State Park.

Segments of the Alligator, Little, North, Pasquotank, Perquimans, Scuppernong, and Yeopim rivers and many of their tributaries, Phelps Lake, Swan Creek Lake, and Sandy

Figure 4.27 Location of the Pasquotank River Basin



Ridge Gut have been designated as High Quality Waters (HQW) or Outstanding Resource Waters (ORW) (NCDWR 2015j, 2015c). The NCDWR assigns best-use classifications to state waters, monitors them to determine if they are supporting their use classification(s), and assigned use-support ratings. These ratings are published in the most recent 303(d) impaired waterbodies list (EPA 2014a; NCDWR 2015a). Table 4.74 provides information on water quality classifications and use-support ratings in the basin.

There are ORW Special Management Strategy Areas in the basin for Lake Phelps Area (15,926 acres) and Alligator River Area (61,608 acres) (NCDWR 2015c). These areas require site-specific provisions to protect resource values (no new discharges or expansion of existing discharges) (see 15A NCAC 02B.0225). There are approximately 43 miles of freshwater streams classified as nutrient-sensitive waters (NSW) in the Pasquotank River Basin (NCDWR 2015a). The NSW classification applies to Black Walnut Swamp and the portions of Edenton Bay, Pembroke Creek, Pollock Swamp, and Queen Anne Creek in the basin (NCDWR 2015c, 2015d). This classification is intended for those waters that need additional nutrient management due to greater vulnerability to excessive aquatic vegetation growth (NCDWQ 2007c).

The NC Division of Marine Fisheries (NCDMF) classifies coastal waters for shellfish harvesting by means of a sanitary survey, which includes a shoreline survey of sources of

TABLE 4.74 Water quality classification and rating information for the Pasquotank River Basin

Classifications	Freshwater Miles	Percent (Basin Waters)	Freshwater Acres	Percent (Basin Waters)	Coastal Acres	Percent (Basin Waters)
Total Basin Waters*	2,487	—	23,541	—	918,532	—
HQW	388	16	—	—	396,132	43
ORW	249	10	15,938	68	43,154	5
Use Ratings	**Freshwater Miles**	**Percent (Monitored Waters)**	**Freshwater Acres**	**Percent (Monitored Waters)**	**Coastal Acres**	**Percent (Monitored Waters)**
Total Named Waters	669	—	22,286	—	918,532	—
Supporting	96	14	16,881	76	419,014	46
Impaired	19	3	—	—	405,977	44
Not Rated	26	4	—	—	—	—
No Data	528	79	5,405	24	93,541	10

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

pollution, a hydrographic and meteorological survey, and a bacteriological survey of growing waters (NCDMF 2015). Sanitary surveys are conducted for all potential shellfish-growing areas in coastal North Carolina and recommendations are made to the NCDMF which areas should be closed for shellfish harvesting. Waters are classified as either 'Approved,' 'Conditionally Approved,' or 'Prohibited' based on the analysis of the data collected from each sampling station. There are 16 designated shellfish harvesting areas around the Albemarle and Currituck sounds that are considered impaired and classified as Prohibited for the harvest of any oysters, clams, or mussels.

4.5.14.3 Aquatic Species

There are six freshwater fish SGCN in the basin. Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN associated with aquatic communities found in this river basin. Table 4.75 identifies the SGCN found in the Pasquotank River Basin.

4.5.14.4 Threats Affecting Aquatic Species

The cumulative effects of nonpoint source pollution are the primary threat to water quality across the state and throughout the Pasquotank River Basin. The presence of nonpoint source pollution can be identified through the NCDWR basinwide plan and the NCDMF sanitary surveys, but actions to address these impacts must be taken at the local level. Without proactive land-use planning initiatives and local water quality strategies,

Table 4.75 SGCN in the Pasquotank River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
FISH	*Acipenser brevirostrum*	Shortnose Sturgeon	E/E
	Acipenser oxyrinchus	Atlantic Sturgeon	E/E
	Enneacanthus chaetodon	Blackbanded Sunfish	—
	Enneacanthus obesus	Banded Sunfish	—
	Fundulus cf. diaphanus	Lake Phelps Killifish	FSC/—
	Notropis chalybaeus	Ironcolor Shiner	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

population growth and development in the basin increases the risk of waterbody impairment (NCDWQ 2007c).

Another major water quality problem in the basin is fecal coliform bacteria contamination (affecting shellfish harvesting). Fecal coliform bacteria contamination is primarily attributed to nonpoint source pollution associated with runoff from urban areas and agricultural lands. The task of quantifying nonpoint sources of pollution and developing management strategies for these impaired waters is very resource intensive. Federal and state stormwater regulations and initiatives are in place to help reduce and prevent stormwater runoff in developing coastal communities (NCDWQ 2007c).

There are 25 permitted Confined Animal Feeding Operations (CAFOs) in the basin, with 60 associated waste lagoons. Waste from these sites is a source of high levels of nutrients (e.g., nitrogen and phosphorus) (NCDWR 2015b). Animal-waste lagoons and spray fields that discharge nutrients and bacteria contamination near or into aquatic environments through runoff, percolation into groundwater, and volatilization of ammonia and the release of bacterial contamination can significantly degrade water quality and endanger health (Mallin 2003; Mallin and Cahoon 2003).

It is important to note that all waters in the state are rated as impaired based on a state-wide fish consumption advisory for mercury contamination. Waters are assessed to determine how well they are meeting classification standards and are given a rating to indicate whether they meet these standards. In some cases, waters may not be assessed or rated, or data is not available for the waterbody to be rated (NCDWQ 2007c). Detailed information on water quality parameters in the basin is available online from the NCDWR Basin Planning Branch (http://portal.ncdenr.org/web/wq/ps/bpu).

4.5.14.5 Recommendations

Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priorities identified in the Pasquotank River Basin are shown in Figure 4.28 and a list of the priority 12-digit HUCs is included in Appendix J.

Basin Specific Recommendations

Surveys. General surveys are needed to complete primary distributional status for SGCN and other priority species (see Table 4.75).

- Fishes—determine distribution and status of priority species (e.g., Banded Sunfish, Blackbanded Sunfish, and Ironcolor Shiner). In addition, conduct exploratory surveys for priority species that have a high potential of occurring in the river basin (e.g., Bridle Shiner), but are not currently known to occur in the river basin.

Figure 4.28 Location of priority watersheds in the Pasquotank River Basin

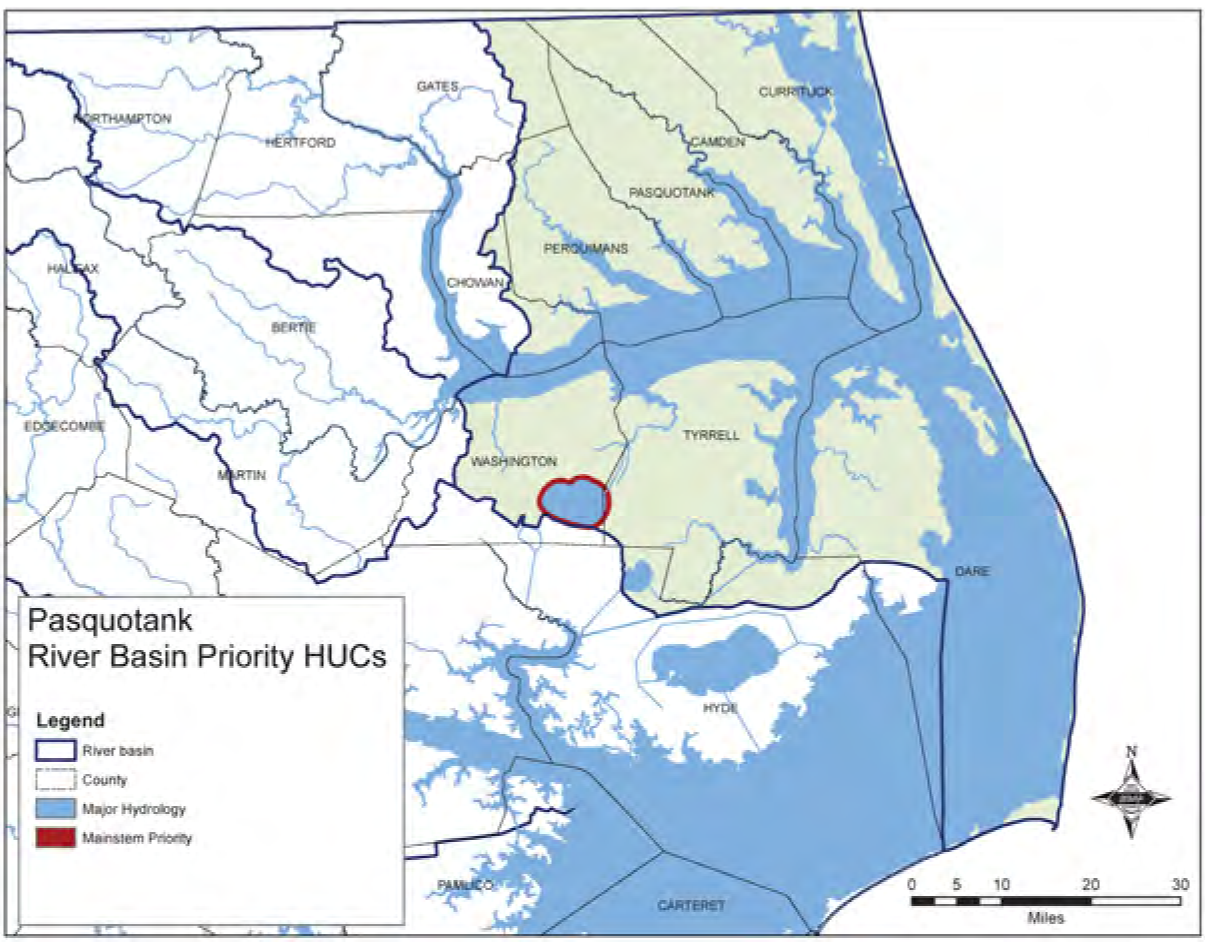


Table 4.76 Knowledge-gap priority species in the Pasquotank River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
FISH	*Fundulus diaphanus*	Banded Killifish	—
	Lepisosteus osseus	Longnose Gar	—
	Petromyzon marinus	Sea Lamprey	—
MUSSEL	*Corbicula fluminea*	Asian Clam [Exotic]	—
	Utterbackia imbecillis	Paper Pondshell	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

- Crayfishes—conduct baseline distribution surveys for all species that occur in the basin.
- Aquatic Snails—conduct baseline distribution survey for all species that occur in the basin.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Identify long-term monitoring sites and develop monitoring protocols for priority species (e.g., Banded Sunfish, Blackbanded Sunfish, Ironcolor Shiner, and Lake Phelps Killifish).

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Study habitat use and life history characteristics of priority species (e.g., Banded Sunfish, Blackbanded Sunfish, Ironcolor Shiner, and Lake Phelps Killifish).
- Support taxonomic research for priority species (e.g., Lake Phelps Killifish).

- Support development of captive propagation techniques for priority species (e.g., Banded Sunfish, Blackbanded Sunfish, and Ironcolor Shiner).

- Support genetics research that informs augmentation policy for priority species (e.g., Banded Sunfish, Blackbanded Sunfish, and Ironcolor Shiner).

- Determine impacts of nonnative species on priority species (e.g, Red Swamp Crawfish).

In addition to the SGCN species found in the basin (see Table 4.75), a list of knowledge-gap priority species is provided in Table 4.76.

Management Practices Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital.

- Support efforts to restore the native aquatic community (e.g., reintroduction or augmentation).

- Support acquisition of land that is adjacent to current conservation holdings or priority watersheds.

- Support other regulatory agencies to minimize impacts on species and habitats.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Wetland and marsh restoration projects and shoreline stabilization are high priorities for areas prone to erosion from natural exposure or from heavy boat traffic.

- The NCDMS has identified targeted local watersheds as restoration priorities in most river basins using 14-digit HUCs. Information about these priorities in the Pasquotank River Basin is available online http://portal.ncdenr.org/web/eep/rbrps/pasquotank.

- Guide academic research projects to help achieve specific conservation goals and objectives.

- Support the development and application of an aquatic nuisance species management plan with other agencies/groups.
- Address secondary and cumulative impacts upon water quality (buffer ordinances, water supply watershed protection, and headwaters protection).
- Work with and promote existing programs that help farmers reduce sedimentation/ erosion (installing fences to keep livestock out of streams, improving tilling practices) as well as reduce pesticide and herbicide use.
- Support stormwater management and wastewater treatment plant improvements and upgrades.

4.5.15 Roanoke River Basin

4.5.15.1 River Basin Description

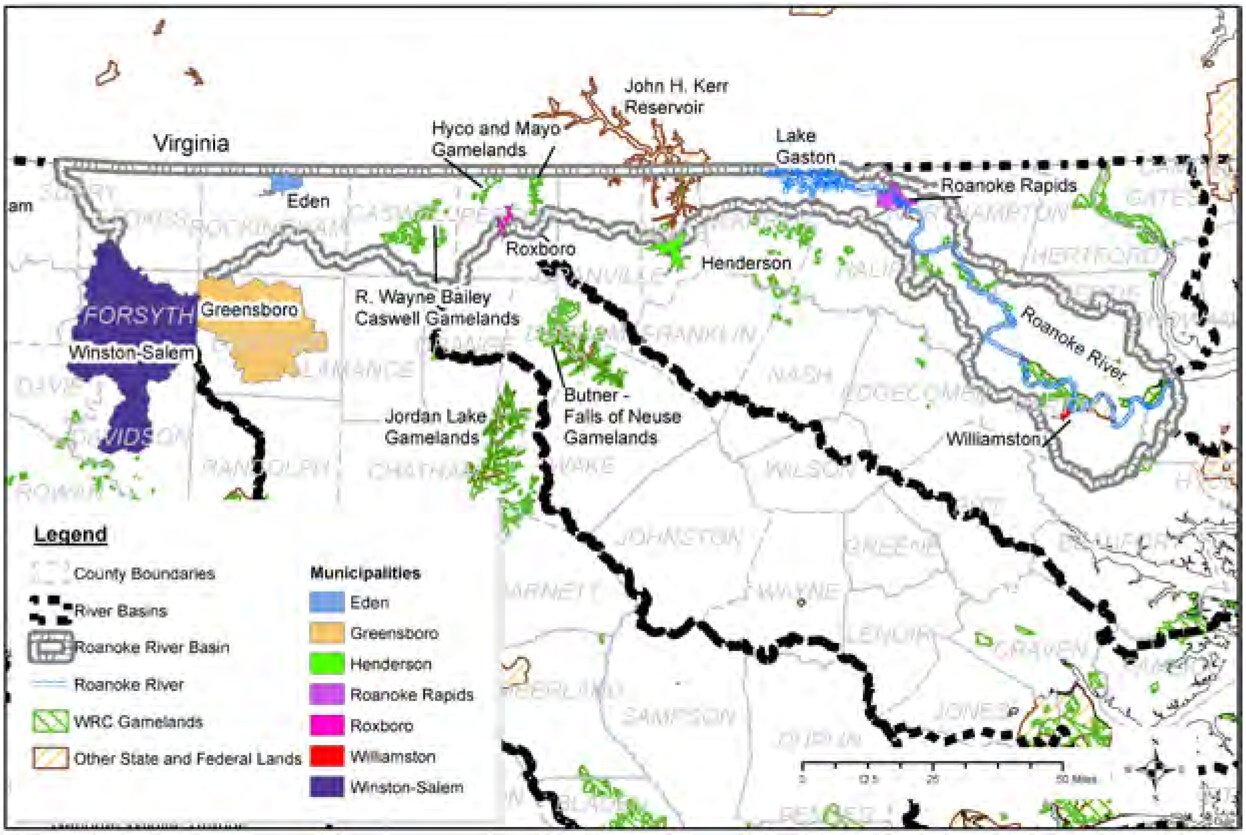
The Roanoke River Basin is an Atlantic Slope basin with headwaters that begin in the Mountains of Virginia and flow eastward to drain into the Albemarle Sound in North Carolina. Nearly 65% of the basin is located in Virginia.The entire basin is approximately 9,766 square miles and in North Carolina it covers 3,493 square miles, making it the sixth largest river basin in the state. The Roanoke River carries the most water and has the widest floodplain (up to 5 miles wide in parts) of any North Carolina river. There are 8,439 freshwater stream miles, 35,955 acres of freshwater lakes and impoundments, and approximately 4.2 miles of coastline in the basin (NCDWR 2015d). According to National Hydrography Dataset, there are 1,476 estuarine acres in the basin (EPA 2014b; Jin et al. 2013). Major tributaries to the Roanoke River include the Dan River, Mayo River, Smith River, Country Line Creek, Hyco Creek/River, Cashie River, and Conoho Creek. Major impoundments include the John H. Kerr Reservoir, Hyco Lake, Lake Gaston, and Belews Lake.

The NC portion has two distinct parts: the western Section in the Piedmont ecoregion, which includes the area above Roanoke Rapids Dam, and the eastern Section in the Coastal Plain ecoregion, which begins below Roanoke Rapids Dam. The upper Dan River watershed in western North Carolina shows characteristics of both the Mountain and Piedmont ecoregions, with fairly steep topography typical of Mountain headwaters. The Piedmont portion features rolling hills and is underlain with crystalline or sedimentary rocks and many tributary streams that carry large sediment bed loads. The transition zone between the Piedmont and Coastal Plain occurs below Roanoke Rapids Lake, with the lower 60 miles of river within the Coastal Plain. The Coastal Plain portion features a flat topography and is underlain by sand, silt, clay, and limestone.

Land use in the basin is approximately 51% forested, 13% wetland, 7% urban or developed, 6% grassland, and 20% agricultural (MRLC 2011; Jin et al. 2013). There are several federal- and state-owned public lands in the basin, including over 1.14 million acres of game lands (e.g., Caswell, Bertie County, Hyco, Roanoke River, Tillery), 32,751 acres of state and federal park lands (Hanging Rock State Park, Kerr Lake Recreation Area), and 29,960 acres of Roanoke River National Wildlife Refuge.

There are 34 municipalities within the 17 counties covered by the basin. The most populated areas are located northeast of the Greensboro/Winston-Salem area and around the larger municipalities in the basin such as Roanoke Rapids, Eden, Williamston, and Plymouth. Figure 4.29 shows the location of the Roanoke River Basin.

Figure 4.29 Location of the Roanoke River Basin



4.5.15.2 Aquatic Resource Conditions

There are about 8,439 miles of streams and rivers, including small intermittent and ephemeral streams, and numerous acres of freshwater and estuarine wetland communities in the basin. Segments of Country Line Creek, South Hyco Creek, Storys Creek, Double Creek, their tributaries, and other streams in the basin have supplemental classifications as High Quality Waters (HQW) or Outstanding Resource Waters (ORW) because they either have excellent water quality or they are a significant resource to humans and/or wildlife (NCDWR 2015c, 2015d).

There are ORW Special Management Strategy Areas in the basin for the Cascade Creek and Indian Creek areas (506 acres) (NCDWR 2015c). These areas require site-specific provisions to protect resource values (no new discharges or expansion of existing discharges) (see 15A NCAC 02B.0225). Table 4.77 provides information on water quality classifications and use-support ratings in the basin.

Another supplemental classification is NCDWR's trout water designation (Tr), which protects freshwaters for natural propagation of trout and survival of stocked trout on a year-round basis. There are about 120 miles of streams in the Roanoke River Basin

Table 4.77 Water quality classification and rating information for the Roanoke River Basin

Classifications	Freshwater Miles	Percent (Basin Waters)	Freshwater Acres	Percent (Basin Waters)	Coastal Acres	Percent (Basin Waters)
Total Basin Waters*	8,439	—	37,927	—	1,476	—
HQW	97	1	1,045	3	—	—
ORW	2	<1	—	—	—	—
Use Ratings	**Freshwater Miles**	**Percent (Monitored Waters)**	**Freshwater Acres**	**Percent (Monitored Waters)**	**Coastal Acres**	**Percent (Monitored Waters)**
Total Named Waters	2,217	—	37,543	—	1,476	—
Supporting	844	38	34,225	91	—	—
Impaired	66	3	2,289	6	—	—
Not Rated	42	2	—	—	—	—
No Data	1,265	57	1,029	3	1,476	100

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

designated Tr. This is not the same as the Commission's designated public Mountain Trout Waters, which is used to designate waters that support trout and are open to public fishing.

4.5.15.3 Aquatic Species

There are 28 SGCN in the basin: one crayfish species, 20 fish species, and seven mussel species. Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN associated with aquatic communities found in this river basin. Table 4.78 identifies the SGCN found in the Roanoke River Basin.

4.5.15.4 Threats Affecting Aquatic Species

There are 37 permitted CAFOs for cattle and swine in the basin, with 54 waste lagoons associated with these facilities (NCDWR 2015b). Nonpoint wastewater discharges from CAFOs contain high levels of nutrients (e.g., nitrogen, phosphorus), as well as fecal coliform bacteria and chemical compounds associated with livestock operations (e.g., antibiotics, hormone products) (NCDWR 2015b). Animal-waste lagoons that use spray fields to discharge wastewater near aquatic environments are a source of contamination because of the runoff, percolation of wastewater into groundwater, and volatilization of ammonia release bacteria that significantly degrade water quality and endanger human and animal health (Mallin 2003; Mallin and Cahoon 2003). Upstream waters located in Virginia are a source of contamination. For example, the waters of Kerr Reservoir in Virginia are considered by the VA

TABLE 4.78 SGCN in the Roanoke River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
CRAYFISH	*Orconectes virginiensis*	Chowanoke Crayfish	FSC/SC
FISH	*Acipenser brevirostrum*	Shortnose Sturgeon	E/E
	Acipenser oxyrinchus	Atlantic Sturgeon	E/E
	Ambloplites cavifrons	Roanoke Bass	FSC/—
	Ameiurus brunneus	Snail Bullhead	—
	Ameiurus platycephalus	Flat Bullhead	—
	Carpiodes sp. cf. cyprinus	a carpsucker	—
	Cottus caeruleomentum	Blue Ridge Sculpin	—/SC
	Enneacanthus chaetodon	Blackbanded Sunfish	—
	Enneacanthus obesus	Banded Sunfish	—
	Etheostoma collis	Carolina Darter	FSC/SC
	Exoglossum maxillingua	Cutlips Minnow	—/SC
	Hypentelium roanokense	Roanoke Hog Sucker	—
	Lampetra aepyptera	Least Brook Lamprey	—/T
	Moxostoma ariommum	Bigeye Jumprock	—/T
	Moxostoma pappillosum	V-lip Redhorse	—
	Notropis chalybaeus	Ironcolor Shiner	—
	Noturus gilberti	Orangefin Madtom	FSC/E
	Percina rex	Roanoke Logperch	E/E
	Salvelinus fontinalis	Brook Trout (Native)	—
	Thoburnia hamiltoni	Rustyside Sucker	FSC/E
MUSSEL	*Alasmidonta undulata*	Triangle Floater	—/T
	Anodonta implicata	Alewife Floater	—/T
	Fusconaia masoni	Atlantic Pigtoe	FSC/E
	Lampsilis cariosa	Yellow Lampmussel	FSC/E
	Lasmigona subviridis	Green Floater	FSC/E
	Pleurobema collina	James Spinymussel	E/E
	Villosa constricta	Notched Rainbow	—/SC

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

Department of Environmental Quality to be impaired for polychlorinated biphenyls (PCBs) and low DO (CBF 2005). Other sources come from point sources that includes industrial and municipal wastewater, selenium ash pond discharge, and urban stormwater discharges that contribute toxic compounds and elements such as ammonia, chlorine, mercury, and various organic compounds. Waters in Welch Creek and Batchelor Bay in the eastern part of the basin are rated impaired for dioxin contamination.

According to an NCDENR dam inventory (NCDEMLR 2014), there are 487 man-made impoundments and ponds in the basin. While most are used for recreation, flood control or stormwater management, irrigation, or water supply, five are licensed for hydroelectric energy production. These can physically alter instream habitat, change flow regimes, and often reduce DO levels. Water withdrawals for irrigation and similar uses further change flow patterns and reduce the quality/quantity of the habitat available for aquatic species (NCDWQ 2012e).

Large reservoirs in the Roanoke River Basin include Hyco, Mayo, Kerr, and Lake Gaston. The Mayo and Hyco reservoirs provide waters for cooling Duke Energy's coal-fired power plants. Hyco Lake has been listed on the state's impaired waters list for exceeding thresholds for mercury. Freshwater streams in the eastern portion of the basin are heavily used by anadromous fishes, and impoundments are barriers to movement between coastal and upstream freshwater spawning habitats.

According to 2010 census data, there was a population increase of roughly 1.5% in the North Carolina portion of the basin from 2000 census data (NCDWR 2012). Recent Census data for the period 2010 to 2014, estimates a slight population decrease for the Roanoke Rapids area and the basin's counties (USCB 2015). However, development in adjacent urbanizing areas of the central Piedmont, including the Greensboro–Highpoint area and the Triangle region, is likely to spur demands for water supplies that could result interbasin withdrawals from the Roanoke River Basin (NCOEE n.d.). The demand for water by consumers living in the basin is expected to increase by as much as 55% by 2020.

4.5.15.5 Recommendations

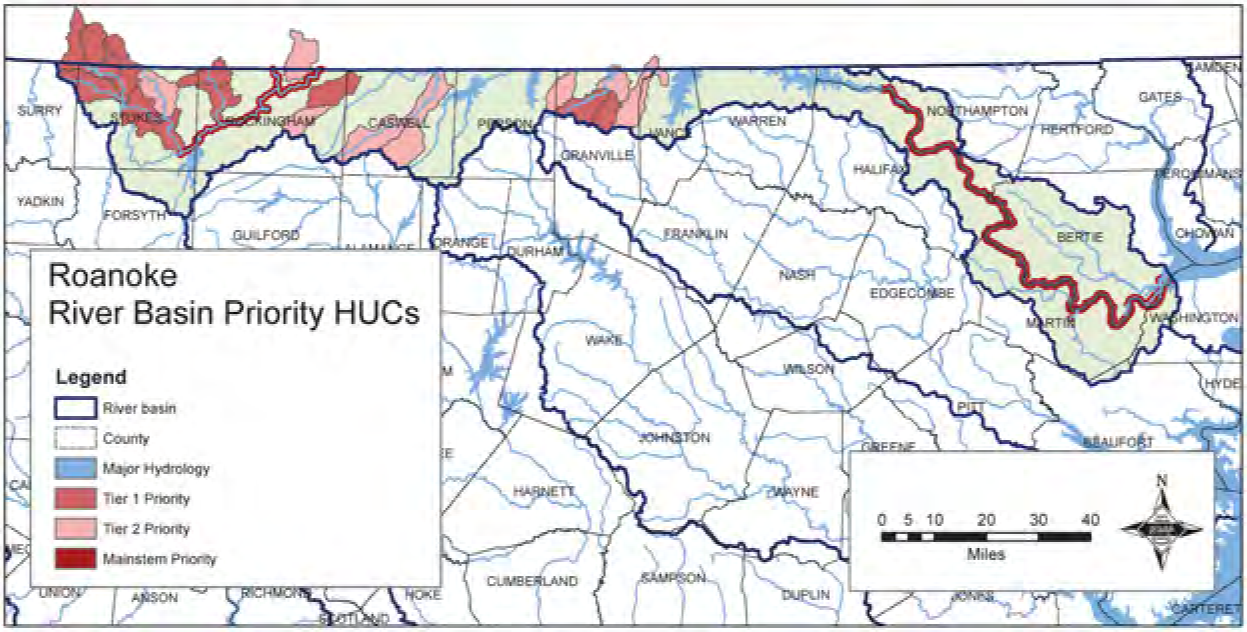
Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priorities identified in the Roanoke River Basin are shown in Figure 4.30 and a list of the priority 12-digit HUCs is included in Appendix J.

Basin Specific Recommendations

Surveys. General surveys are needed to complete primary distributional status for SGCN and other priority species (see Table 4.78).

- Fishes—determine distribution and status of priority species (e.g., Bigeye Jumprock, Black Banded Sunfish, Cutlips Minnow, Ironcolor Shiner, Least Brook Lamprey, Orangefin Madtom, Roanoke Logperch, and Rustyside Sucker). In addition, conduct exploratory surveys for priority species that have a high potential of occurring in the river basin (e.g., Bridle Shiner), but are not currently known to occur in the river basin.

Figure 4.30 Location of priority watersheds in the Roanoke River Basin



- Mussels—determine distribution and status of priority species (e.g., Alewife Floater, Atlantic Pigtoe, Green Floater, and James Spinymussel).

- Crayfishes—determine distribution and status of priority species (e.g., Carolina Ladle Crayfish).

- Snails—conduct baseline distribution surveys for all species that occur in the basin.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Identify long-term monitoring sites and develop monitoring protocols for priority species (e.g., Bigeye Jumprock, Chowanoke Crayfish, Green Floater, Ironcolor Shiner, Orangefin Madtom, and Roanoke Logperch).

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed. In addition to the SGCN species found in the basin (see Table 4.78), a list of knowledge-gap priority species is provided in Table 4.79.

- Study habitat use and life history characteristics of priority species (e.g., Bigeye Jumprock, Chowanoke Crayfish, Green Floater, Least Brook Lamprey, Roanoke Logperch, Triangle Floater, and V-lip Redhorse).
- Support taxonomic research for priority species (e.g., *Cambarus sp. C* complex and the mussel genus *Elliptio)*.
- Support development of captive propagation techniques for priority species (e.g., Green Floater, Ironcolor Shiner, Orangefin Madtom, Roanoke Logperch, and Triangle Floater).

Table 4.79 Knowledge-gap priority species in the Roanoke River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
AQ SNAIL	*Cipangopaludina japonica*	Japanese Mystery Snail [Exotic]	—
CRAYFISH	*Cambarus davidi*	Carolina Ladle Crayfish	—
FISH	*Chrosomus oreas*	Mountain Redbelly Dace	—
	Etheostoma podostemone	Riverweed Darter	—/SC
	Etheostoma vitreum	Glassy Darter	—
	Fundulus diaphanus	Banded Killifish	—
	Lepisosteus osseus	Longnose Gar	—
	Moxostoma cervinum	Blacktip Jumprock	—
	Nocomis raneyi	Bull Chub	—
	Percina nevisense	Chainback Darter	—
	Percina roanoka	Roanoke Darter	—
	Petromyzon marinus	Sea Lamprey	—
MUSSEL	*Corbicula fluminea*	Asian Clam [Exotic]	—
	Elliptio fisheriana	Northern Lance	—
	Elliptio icterina	Variable Spike	—
	Elliptio roanokensis	Roanoke Slabshell	—/T
	Lampsilis radiata	Eastern Lampmussel	—/T
	Ligumia nasuta	Eastern Pondmussel	—/T
	Pyganodon cataracta	Eastern Floater	—
	Strophitus undulatus	Creeper	—/T
	Uniomerus carolinianus	Florida Pondhorn	—
	Utterbackia imbecillis	Paper Pondshell	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

- Support genetics research that informs augmentation policy for priority species (e.g., Atlantic Pigtoe, Orangefin Madtom, Green Floater, Ironcolor Shiner, James Spinymussel, Triangle Floater, and Roanoke Logperch).
- Determine impacts of nonnative species on priority species (e.g, Japanese Mysterysnail, Virile Crayfish, and Flathead Catfish).

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital.

- Support efforts to restore the native aquatic community through reintroduction or augmentation.
- Support acquisition of land that is adjacent to current conservation holdings or priority watersheds.
- Support other regulatory agencies to minimize impacts on species and habitats.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Work with and promote existing programs that help farmers reduce sedimentation/erosion (e.g., install fences to keep livestock out of streams, improve tilling practices) as well as reduce pesticide and herbicide use.
- Support stormwater management and wastewater treatment plant improvements and upgrades.

4.5.16 Savannah River Basin

4.5.16.1 River Basin Description

The headwaters of the Savannah River Basin begin along the eastern slopes of the Blue Ridge Mountains and flow south through Georgia and South Carolina to empty into the Atlantic Ocean. Only 2% of the total Savannah River Basin is within North Carolina. The basin encompasses 172 square miles, making it the smallest of the state's river basins. The North Carolina portion has approximately 176 miles of streams and 1,366 reservoir acres.

Streams in the North Carolina portion of this river basin are part of the Tugaloo River and Seneca River subbasins (South Carolina); however, both of these named rivers begin outside the state. Major tributaries of the Tugaloo in North Carolina are the Overflow and Big creeks, and the Chattooga River. Major tributaries of the Seneca River in North Carolina include the Toxaway, Horsepasture, Thompson, and Whitewater rivers.

Land use cover in the basin is 91% forested, 1% agricultural, 7% urban or developed, and less than 1% grassland and wetland (MRLC 2011; Jin et al. 2013). A significant portion of the basin is publicly owned land, primarily Nantahala National Forest (189,060 acres), Pisgah National Forest (107,111 acres), NCWRC game lands (nearly 3,000 acres), and Gorges State Park (7,640 acres).

The basin encompasses all or part of four counties (Clay, Jackson, Macon, and Transylvania) and has one sizable municipality (Highlands). Figure 4.31 depicts the location of the basin.

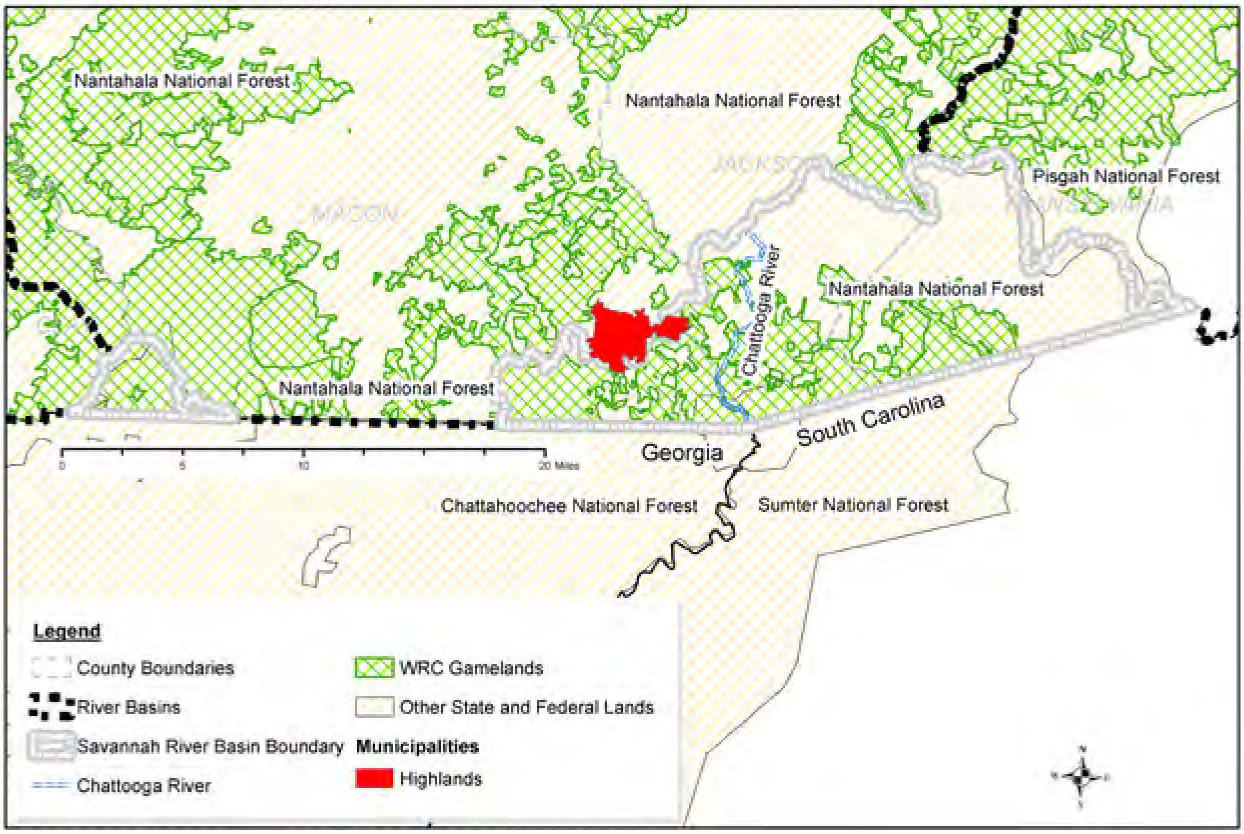
4.5.16.2 Aquatic Resource Conditions

Water quality is generally good for areas where data are available; however, there are problems in parts of the basin (described below), and the lack of data for nearly half the basin provides an unclear assessment of overall water quality. Most of the Tugaloo River tributaries in North Carolina and four miles of the Horsepasture River are designated Outstanding Resource Waters (ORW), and portions of Bearwallow Creek and Whitewater River are designated High-Quality Waters (HQW). The requirements for classification as ORW are more stringent than those for HQW and in some circumstances, the unique characteristics of the resources require that a specialized management strategy be developed (NCDWR 2015d).

Table 4.80 provides information on water quality classifications and use-support ratings in the basin.

Water quality in the Savannah River Basin is excellent in major streams and most small headwater streams. There are 211 miles and 619 acres of NCDWR designated Trout waters (Tr) in the basin. This is not the same as the Commission's designated public Mountain

FIGURE 4.31 Location of the Savannah River Basin



Trout Waters, which is used to designate waters that are open to public trout fishing. There are several small reservoirs, including Cashiers Reservoir, Fairfield Reservoir, and Toxaway Reservoir, and many smaller ponds associated with golf courses and second home developments in the Cashiers/Highlands area.

4.5.16.3 Aquatic Species

There are nine SGCN in the basin: two crayfish species and seven freshwater fish species. Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN associated with aquatic communities found in this river basin. Table 4.81 identifies the priority species found in the Savannah River Basin.

4.5.16.4 Threats Affecting Aquatic Species

While much of the North Carolina portion of the basin is in national forest and state-owned lands, development is increasing on private lands. There are no permitted CAFOs in the basin, but nutrient enrichment may be a problem (NCDWQ 2012f). Nonpoint source problems

TABLE 4.80 Water quality classification and rating information for the Savannah River Basin

Classifications	Freshwater Miles	Percent (Basin Waters)	Freshwater Acres	Percent (Basin Waters)
Total Basin Waters*	323	—	875	—
HQW	21	7	—	—
ORW	41	13	24	3
Use Ratings	**Freshwater Miles**	**Percent (Monitored Waters)**	**Freshwater Acres**	**Percent (Monitored Waters)**
Total Named Waters	194	—	691	—
Supporting	83	43	—	—
Impaired	—	—	—	—
Not Rated	3	1	—	—
No Data	109	56	691	100

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

TABLE 4.81 SGCN in the Savannah River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
CRAYFISH	*Cambarus chaugaensis*	Chauga Crayfish	FSC/SC
	Cambarus reburrus	French Broad River Crayfish	FSC/—
FISH	*Ameiurus brunneus*	Snail Bullhead	—
	Ameiurus platycephalus	Flat Bullhead	—
	Etheostoma inscriptum	Turquoise Darter	—/T
	Hybopsis rubifrons	Rosyface Chub	—/T
	Notropis lutipinnis	Yellowfin Shiner	—/SC
	Percina nigrofasciata	Blackbanded Darter	—/T
	Salvelinus fontinalis	Brook Trout (Native)	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

(primarily erosion and sedimentation) from land clearing, removal of riparian vegetation, and rural roads are potential problems.

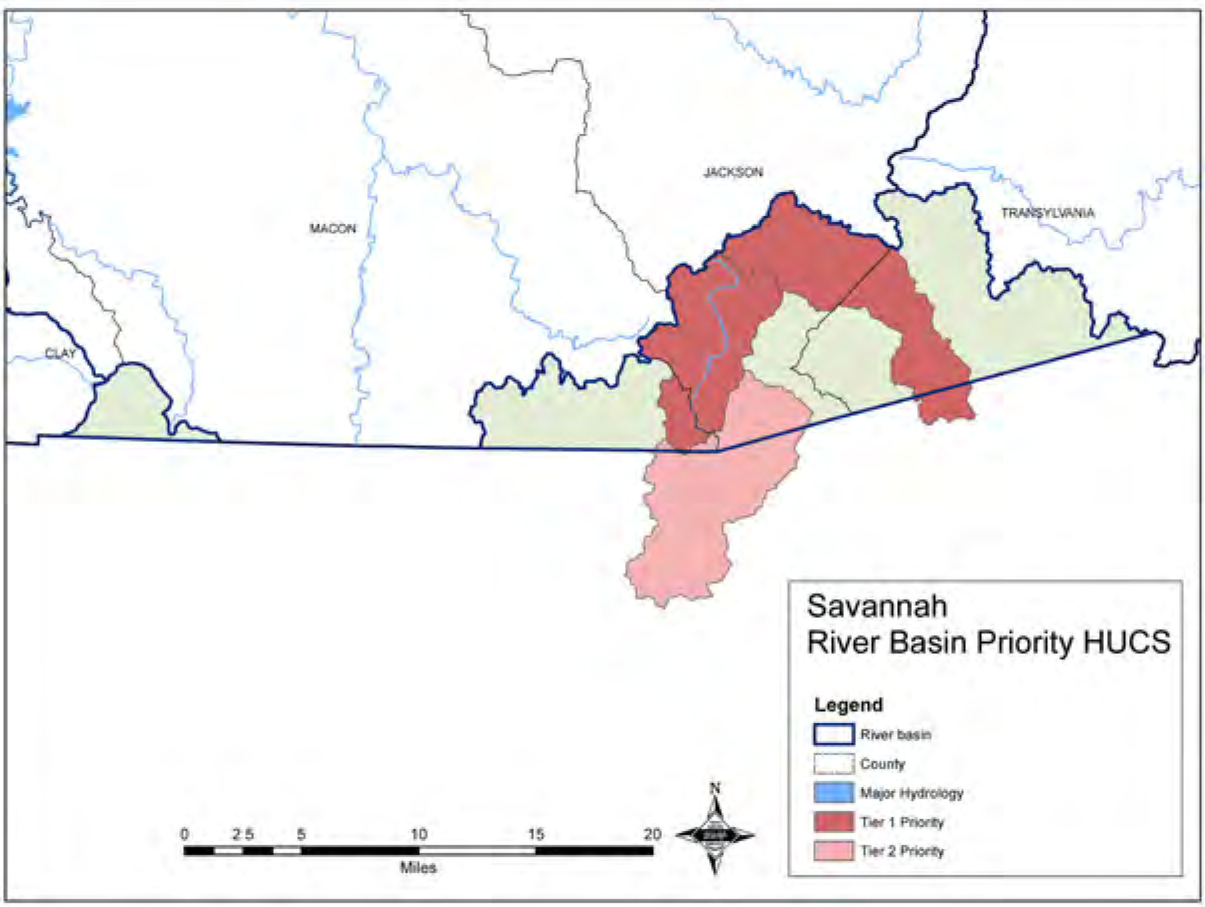
According to an NCDENR dam inventory (NCDEMLR 2014), there are 49 impoundments in the basin. Most are small privately owned lakes used for recreation, and these small impoundments fragment headwater habitats, contribute to temperature pollution, and can be a source of nonnative introductions. All of the major tributaries in North Carolina are upstream from major impoundments in Georgia and South Carolina that isolate them from the rest of the basin. Short reaches of the Horsepasture and Toxoway rivers are impounded just inside the North Carolina border (Lake Jocassee, Duke Energy).

Little is known of the extent to which nonnative aquatic species have become established in the Savannah River Basin in North Carolina. Nonnative vegetation can also negatively impact native aquatic animal communities. This includes both aquatic and riparian plant species and nonnative plant pathogens that can alter riparian vegetation and affect aquatic habitats (e.g., Hemlock Wooly Adelgid).

4.5.16.5 Recommendations

Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priorities identified in the Savannah River Basin are shown in Figure 4.32 and a list of the priority 12-digit HUCs is included in Appendix J.

FIGURE 4.32 Location of priority HUC12 watersheds in the Savannah River Basin



Basin Specific Recommendations

Surveys. General surveys are still needed to complete primary distributional status for SGCN and other priority species (see Table 4.81).

- Aquatic Snails—complete primary distribution inventories; determine potential habitats and distribution surveys for hydrobiids.
- Determine distribution of nonnative species.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible. Continue periodic monitoring of priority areas and species.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed. In addition to the SGCN found in the basin (see Table 4.81), Saffron Shiner is a knowledge-gap priority species in the Savannah River Basin.

- Resolve taxonomic problems with crayfishes.
- Investigate impacts of fragmentation on priority species.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital.

- Support conservation and restoration of streams and riparian zones in priority areas.
- Incorporate management goals for aquatic community conservation and enhancement planning for Gorges State Park and Toxaway Game Lands.

- Prioritize education and other measures to prevent the introduction or spread of invasive nonnative species, particularly crayfishes.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Support the Watershed Restoration Plan (WRP) developed by NCDMS for the Savannah River Basin (NCWRP 2001d).

- Cooperate with NC Division of Parks and Recreation (NCDPR), the US Forest Service (USFS), and NCWRC, who manage much of the basin in North Carolina.

4.5.17 Tar–Pamlico River Basin

4.5.17.1 River Basin Description

The Tar–Pamlico River Basin covers 6,148 square miles, making it the fourth-largest river basin in North Carolina. It is one of only four river basins whose boundaries are located entirely within the state. The Tar River and its headwaters originate in Person, Granville, and Vance counties in the north central part of the Piedmont. It flows southeast until it reaches tidal waters near Washington and becomes the Pamlico River and empties into the Pamlico Sound. Major tributaries include Fishing Creek, Swift Creek, Cokey Swamp, Tranters Creek, and the Pungo River (NCDWR 2015d).

There are two distinct portions of the Tar–Pamlico River Basin: the upper one-fifth, which is in the Piedmont physiographic region, and the lower four-fifths, which is in the Coastal Plain physiographic region.

- The Piedmont portion, running from the river headwaters to the fall line, lies on the Carolina Slate Belt and Triassic Basin geologic units. This portion of the basin features low gradients with sluggish pools separated by riffles and occasional small rapids. Soils are highly erodible and are underlain by fractured rock formations that have limited water storage capacity. Streams in the Piedmont tend to have low summer flows and limited ability to assimilate oxygen-consuming wastes (NCDWR 2014d).

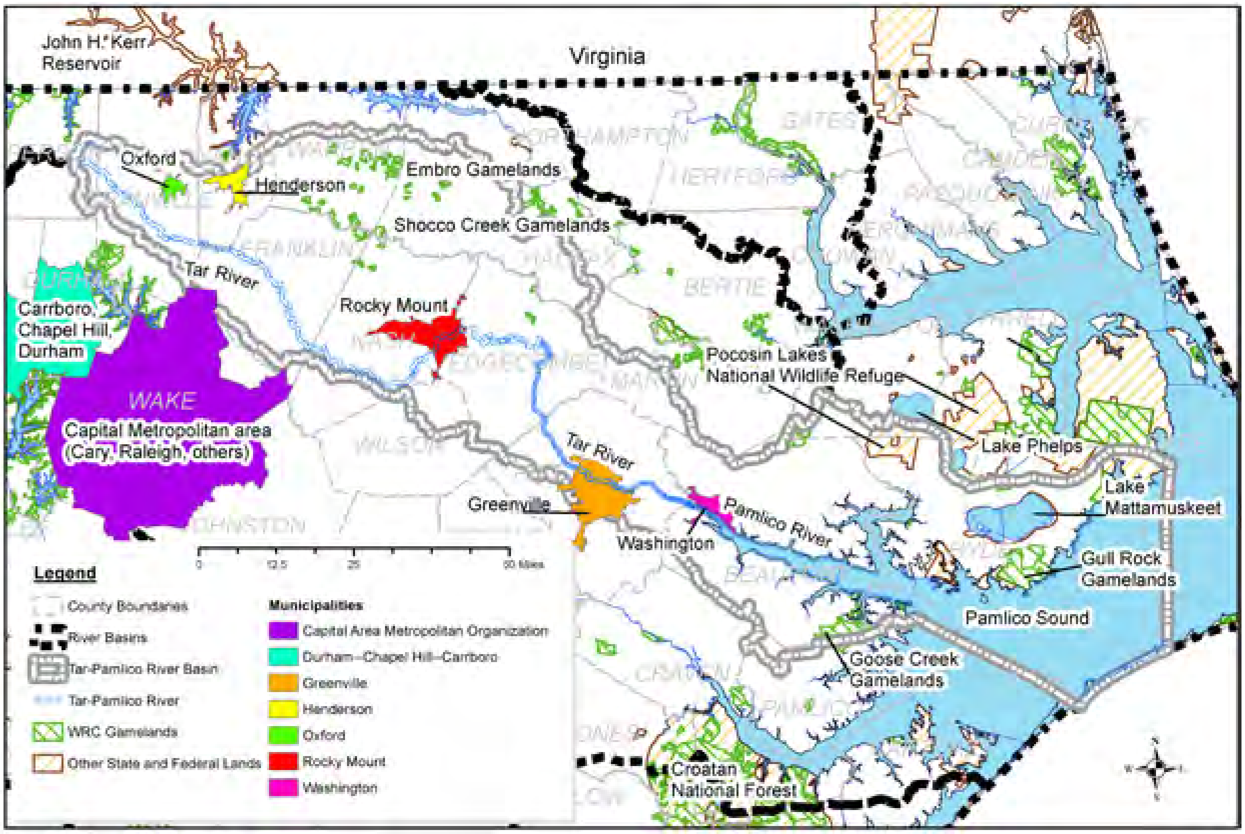
- The Coastal Plain portion features slow-moving blackwater streams, low-lying swamps, and productive estuarine waters. The larger waterbodies are meandering, often lined with swamps and bottomland hardwoods, and have naturally low levels of DO and low pH. Soils are deep sands that have a high groundwater storage capacity. Natural lakes include the remnants of bay lakes in the lower Coastal Plain (NCDWR 2014d).

Land use in the basin is approximately 26% forested, 22% agricultural, 18% wetland, 5% urban or developed, and 3% grassland (MRLC 2011; Jin et al. 2013). Publicly owned lands include nearly 38,000 acres of NCWRC game lands, including Butner–Falls of Neuse, Carteret, Croatan NF, and Neuse River, three national wildlife refuges (Lake Mattamuskeet, Pocosin Lakes, and Swanquarter) and two state parks (Goose Creek and Medoc Mountain). North Carolina's largest natural lake, Lake Mattamuskeet, also is located in this basin.

The Tar–Pamlico River Basin contains all or parts of 19 counties and 52 municipalities of varying size, including Rocky Mount, Greenville, Henderson, Oxford, Tarboro, and Washington.

Figure 4.33 depicts the location of the basin.

Figure 4.33 Location of the Tar–Pamlico River Basin



4.5.17.2 Aquatic Resource Conditions

There are about 9,766 miles of streams and rivers, including small intermittent and ephemeral streams, and numerous acres of freshwater and estuarine wetland communities in the basin. Segments of the Pamlico, Pungo, and Long Shoal rivers and their tributaries have supplemental classifications as High Quality Waters (HQW) or Outstanding Resource Waters (ORW) because they either have excellent water quality or they are a significant resource to humans and/or wildlife (NCDWR 2015c, 2015d). Coastal estuarine waters of Core Sound, Swanquarter Bay Refuge, and Juniper, Back, Rose, Wysocking, Germantown, Deep, Spencer and other bays carry either a HWQ or ORW classification (NCDWR 2015a, 2015c, 2015d).

There are ORW Special Management Strategy Areas in the basin for the Swift Creek area (116,782 acres) and Swanquarter Bay and Juniper Bay areas (28,536 acres) (NCDWR 2015c). These areas require site-specific provisions to protect resource values (no new discharges or expansion of existing discharges) (see 15A NCAC 02B .0225).

Table 4.82 provides information on water quality classifications and use support in the basin. Detailed information on water quality parameters in the basin is available online from the NCDWR Basin Planning Branch http://portal.ncdenr.org/web/wq/ps/bpu.

Table 4.82 Water quality classification and rating information for the Tar–Pamlico River Basin

Classifications	Freshwater Miles	Percent (Basin Waters)	Freshwater Acres	Percent (Basin Waters)	Coastal Acres	Percent (Basin Waters)
Total Basin Waters	9,766	—	63,936	—	614,982	—
HQW	635	7	99	<1	536,602	87
ORW	231	2	—	—	24,178	4
Use Ratings	**Freshwater Miles**	**Percent (Monitored Waters)**	**Freshwater Acres**	**Percent (Monitored Waters)**	**Coastal Acres**	**Percent (Monitored Waters)**
Total Monitored	2,544	—	3,977	—	663,504	—
Supporting	931	37	3,602	91	585,813	88
Impaired	98	4	370	9	73,344	11
Not Rated	161	6	—	—	—	—
No Data	1,353	53	5	<1	4,347	<1

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

The Pamlico Sound estuarine system is somewhat protected from oceanic influences because of the Outer Banks barrier islands. The estuary dynamics, including tidal, climatic, long retention time and nutrient loading conditions, enable eutrophication processes within the Pamlico River. During low-flow conditions, wind and tidal saltwater intrusion in the Tar River has been documented up to Greenville.

Due to excessive levels of nutrients resulting in massive algal blooms and fish kills, the entire Tar–Pamlico River Basin was designated as nutrient-sensitive water (NSW) in 1989. This designation resulted in the development and implementation of a nutrient management strategy to achieve a decrease in total nitrogen by 30% and no increase in total phosphorus loads compared to 1991 conditions.

There are no natural lakes in the Piedmont, but there are a few reservoirs that serve as water supplies and flood control structures. Old millponds and Beaver impoundments are scattered across this region. The most recent version of the NCDENR dam inventory reports 255 registered impoundments in the Tar–Pamlico River Basin; 227 of these are listed as privately owned ponds or lakes used primarily for recreation (NCDEMLR 2014). Impoundments and reservoirs owned by local governments or agencies are used primarily for drinking water supply, recreation, or irrigation.

4.5.17.4 Aquatic Species

There are 21 SGCN in the basin: 1 crayfish species, 11 freshwater or anadromous fishes, and 9 mussel species. Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN associated with aquatic communities found in this river basin. Table 4.83 identifies the SGCN found in the Tar–Pamlico River Basin.

In general, our knowledge of aquatic species distributions in the basin has improved through implementation of the priorities outlined in the 2005 WAP, which called for status, distribution, and life history surveys and population monitoring to be conducted in the basin. This knowledge has been critical in developing management strategies for these populations.

4.5.17.5 Threats Affecting Aquatic Species

Invasive species (e.g., Red Swamp Crawfish, Green Sunfish, Redear Sunfish, Channel and Flathead Catfish, Asian Clam) have become established in the basin and continue to negatively impact native species populations (Fuller et al. 1999; Cooper 2005).

Nutrient enrichment of the waterbodies within this basin continues to be the main water quality issue and the focus of regulatory- and strategy-related activities. Overall water quality in the Fishing Creek watershed is considered excellent; however, nutrient data analysis conducted by NCDWR indicates an increase in nitrogen concentrations since 1991. This watershed is a NCDWR priority for aquatic threatened and endangered species protection. Water quality standards have not been met in the Pamlico River Estuary even though the NSW strategy has been implemented by wastewater treatment plant dischargers, municipal stormwater programs, and agricultural programs. The trend analyses point toward a rise in organic nitrogen. This warrants identifying sources and reducing inputs of organic nitrogen throughout the basin. Potential sources that need more research include groundwater and atmospheric deposition (NCDWR 2014).

There are 131 permitted CAFOs for cattle, poultry, and swine production in the Tar–Pamlico River Basin with 272 waste lagoons associated with the facilities. Waste from these sites contains high levels of nutrients (e.g., nitrogen and phosphorus) in addition to fecal coliform bacteria and any chemical compounds, such as antibiotics or hormone products used in commercial feeding operations (NCDWR 2015b). Animal-waste lagoons and spray fields that discharge near or into aquatic environments are a source of contamination from runoff, percolation into groundwater, and volatilization of ammonia and the release of bacterial contamination. These sources can significantly degrade water quality and endanger human and animal health (Mallin 2003; Mallin and Cahoon 2003).

Table 4.83 SGCN in the Tar–Pamlico River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
CRAYFISH	*Procambarus medialis*	Pamlico Crayfish	—
FISH	*Acipenser oxyrinchus*	Atlantic Sturgeon	E/E
	Ambloplites cavifrons	Roanoke Bass	FSC/—
	Ameiurus platycephalus	Flat Bullhead	—
	Enneacanthus chaetodon	Blackbanded Sunfish	—
	Enneacanthus obesus	Banded Sunfish	—
	Etheostoma collis	Carolina Darter	FSC/SC
	Lampetra aepyptera	Least Brook Lamprey	—/T
	Moxostoma pappillosum	V-lip Redhorse	—
	Notropis chalybaeus	Ironcolor Shiner	—
	Notropis volucellus	Mimic Shiner	—
	Noturus furiosus	Carolina Madtom	FSC/T
MUSSEL	*Alasmidonta heterodon*	Dwarf Wedgemussel	E/E
	Alasmidonta undulata	Triangle Floater	—/T
	Elliptio lanceolata	Yellow Lance	FSC/E
	Elliptio steinstansana	Tar River Spinymussel	E/E
	Fusconaia masoni	Atlantic Pigtoe	FSC/E
	Lampsilis cariosa	Yellow Lampmussel	FSC/E
	Lampsilis sp. 2	Chameleon Lampmussel	—
	Lasmigona subviridis	Green Floater	FSC/E
	Villosa constricta	Notched Rainbow	—/SC

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

The Tar–Pamlico Basin Association (TPBA) currently has 16 members representing 20 discharge facilities that account for 98% of the known effluent flow to the basin. The remaining 2% of effluent flow is from 18 small facilities that have permit limits based on their size and capability. All National Pollutant Discharge Elimination System (NPDES) permitted facilities use 7Q10 standards (the lowest stream flow for seven consecutive days that would be expected to occur once in 10 years) as critical flow in determining permit limits for non-carcinogen toxicants (EPA 2013b). Low-flow conditions impact the ability of a stream to assimilate both point and nonpoint source pollutants. Droughts, as well as the demand on water resources, are likely to increase; therefore, the reevaluation of stream flow will become more critical to water quality in the future (NCDWR 2015d).

The progress achieved by the agriculture sector in implementing the Tar–Pamlico Agriculture Nutrient Control Strategy Rule is well documented in the Annual Agricultural Progress Reports submitted to the NCDENR Environmental Management Commission (EMC) every fall since 2003. As of 2002, the agriculture sector exceeded its collective 30%

nutrient reduction goal, and in 2013, reported a 43% reduction in estimated nitrogen loss to the basin through the implementation of a combination of BMPs, crop shifts, fertilization rate reductions, and loss of overall cropland acres (NCDWR 2015d).

Nutrient stormwater controls are in place for only 54% of the basin. The Tar–Pamlico stormwater rule establishes nutrient export goals for new residential and commercial development projects within the planning and zoning jurisdictions of six of the largest and fastest-growing local municipalities and five counties within the basin. The municipalities are: Greenville, Henderson, Oxford, Rocky Mount, Tarboro, and Washington. The counties are: Beaufort, Edgecombe, Franklin, Nash, and Pitt. Each of these local governments has successfully implemented and managed its stormwater program since 2006 and continues to achieve nutrient export targets through a combination of on-site BMPs and off-site nutrient offsets (NCDWR 2014).

The Upper Tar subbasin has and will likely continue to observe the largest population growth of any of the subbasins, due in large part to its proximity to Raleigh. As the population continues to increase in areas of the basin, the potential exists for the basin to become more vulnerable to water quantity demands and other water management issues.

4.5.17.6 Recommendations

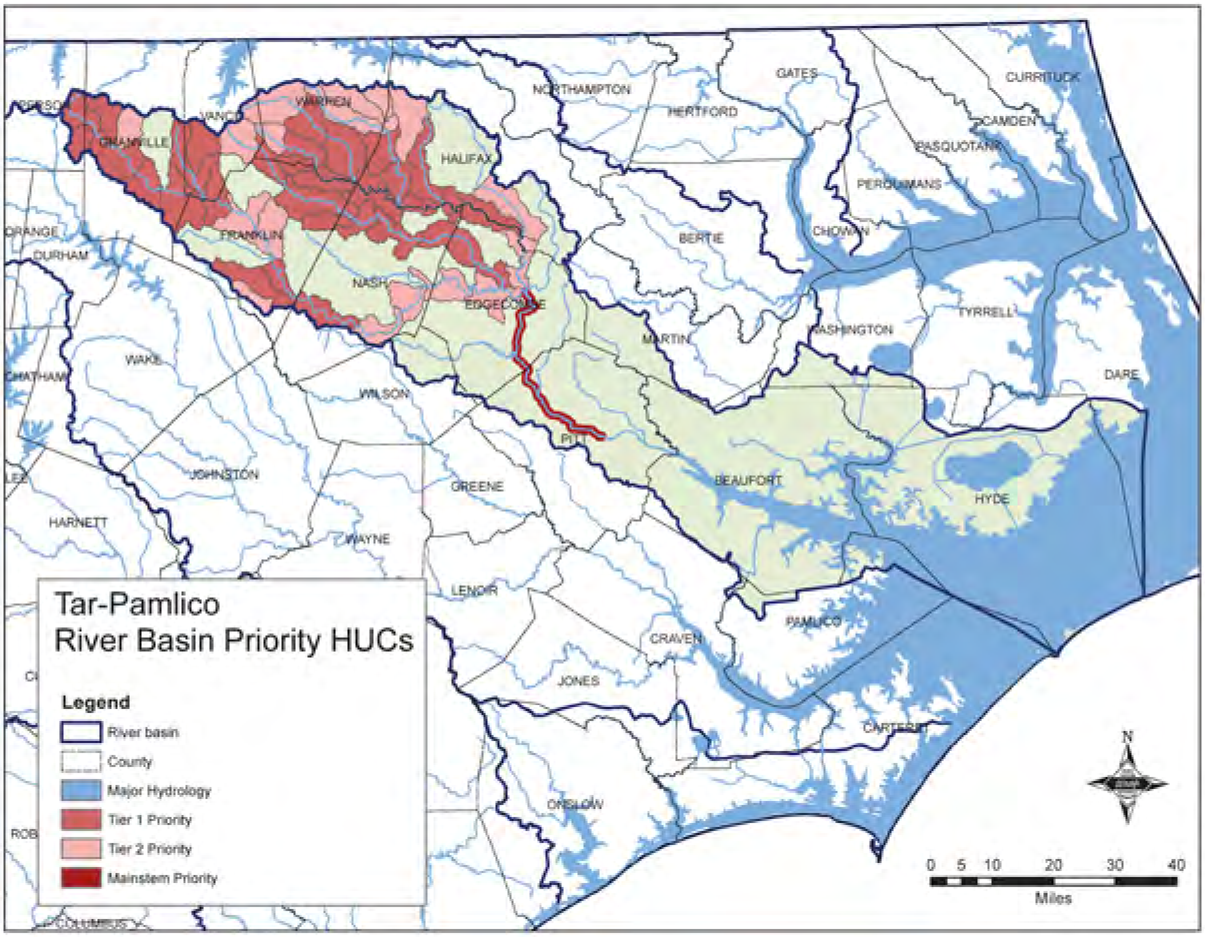
Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priorities identified in the Tar–Pamlico River Basin are shown in Figure 4.34 and a list of the priority 12-digit HUCs is included in Appendix J.

Basin Specific Recommendations

Surveys. General surveys are needed to complete primary distributional status for SGCN and other priority species (see Table 4.83).

- Fishes—determine distribution and status of priority species (e.g., Banded Sunfish, Black Banded Sunfish, Carolina Madtom, Ironcolor Shiner, Least Brook Lamprey, Mimic Shiner, and V-lip Redhorse). In addition, conduct exploratory surveys for priority species that have a high potential of occurring in the river basin (e.g., Bridle Shiner), but are not currently known to occur.
- Mussels—determine distribution and status of priority species (e.g., Atlantic Pigtoe, Green Floater, Tar River Spinymussel, Triangle Floater, and Yellow Lance).
- Crayfishes—determine distribution and status of priority species (e.g., Carolina Ladle Crayfish and Pamlico Crayfish).

FIGURE 4.34 Location of priority watersheds in the Tar–Pamlico River Basin



- Snails—conduct baseline distribution surveys on all species that occur in the basin.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Identify long-term monitoring sites and develop monitoring protocols for priority species (e.g., Atlantic Pigtoe, Carolina Madtom, Dwarf Wedgemussel, Green Floater, Ironcolor Shiner, and Yellow Lance).

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species, as well as investigations aimed at resolving taxonomic status are needed.

- Study habitat use and life history characteristics of priority species (e.g., Carolina Ladle Crayfish, Green Floater, Least Brook Lamprey, Triangle Floater, and V-lip Redhorse).

- Support taxonomic research for priority species (e.g., *Cambarus sp. C* complex, Chameleon Lampmussel, Mimic Shiner, and the mussel genus *Elliptio*).

- Support development of captive propagation techniques for priority species (e.g., Carolina Madtom, Green Floater, Ironcolor Shiner, and Triangle Floater).

- Support genetics research that informs augmentation policy for priority species (e.g., Atlantic Pigtoe, Carolina Madtom, Chameleon Lampmussel, Dwarf Wedgemussel, Green Floater, Ironcolor Shiner, Tar River Spinymussel, Triangle Floater, and Yellow Lance).

- Determine impacts of nonnative species on priority species (e.g., Red Swamp Crawfish and Flathead Catfish).

In addition to the SGCN species found in the basin (see Table 4.83), a list of knowledge-gap priority species is provided in Table 4.84.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital.

- Support efforts to restore the native aquatic community through reintroduction or augmentation.

- Support acquisition of land that is adjacent to current conservation holdings or priority watersheds.

- Support other regulatory agencies to minimize impacts on species and habitats.

- Support dam removal where appropriate.

Table 4.84 Knowledge-gap priority species in the Tar–Pamlico River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
CRAYFISH	*Cambarus davidi*	Carolina Ladle Crayfish	
FISH	*Chrosomus oreas*	Mountain Redbelly Dace	—
	Etheostoma vitreum	Glassy Darter	—
	Fundulus diaphanus	Banded Killifish	—
	Lepisosteus osseus	Longnose Gar	—
	Moxostoma cervinum	Blacktip Jumprock	—
	Nocomis raneyi	Bull Chub	—
	Percina nevisense	Chainback Darter	—
	Percina roanoka	Roanoke Darter	—
	Petromyzon marinus	Sea Lamprey	—
MUSSEL	*Corbicula fluminea*	Asian Clam [Exotic]	—
	Elliptio fisheriana	Northern Lance	—
	Elliptio icterina	Variable Spike	—
	Elliptio roanokensis	Roanoke Slabshell	—/T
	Lampsilis radiata	Eastern Lampmussel	—/T
	Ligumia nasuta	Eastern Pondmussel	—/T
	Pyganodon cataracta	Eastern Floater	—
	Strophitus undulatus	Creeper	—/T
	Uniomerus carolinianus	Florida Pondhorn	—
	Utterbackia imbecillis	Paper Pondshell	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Guide academic research projects to help achieve specific conservation goals and objectives.
- Support the development and application of an aquatic nuisance species management plan with other agencies/groups.
- Address secondary and cumulative impacts upon water quality (buffer ordinances, water supply watershed protection, and headwaters protection).

- Work with and promote existing programs that help farmers reduce sedimentation/erosion (installing fences to keep livestock out of streams, improving tilling practices) as well as reduce pesticide and herbicide use.
- Support stormwater management and wastewater treatment plant improvements and upgrades.

4.5.18 Watauga River Basin

4.5.18.1 River Basin Description

The Watauga River watershed drains northwest into Tennessee where it flows into Watauga Reservoir. The Watauga River is a tributary of the Holston River, which is a major tributary of the Tennessee River. The basin is one of the smallest in North Carolina, encompassing only 205 square miles and approximately 270 stream miles, and is entirely within the Mountain ecoregion. The Elk River is a major tributary.

Based on 2011 National Land Cover Dataset information (MRLC 2011; Jin et al. 2013), land use cover in the basin is 79% forested, 10% agricultural, 10% developed or urban, 1% grassland, and less than 1% wetland (MRLC 2011; Jin et al. 2013). Most land ownership is private, with less than 10% public lands (which includes portions of the Pisgah National Forest, Blue Ridge Parkway, Elk Knob Game Land, and Grandfather Mountain State Park).

The basin encompasses parts of two counties (Avery and Watauga) and has six municipalities, including Banner Elk, Beech Mountain, Seven Devils, and Sugar Mountain. Figure 4.35 depicts the location of the basin.

4.5.18.2 Aquatic Resource Conditions

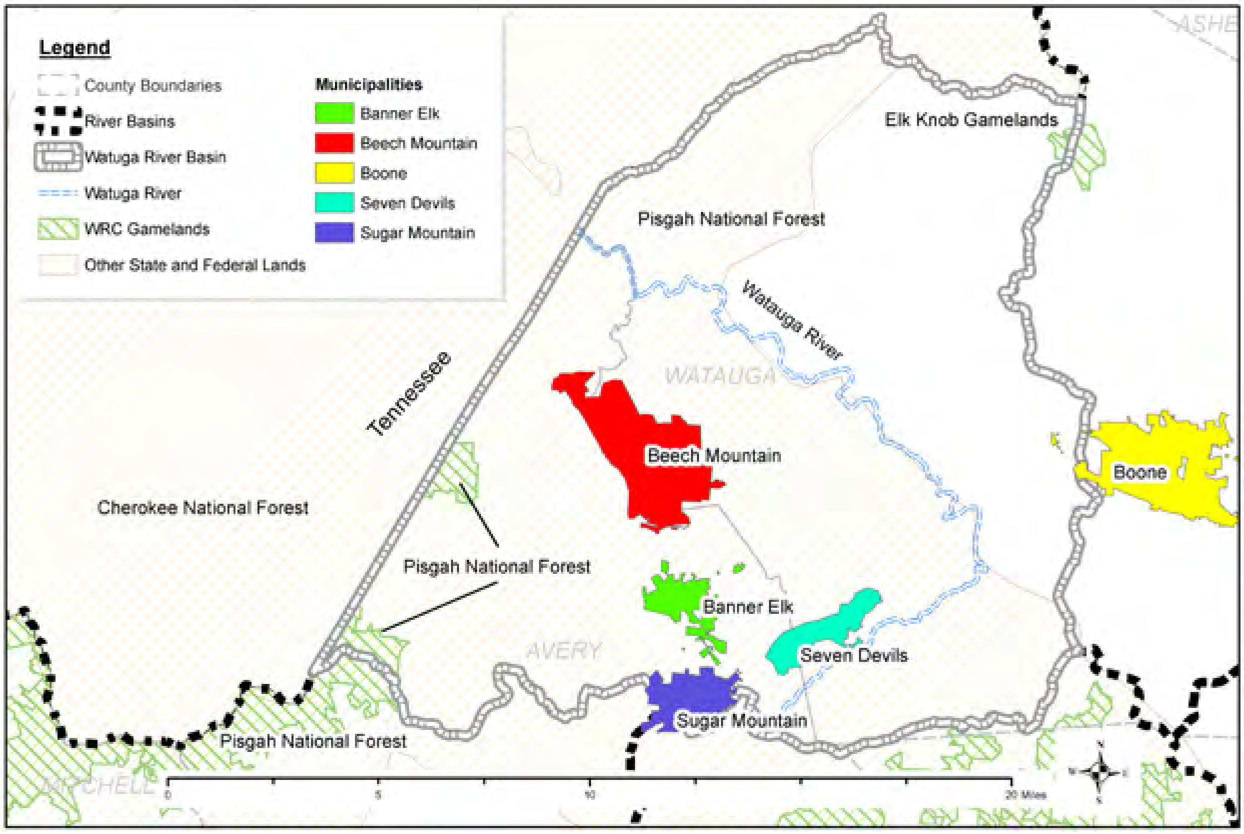
Water quality is generally good for areas where data are available; however, there are problems in parts of the basin (described below) and the lack of data for nearly half the basin provides an unclear assessment of overall water quality. There are more than 300 miles of freshwater streams in the basin that have been classified by NCDWR for best uses (NCDWR 2015d). Table 4.85 provides information on water quality classifications and use-support ratings in the basin.

There are 171 miles of NCDWR-designated trout waters (Tr) in the basin. The mainstem Watauga River is designated High-Quality Waters (HQW) and the Boone Fork and headwaters are designated Outstanding Resource Waters (ORW) (NCDWR 2015d).There is one HQW Special Management Strategy Area (SMSA) for the Watauga River (28,790 acres) and one ORW SMSA for the Boone Fork Area (6,302 acres) in the basin (NCDWR 2015c). These areas require site-specific provisions to protect resource values (no new discharges or expansion of existing discharges) (see 15A NCAC 02B .0225).

4.5.18.3 Aquatic Species

There are four SGCN in the basin: one crayfish species, two freshwater fishes, and one freshwater mussel species. Appendix G provides a list of SGCN and species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN associated with

Figure 4.35 Location of the Watauga River Basin



aquatic communities found in this river basin. Table 4.86 identifies the SGCN found in the Watauga River Basin.

4.5.18.4 Threats Affecting Aquatic Species

While water quality conditions are generally very good at present, past pollution events may have had a profound effect on the extant aquatic fauna in the Watauga River Basin. A tannery near Valle Crucis caused severe pollution in the early 20th century and may have led to the extirpation of many native species. Apparently, no extensive surveys for aquatic species were made prior to this period of degradation and the extent of species loss is unknown.

Presently, excessive erosion and sedimentation from nonpoint sources are the primary problems affecting species and habitats. Most development and agricultural activities are located in the valleys due to abundance of steep slopes within the watershed. Narrow riparian corridors or total lack of riparian vegetation along portions of the Watauga River and many tributaries have led to excessive stream bank erosion and loss of habitat due to sediment deposition and over-widening of channels. Impacts from row-crop agriculture and

Table 4.85 Water quality classification and rating information for the Watauga River Basin

Classifications	Freshwater Miles	Percent (Basin Waters)	Freshwater Acres	Percent (Basin Waters)
Total Basin Waters*	650	—	54	—
HQW	51	8	—	—
ORW	21	3	—	—
Use Ratings	**Freshwater Miles**	**Percent (Monitored Waters)**	**Freshwater Acres**	**Percent (Monitored Waters)**
Total Named Waters	279		—	—
Supporting	117	42	—	—
Impaired	9	3	—	—
Not Rated	15	5	—	—
No Data	142	50	—	—

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

poorly managed livestock pasture (causing sedimentation from runoff and stream bank erosion) are also significant.

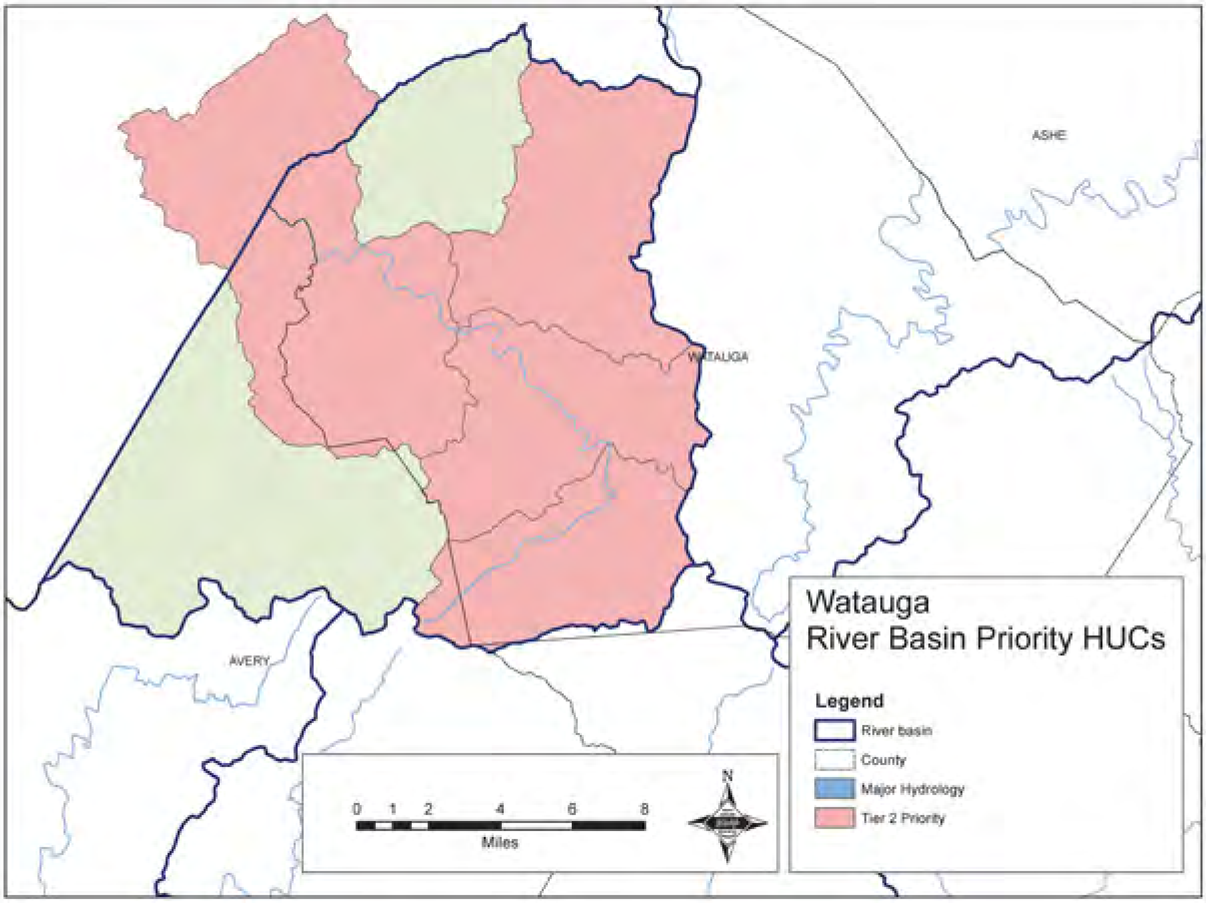
The area appears to be experiencing an acceleration of development, and threats to water and habitat quality are increasing. Development (primarily home construction) is rapidly increasing on steeper slopes. As related development increases (e.g., golf courses, commercial), stormwater runoff contributes more sedimentation and other nonpoint problems. Christmas tree farming is also increasing in the basin. Relatively large amounts of herbicides and pesticides are used in this form of silviculture, but the relative impacts of runoff from tree farms is unclear. Impacts from nonnative species (e.g., Margined Madtom) are also unclear, but could negatively affect native fish communities.

According to the NCDENR dam inventory (NCDEMLR 2014), there are 20 impoundments in the basin. Most are small privately owned lakes used for recreation. There are no major impoundments within the North Carolina portion of the basin. There is one run-of-river hydroelectric facility on the Watauga River (Ward Mill Dam). There are several small impoundments on tributaries, including Beech Mountain Reservoir on Buckeye Creek (drinking water reservoir) and Seven Devils Resort Lake on an unnamed tributary to the Watauga River (recreation).

4.5.18.5 Recommendations

Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priorities identified in the Watauga River Basin are shown in Figure 4.36 and a list of the priority 12-digit HUCs is included in Appendix J.

Figure 4.36 Location of priority watersheds in the Watauga River Basin



Basin Specific Recommendations

Surveys. While the general distribution of most species is known, surveys are still needed to complete primary distributional status for some SGCN (see Table 4.86).

- Aquatic Snails—complete primary distribution inventories; determine potential habitats and distribution surveys for hydrobiids.
- Determine distribution of nonnative species.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. Baseline data and monitoring strategies have been developed for most priority species and habitats in the basin. These efforts will inform

Table 4.86 SGCN in the Watauga River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
CRAYFISH	*Cambarus eeseeohensis*	Grandfather Mountain Crayfish	FSC/—
FISH	*Cottus carolinae*	Banded Sculpin	—
	Salvelinus fontinalis	Brook Trout (Native)	—
MUSSEL	*Lasmigona subviridis*	Green Floater	FSC/E

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

species and habitat management decisions. Monitoring plans should be coordinated with other existing monitoring programs where feasible.

- Continue periodic monitoring of priority areas and species. The status of Green Floater, petitioned for federal listing, is of particular interest.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Investigate aquatic community response to restoration projects in priority areas.
- Investigate potential for species reintroduction in the basin, particularly native mussels in the Watauga River.
- Obtain more information on impacts and mitigation of water withdrawals in headwater systems.

In addition to the SGCN species found in the basin (see Table 4.86), a list of knowledge-gap priority species is provided in Table 4.87.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital. Specific issues in this basin include secondary and cumulative impacts upon water

Table 4.87 Knowledge-gap priority species in the Watauga River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
FISH	*Chrosomus oreas*	Mountain Redbelly Dace [Nonnative in this basin]	—
	Etheostoma chlorobranchium	Greenfin Darter	—
	Notropis photogenis	Silver Shiner	—
	Notropis telescopus	Telescope Shiner	—
	Percina aurantiaca	Tangerine Darter	—
	Pimephales notatus	Bluntnose Minnow	—
MUSSEL	*Corbicula fluminea*	Asian Clam [Exotic]	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

quality, riparian vegetation and stream bank restoration and conservation, mitigation of hydropower development impacts, and species restoration opportunities.

- Prioritize education and other measures to prevent the introduction or spread of invasive nonnative species, particularly crayfishes.
- Support stream and riparian area conservation and restoration throughout the basin, particularly in priority areas.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Support the Watershed Restoration Plan (WRP) and River Basin Restoration Priorities (RBRP) developed by NCDMS for the Watauga River Basin (NCWRP 2002b; NCEEP 2009b).
- Work together with Soil and Water Conservation District programs, such as the Agriculture Cost Share Program, to conserve priority areas.

4.5.19 White Oak River Basin

4.5.19.1 River Basin Description

The White Oak River Basin lies entirely within the Coastal Plain, and is composed of four small river systems (New River, White Oak River, Newport River, and North River), which all drain south directly into the Atlantic Ocean and associated sounds. The White Oak River is approximately 40 miles long and is a blackwater river. This basin encompasses 1,382 square miles, making it the smallest basin contained entirely within the state. There are 1,571 stream miles, 3,777 acres of freshwater lakes and impoundments, and 132 miles of Atlantic coastline in the basin (NCDWR 2015d, 2015j). Due to the location and size of this basin, there is a relatively small amount of freshwater habitat available, but what is available has the characteristics typical of Coastal Plain streams: meandering waters associated with swamps, hardwood bottomlands, and wetland communities (NCDWQ 2007d).

Land use in the basin is 25% forested, 32% wetland, 12% urban or developed, 3% grassland, and 11% agricultural (MRLC 2011). Public lands make up a large portion of this basin and include all or portions of the Croatan National Forest, Hoffman State Forest, Rocky Run, Stones Creek, Carteret County and White Oak River Game Lands, and Camp Lejeune. The estimated 2010 human population was 336,209, which represents an increase of more than 40% since 1990 and significantly exceeds predicted increases (USCB 2012; NCDWR 2015j).

The White Oak River Basin is located mostly in Onslow County and the southern portions of Jones, Craven, and Carteret counties. All or parts of 16 municipalities are located in the basin, including Jacksonville, Newport, Morehead City, and Beaufort. Figure 4.37 depicts the geographic location of the basin.

4.5.19.2 Aquatic Resource Conditions

There are a number of impaired streams in this drainage, totaling 169.3 miles (NCDWR 2014a). There are 68 water bodies (stream reaches, intracoastal waterways, sounds, bays) that have an Outstanding Resource Waters (ORW) classification and 187 water bodies that have a High-Quality Waters (HQW) classification, because they either have excellent water quality or they are a significant resource to humans and/or wildlife (NCDWQ 2015d).

The southernmost sections of the New, White Oak, and Newport rivers, and the entirety of the North River drainage, have supplemental classifications as HQW or ORW. There are ORW Special Management Strategy Areas in the basin for Western Bogue Sound and Bear Island Area (19,859 acres); Roosevelt Natural Areas (561 acres); and Stump Sound Area (4,355 acres) (NCDWR 2015c). These areas require site-specific provisions to protect resource values (no new discharges or expansion of existing discharges) (see 15A NCAC 02B.0225).

FIGURE 4.37 Location of the White Oak River Basin

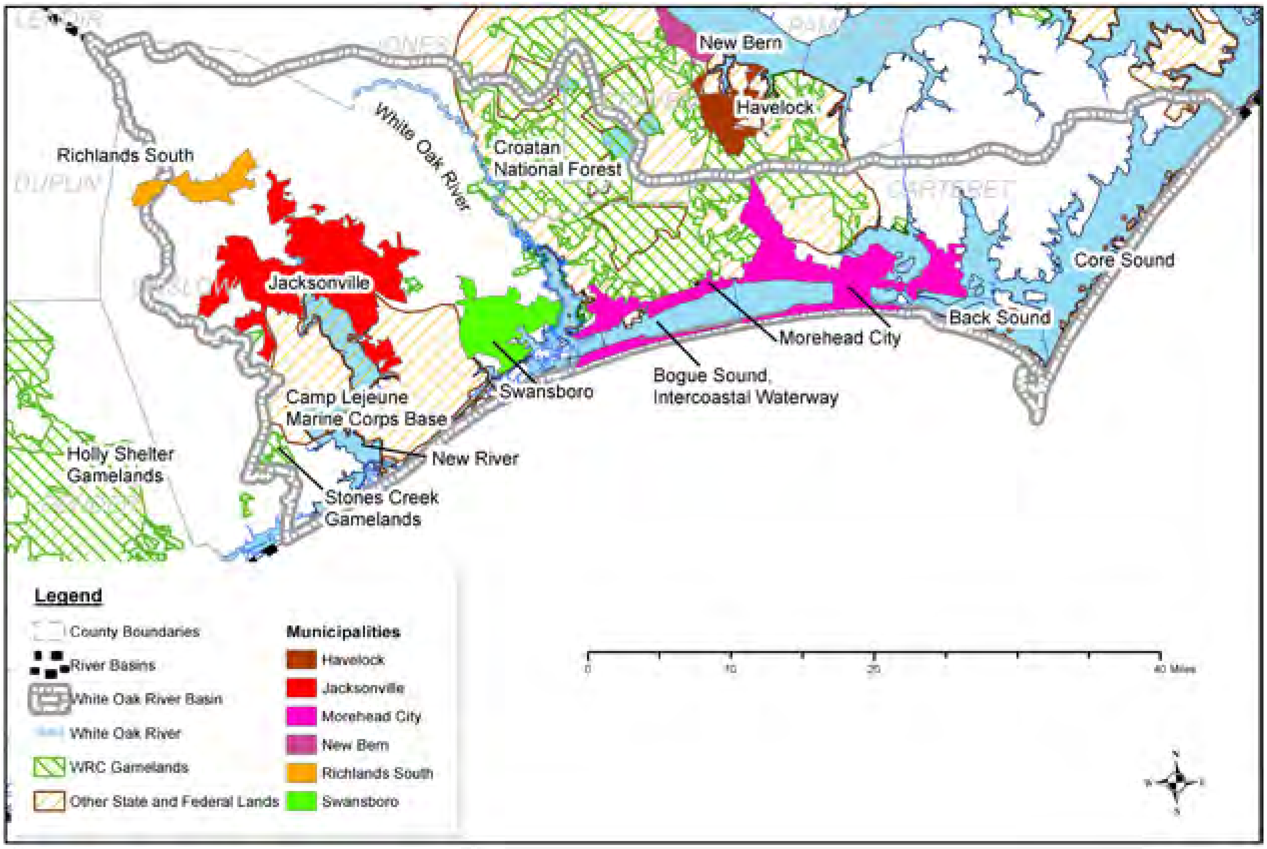


Table 4.88 provides information on water quality classifications and use support ratings in the basin.

4.5.19.3 Aquatic Species

There are four SGCN in the basin; all are fishes. Table 4.89 identifies the SGCN found in the White Oak River Basin. Appendix G provides a statewide list of all species identified by the Taxa Teams as priority species.

4.5.19.4 Threats Affecting Aquatic Species

Impacts affecting species and their habitats within the White Oak RiverBasin include non-point sources of pollution resulting from inadequate management practices related to agriculture, forestry, construction, and stormwater discharges. Sedimentation due to erosion is one of the most significant causes of habitat loss in this and all other North Carolina river basins.

TABLE 4.88 Water quality classification and rating information for the White Oak River Basin

Classifications	Freshwater Miles	Percent (Basin Waters)	Freshwater Acres	Percent (Basin Waters)	Coastal Acres	Percent (Basin Waters)
Total Basin Waters*	1,571	—	3,777	—	140,104	—
HQW	3	<1	—	—	90,651	65
ORW	—	—	110	3	65,574	47
Use Ratings	**Freshwater Miles**	**Percent (Monitored Waters)**	**Freshwater Acres**	**Percent (Monitored Waters)**	**Coastal Acres**	**Percent (Monitored Waters)**
Total Named Waters	320	—	3,886	—	143,902	—
Supporting	77	24	3,755	97	91,331	63
Impaired	11	3	—	—	49,344	34
Not Rated	—	—	—	—	29	<1
No Data	232	73	131	3	3,199	2

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

There are 46 permitted CAFOs in the White Oak River Basin, with 63 associated waste lagoons. Most are located in the northwestern portion of the basin along the New and White Oak rivers. Waste from these sites contains high levels of nutrients (e.g., nitrogen and phosphorus) in addition to fecal coliform bacteria and any chemical compounds, such as antibiotics or hormone products used in commercial feeding operations (NCDWR 2015b). Animal-waste lagoons and spray fields that discharge near or into aquatic environments through runoff, percolation into groundwater, and volatilization of ammonia and the release of bacterial contamination can significantly degrade water quality and endanger human and animal health (Mallin 2003; Mallin and Cahoon 2003).

The National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources, such as industrial, municipal, and other facilities that discharge pollutants into surface waters. Point source water pollution can include toxic compounds and elements such as ammonia, chlorine, and mercury. Individual permits are written to address the specific design and applicable water quality standards to an individual facility, while general permits authorize a category of discharges within a geographical area (EPA 2015). In the White Oak River Basin there are 37 individual NPDES permits and 14 general permits (NCDWR 2015f, 2015e). Four of the individual permits are for major discharges from industrial processes and commercial facilities or municipal wastewater treatment plans that discharge one million gallons per day or more.

According to an NCDENR dam inventory (NCDEMLR 2014), there are relatively few man-made impoundments in the basin. Those present can physically alter instream habitat, change flow regimes, and often reduce DO levels. Water withdrawals for irrigation and similar uses further change flow patterns and reduce the quality and quantity of habitat available for aquatic species (NCDWQ 2012e).

Invasive species (e.g., Flathead Catfish and Red Swamp Crayfish) are established in the White Oak River Basin and continue to negatively impact native species populations (Fuller et al. 1999; Cooper 2005) via predation and competition.

4.5.19.5 Recommendations

Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priorities identified in the White Oak River Basin are shown in Figure 4.38 and a list of the priority 12-digit HUCs is included in Appendix J.

Basin Specific Recommendations

Surveys. Priorities for distribution and status surveys should focus on aquatic SGCN believed to be declining or dependent on at-risk or sensitive communities (see Table 4.89).

- Basin-specific priorities include the Ironcolor Shiner and the Banded Sunfish.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters. Studies include identification of population trends, as well as assessment of conservation or development activities. These efforts will inform species and habitat management decisions. Monitor the presence and distribution of exotic species in the basin.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics. Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. Studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Determine vulnerability of species across all taxa groups to emerging threats such as endocrine-disrupting chemicals (EDCs) and other compounds that are present, as well as the prevalence of these compounds in this unique watershed, in the waterways of the White Oak River Basin.

Figure 4.38 Location of priority watersheds in the White Oak River Basin

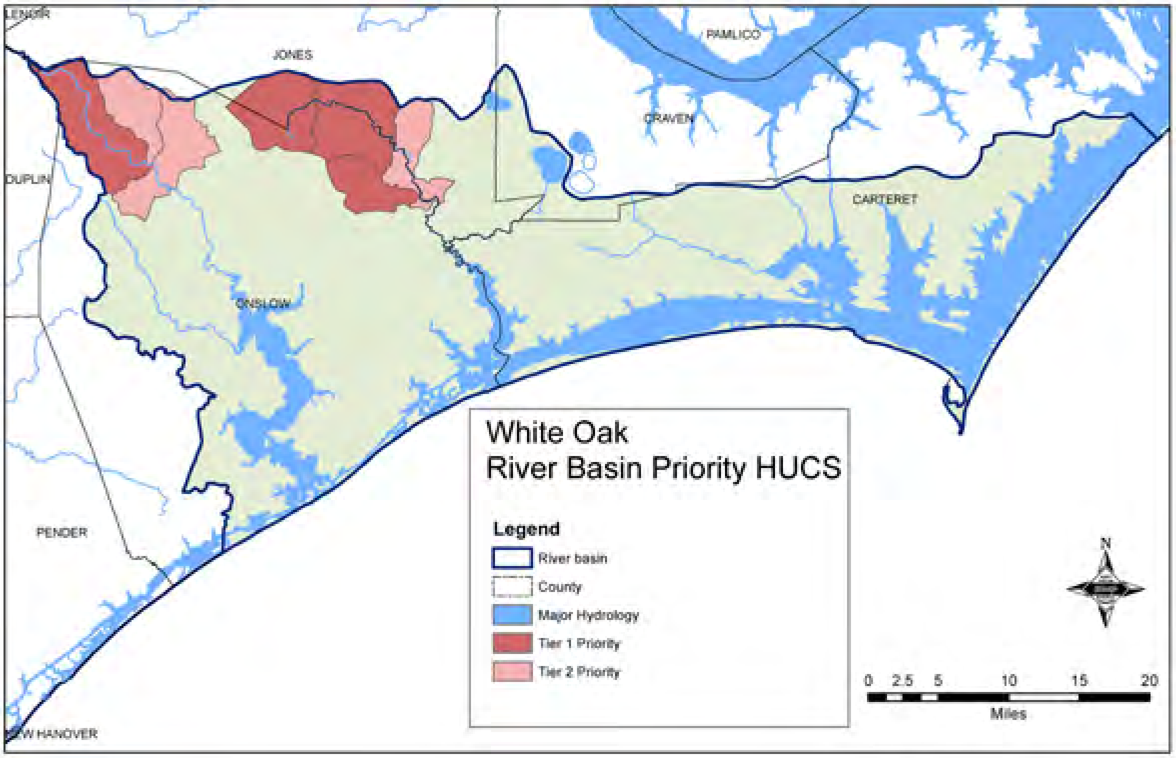


Table 4.89 SGCN priority species in the White Oak River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
FISH	*Acipenser oxyrinchus*	Atlantic Sturgeon	E/E
	Enneacanthus chaetodon	Blackbanded Sunfish	—
	Enneacanthus obesus	Banded Sunfish	—
	Notropis chalybaeus	Ironcolor Shiner	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

- Support research on the effects of climate change, particularly changes in temperature regimes, sea level rise, and extreme weather patterns, on aquatic communities in the basin.
- Support research investigating drivers behind the apparent decline in the Ironcolor Shiner.

In addition to the SGCN found in the basin (see Table 4.89), a list of knowledge-gap priority species is provided in Table 4.90.

TABLE 4.90 Knowledge-gap priority species in the White Oak River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
CRAYFISH	*Procambarus plumimanus*	Croatan Crayfish	—
FISH	*Fundulus diaphanus*	Banded Killifish	—
	Lepisosteus osseus	Longnose Gar	—
MUSSEL	*Corbicula fluminea*	Asian Clam [Exotic]	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital.

- Promote programs to upgrade/increase compliance at wastewater treatment facilities and animal feeding operations (CAFOs).
- Provide support for land protection, particularly in riparian areas (acquisition, easements).
- Continue to identify areas critical to aquatic ecosystem health for conservation or restoration.
- Coordinate and provide management guidance on managed properties, such as military bases and national forests, to maximize effective conservation and restoration activities on these public lands.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Guide academic research projects to help achieve specific conservation goals and objectives.
- Support the development and application of an aquatic nuisance species management plan with other agencies and groups.

- Address secondary and cumulative impacts upon water quality (buffer ordinances, water supply watershed protection, headwaters protection) (NCWRC 2002).
- Work with and promote existing programs that help farmers reduce sedimentation/erosion (e.g., install fences to keep livestock out of streams) as well as reduce pesticide and herbicide use.
- Support programs providing education and guidance about protecting aquatic habitats and water quality to landowners, developers, and municipal planners.

4.5.20 Yadkin — Pee Dee River Basin

4.5.20.1 River Basin Description

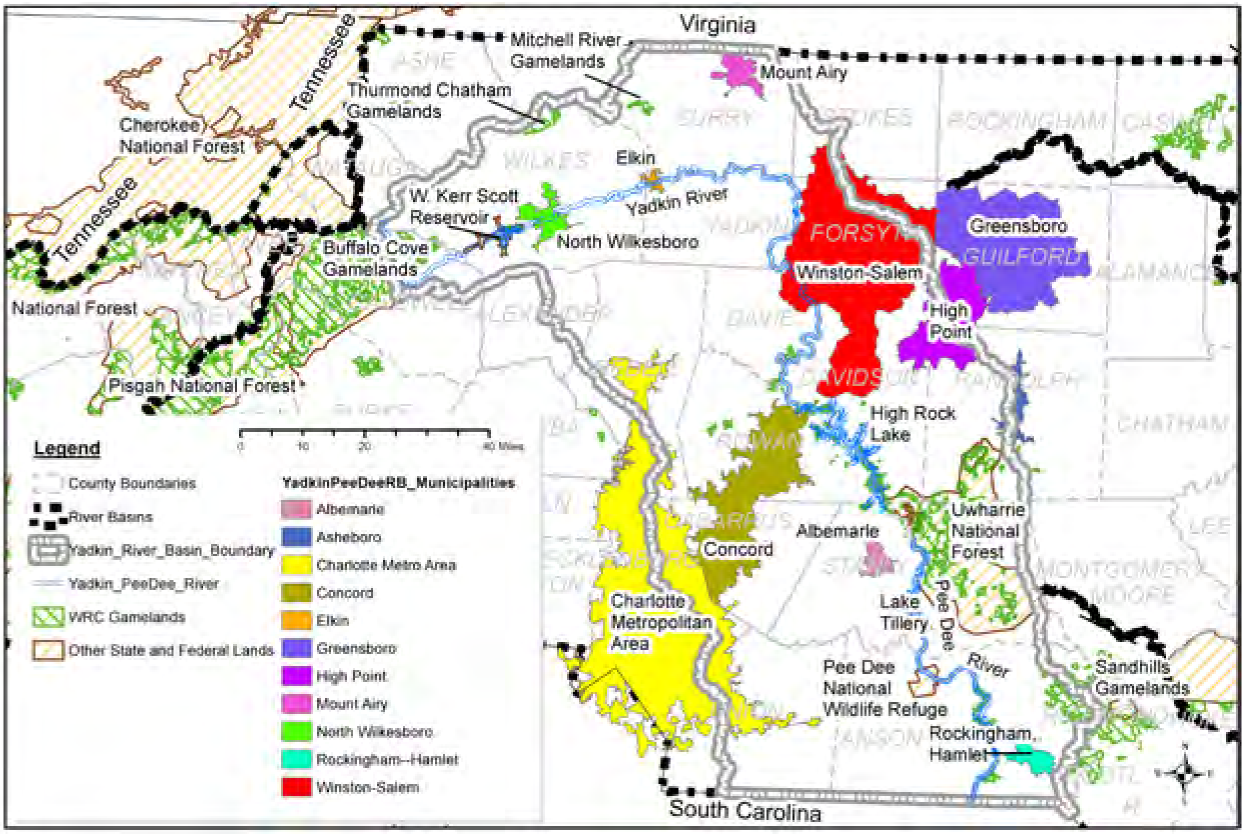
The majority of the North Carolina Section of the Yadkin — Pee Dee River Basin is located in the Piedmont ecoregion. The headwaters, which are partially in the Mountain ecoregion, are located in northwestern North Carolina and a small portion of southern Virginia. The Yadkin River flows east before turning southeast, and at the confluence with the Uwharrie River, the name changes to the Pee Dee River. The Pee Dee River continues into South Carolina south of Rockingham and ultimately empties into Winyah Bay along the Atlantic coast (NCDWQ 2008b). The North Carolina portion of the Yadkin — Pee Dee River drains an area of about 7,213 square miles, making it the second largest river basin in the state (NCDWQ 2008b).

There are approximately 5,862 stream miles and 22,988 lake acres in the basin (NCDWQ 2003). Major tributaries in the Yadkin — Pee Dee basin are South Yadkin, Uwharrie River, and Rocky River. There are eight impoundments on the main stem of the Yadkin and Pee Dee rivers (W. Kerr Scott Reservoir, Idols Dam, High Rock Lake, Tuckertown Reservoir, Badin Lake, Falls Reservoir, Lake Tillery, and Blewett Falls Lake), plus many smaller reservoirs on tributaries. Many tributaries flow through densely populated areas of central North Carolina such as Charlotte, Winston-Salem, and their suburban areas. The Uwharrie Lakes region is comprised of impounded waters from six major hydroelectric projects which include the four upstream dams operated by Alcoa Power Generating, Inc. (APGI) and two lower dams operated by Duke Energy (Burns et al. 2012).

Land use in the basin is 55% forested, 24% agricultural, 13% urban or developed, 6% grassland, and 1% wetland (MRLC 2011; Yin et al. 2013). Urban and developed areas have steadily increased in size as the populations of Charlotte and other cities in the basin have grown. Public lands make up less than 5% of the Yadkin — Pee Dee River Basin.

Figure 4.39 depicts the geographic location of the basin. The Yadkin — Pee Dee River Basin crosses 21 counties, and 93 municipalities are completely or partially located within the basin. There are several large population centers formed by adjacent municipalities, such as Charlotte, Matthews, Mint Hill and others that comprise the Charlotte–Mecklenburg area; the High Point, Thomasville, and Trinity area; and the Winston-Salem, Kernersville, Clemmons, and Lewisville area. The estimated 2000 population of urban areas in the basin was 1,463,535 (163 persons per square mile); the basin population is projected to increase 36% to about 2 million people by 2020 (NCDWQ 2008b). The largest population increases are projected for Union, Mecklenburg, Cabarrus, and Iredell Counties.

Figure 4.39 Location of the Yadkin — Pee Dee River Basin



4.5.20.2 Aquatic Resource Conditions

There are over 7,800 miles of freshwater streams in the basin that have been classified by NCDWR for best uses (NCDWR 2015d). In addition to the best-use classifications, NCDWR also monitors state waters to determine if they are supporting their use classification(s), and assigns use-support ratings based on that information. These ratings are published in the most recent 303(d) impaired waterbodies list (NCDWQ 2015a, 2015b). Table 4.91 provides information on water quality classifications and use-support ratings.

Some waterbodies in the basin have supplemental classifications as High-Quality Waters (HQW) or Outstanding Resource Waters (ORW), because they either have excellent water quality or they are a significant resource to humans or wildlife (NCDWQ 2015d). There are 112 stream reaches that have a HQW classification, including portions of Elkin Creek (River), Dutch Buffalo Creek, Denson's Creek and the Fisher, Little, Reddies, and South Yadkin rivers as well as other headwaters and tributaries (NCDWR 2015a). There are 58 stream reaches that have a supplemental ORW classification including Mitchell River, Elk Creek, Laurel Creek, Stewart Fork and other headwaters and tributaries.

Table 4.91 Water quality classification and rating information for the Yadkin — Pee Dee River Basin

Classifications	Freshwater Miles	Percent (Basin Waters)	Freshwater Acres	Percent (Basin Waters)
Total Basin Waters*	9,450	—	38,727	—
HQW	543	6	315	1
ORW	202	2	—	—
Use Ratings	**Freshwater Miles**	**Percent (Monitored Waters)**	**Freshwater Acres**	**Percent (Monitored Waters)**
Total Named Waters	5,986	—	37,435	—
Supporting	1,671	28	4,589	12
Impaired	742	12	32,308	86
Not Rated	91	2	—	—
No Data	3,483	58	537	2

* Total Basin Waters estimated from National Hydrography Dataset (NHD), April 2015 (EPA 2014b).

There are seven HQW Special Management Strategy Areas (SMSAs) totaling over 49,000 acres in the basin including Denson's Creek (17,490 acres), Little River (12,594 acres), Rocky Creek (6,638 acres), Bridger Creek (4,754 acres), and four other locations (NCDWR 2015c). There are four ORW SMSAs covering more than 92,975 acres in the basin, including Mitchell River Area (32,149 acres) and Elk Creek Area (32,284 acres) (NCDWR 2015c). These areas require site-specific provisions to protect resource values (e.g., no new discharges or expansion of existing discharges) (see 15A NCAC 02B.0225).

Another supplemental classification is NCDWR's trout water designation (Tr), which protects freshwaters for natural propagation of trout and survival of stocked trout on a year-round basis. There are about 703 miles of streams in the Yadkin — Pee Dee River Basin designated as Tr waters. This is not the same as the Commission's public Mountain Trout Waters, which is used to designate waters that support trout and are open to public fishing.

4.5.20.3 Aquatic Species

There are 30 SGCN in the basin: 1 crayfish species, 17 fishes, and 12 mussel species. Appendix G provides a list of SGCN and other priority species for which there are knowledge gaps or management concerns. Appendix H identifies SGCN associated with aquatic communities found in this river basin. Table 4.92 identifies the SGCN found in the Yadkin — Pee Dee River Basin.

Table 4.92 SGCN in the Yadkin — Pee Dee River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
CRAYFISH	*Cambarus catagius*	Greensboro Burrowing Crayfish	—/SC
FISH	*Acipenser brevirostrum*	Shortnose Sturgeon	E/E
	Acipenser oxyrinchus	Atlantic Sturgeon	E/E
	Ameiurus brunneus	Snail Bullhead	—
	Ameiurus platycephalus	Flat Bullhead	—
	Carpiodes sp. cf. cyprinus	a carpsucker	—
	Carpiodes sp. cf. velifer	Atlantic Highfin Carpsucker	—/SC
	Cyprinella sp. cf. zanema	Thinlip Chub	—/SC
	Enneacanthus chaetodon	Blackbanded Sunfish	—
	Etheostoma collis	Carolina Darter	FSC/SC
	Moxostoma pappillosum	V-lip Redhorse	—
	Moxostoma robustum	Robust Redhorse	FSC/E
	Moxostoma sp. carolina	Carolina Redhorse	FSC/T
	Notropis chalybaeus	Ironcolor Shiner	—
	Salvelinus fontinalis	Brook Trout (Native)	—
	Semotilus lumbee	Sandhills Chub	FSC/SC
MUSSEL	*Alasmidonta sp. 2*	a freshwater bivalve	—
	Alasmidonta undulata	Triangle Floater	—/T
	Alasmidonta varicosa	Brook Floater	FSC/E
	Fusconaia masoni	Atlantic Pigtoe	FSC/E
	Lampsilis cariosa	Yellow Lampmussel	FSC/E
	Lasmigona decorata	Carolina Heelsplitter	E/E
	Lasmigona subviridis	Green Floater	FSC/E
	Toxolasma pullus	Savannah Lilliput	FSC/E
	Villosa constricta	Notched Rainbow	—/SC
	Villosa delumbis	Eastern Creekshell	—
	Villosa vaughaniana	Carolina Creekshell	FSC/E

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

4.5.20.4 Threats Affecting Aquatic Species

Invasive species (e.g., Flathead Catfish, Blue Catfish, Red Swamp Crawfish) are established in the Yadkin — Pee Dee River Basin and continue to negatively impact native species populations (Fuller et al. 1999; Cooper 2005; NCWRC 2005) via predation and competition.

The Yadkin — Pee Dee River Basin has numerous problems affecting both species and their habitats. There is a significant loss of riverine habitat in this basin due to eight mainstem dams and the numerous impoundments on tributaries (hydroelectric plants, water supply lakes, and mill dams). Impoundments can physically alter instream habitat, change flow regimes, and often reduce DO levels. Water withdrawals for irrigation and similar uses further change flow patterns and reduce the quality and quantity of habitat available for aquatic species (NCDWQ 2008b). According to a NCDENR dam inventory (NCDEMLR 2014), there are 1,289 impoundments in the basin.

Streams are being impacted by excessive sedimentation and changes in hydrology and geomorphology, all due to urban development, agriculture, and instream mining (Williams et al. 1993; Etnier 1997; Neves et al. 1997; Warren et al. 2000). Water quality is also degraded by excessive nutrient input and other chemicals from wastewater discharges and surface water runoff from agriculture. There are 358 permitted discharges in the 21 counties of the Yadkin — Pee Dee River Basin, 46 of which are major discharges with ≥1 million gallons per day (NCDWQ 2015a).

There are 188 permitted CAFOs for cattle and swine production in the Yadkin — Pee Dee River Basin with 312 waste lagoons associated with the facilities. Waste from these sites contains high levels of nutrients (e.g., nitrogen and phosphorus) in addition to fecal coliform bacteria and any chemical compounds, such as antibiotics or hormone products used in commercial feeding operations (NCDWR 2015b). Animal-waste lagoons and spray fields that discharge near or into aquatic environments are a source of contamination from runoff, percolation into groundwater, and volatilization of ammonia and the release of bacterial contamination. These sources can significantly degrade water quality and endanger human and animal health (Mallin 2003; Mallin and Cahoon 2003).

4.5.20.5 Recommendations

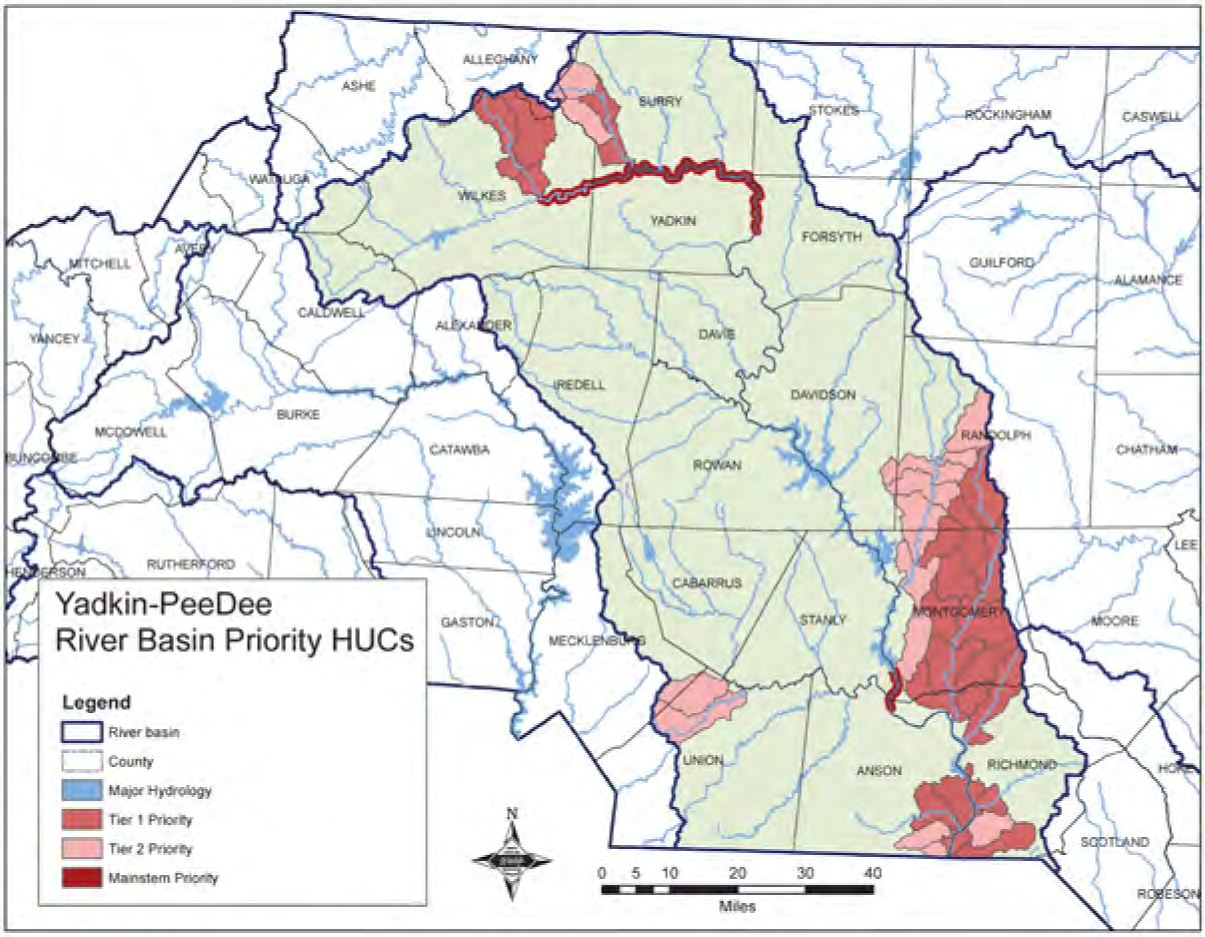
Conservation priorities that apply statewide to all river basins are presented in Section 4.5.3.3. Priorities identified in the Yadkin — Pee Dee River Basin are shown in Figure 4.40 and a list of the priority 12-digit HUCs is included in Appendix J.

Basin Specific Recommendations

Surveys. Priorities for distribution and status surveys should focus on aquatic snails, crayfish, mussels, and fish believed to be declining or dependent on at-risk or sensitive communities (see Table 4.92). Conduct distribution and status surveys for priority species such as the Brook Floater, Savannah Lilliput, Atlantic Pigtoe, and Carolina Redhorse.

Monitoring. Long-term monitoring is critical to assessing species and ecosystem health over time and gauging the resilience of organisms to continued impacts to state waters. Studies should include identification of population trends, as well as assessment of impacts from conservation or development activities. These efforts will inform species and habitat management decisions. Long-term monitoring sites need to be identified and monitoring

FIGURE 4.40 Location of priority watersheds in the Yadkin — Pee Dee River Basin



protocols developed for all priority species. Monitoring plans should be coordinated with other existing monitoring programs where feasible. Monitor the presence and distribution of exotic species in the basin.

Research. Research topics that facilitate appropriate conservation actions include habitat use and preferences, reproductive behavior, fecundity, population dynamics and genetics, feeding, competition, and food web dynamics.Increased understanding of life histories and status helps determine the vulnerability of priority species to further imperilment, in addition to identifying possibilities for improved management and conservation. All studies should provide recommendations for mitigation and restoration. Formal descriptions for known or putative undescribed species and investigations aimed at resolving taxonomic status are needed.

- Support species descriptions for undescribed taxa (e.g., Carolina Redhorse).

- Determine vulnerability of species across all taxa groups to emerging threats such as endocrine-disrupting chemicals (EDCs) and other compounds present in many of the waterways of the Yadkin — Pee Dee Basin.

- Identify limiting factors of declining species.

In addition to the SGCN species found in the basin (see Table 4.92), a list of knowledge-gap priority species is provided in Table 4.93. These are a lower priority for research as compared to SGCN for which there are knowledge gaps in the basin.

Management Practices. Management practices that reduce impacts and work synergistically with other conservation actions are needed to enhance the resilience of natural resources. Particular needs include preserving biodiversity, protecting native populations and their habitats, and improving degraded habitats. In addition, education about, and regulation and prevention of the introduction and spread of exotic or invasive species are vital. Specific issues in this basin include secondary and cumulative impacts upon water quality, riparian vegetation and stream bank restoration and conservation, mitigation of hydropower development impacts, and species restoration opportunities.

- Promote programs to upgrade or increase compliance at wastewater treatment facilities and CAFOs.

Table 4.93 Knowledge-gap priority species in the Yadkin — Pee Dee River Basin

Taxa Group	Scientific Name	Common Name	Federal/ State Status*
AQ SNAIL	*Cipangopaludina japonica*	Japanese Mystery Snail [Exotic]	—
CRAYFISH	*Cambarus howardi*	Chattahoochee Crayfish	—
	Cambarus johni	Carolina Foothills Crayfish	—
FISH	*Chrosomus oreas*	Mountain Redbelly Dace [Exotic]	—
	Cyprinella labrosa	Thicklip Chub	—
	Lepisosteus osseus	Longnose Gar	—
	Petromyzon marinus	Sea Lamprey	—
MUSSEL	*Corbicula fluminea*	Asian Clam [Exotic]	—
	Elliptio icterina	Variable Spike	—
	Elliptio roanokensis	Roanoke Slabshell	—/T
	Lampsilis radiata	Eastern Lampmussel	—/T
	Ligumia nasuta	Eastern Pondmussel	—/T
	Pyganodon cataracta	Eastern Floater	—
	Strophitus undulatus	Creeper	—/T
	Uniomerus carolinianus	Florida Pondhorn	—
	Utterbackia imbecillis	Paper Pondshell	—

* See Table 4.43 in Section 4.5.3.2 for abbreviations.

- Provide support for land protection, particularly in riparian areas through acquisition or easements.
- Support well-planned stream restoration work in collaboration with other organizations.
- Support dam removal where appropriate.
- Reintroduce or augment rare mollusk and fish species populations in areas where water quality and stream habitats have recovered sufficiently to support them.
- Continue to identify areas critical to aquatic ecosystem health that can be conserved or restored.

Conservation Programs and Partnerships. Conservation programs, incentives, and partnerships should be utilized to the fullest extent in order to preserve high-quality resources and protect important natural communities. Protective measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable. Land conservation or preservation can serve numerous purposes in the face of anticipated climate change, but above all, it promotes ecosystem resilience.

- Guide academic research projects to help achieve specific conservation goals and objectives.
- Support application of an aquatic nuisance species management plan with other agencies/groups.
- Address secondary and cumulative impacts upon water quality (buffer ordinances, water supply watershed protection, headwaters protection) (NCDWQ 2008b; NCWRC 2002).
- Work with and promote existing programs that help farmers reduce sedimentation and erosion (installing fences to keep livestock out of streams) as well as reduce pesticide and herbicide use.

References

Abell RA, Olsen DM, Dinerstein E, Hurley PT, Diggs, JT, Eichbaum, W, Walters S, Wettengel W, Allnutt T, Loucks CJ, Hedao P. 2000. Freshwater ecoregions of North America: a conservation assessment. Washington (DC): Island Press. 319 p.

Abell R, Thieme ML, Revenga C, Bryer M, Kottelate M, Bogutskaya N, Coad B, Mandrak N, Balderas SC, Bussing W, et al. 2008. Freshwater ecoregions of the world: a new map of biogeographic units for freshwater biodiversity conservation. BioSci. 58(5):403–414.

Abrams MD. 1992. Fire and the development of oak forests. BioSci. 42:346–353.

[ACJV] Atlanta Coast Joint Venture. 2004. Atlantic Coast Joint Venture Strategic Plan. [accessed 2015 September] http://www.acjv.org/documents/acjv_strategic_plan.pdf. 39 p.

[ACJV] Atlanta Coast Joint Venture. 2009. Strategic plan. [accessed 2015 August]. http://acjv.org/documents/ACJV_StrategicPlan_2009update_final.pdf.

Adams WF, Alderman JM, Biggins RG, Gerberich AG, Keferl EP, Porter HJ, Van Devender AS. 1990. A report on the conservation status of North Carolina's freshwater and terrestrial molluscan fauna. Raleigh (NC): NC Wildlife Resources Commission; [accessed 2015 July]. http://www.fws.gov/raleigh/pdfs/ES/Tar_Spinymussel/Adamsetal_AReportOnTheConservationStatusOfNorthCarolina'sFreshwaterAndTerrestrialMolluscanFaunaMay1990.pdf.

[AHG] Aquatic Habitat Guides [internet]. n.d. The Nature Conservancy; [accessed 2015 February]. http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/hg/fw/Pages/default.asp.

Alexander DE, Fairbridge RW, editors. 1999. Encyclopedia of environmental sciences. Springer Science & Business Media Vol. 20. Dordrecht (Netherlands): Klower Academia Publishers. 685 p.

Allan JD, Palmer M, Poff NL. 2005. Climate change and freshwater ecosystems. In: Lovejoy TE, Hannah L, editors. Climate change and biodiversity. New Haven (CT): Yale University Press. p. 272–290.

American Rivers. 2007. America's most endangered rivers 2007. Washington (DC): American Rivers; [accessed 2015 March]. http://www.americanrivers.org/newsroom/resources/americas-most-endangered-rivers-report-2007-edition/.

American Rivers. 2012. Removing the Milburnie Dam, Neuse River, North Carolina. The River Blog [web page]; [accessed 2015]. http://www.americanrivers.org/blog/removing-the-milburnie-dam-neuse-river-north-carolina/.

Anderson DM. 1994. Red tides. Sci Am. 271(2):52–58.

Anderson JR, Hardy EE, Roach JT, Witmer RE. 1976. A land use and land cover classification system for use with remote sensor data. Geological Survey Professional Paper 964. Washington (DC): US Government Printing Office; [accessed 2015 July]. http://landcover.usgs.gov/pdf/anderson.pdf.

Anderson MG, Barnett A, Clark M, Ferree C, Olivero Sheldon A, Prince J. 2014. Resilient sites for terrestrial conservation in the southeast region. Boston (MA): The Nature Conservancy, Eastern Conservation Science; [accessed 2015 February]. http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/resilience/se/Pages/default.aspx.

[APNEP] Albemarle–Pamlico National Estuary Program. 2012. Comprehensive conservation and management plan 2012–2022. Raleigh (NC): NC Department of Environment and Natural Resources.

Arbogast BS, Browne RA, Weigl PD, Kenagy GJ. 2005. Conservation genetics of endangered flying squirrels (*Glaucomys*) from the Appalachian mountains of eastern North America. Anim Conserv. 8(2):123–133.

Armstrong DS, Richards TA, Parker GW. 2001. Assessment of habitat, fish communities and streamflow requirements for habitat protection, Ipswich River, Massachusetts, 1998-1999. USGS, Water Resources Investigations Report 01-4161, 72 p. [accessed 2015 July]. http://pubs.usgs.gov/wri/wri01-4161/.

Artman VL, Downhower JF. 2003. Wood thrush (*Hylocichla mustelina*) nesting ecology in relation to prescribed burning of mixed-oak forest in Ohio. Auk. 120(3):874–882.

Aucott WR. 1996. Hydrology of the Southeastern Coastal Plain aquifer system in South Carolina and parts of Georgia and North Carolina [Report]. US Geological Survey Professional Paper 1410–E. Denver (CO): US Geological Survey 95 p.

Augspurger T, Fischer JR, Thomas NJ, Sileo L, Brannian RE, Miller KJG, Rocke TE. 2003. Vacuolar myelinopathy in waterfowl from a North Carolina impoundment. J Wildl Dis. 39:412–417.

Bailey MA, Holmes JN, Buhlmann KA, Mitchell JC. 2006. Habitat management guidelines for amphibians and reptiles of the southeastern United States. Technical Publication HMG-2. Montgomery (AL): Partners in Amphibian and Reptile Conservation. 88 p.

Bailey RG. 1995. Description of the ecoregions of the United States. 2nd ed. (rev.). Misc. Publ. No. 1391. Washington (DC): US Department of Agriculture, Forest Service 108 p.

Bailey RG. 1998. Ecoregions: the ecosystem geography of the oceans and the continents. New York (NY): Springer-Verlag 192 p.

Bailey RG. 2009. Ecosystem geography: from ecoregions to sites. 2nd ed. New York (NY): Springer-Verlag 252 p.

Bakalowicz M. 2005. Karst groundwater: a challenge for new resources. Hydrogeol J. 13:148–160.

Bakke P. 2008. Physical processes and climate change: a guide for biologists [Unpublished report]. Washington (DC): US Department of Interior, Fish and Wildlife Service 28p.

Band L, Salvesen D, editors. 2009. The University of North Carolina at Chapel Hill: Climate Change Committee report. Chapel Hill (NC): UNC Institute for the Environment; [accessed 2015 July]. http://ie.unc.edu/PDF/Climate_Change_Report.pdf.

Barden LS. 1997. Historic prairies in the Piedmont of North and South Carolina, USA. Nat Areas J. 17:149–152.

Barnes-Svarney P, Svarney TE. 2004. Handy geology answer book. n.p.: Visible Ink Press.Chapter 1, Details of geology; p. 1–12

Barr Jr. TC, Holsinger JR. 1985. Speciation in cave faunas. Annu Rev of Ecol Syst. 16:313–337.

Baxter RM. 1977. Environmental effects of dams and impoundments. Annu Rev Ecol Syst. 8:255–283.

Benke AC, Cushing CE, editors. 2005. Rivers of North America. Amsterdam (Netherlands): Elsevier. Chapter 1, Background and approach; p. 1–18.

Bender MJ, Castleberry SB, Miller DA, Wigley Jr. TB. 2015. Site occupancy of foraging bats on landscapes of managed pine forest. For Ecol Manag. 336:1–10.

Bibb KA, Walsh SJ, Biggins RG, Mudrak VA, Burkhead NM. 2002. Strategy for the conservation of southeastern imperiled fishes. Developed from the proceedings of a workshop held by a Southeastern Imperiled Fishes Working Group, October 26–28, 1999, Chattanooga, TN.

Biggins RG, Neves RJ, Dohner CK. 1997. National strategy for the conservation of native freshwater mussels. Asheville (NC): US Fish & Wildlife Service.

Bin O. 2008. Measuring the impacts of sea-level rise on coastal real estate in North Carolina. Greenville (NC): Center for Natural Hazards Research, East Carolina University. 27 p.

Bin O, Dumas C, Poulter B, Whitehead J. 2007. Measuring the impacts of climate change on North Carolina coastal resources. Prepared for National Commission on Energy Policy, Washington, DC. http://econ.appstate.edu/climate/NC-NCEP%20final%20report.031507.pdf.

Blaustein L, Garb JE, Shebitz D, Nevo E. 1999. Microclimate, developmental plasticity and community structure in artificial temporary ponds. Hydrobiol. 392:187–196.

Blazer VS, Lilley JH, Schill WB, Kiryu Y, Densmore CL, Panyawachira V, Chinabut S. 2002. *Aphanomyces invadans* in Atlantic Menhaden along the East Coast of the United States. J Aquat Anim Health. 14:1–10.

Blehert DS, Hicks AC, Behr M, Meteyer CU, Berlowski-Zier BM, Buckles EL, Coleman JTH, Darling SR, Gargas A, Niver R, et al. 2009. Bat white-nose syndrome: an emerging fungal pathogen? Science. 323(5911): 227.

Block BA, Jonsen ID, Jorgensen SJ, Winship AJ, Shaffer SA, Bograd SJ, Hazen EL, Foley DG, Breed GA, Harrison A, et al. 2011. Tracking apex marine predator movements in a dynamic ocean. Nature. 475(7354):86–90.

Blue Ridge National Heritage Area. 2015. New River State Park. Asheville (NC): Blue Ridge National Heritage Area; [accessed 2015 May]. http://www.blueridgeheritage.com/attractions-destinations/new-river-state-park.

Bogan AE. 1993. Freshwater bivalve extinctions: search for a cause. Am Zool. 33:599–609.

Bogner HE, Baldassarre GA. 2002. Home range, movement and nesting of least bitterns in western New York. Wilson Bull. 114(3):297–308.

Brantley CG, Platt SG. 2001. Canebrake conservation in the southeastern United States. Wildl Soc Bull. 29(4):1175–1181.

Braswell AL. 1993. Status report on Rana capito capito LeConte, the Carolina gopher frog in North Carolina. Unpublished report to NC Wildlife Resources Commission Nongame and Endangered Wildlife Program. Raleigh (NC). 20 p.

Brinkmann R, Parise M. 2012. Karst environments: problems, management, human impacts, and sustainability – an introduction to the special issue. J Cave Karst Stud. 74(2):135–136.

Brinson MM. 1993. A hydrogeomorphic classification for wetlands. Wetlands Research Program Technical Report WRP-DE-4. Washington (DC): US Army Corps of Engineers 103 p.

Brooks RJ, Bobyn ML, Galbraith DA. 1991. Maternal and environmental influences on growth and survival of embryonic and hatchling snapping turtles (*Chelydra serpentina*). Can J Zool. 69:2667–2676.

Brown MJ, Sheffield RM. 2003. Forest statistics for the Piedmont of North Carolina, 2002. Asheville (NC): US Department of Agriculture, Forest Service, Southern Research Station. Resource Bulletin SRS-86.

Bull JJ. 1980. Sex determination in reptiles. Q Rev Biol. 55(1):3–21.

Bull JJ, Vogt RC, McCoy CJ. 1982. Sex determining temperatures in turtles: a geographic comparison. Evol. 36(2):326-332.

Bunn SE, Arthington AH. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environ Manag. 30(4):492–507.

Burger J, Niles L, Clark KE. 1997. Importance of beach, mudflat and marsh habitats to migrant shorebirds on Delaware Bay. Biol Conserv. 79:283–292.

Burhans DE, Thompson III FR. 1999. Habitat patch size and nesting success of yellow-breasted chats. Wilson Bull. 111(2):210–215.

Burke MK, King SL, Gartner D, Eisenbies MH. 2003. Vegetation, soil, and flooding relationships in a blackwater floodplain forest. Wetl. 23(4):988–1002.

Burkett V, Ritschard R, McNulty S, O'Brien JJ, Abt R, Jones J, Hatch U, Murray B, Jagtap S, Cruise J. 2000. Potential consequences of climate variability and change for the southeastern United States. [accessed 2010 July 20]. http://www.usgcrp.gov/usgcrp/nacc/se-mega-region.htm.

Burkhead NM. 2012. Extinction rates in North American freshwater fishes, 1900–2010. BioSci. 62(9):798–808.

Burkholder JM, Glasgow Jr. HB, Cooke JE. 1994. Comparative effects of water-column nitrate enrichment on eelgrass *Zostera marina*, shoalgrass *Halodule wrightii*, and widgeon grass *Ruppia maritima*. Mar Ecol Prog Ser. 105:121–138.

Burkholder JM, Mason KM, Glasgow Jr. HB. 1992. Water-column nitrate enrichment promotes decline of eelgrass *Zostera marina L.*: evidence from seasonal mesocosm experiments. Mar Ecol Prog Ser. 81:163–178.

Burns CE, Peoples C, Fields M, Barnett A. 2012. Protecting North Carolina's freshwater systems: a state-wide assessment of biodiversity, condition and opportunity. Durham (NC): The Nature Conservancy.

Burr BM, Mayden RL. 1992. Phylogenetics and North American freshwater fishes. In: Mayden RL, editor. Systematics, historical ecology, and North American freshwater fishes. Stanford (CA): Stanford University Press. p. 18–75

Butler RS. 2002a. Crayfishes of the southern Appalachian ecosystem, with emphasis on the imperiled fauna. Asheville (NC): US Fish and Wildlife Service.

Butler RS. 2002b. Imperiled fishes of the Southern Appalachian ecosystem, with emphasis on the nonfederally listed fauna. Asheville (NC): US Fish and Wildlife Service.

Ó Cléirigh B. 2000. Assessment of impact of offshore wind energy structures on the marine environment [Report]. Southampton (England): University of Southampton School of Ocean and Earth Sciences. 42p.

Caissie D. 2006.The thermal regime of rivers: a review. Freshw Biol. 51:1389–1406.

Cameron WM, Pritchard DW. 1963. Estuaries. In: Hill MN, editor. The sea. Vol. 2. New York (NY): John Wiley and Sons. p. 306–324.

Campbell BG, Coes AL, editors. 2010. Groundwater availability in the Atlantic Coastal Plain of North and South Carolina. US Geological Survey Professional Paper 1773. Denver (CO): USGS; [accessed 2015]. 241 p. http://pubs.usgs.gov/pp/1773/pdf/pp1773.pdf.

Calo F, Parise M. 2009. Waste management and problems of groundwater pollution in karst environments in the context of a postconflict scenario: the case of Mostar (Bosnia Herzegovina). Habitat Int. 33(1):63–72.

Carr CS. 2010. The status of nutria (*Myocastor coypus*) in North Carolina [thesis]. [Raleigh (NC)]: North Carolina State University College of Natural Resources.

[CBF] Chesapeake Bay Foundation. 2005. Roanoke River fact sheet [web page]; [accessed 2015 August]. http://www.cbf.org/Document.Doc?id=239. 2 p.

Christensen NL, Bartuska AM, Brown JH, Carpenter S, D'Antonio C, Francis R, Franklin JF, MacMahon JA, Noss RF, Parsons DJ, et al. 1996a. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. Ecol Appl. 6:665–691

Christensen DL, Herwig BR, Schindler DE, Carpenter SR. 1996b. Impacts of lakeshore residential development on coarse woody debris in north temperate lakes. Ecol Appl. 6:1143–1149.

Christman MC, Culver DC. 2001. The relationship between cave biodiversity and available habitat. J Biogeogr. 28:367–380.

Clamp JC, Adams WF, Reid JW, Taylor AY, Cooper JE, McGrath C, Williams DJ, DeMont DJ, McLarney WO, Mottesi G, et al. 1999. A report on the conservation status of North Carolina's freshwater and terrestrial crustacean fauna. Raleigh (NC): NC Wildlife Resources Commission.

Clarkson RW, Childs MR. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River Basin big-river fishes. Copeia. 2000:402–412.

Close DD. 1996. Evaluation of herbaceous diversity and differential species in mature forest stands at land Between the Lakes, Kentucky and Tennessee [thesis]. [Carbondale (IL)]: Southern Illinois University.

Cobb SP, Kaufman J. 1993. Clearing and snagging. In: Bryan CF, Rutherford DA, editors. Impacts on warmwater streams: guidelines for evaluation. Little Rock (AR): American Fisheries Society, Southern Division. p. 169–180

Collen B, Whitton F, Dyer EE, Baillie JEM, Cumberlidge N, Darwall WRT, Pollock C, Richman NI, Soulsby AM, Bohm M. 2014. Global patterns of freshwater species diversity, threat and endemism. Glob Ecol Biogeogr. 23:40–51.

Conn KE, Barber LB, Brown GK, Siegrist RL. 2006. Occurrence and fate of organic contaminants during onsite wastewater treatment. Environ Sci & Technol. 40(23):7359–7366.

Conway CJ, Sulzman C, Raulston BE. 2004. Factors affecting detection probability of California black rails. J Wildl Manag. 68(2):360–370.

Cooper JE. 2005. A report on adventive crayfishes in North Carolina [Unpublished report]. Raleigh (NC): NC Museum of Natural Sciences.

Cooper RJ. 2000. Draft Partners in Flight Southern Piedmont Bird Conservation Plan (Physiographic Area 11). Athens (GA): University of Georgia. 47p.

Covich AP, Palmer MA, Crowl TA. 1999. The role of benthic invertebrate species in freshwater ecosystems. BioSci. 49:119–127.

Cowardin LM, Carter V, Golet FC, LaRoe ET. 1979. Classification of wetlands and deepwater habitats of the United States. Washington (DC): US Department of the Interior, Fish and Wildlife Service; [accessed 2015]. http://www.npwrc.usgs.gov/resource/wetlands/classwet/index.htm.

Cowen RK, Sponaugle S. 2009. Larval dispersal and marine population connectivity. Annu Rev Mar Sci. 1:443–466.

Crase L, Gillespie R. 2008. The impact of water quality and water level on the recreation values of Lake Hume. Australas J Environ Manag. 15:21–29.

[CSCOR] Center for Sponsored Coastal Ocean Research. 2012. Coastal ecosystem effects of climate change fact sheet. NOAA National Centers for Coastal Ocean Science; [accessed 2012 May 3]. www.cop.noaa.gov/stressors/climatechange/climate_changefs.pdf.

Culver DC, Holsinger JR. 1969. Preliminary observations on sex ratios in the subterranean amphipod genus *Stygonectes* (*Gammaridae*). Am Midl Nat. 82:631–633.

Culver DC, Holsinger JR, Christman MC, Pipan T. 2010. Morphological differences among eyeless amphipods in the genus *Stygobromus* dwelling in different subterranean habitats. J Crustac Biol. 30:68–74.

Culver DC, Holsinger JR, Feller DJ. 2012. The fauna of seepage springs and other shallow subterranean habitats in the Mid-Atlantic Piedmont and Coastal Plain. Northeast Nat. 19(m9):1–42.

Culver DC, Master LL, Christman MC, Hobbs HH III. 2000. Obligate cave fauna of the 48 contiguous United States. Conserv Biol. 14:386–401.

Culver DC, Pipan T. 2008. Superficial subterranean habitats: gateway to the subterranean realm? Cave Karst Sci. 35:5–12.

Culver DC, Pipan T. 2009. The biology of caves and other subterranean habitats. Oxford (England): Oxford University Press 254 p.

Culver DC, Pipan T, Gottstein S. 2006. Hypotelminorheic: a unique freshwater habitat. Subterr Biol. 4:1–7.

Culver DC, Poulson TL. 1971. Oxygen consumption and activity in closely related amphipod populations from cave and surface habitats. Am Midl Nat. 85:74–84.

Culver DC, Šereg I. 2004. Kenk's amphipod (*Stygobromus kenki*) and other amphipods in Rock Creek Park, Washington, DC. Unpublished report to the National Park Service. Washington (DC): Environmental Studies Program, American University. 147 p.

Cushman RM. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. N Am J Fish Manag. 5(3A):330–339.

Davis Jr. JE, McRae C, Estep BL, Barden LS, Matthews JF. 2002. Vascular flora of Piedmont Prairies: evidence from several prairie remnants. Castanea. 67:1–12.

Deaton AS, Chappell WS, Hart K, O'Neal J, Boutin B. 2010. North Carolina coastal habitat protection plan. Morehead City (NC): NC Department of Environment and Natural Resources, Division of Marine Fisheries. 659 p.

Denver JM, Ator SW, Fischer Jm, Harned DC, Schubert C, Szabo Z. 2014. The quality of our nation's waters—water quality in the Northern Atlantic Coastal Plain surficial aquifer system, Delaware, Maryland, New Jersey, New York, North Carolina, and Virginia, 1988–2009. US Geol Surv Circ. [accessed 2015 July];1353. http://dx.doi.org/10.3133/cir1353.

De Steven D, Toner MM. 2004. Vegetation of upper coastal plain depression wetlands: environmental templates and wetland dynamics within a landscape framework. Wetl. 24:23–42.

DeWan A, Dubois N, Theoharides K, Boshoven J. 2010. Understanding the impacts of climate change on fish and wildlife in North Carolina. Washington (DC): Defenders of Wildlife; [accessed 2015]. http://www.ncwildlife.org/Portals/0/Conserving/documents/ActionPlan/Revisions/FullReportDefendersofWildlifeUnderstandingtheimpactofclimatechangeNC.pdf.

DiBacco C, Levin LA, Sala E. 2006. Connectivity in marine ecosystems: the importance of larval and spore dispersal. In: Crooks KR, Sanjayan M, editors. Connectivity conservation: conservation biology. No. 14. Cambridge (England): Cambridge University Press. p. 184–212.

Dinsmore SJ, Collazo JA, Walters JF. 1998. Seasonal numbers and distribution of shorebirds on North Carolina's Outer Banks. Wilson Bull. 110(2):171–181.

Doherty P, Grubb T. 2000. Habitat and landscape correlates of presence, density, and species richness of birds wintering in forest fragments in Ohio. Wilson Bull. 112:388–394.

Domenico PA, Schwartz FW. 1998. Physical and chemical hydrogeology. 2nd ed. New York (NY): John Wiley & Sons. 506 p.

Donovan TM, Beardmore CJ, Bonter DN, Brawn DJ, Cooper RJ, Fitzgerald JA, Ford R, Gauthreaux SA, George TL, Hunter WC, et al. 2002. Priority research needs for the conservation of neotropical migrant landbirds. J Field Ornithol. 73(4):329–339.

Downing JA, Prairie YT, Cole JJ, Duarte CM, Tranvik LJ, Striegl RG, McDowell WH, Kortelainen P, Caraco NF, Melack JM, et al. 2006. The global abundance and size distribution of lakes, ponds, and impoundments. Limnol Oceanogr. 51(5):2388–2397.

Downing JA, Watson SB, McCauley E. 2001. Predicting cyanobacteria dominance in lakes. Can J Fish Aquat Sci. 58(10):1905–1908.

Duchamp JE, Arnett EA, Larson MA, Swihart RK. 2007. Ecological considerations for landscape-level management of bats. In: Lacki MJ, Hayes JP, Kurta A, editors. Bats in forests, conservation and management. Baltimore (MD): John Hopkins University Press. p. 237–261.

Dudgeon D, Arthington AH, Gessner MO, Kawabata ZI, Knowler DJ, Leveque C, Naiman RJ, Prieur-Richard AH, Soto D, Stiassny MLJ, et al. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biol Rev. 81:163–182.

Dugan JE, Hubbard DM. 2006. Ecological responses to coastal armoring on exposed sandy beaches. Shore & Beach. 74(1):10–16.

Dugan JE, Hubbard DM, McCrary MD, Pierson MO. 2003. The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed sandy beaches of Southern California. Estuar Coast Shelf Sci. 58(S):25–40.

Dukes JS, Pontius J, Orwig D, Garnas JR, Rodgers VL, Brazee N, Cooke B, Theoharides KA, Stange EE, Harrington R, et al. 2009. Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: what can we predict? Can J For Res. 39(2):231–248.

Dynesius M, Nilsson C. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. Sci. 266:753–762.

Eaton JG, McCormick JH, Goodno BE, O'Brien DG, Stefany HG, Hondzo M, Scheller RM. 1995. A field information-based system for estimating fish temperature tolerances. Fish. 20:10–18.

Eaton JG, Scheller RM. 1996. Effects of climate warming on fish thermal habitat in streams of the United States. Limnol Oceanogr. 41:1109–1115.

Elliott WR. 2004. Protecting caves and cave life. In: Culver DC, White WB, editors. The encyclopedia of caves. Amsterdam (Netherlands): Elsevier Academic Press. p. 458–467.

Ellis AM, Patton LL, Castleberry SB. 2002. Bat activity in upland and riparian habitats in the Georgia Piedmont. Proc Annu Conf Southeast Assoc Fish Wildl Agencies. 56:210–218.

Elrod J, Twidwell D, Huang YW. 2003a. Assessment of water quality, endocrine disruption, and hematology of Ozark hellbenders (*Cryptobranchus alleganiensis bishopi*) in Eleven Point and White Rivers. Paper presented at: Semi-annual Hellbender Working Group Meeting; West Plain, Missouri.

Elrod J, Huang YW, Nam P, Twidwell D. 2003b. Endocrine disruption study of Ozark hellbenders (*Cryptobranchus alleganiensis bishopi*) in Eleven Point and White Rivers. Online abstract in the Missouri Life Sciences Week, March 2003, Missouri, USA.

Emery D, Myers KJ, editors. 1996. Sequence stratigraphy. Oxford (England): Blackwell Publishing. 297 p.

[EPA] US Environmental Protection Agency. 2012a. Coastal watershed factsheets – estuaries and your coastal watershed [web page]. [accessed 2015 August]. http://water.epa.gov/type/oceb/fact5.cfm.

[EPA] US Environmental Protection Agency. 2012b. Primer for identifying coldwater refuges to protect and restore thermal diversity in riverine landscapes. EPA 910-C-12-001. Seattle (WA): Office of Water and Watersheds, Water Division. 91 p.

[EPA] US Environmental Protection Agency. 2013a. My WATERS Mapper [Internet]. Washington (DC): US Environmental Protection Agency, Office of Water; [accessed 2015 January]. http://watersgeo.epa.gov/mwm/.

[EPA] US Environmental Protection Agency. 2013b. Water quality models and tools – DFLOW. Washington (DC): US Environmental Protection Agency; [accessed 2015 May]. http://water.epa.gov/scitech/datait/models/dflow/.

[EPA] US Environmental Protection Agency. 2014a. 303(d) listed impaired waters NHDPlus indexed dataset with program attributes [web page]. [accessed 2015 March]. http://water.epa.gov/scitech/datait/tools/waters/data/downloads.cfm#303(d) Listed Impaired Waters.

[EPA] US Environmental Protection Agency. 2014b. NHDPlus in waters [web page]. [accessed 2015 March] http://water.epa.gov/scitech/datait/tools/waters/docs/nhd_model.cfm.

[EPA] US Environmental Protection Agency. 2015. NPDES Wastewater and Stormwater Permits [web page]. [last updated 2015 June 30; accessed 2015 August]. http://www.epa.gov/region9/water/npdes/.

Eschmeyer RW. 1936. Essential considerations for fish management in lakes. In: Anonymous, editor. Proceedings from the North American Wildlife Conference. Washington (DC): US Government Printing Office. p. 332–339.

Etnier DA. 1997. Jeopardized southeastern freshwater fishes: a search for causes. In: Benz GW, Collins DE, editors. Aquatic fauna in peril: the southeastern perspective. Decatur (GA): Southeast Aquatic Research Institute. p. 87–104.

Evans AM, Gregoire TG. 2007. A geographically variable model of hemlock woolly adelgid spread. Biol Invasions. 9:368–382.

Fahrig L, Pedlar JH, Pope SE, Taylor PD, Wegner JF. 1995. Effect of road traffic on amphibian density. Biol Conserv. 73:177–182.

[FGDC] Federal Geographic Data Committee. 2013. Classification of wetlands and deepwater habitats of the United States. 2nd ed. FGDC-STD-004-2013. Washington (DC): Wetlands Subcommittee, Federal Geographic Data Committee, and US Fish and Wildlife Service.

Ferrell GM, Yearout MS, Grimes BH, Graves AK, Fitzgerald SA, Meyer MT. 2014. Water-quality characteristics indicative of wastewater in selected streams in the upper Neuse River Basin, Durham and Orange Counties, North Carolina, from 2004 to 2013. US Geological Survey Open-File Report 2014–1215. Reston (VA): US Geological Survey; [accessed 2015 July]. 62 p. http://dx.doi.org/10.3133/ofr20141215.

Fetter CW. 2001. Applied hydrogeology. 4th edition. Upper Saddle River (NJ): Prentice Hall. 598 p.

Ficke AD, Myrick CA, Avila LJ. 2007. Potential impacts of global climate change on freshwater fisheries. Rev Fish Biol Fish. 17:581–613.

Findlay CS, Lenton J, Zheng LG. 2001. Land-use correlates of anuran community richness and composition in southeastern Ontario wetlands. Ecosci. 8:336–343.

FitzGerald DM, Fenster MS, Argow BA, Buynevich lV. 2007. Coastal impacts due to sea-level rise. Ann Rev Earth Planet Sci. 36:601–647; [accessed 2015]. https://darchive.mblwhoilibrary.org/handle/1912/2273.

Fleury S. 2009. Land use policy and practice on karst terrains. Dordrecht (Netherlands): Springer. Chapter 1, Karst processes, landforms and issues; p. 1–18.

Florida Natural Areas Inventory. 1990. The natural communities of Florida. Tallahassee (FL): Florida Department of Natural Resources.

Ford WM, Dobony CA, Edwards JW. 2002. Shrews in managed northern hardwood stands in the Allegany Mountains of West Virginia. Proc Annu Conf Southeast Assoc Fish Wildl Agencies. 56:374–384.

Ford WM, Menzel MA, McCay TS, Gassett JW, Laerm J. 2000. Woodland salamander and small mammal responses to alternative silvicultural practices in the southern Appalachians of North Carolina. Proc Annu Conf Southeast Assoc Fish Wildl Agencies. 54:241–250.

Foulds DM. 1977. Lake levels and shore damages. Can Water Res J. 2: 43–54.

Franklin SB, Kupfer JA. 2004. Forest communities of Natchez Trace State Forest, Western Tennessee Coastal Plain. Castanea. 69(1):15–29.

Franssen N, Tobler M. 2013. Upstream effects of a reservoir on fish assemblages 45 years following impoundment. J Fish Biol. 82(5):1659–1670.

Freeze RA, Cherry JA. 1979. Groundwater. Englewood Cliffs (NJ): Prentice-Hall. 604 p.

Frick WF, Puechmaille SJ, Hoyt JR, Nickel BA, Langwig KE, Foster JT, Barlow KE, Bartonicka T, Feller D, Haarsma AJ, et al. 2015. Disease alters macroecological patterns of North American bats. Global Ecol Biogeogr. 24:741–749.

Fuller PL, Nico LG, Williams JD. 1999. Nonindigenous fishes introduced into inland waters of the United States. Special Publication 27. Bethesda (MD): American Fisheries Society.

Funderburk SL, Mihursky JA, Jordan SJ, Riley D. 1991. Habitat requirements for Chesapeake Bay living resources. Solomons (MD): Habitat Objectives Workgroup, Living Resources Subcommittee, and Chesapeake Research Consortium with assistance from Maryland Department of Natural Resources.

Fussell JO, Webster WD, Hall SP, LeGrand HE, Schafale MP, Russo MJ. 1995. Ecosystem survey of Dare County Air Force Range, North Carolina. Report to NC Natural Heritage Program. Raleigh (NC): NC Department of Environment and Natural Resources.

Gaff H, DeAngelis DL, Gross LJ, Salinas R, and Shorrash M. 2000. A dynamic landscape model for fish in the Everglades and its application to restoration. Ecol Model. 127(1):33–52; [accessed 2015]. http://www.sciencedirect.com/science/article/pii/S0304380099002021

Gallant AL, Loveland TR, Sohl TL, Napton DE. 2004. Using an ecoregion framework to analyze land-cover and land-use dynamics. Environ Manag. 34(supplement 1):S89–S110.

Gillieson D. 1996. Caves: processes, development and management. Oxford (England): Wiley-Blackwell Publishing. 336 p.

Godfrey MA. 1997. Field guide to the Piedmont. Chapel Hill (NC): University of North Carolina Press.

Gordon ND, McMahon TA, Finlayson BL. 1992. Stream hydrology: an introduction for ecologists. West Sussex (UK): Wiley.

Gothe E, Friberg N, Kahlert M, Temnerud J, Sandin L. 2014. Headwater biodiversity among different levels of stream habitat hierarchy. Biodivers Conserv. 23:63–80.

Graves GR. 2001. Factors governing the distribution of Swainson's Warbler along a hydrological gradient in Great Dismal Swamp. Auk. 118(3):650–664.

Gregory JD, Watershed Hydrology Consultants. 2009. Headwaters streams & riparian corridors – the key to watershed management. Powerpoint presented at: Lake George Watershed Coalition Annual Forum, Lake George (NY); [accessed 2015]. http://www.lakegeorge2000.org/Presentations%20and%20Papers/2009%20Forum%20Presentations/Gregory%201%20-Headwaters%20streams%20&%20riparian%20corridors.pdf.

Griffith GE, Omernik JM, Woods AJ. 1999. Ecoregions, watersheds, basins, and HUCs: how state and federal agencies frame water quality. J Soil Water Conserv. 54(4):666–677.

Gunn J, Hardwick P, Wood PJ. 2000. The invertebrate community of the Peak-Speedwell Cave system, Derbyshire, England: pressures and considerations for conservation management. Aquat Conserv: Mar Freshw Ecosyst. 10:353–369.

Haas TC, Blum MJ, Heins DC. 2010. Morphological responses of a stream fish to water impoundment. Biol Lett. 6(6):803–806.

Haase AT, Eggleston DB, Luettich RA, Weaver RJ, Puckett BJ. 2012. Estuarine circulation and predicted oyster larval dispersal among a network of reserves. Estuar Coast Shelf Sci. 101:33–43.

Hackney DT, Yelverton GF. 1990. Effects of human activities and sea level rise on wetland ecosystems in the Cape Fear River estuary, North Carolina, USA. In: Whigham DF, Good RF, Kvet Y, editors. Wetland ecology and management: case studies. Amsterdam (Netherlands): Kluwer Academic Publishers. p. 55–61.

Hahn HJ. 2009. A proposal for an extended typology of groundwater habitats. Hydrogeol J. 17:77–81.

Hall LS, Krausman PR, Morrison ML. 1997. The habitat concept and a plea for standard terminology. Wildl Soc Bull. 25(1):173–182.

Hambright KD, Eckert W, Leavitt PR, Schelske CL. 2004. Effects of historical lake level and land use on sediment and phosphorus accumulation rates in lake Kinneret. Environ Sci Technol. 38:6460–6467.

Hampson PS, Treece Jr. MW, Johnson GC, Ahlstedt SA, Connell JF. 2000. Water quality in the Upper Tennessee River Basin, Tennessee, North Carolina, Virginia, and Georgia, 1994–1998. Washington (DC): US Geological Survey Circular 1205. 32 p.

Hassler WW, Hill NL, Brown JT. 1981. The status and abundance of striped bass, *Morone saxatilis*, in the Roanoke River and Albemarle Sound, North Carolina, 1966–1980. Special Scientific Report No. 38, Project AFS-14. Morehead City (NC): NC Division of Marine Fisheries. 156 p.

Havel JE, Lee CE, VanderZanden JM. 2005. Do reservoirs facilitate invasions into landscapes? BioSci. 55(6):518–525.

Hawkes LA, Broderick AC, Godfrey MH, Godley BJ. 2009. Climate change and marine turtles. Endanger Species Res. 7:135–154.

Hayes MA. 2012. The *Geomyces* fungi: ecology and distribution. BioSci. 62(9):819–823.

Hayes TB, Case P, Chui S, Chung D, Haeffele C, Haston K. 2006. Pesticide mixtures, endocrine disruption, and amphibian declines: are we underestimating the impact? Environ Health Perspect. 114(S1):40–50.

Heath RC, Spruill RK. 2003. Cretaceous aquifers in North Carolina: analysis of safe yield based on historical data. Hydrogeol J. 11:249–258.

Hennessey J, Nichols B, State Ocean Caucus, editors. 2011. Marine spatial planning in Washington: final report and recommendations of the State Ocean Caucus to the Washington State Legislature. Publication no. 10-06-027. Olympia (WA): Washington Department of Ecology.

Herman DW, Tryon BW. 1997. Land use, development, and natural succession and their effects on bog turtle habitat in the southeastern United States. In: Van Abbema J, editor. Proceedings: conservation, restoration, and management of tortoises and turtles — an international conference. New York (NY): New York Turtle and Tortoise Society. p. 364–371.

Higgins JV, Bryer M, Khoury M, Fitzhugh T. 2005. A freshwater classification approach for biodiversity conservation planning. Conserv Biol. 9:432–445.

Holman W, Wooten T, McGlade K. 2010. Overview of climate change adaptation in the Southeastern US with a focus on water and coastal resources. Washington (DC): US Environmental Protection Agency, Office of Air and Radiation, Climate Change Division. 74 p.

Homyack J, O'Bryan C, Thornton J, Baldwin R. 2014. Anuran assemblages associated with roadside ditches in a managed pine landscape. For Ecol Manag. 334:217-231.

Hrodey PJ, Sutton TM. 2008. Fish community responses to half-log additions in warmwater streams. N Am J Fish Manag. [accessed 2015];28(1):70–80. http://dx.doi.org/10.1577/M06-168.1.

Hrodey PJ, Sutton TM, Frimpong EA, Simon TP. 2009. Land-use impacts on watershed health and integrity in Indiana warmwater streams. Am Midl Nat. 161(1):76–95.

[HRWC] Hiwassee River Watershed Coalition. 2007. Lake Chatuge watershed action plan. Murphy (NC): Hiwassee River Watershed Coalition; [accessed 2015 April]. 88 pp. http://www.hrwc.net/lakechatugeplan.htm.

Huang S, Budd W, Chan S, Lin Y. 2007. Stream order, hierarchy, and energy convergence of land use. Ecol Model. 205:255–264.

Huang YW, Elrod J, Twidwell D, Solis M, Phillips J. 2003a. Finding possible causes of the population decline in Ozark hellbenders (*Cryptobranchus alleganiensis bishopi*): water-quality analysis, endocrine disruption, and hematology. Paper presented at: Semi-annual Hellbender Working Group Meeting; Unicoi State Park, Helen, GA.

Huang YW, Twidwell DL, Elrod JC. 2003b. Occurrence and effects of endocrine disrupting chemicals in the environment. Pract Period Hazard Toxic Radioact Waste Manag. 7(4):241–252.

Huang C, Ling PY, Zhu Z. 2015. North Carolina's forest disturbance and timber production assessed using time series landsat observations. Int J Digit Earth. [accessed 2015];1–41. doi: 10.1080/17538947.2015.1034200.

Hubbard DM, Dugan JE, Schooler NK, Viola SM. 2013. Local extirpations and regional declines of endemic upper beach invertebrates in southern California. Estuar Coast Shelf Sci. [accessed 2015];150:67–75. doi:10.1016/j.ecss.2013.06.017.

Huff RP, Coyle FA. 1992. Systematics of *Hypochilus sheari* and *Hypochilus coylei*, two southern Appalachian lampshade spiders (Araneae, Hypochilidae). J Arachnol. 20(1):40–46.

Huisman J, Matthijs HCP, Visser PM, editors. 2005. Harmful cyanobacteria. Cyanobacteria, volume 3. Dordrecht (Netherlands): Springer. 241 p.

Humphrey SR. 1978. Status, winter habitat, and management of the endangered Indiana bat (*Myotis sodalis*). Fla Sci. 41:65–76.

Hunter WC, Collazo J, Noffsinger B, Winn B, Allen D, Harrington B, Epstein M, Saliva J. 2000. Southeastern Coastal Plain – Caribbean Regional Shorebird Plan, Version 1. Atlanta (GA): US Fish & Wildlife Service; [accessed 2015 July]. 51 p. http://www.acjv.org/documents/shorebird_plan_se_car.pdf.

Hunter WC, Buehler DA, Canterbury RA, Confer JL, Hamel PB. 2001a. Conservation of disturbance-dependent birds in eastern North America. Wildl Soc Bull. 29(2):440–455.

Hunter WC, Katz R, Pashley D, Ford B. 1999. Partners in Flight bird conservation plan for the Southern Blue Ridge. The Plains (VA): American Bird Conservancy.

Hunter WC, Peoples L, Collazo J. 2001b. Partners in Flight bird conservation plan for the South Atlantic Coastal Plain. The Plains (VA): American Bird Conservancy.

Hupp CR. 2000. Hydrology, geomorphology and vegetation of coastal plain rivers in the south-eastern USA. Hydrol Process. 14:2991–3010.

Hynes HBN. 1983. Groundwater and stream ecology. Hydrobiol. 100:93–99.

Jacobs K, Adams D, Gleick P. 2000. Water resources. In: Potential consequences of climate variability and changes for the water resources of the United States. Report by the National Assessment and Synthesis Team, US Global Change Research. Chapter 14. [accessed 2015 July]. http://data.globalchange.gov/assets/e9/97/436129058f2107f4925aeec13ed8/nca-2000-foundation-report.pdf.

Jenkinson JJ, Todd RM. 1997. Management of native mollusk resources. In: Benz GW, Collins DE, editors. Aquatic fauna in peril: the southeastern perspective. Decatur (GA): Southeast Aquatic Research Institute. p. 283–305

Jensen A. 1985. The effect of cattle and sheep grazing on salt-marsh vegetation at Skallingen, Denmark. Veg. 60(1):37–48.

Jeyasuria P, Place AR. 1997. Temperature-dependent aromatase expression in developing diamondback terrapin (*Malaclemys terrapin*) embryos. J Steroid Biochem Mol Biol 6:415–25.

Jin S, Yang L, Danielson P, Homer C, Fry J, Xian G. 2013. A comprehensive change detection method for updating the National Land Cover Database to circa 2011. Remote Sens Environ. 132:159–175.

Johns ME. 2004. North Carolina bird species assessment. Raleigh (NC): NC Partners in Flight.

Johnson B. 2015. Occupancy and community characteristics of ephemeral aquatic systems in managed forests of the southeastern Atlantic Coastal Plain [thesis]. [Clemson (SC)]: Clemson University.

Jones P, Hanberry BB, Demarais S. 2008. Biodiversity response to stand structural features in southern pine forests: a literature review. Research Triangle Park (NC): National Council for Air and Stream Improvement.

Joss A, Zabczynski S, Gobel A, Hoffmann B, Loffler D, McArdell CS, Ternes TA, Thomsen A, Siegrist H. 2006. Biological degradation of pharmaceuticals in municipal wastewater treatment: proposing a classification scheme. Water Res. 40: 1686–1696.

Junk WJ, Welcomme RL. 1990. Floodplains. In Patten BC, editor. Wetlands and shallow continental water bodies: Volume 1, Natural and human relationships. The Hague (Netherlands): SPB Academic Publishing. 758 p.

Kalo JJ, Schiavinato LC. 2009. Wind over North Carolina waters: the state's preparedness to address offshore and coastal water-based wind energy projects. N C Law Rev. [accessed 2015 July];87:1819–1868. http://ncseagrant.ncsu.edu/ncseagrant_docs/coastallaw/pubs/Kalo_Schiavinato_windNC09.pdf.

Kanno Y, Vokoun JD. 2010. Evaluating effects of water withdrawals and impoundments on fish assemblages in southern New England streams, USA. Fish Manag Ecol. 17(3):272–283.

Karl TR, Melillo JM, Peterson TC. 2009. Global climate change impacts in the United States. New York (NY): Cambridge University Press.

Karriker KS. 1993. Effects of intensive silviculture on breeding and wintering birds in North Carolina pocosins [thesis]. [Raleigh (NC)]: North Carolina State University.

Kashiwagi MT, Miranda LE. 2009. Influence of small impoundments on habitat and fish communities in headwater streams. Southeast Nat. 8(1):23–36.

Kasprzyk-Hordern B, Dinsdale RM, Guwy AJ. 2008. The occurrence of pharmaceuticals, personal care products, endocrine disruptors and illicit drugs in surface water in South Wales, UK. Water Res. 42:3498–3518.

Keim BD. 1997. Preliminary analysis of the temporal patterns of heavy rainfall across the southeastern United States. Prof Geogr 49:94–104.

Kellison RC, Young MJ, Braham RR, Jones EJ. 1998. Major alluvial floodplains. In: Messina MG, Conner WH, editors. Southern forested wetlands: ecology and management. Boca Raton (FL): Lewis Publishers. p. 291–323.

Kelly DM, Dodd N. 2010. Beach-face evolution in the swash zone. J Fluid Mech. 661:316–340.

Kenk R. 1935. Studies on Virginia triclads. J Elisha Mitchell Sci Soc. 51:79–133.

Kenk R. 1972. Freshwater planarians (*Turbellaria*) of North America. Biota of Freshwater Ecosystems Identification Manual No. 1. Washington (DC): US Environmental Protection Agency. 81 p.

Kenk R. 1977a. Freshwater triclads (*Turbellaria*) of North America, IX: the genus *Sphalloplana*. Smithsonian Contributions to Zoology Series, No. 246. Washington (DC): Smithsonian Institution Press. 38 p.

Kenk R. 1977b. Freshwater triclads (*Turbellaria*) of North America, X: three new species of *Phagocata* from the eastern United States. Proc Biol Soc Wash. 56:645–652.

Kessler RA, Black TR, Fraley SJ, Gangloff MM. Forthcoming. Molecular and morphological evidence for multiple cryptic crayfish invasions in the southern Appalachian Mountains.

Kim SD, Cho J, Kim IS, Vanderford BJ, Snyder SA. 2007. Occurrence and removal of pharmaceuticals and endocrine disruptors in South Korean surface, drinking, and waste waters. Water Res. 41:1013–1021.

Kirkman LK, Golladay SW, Laclaire L, Sutter R. 1999. Biodiversity in southeastern, seasonally ponded, isolated wetlands: management and policy perspectives for research and conservation. J N Am Benthol Soc. 18(4):553–562.

Kirkman LK, Goebel PC, West L, Drew MB, Palik BJ. 2000. Depressional wetland vegetation types: a question of plant community development. Wetl. 20:373–385.

Klemens MW. 1993. Standardized bog turtle site-quality analysis. Unpublished report to USFWS, December 31, 1993. New York (NY): American Museum of Natural History, New York. 7p.

Kokkonen T, Jakeman AJ, Koivusalo H, Norton JP, editors. 2011. Computational methods for water resource assessments: an exercise kit. International Environmental Modelling and Software Society; [accessed 2015]; 97 p. http://www.iemss.org/society/index.php/view-public-documents/cat_view/63-teaching-material-open.

Kolpin DW, Furlong ET, Meyer MT, Thurman EM, Zaugg SD, Barber LB, Buxton HT. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999-2000: a national reconnaissance. Environ Sci Technol. 36(6):1202–1211.

Kopachena JG, Crist CJ. 2000. Macro-habitat features associated with painted bunting and indigo bunting in northeast Texas. Wilson Bull. 112(1):108–114.

Kushlan JA. 1990. Freshwater marshes. In: Myers RL, Ewel JJ, editors. Ecosystems of Florida. Orlando (FL): University of Central Florida Press. p. 324–363.

Kushlan JA, Steinkamp MJ, Parsons KC, Capp J, Cruz MA, Coulter M, Davidson I, Dickson L, Edelson N, Elliot R, et al. 2002. Waterbird Conservation for the Americas: the North American waterbird conservation plan, Version 1. Washington (DC): Waterbird Conservation for the Americas.

LaClaire LV. 2001. Endangered and threatened wildlife and plants; final rule to list the Mississippi gopher frog distinct population segment of dusky gopher frog as endangered. Fed Regist. 66:62993–63001.

Land LA, Lautier Jc, Wilson NC, Chianese G, Webb S. 2004. Geophysical monitoring and evaluation of Coastal Plain aquifers. Ground Water 42(1):59–67.

Lanyon SM, Thompson CF. 1986. Site fidelity and habitat quality as determinants of settlement pattern in male painted buntings. Condor 88:206–210.

LeGrand H, Haire J, Iyoob A, Howard T. 2012. Birds of North Carolina: their distribution and abundance. [website]; [accessed 2012 May 7]. http://www.carolinabirdclub.org/ncbirds/accounts.php.

Leigh DS. 2008. Late Quaternary climates and river channels of the Atlantic Coastal Plain, Southeastern USA. Geomorphol. 101:90–108.

Leigh DS, Srivastava P, Brook GA. 2004. Late Pleistocene braided rivers of the Atlantic Coastal Plain, USA. Quat Sci Rev. 23:65–84.

Leopold LB, Wolman MG, Miller JP. 1964. Fluvial Processes in Geomorphology. San Francisco (CA): W. H. Freeman. 522 p.

Lessard JL, Hayes DB. 2003. Effects of elevated water temperature on fish and macroinvertebrate communities below small dams. River Res Applic. 19(7):721–732.

Levin LA, Boesch DF, Covich A, Dahm C, Erséus C, Ewel KC, Kneib RT, Moldenke A, Palmer MA, Snelgrove P, et al. 2001.The function of marine critical transition zones and the importance of sediment biodiversity. Ecosyst 4:430–451.

Litvaitis JA. 2001. Importance of early successional habitats to mammals in eastern forests. Wildl Soc Bull. 29(2):466–473.

Lobb III MD, Orth DJ. 1991. Habitat use by an assemblage of fish in a large warmwater stream. Trans Am Fish Soc. 120(1):65–78.

Loder ER. 2008. Breath of life: ethical wind power and wildlife. VT J Environ Law. 10: 507–531.

Loeb SC. 1999. Responses of small mammals to coarse woody debris in a southeastern pine forest. J Mammal. 80(2):460–471.

Loeb SC, Tainter FH, Cazares E. 2000. Habitat associations of *Hypogeous* fungi in the southern Appalachians: implications for the endangered northern flying squirrel (*Glaucomys sabrinus coloratus*). Am Midl Nat. 144:286–296.

Loehle C, Wigley TB, Rutzmoser SH, Gerwin JA, Keyser PD, Lancia RA, Reynolds CJ, Thill RE, Weih R, White Jr. D, et al. 2005. Managed forest landscape structure and avian species richness in southeastern U.S. For Ecol Manag. 214:279–293.

Logan JA, Régnière J, Powell JA. 2003. Assessing the impacts of global warming on forest pest dynamics. Front Ecol Environ. 1:130–137.

Lorch JM, Meteyer CU, Behr MJ, Boyles JG, Cryan PM, Hicks AC, Ballmann AE, Coleman JTH, Redell DN, Reeder DM, et al. 2011, Experimental infection of bats with *Geomyces destructans* causes white-nose syndrome. Nat. 480(7377):376–378.

[LTLT] Land Trust for the Little Tennessee. 2011. The state of the streams in the upper Little Tennessee watershed. 2nd ed. Franklin (NC): Land Trust for the Little Tennessee.

[MACTEC, NCEEP, and WPCG] MACTEC Engineering & Consulting, NC Ecosystem Enhancement Program, and Western Piedmont Council of Governments. 2006. Lower creek watershed management plan: Catawba River Basin, Caldwell and Burke counties, North Carolina. Raleigh (NC): NC Ecosystem Enhancement Program; [accessed 2015]. http://portal.ncdenr.org/c/document_library/get_file?uuid=a286779c-81cc-4ea1-bfe1-15d60ea1cf2a&groupId=60329.

Mallin MA. 2003. Impacts of industrial animal production on rivers and estuaries. Am Sci. 88(1):26–37.

Mallin MA, Burkholder JM, Cahoon LB, Posey MH. 2000a. North and South Carolina coasts. Mar Pollut Bull. 41(1–6):56–75.

Mallin MA, Cahoon LB. 2003. Industrialized animal production: a major source of nutrient and microbial pollution to aquatic systems. Popul Environ. 24(5):369–385.

Mallin MA, Cahoon LB, Posey MH, Leonard LA, Parsons DC, Johnson VL, Wambach EJ, Alphin TD, Nelson KA, Merritt JF. 2002b. Environmental quality of Wilmington and New Hanover County watersheds, 2000-2001. Wilmington (NC): Center for Marine Science, UNC-W. 102 p.

Malmqvist B, Rundle S. 2002. Threats to running water ecosystems of the world. Environ Conserv. 29:134–153.

Manning LM, Peterson CH, Fegley SR. 2013. Degradation of surf-fish foraging habitat driven by persistent sedimentological modifications caused by beach nourishment. Bull Mar Sci. 89(1):83–106.

Manooch III CS, Rulifson RA, editors. 1989. Roanoke River Flow Committee report: a recommended water flow regime for the Roanoke River, North Carolina, to benefit anadromous striped bass and other below-dam resources and users. NOAA Technical Memorandum NMFS-SEFC-216. Beaufort (NC): US National Marine Fisheries Service.

Marshall DW, Otto M, Panuska JC, Jaeger SR, Sefton D, Baumberger TR. 2006. Effects of hypolimnetic releases on two impoundments and their receiving streams in southwest Wisconsin. Lake Reserv Manag. 22(3):223–232.

Martin KW, Leslie Jr. DM, Payton ME, Puckette WL, Hensley SL. 2006. Impacts of passage manipulation on cave climate: conservation implications for cave-dwelling bats. Wildl Soc Bull. 34(1):137–143.

Martinez PJ, Chart TE, Trammell MA, Wullschleger JG, Bergersen EP. 1994. Fish species composition before and after construction of a main stem reservoir on the White River, Colorado. Environ Biol Fish. 40:227–239.

Master LL, Flack SR, Stein BA, editors. 1998. Rivers of life: critical watersheds for protecting freshwater biodiversity. Arlington (VA): The Nature Conservancy.

McAllister TL, Overton MF, Brill ED. 1996. Cumulative impact of marinas on estuarine water quality. Environ Manag. 20(3):385–396.

McComb WC, Bonney SA, Sheffield RM, Cost ND. 1986. Den tree characteristics and abundance in Florida and South Carolina. J Wildl Manag. 50(4):584–591.

McCullough DA, Bartholow JM, Jager HI, Beschta RL, Cheslak EF, Deas ML, Ebersole JL, Foott JS, Johnson SL, Marine KR, et al. 2009. Research in thermal biology: burning questions for coldwater stream fishes. Rev Fish Sci. 17(1):90–115.

McDaniel MD. 1993. Point-source discharges. In: Bryan CF, Rutherford DA, editors. Impacts on warmwater streams: guidelines for evaluation. Little Rock (AR): American Fisheries Society, Southern Division. p. 1–56

McFaul EJ, Mason Jr. GT, Ferguson WB, Lipen BR. 2000. US Geological Survey mineral databases–MRDS and MAS/MILS. US Geological Survey Digital Data Series DDS-52. Washington (DC): US Geological Survey; [accessed 2015 July]. http://pubs.er.usgs.gov/publication/ds52 and http://mrdata.usgs.gov/mrds/.

McGinley M. 2013. Aquifer [encyclopedia article]. Encyclopedia of the Earth; [updated 2013 March 28]. http://www.eoearth.org/view/article/150158.

McGowan EM. 1993. Experimental release and fate study of the Allegheny woodrat (*Neotoma magister*). Federal Aid Project W-166-E; E-1, Job No. VIII-7. New York (NY): NY Department of Environmental Protection.

McLachlan A, Brown AC. 2010. The ecology of sandy shores. 2nd ed. Burlington (MA): Academic Press. 392 p. ProQuest; [accessed 2015 July]. http://site.ebrary.com.prox.lib.ncsu.edu/lib/ncsu/detail.action?docID=10150588 [members-only-access].

McNab BL. 1974. The behavior of temperate cave bats in a subtropical environment. Ecol. 55:943–958.

McSwain KB, Gurley LN, Antolino DJ. 2014. Hydrogeology, hydraulic characteristics, and water-quality conditions in the surficial, Castle Hayne and Peedee aquifers of the greater New Hanover County area, North Carolina, 2012–13: U.S. Geological Survey Scientific Investigations Report 2014–5169, 52 p. http://dx.doi.org/10.3133/sir20145169.

[MDA] Maryland Department of Agriculture. 2010. Forest pest management hemlock woolly adelgid treatment and suppression plan. [accessed 2015 July]. 11 pp. http://www.dnr.state.md.us/forests/pdfs/Hemlock_WoolyAdelgidManagmentPlan.pdf.

[MEA] Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: synthesis. Washington (DC): Island Press.

Meyer JL, Kaplan LA, Newbold D, Strayer DL, Woltemade CJ, Zedler JB, Beilfuss R, Carpenter Q, Semlitsch R, Watzin MC, et al. 2003. Where rivers are born: the scientific imperative for defending small streams and wetlands. Sponsored by American Rivers and Sierra Club. [accessed 2015]. http://www.americanrivers.org/assets/pdfs/reports-and-publications/WhereRiversAreBorn1d811.pdf

Meyer JL, Strayer DL, Wallace JB, Eggert SL, Helfman GS, Leonard NE. 2007. The contribution of headwater streams to biodiversity in river networks. J Am Water Resour Assoc. 43(1):86–103.

Miles N, West R. 2011. The use of an aeration system to prevent thermal stratification of a freshwater impoundment and its effect on downstream fish assemblages. J Fish Biol. 78(3):945–952.

Miller DA, Wigley TB, Miller KV. 2009. Managed forests and conservation of terrestrial biodiversity in the southern United States. J For. 107:197–203.

Miller JD, Dinkelacker SA. 2008. Reproductive structures and strategies of turtles. In: Wyneken J, Godfrey MH, Bels V, editors. Biology of turtles. Boca Raton (FL): CRC Press. p. 225–261.

Miller JH, Zutter BR, Newbold RA, Edwards MB, Zedaker SM. 2003. Stand dynamics and plant associates of loblolly pine plantations to midrotation after early intensive vegetation management - a southeastern United States regional study. South J Appl For. 27:221–236.

Mitchell MS. 1992. Effects of intensive forest management on the mammal communities of selected North Carolina pocosin habitats [thesis]. [Raleigh: (NC)]: North Carolina State University. 147 p.

Mitsch WJ, Gosselink JG. 1993. Wetlands. 2nd ed. New York (NY): John Wiley & Sons.

Mohseni O, Stefan HG, Eaton JG. 2003. Global warming and potential changes in fish habitat in US streams. Clim Change. 59:389–409.

Molinos JG, Viana M, Brennan M, Donohue I. 2015. Importance of long-term cycles for predicting water level dynamics in natural lakes. PLoS ONE. 10(3): e0119253. DOI:10.1371/journal.pone.0119253.

Moore AA, Palmer MA. 2005. Invertebrate biodiversity in agricultural and urban headwater streams: implications for conservation and management. Ecol Appl. 15(4):1169–1177.

Morris AD, Miller DA, Kalcounis-Rueppell MC. 2010. Use of forest edges by bats in a managed pine forest landscape. J Wildl Manag. 74:26–34.

Morrison ML, Marcot B, Mannan W. 2012. Wildlife–habitat relationships: concepts and applications. 3rd ed. Washington (DC): Island Press. 520 p.

Moyle PB, Vondracek B. 1985. Persistence and structure of the fish assemblage in a small California stream. Ecol. 66(1):1–13.

[MRLC] Multi-Resolution Land Characteristics. 2011. National land cover database 2011 [online database]. Sioux Falls (SD): US Geological Survey, Earth Resources Observation and Science Center; [accessed 2015]. http://www.mrlc.gov/nlcd11_leg.php.

NatureServe. 2007. International ecological classification standard: terrestrial ecological classifications. Arlington (VA): NatureServe; [updated 2007 October 6; accessed 2013]. http://www.basic.ncsu.edu/segap/.

[NCDCM] NC Division of Coastal Management. 2007. State of North Carolina 2007 Coastal and Estuarine Land Conservation Program (CELCP) plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed]; 57 p. http://coastalmanagement.noaa.gov/land/media/celcpplanncfinal.pdf.

[NCDCM] NC Division of Coastal Management. 2011. State of North Carolina 2007 Coastal and Estuarine Land Conservation Program (CELCP) plan. Raleigh (NC): NC Department of Environment and Natural Resources 63 p.

[NCDEMLR] NC Division of Energy, Mineral, and Land Resources, Dam Program. 2014. North Carolina dam inventory as of December 2, 2014. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015 February 19]. http://portal.ncdenr.org/web/lr/dams.

[NCDMF] NC Division of Marine Fisheries. 2010. Research needs identified by the North Carolina Coastal Habitat Protection Plan. Morehead City (NC): Department of Environment and Natural Resources; [accessed 2015]; 10 p. http://portal.ncdenr.org/web/mf/59.

[NCDMF] NC Division of Marine Fisheries. 2015. Shellfish closure proclamations and closure maps. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015 April].http://portal.ncdenr.org/web/mf/proclamations-polluted-areas and http://portal.ncdenr.org/web/mf/shellfish-closure-maps#MapList.

[NCDPH] NC Division of Public Health. 2014. Occupational and environmental epidemiology: fish consumption advisories. Raleigh (NC): NC Department of Health and Human Services; [accessed 2015 March]. http://epi.publichealth.nc.gov/oee/programs/fish.html.

[NCDPR] NC Division of Parks and Recreation. 2015. New River State Park. Raleigh (NC): NC Division of Parks and Recreation; [accessed 2015 May]. http://www.ncparks.gov/Visit/parks/neri/history.php.

[NCDWQ] NC Division of Water Quality. n.d. Falls Lake special studies. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed]. http://portal.ncdenr.org/web/wq/ps/mtu/specialstudies and http://portal.ncdenr.org/web/wq/fallsjordan.

[NCDWQ] NC Division of Water Quality. 2005a. Cape Fear River basinwide water quality plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://portal.ncdenr.org/web/wq/ps/bpu/basin/capefear/2005.

[NCDWQ] NC Division of Water Quality. 2007a. Chowan River basinwide water quality plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://portal.ncdenr.org/web/wq/ps/bpu/basin/chowan/2007.

[NCDWQ] NCDivision of Water Quality. 2007b. Little Tennessee River basinwide water quality plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://portal.ncdenr.org/web/wq/ps/bpu/basin/littletennessee/2007.

[NCDWQ] NC Division of Water Quality. 2007c. Pasquotank River basinwide water quality plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://portal.ncdenr.org/web/wq/ps/bpu/basin/pasquotank/2007.

[NCDWQ] NC Division of Water Quality. 2007d. White Oak River basinwide water quality plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. Available online: http://portal.ncdenr.org/web/wq/ps/bpu/basin/whiteoak/2007.

[NCDWQ] NC Division of Water Quality. 2008a. Broad River Basin, basinwide water quality plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015] http://portal.ncdenr.org/web/wq/ps/bpu/basin/broad/2008.

[NCDWQ] NC Division of Water Quality. 2008b. Yadkin – Pee Dee River Basin, basinwide water quality plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015] http://portal.ncdenr.org/web/wq/ps/bpu/basin/yadkinpeedee.

[NCDWQ] NC Division of Water Quality. 2009. Neuse River basinwide water quality plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://portal.ncdenr.org/web/wq/ps/bpu/basin/neuse/2009.

[NCDWQ] NC Division of Water Quality. 2010. Lumber River basinwide water quality plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015 August]. http://portal.ncdenr.org/web/wq/ps/bpu/basin/lumber/2010.

[NCDWQ] NC Division of Water Quality. 2011a. Guide to surface freshwater classifications in North Carolina. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015 July]. http://portal.ncdenr.org/c/document_library/get_file?p_l_id=1169848&folderId=2209568&name=DLFE-35732.pdf.

[NCDWQ] NC Division of Water Quality. 2011b. Lake and reservoir assessments Chowan River Basin. Raleigh (NC): NC Department of Environment and Natural Resources. 8 p.

[NCDWQ] NC Division of Water Quality. 2011c. New River basinwide water quality plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://portal.ncdenr.org/web/wq/ps/bpu/basin/new/2011.

[NCDWQ] NC Division of Water Quality. 2012a. Basinwide assessment report: Neuse River Basin. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://portal.ncdenr.org/c/document_library/get_file?uuid=3e702cb4-4068-4053-a2ca-e08c467e6fa2&groupId=38364.

[NCDWQ] NC Division of Water Quality. 2012b. Hiwassee River basinwide water quality plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://portal.ncdenr.org/web/wq/ps/bpu/basin/hiwassee/2012.

[NCDWQ] NC Division of Water Quality. 2012c. Little Tennessee River basinwide water quality plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://portal.ncdenr.org/web/wq/ps/bpu/basin/littletennessee/2012.

[NCDWQ] NC Division of Water Quality. 2012d. Neuse River Basin ambient monitoring system report. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://portal.ncdenr.org/c/document_library/get_file?uuid=8afbc7a0-14d6-4f49-a06e-263bd78c7376&groupId=38364.

[NCDWQ] NC Division of Water Quality. 2012e. 2012 North Carolina integrated report. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://portal.ncdenr.org/c/document_library/get_file?uuid=b3692eed-6b8f-4a65-b2de-9285d2befb98&groupId=38364.

[NCDWQ] NC Division of Water Quality. 2012f. Savannah River basinwide water quality plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://portal.ncdenr.org/web/wq/ps/bpu/basin/savannah/2012.

[NCDWR] NC Division of Water Resources. 2007. Catawba River Basin water resources plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://www.ncwater.org/files/publications/Final_Draft_Catawba_River_Basin_Plan_2007.pdf.

[NCDWR] NC Division of Water Resources. 2010. North Carolina aquifers. Raleigh (NC): NC Division of Water Resources; [accessed 2015 February]. http://geodata.lib.ncsu.edu/stategov/gws/2010/Aquifer%20Characteristics.htm.

[NCDWR] NC Division of Water Resources. 2012. Roanoke River basinwide water quality plan. NC Department of Environment and Natural Resources; [accessed 2015 August]. http://portal.ncdenr.org/web/wq/ps/bpu/basin/roanoke/2012. 319 p.

[NCDWR] NC Division of Water Resources. 2014a. 2014 integrated report, 305(b) list. Raleigh (NC): NC Department of Environment and Natural Resources; [updated 2015 March 24]. http://ncdenr.maps.arcgis.com/home/item.html?id=6191a89359e448058d8b5775174c1700.

[NCDWR] NC Division of Water Resources. 2014b. Local water supply plans. Raleigh (NC): NC Division of Water Resources; [accessed 2015 April]. http://www.ncwater.org/Water_Supply_Planning/Local_Water_Supply_Plan/index.php.

[NCDWR] NC Division of Water Resources. 2014c. Surface water classifications. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2014 November 7]. http://portal.ncdenr.org/web/wq/ps/csu/classifications.

[NCDWR] NC Division of Water Resources. 2014d. Tar-Pamlico River basinwide water resources management plan. Raleigh (NC): NC Department of Environment and Natural Resources; [updated April 10, 2015; accessed 2015 July].http://www.ncwater.org/basins/Tar-Pamlico/index.php.

[NCDWR] NC Division of Water Resources. 2015a. 2014 integrated report; detailed parameter categories (305(b) List). Raleigh (NC): NC Department of Environment and Natural Resources; [updated 2015 March 16]. http://ncdenr.maps.arcgis.com/home/item.html?id=1498920b96d54536ac7b465b3cc5bef0.

[NCDWR] NC Division of Water Resources. 2015b. Animal feeding operations program. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015 March]. http://portal.ncdenr.org/web/wq/aps/afo/perm.

[NCDWR] NC Division of Water Resources. 2015c. DWR ORW HQW management areas (polygons). Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015 March]. http://ncdenr.maps.arcgis.com/home/item.html?id=5f7ed790f988481a9af3e4633d4d8f38.

[NCDWR] NC Division of Water Resources. 2015d. DWR surface water classifications. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015 March]. http://ncdenr.maps.arcgis.com/home/item.html?id=c3dab4ac1eac44bd8fae5c8ecb520494.

[NCDWR] NC Division of Water Resources. 2015e. List of active general permits. National Pollutant Discharge Elimination System. Raleigh (NC): NC Division of Water Resources; [updated 2015 June 1; accessed 2015 August]. http://portal.ncdenr.org/c/document_library/get_file?uuid=e1a48dde-890a-4c1c-9516-44a0a4505575&groupId=38364.

[NCDWR] NC Division of Water Resources. 2015f. List of active individual permits. National Pollutant Discharge Elimination System. Raleigh (NC): NC Division of Water Resources; [updated 2015 August 18; accessed 2015 August]. http://portal.ncdenr.org/c/document_library/get_file?uuid=2fc14699-616a-4c13-9ec1-2f2b028163ea&groupId=38364.

[NCDWR] NC Division of Water Resources. 2015g. Neuse River Basin. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://www.ncwater.org/?page=211&basin=neuse.

[NCDWR] NC Division of Water Resources. 2015h. Neuse River Basin model. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://www.ncwater.org/Data_and_Modeling/Neuse_River_Basin_Model.

[NCDWR] NC Division of Water Resources. 2015i. Regional aquifers: potentiometric surface maps matrix (png & pdf files). Raleigh (NC): NC Division of Water Resources; [accessed 2015 February]. http://www.ncwater.org/?page=527.

[NCDWR] NC Division of Water Resources. 2015j. River basins, basin summaries [web page]. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://www.ncwater.org/?page=4.

[NCEEP] NC Ecosystem Enhancement Program. 2003. Mud Creek local watershed plan. Raleigh (NC); [accessed 2015 May]. http://www.nceep.net/services/lwps/Mud_Creek/.

[NCEEP] NC Ecosystem Enhancement Program. 2004. Catawba River Basin watershed restoration plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://www.nceep.net/services/restplans/catawba-04.pdf.

[NCEEP] NC Ecosystem Enhancement Program. 2005. French Broad River Basin watershed restoration plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015 May]. http://www.nceep.net/services/restplans/French_Broad_Plan.pdf.

[NCEEP] NC Ecosystem Enhancement Program. 2006. Bald Creek Local watershed plan. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015 May]. http://www.nceep.net/services/lwps/Bald_Creek/Bald_Creek_Watershed_Plan-FINAL4.pdf.

[NCEEP] NC Ecosystem Enhancement Program. 2007a. Lower Catawba River Basin restoration priorities. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://www.nceep.net/services/restplans/LowerCatawbaRBRP_Final_v20070928.pdf.

[NCEEP] NC Ecosystem Enhancement Program. 2007b. Peachtree-Martins Creek local watershed plan. Raleigh (NC): Division of Mitigation Services; [accessed 2015]. http://portal.ncdenr.org/c/document_library/get_file?uuid=54e2f2ac-6a3d-45ee-8231-9e70b0dabe92&groupId=60329.

[NCEEP] NC Ecosystem Enhancement Program. 2008a. Hiwassee River Basin restoration priorities. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://portal.ncdenr.org/c/document_library/get_file?uuid=ea2df99d-3031-4c7b-87ea-79d56a3e4a1e&groupId=60329.

[NCEEP] NC Ecosystem Enhancement Program. 2008b. Little Tennessee River Basin restoration priorities. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://www.nceep.net/services/lwps/Little_Tennessee/RBRP_LTN_2008.pdf.

[NCEEP] NC Ecosystem Enhancement Program. 2008c. Lumber River Basin restoration priorities. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://portal.ncdenr.org/c/document_library/get_file?uuid=717199f1-8604-4487-bd2b-e076bd5a9612&groupId=60329.

[NCEEP] NC Ecosystem Enhancement Program. 2009a. Broad River Basin restoration priorities. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://portal.ncdenr.org/web/eep/rbrps/broad.

[NCEEP] NC. Ecosystem Enhancement Program. 2009b. Watauga Basin restoration priorities. Raleigh (NC): NC Division of Mitigation Services; [accessed 2015]. http://www.nceep.net/services/restplans/Watauga_RBRP_2009.pdf

[NCEEP] NC Ecosystem Enhancement Program. 2011. Franklin to Fontana local watershed plan, Phase III. Raleigh (NC): Division of Mitigation Services; [accessed 2015]. http://portal.ncdenr.org/c/document_library/get_file?uuid=768818ab-6947-49eb-8233-b33b6aee4902&groupId=60329.

[NCGAP] NC Gap Analysis Project. 2009. Geo-data server online tool. [accessed 2015 March]. http://www.gapserve.ncsu.edu/ncgap/ncgap/.

[NCGS] NC General Statutes. n.d. Natural and Scenic Rivers Act of 1971. Raleigh (NC): NC General Assembly; [accessed 2015 April]. http://www.ncleg.net/EnactedLegislation/Statutes/HTML/ByArticle/Chapter_113A/Article_3.html.

[NCOEE] NC Office of Environmental Education. n.d. Roanoke River Basin. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015 August]. 8 p. http://www.eenorthcarolina.org/images/River%20Basin%20Images/roanoke.150dpi.pdf.

[NCOEE] NC Office of Environmental Education. 2007. Neuse River Basin. Raleigh (NC): NC Department of Environment and Natural Resources. 8 p.

[NCOEE] NC Office of Environmental Education. 2015. River Basin brochures [web page]. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015]. http://www.eenorthcarolina.org/publications-riverbasin-inserts.html.

[NCNHP] NC Natural Heritage Program. 2010. North Carolina ecosystem response to climate change: DENR assessment of effects and adaptation measures. Raleigh (NC): NC Department of Environment and Natural Resources.

NC Sea Grant. 1997. Coastal water quality. UNC-SG-97-04. Raleigh (NC): NC State University. 72 pp.

[NCWRC] NC Wildlife Resources Commission. 2002. Guidance memorandum to address and mitigate secondary and cumulative impacts to aquatic and terrestrial wildlife resources and water quality. Raleigh (NC): NC Wildlife Resources Commission.

[NCWRC] NC Wildlife Resources Commission. 2005. North Carolina wildlife action plan. Raleigh (NC): NC Wildlife Resources Commission; [accessed 2015]. 700 p. http://www.ncwildlife.org/plan.aspx#2423465-downloadsbr-br-.

[NCWRC] North Carolina Wildlife Resources Commission. 2012. Conservation recommendations for priority terrestrial wildlife species and habitats in North Carolina [web page]. [accessed 2015 May]. http://www.ncwildlife.org/Portals/0/Conserving/documents/ConservingTerrestrialHabitatsandSpecies.pdf.

[NCWRP] NC Wetlands Restoration Program. 2001b. Watershed restoration plan for the French Broad River Basin. Raleigh (NC): NC Wetlands Restoration Program; [accessed 2015 May]. http://www.nceep.net/services/restplans/french%20broad%202001.pdf.

[NCWRP] NC Wetlands Restoration Program. 2001c. Watershed restoration plan for the Hiwassee River Basin. Raleigh (NC): NC Wetlands Restoration Program; [accessed 2015]. http://www.nceep.net/services/restplans/hiwassee_2001.pdf

[NCWRP] NC Wetlands Restoration Program. 2001d. Watershed restoration plan for the Savannah River Basin. Raleigh (NC): NC Wetlands Restoration Program; [accessed 2015]. http://www.nceep.net/services/restplans/savannah_2001.pdf

[NCWRP] NC Wetlands Restoration Program. 2002a. Watershed restoration plan for the Little Tennessee River Basin. Raleigh (NC): NC Wetlands Restoration Program; [accessed 2015]. http://www.nceep.net/services/restplans/Little_Tennessee_2002.pdf

[NCWRP] NC Wetlands Restoration Program. 2002b. Watershed restoration plan for the Watauga River Basin. Raleigh (NC): NC Wetlands Restoration Program; [accessed 2015]. http://www.nceep.net/services/restplans/Watauga_Plan_2002.pdf.

[NCWRP] NC Wetlands Restoration Program. 2003. Broad River Basin watershed restoration plan. Raleigh (NC): NC Wetlands Restoration Program; [accessed 2015]. http://portal.ncdenr.org/c/document_library/get_file?uuid=b903e88e-1b42-4920-b237-e5dbee6d11ee&groupId=60329.

Nealson K. 2012. A brief overview of hydrilla within Eno River State Park [web page]. [accessed 2015 August]. http://nc-ipc.weebly.com/eno-river-hydrilla-project.html. 4 p.

Neuendorf KKE, Mehl Jr. JP, Jackson JA. 2005. Glossary of geology. 5th ed. Alexandria (VA): American Geological Institute. 779 p.

Neves RJ, Bogan AE, Williams JD, Ahlstedt SA, Hartfield PW. 1997. Status of aquatic mollusks in the southeastern United States: a downward spiral of diversity. In: Benz GW, Collins DE, editors. Aquatic fauna in peril: the southeastern perspective. Special Publication 1. Decatur (GA): Southeast Aquatic Research Institute. 44 pp.

Nevins HM, Donnelly-Greenan EL, Harvey JT. 2014. Impacts of marine debris measured by beach combers: plastic ingestion and entanglement in marine birds and mammals. Monterey (CA): Monterey Bay National Marine Sanctuary. http://montereybay.noaa.gov/research/techreports/nevins_etal_2014.pdf.

Nicholas NS, Eager C, Peine JD. 1999. Threatened ecosystem: high-elevation spruce-fir forest. In: Peine JD, editor. Ecosystem management for sustainability: principles and practices. Boca Raton (FL): Lewis Publishers.p. 431–454

[NIEPS] Nicholas Institute for Environmental Policy Solutions. 2010. Climate ready estuaries: a blueprint for change. Durham (NC): Nicholas Institute for Environmental Policy Solutions, Duke University 60 p.

[NOAA] National Oceanic and Atmospheric Administration. 2014. Habitat conservation: who we are. Silver Spring (MD): Office of Habitat Conservation; [accessed 2015]. http://www.habitat.noaa.gov/aboutus/whoweare.html.

Nordstrom KF, Jackson NL, Smith DR, Weber RG. 2006. Transport of horseshoe crab eggs by waves and swash on an estuarine beach: implications for foraging shorebirds. Estuar, Coast Shelf Sci. 70:438–448.

Nordstrom KF, Jackson NL, Freestone AL, Korotky KH, Puleo JA. 2012. Effects of beach raking and sand fences on dune dimensions and morphology. Geomorphol. 179:106–115.

Norris DJ, Elder WH. 1982. Distribution and habitat characteristics of the painted bunting in Missouri. Trans Mo Acad Sci. 16:77–83.

Noss RF, LaRoe ET, Scott JM. 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. Biological Report 28. Washington (DC): US Department of the Interior National Biological Service.

Nowotny N, Epp B, Von Sonntag C, Fahlenkamp H. 2007. Quantification and modeling of the elimination behavior of ecologically problematic wastewater micropollutants by adsorption on powdered and granulated activated carbon. Environ Sci Technol. 41(6):2050–2055.

[NWSRS] National Wild and Scenic Rivers System. n.d. North Carolina. Burbank (WA): US Fish and Wildlife Service; [accessed 2015 April]. http://www.rivers.gov/north-carolina.php.

[NWSRS] National Wild and Scenic Rivers System. 2015. New River (South Fork), North Carolina. Burbank (WA): US Fish and Wildlife Service; [accessed 2015 May]. http://www.rivers.gov/rivers/new.php.

O'Bryan C. 2014. Persistence of a vulnerable semi-aquatic turtle in an intensively-managed forest landscape [thesis]. [Clemson (SC)]: Clemson University.

Olivero A, Anderson M. 2008. Northeast aquatic habitat classification. Boston (MA): The Nature Conservancy. 88 p.

Olivero-Sheldon A, Anderson M. 2013. Stream classification framework for the SARP region. Boston (MA): The Nature Conservancy. 30 p.

Omernik JM. 1987. Map supplement: ecoregions of the conterminous United States. Ann Assoc Am Geogr. 77(1):118–125.

Omernik J, Griffith G. 2008. Ecoregions of North Carolina and South Carolina. Encyclopedia of the Earth; [updated 2008 July 6]. http://www.eoearth.org/view/article/152148

Opdam P, Wascher D. 2004. Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. Biol Conserva. 117:285–297.

Olden JD, Naiman RJ. 2010. Incorporating thermal regimes into environmental assessments: modifying dam operations to restore freshwater ecosystem integrity. Freshw Biol. 55:86–107.

Onken B, Reardon R (editors). 2005. Third symposium on hemlock woolly adelgid in the eastern United States. Asheville (NC): US Department of Agriculture, Forest Service; [accessed 2015 July]. http://na.fs.fed.us/fhp/hwa/.

Pandolfo TJ, Cope WG, Arellano C, Bringolf RB, Barnhart MC, Hammer E. 2010. Upper thermal tolerances of early life stages of freshwater mussels. J N Am Benthol Soc. 29(3):959–969.

Paradis A, Elkinton J, Hayhoe K, Buonaccorsi J. 2007. Role of winter temperature and climate change on the survival and future range expansion of the hemlock woolly adelgid (*Adelges tsugae*) in eastern North America. Mitig Adapt Strateg Glob Chang. 13:541–554.

Pashley DN, Beardmore CJ, Fitzgerald JA, Ford RP, Hunter WC, Morrison MS, Rosenberg KV. 2000. Partners in Flight: conservation of the land birds of the United States. The Plains (VA): American Bird Conservancy.

Patton D, DeHan B. 1998. Water issues: global, national, state, ecosystem. In: Fernald EA, Purdum ED, editors. Water resources atlas of Florida. Tallahassee (FL): Florida State University. p. 2–14.

Pearsall S, Poulter B. 2005. Adapting coastal lowlands to rising seas. In: Groom MJ, Meffe GK, Carroll CR, editors. Principles of conservation biology. 3rd ed. Sunderland (MA): Sinauer Associates. p. 366–369.

Perkins MW, Johnson RJ, Blankenship EE. 2003. Response of riparian avifauna to percentage and pattern of woody cover in an agricultural landscape. Wildl Soc Bull. 31(3):642–660.

Persinger JW, Orth DJ, Averett AW. 2011. Using habitat guilds to develop habitat suitability criteria for a warmwater stream fish assemblage. River Res Appl 27: 956–966. DOI: 10.1002/rra.1400.

Peterson CH, Manning L. 2001. How beach nourishment affects the habitat value of intertidal beach prey for surf fish and shorebirds and why uncertainty still exists. Paper presented at: the Coastal Ecosystems and Federal Activities Technical Training Symposium; Gulf Shores State Park, Gulf Shores, Alabama.

Peterson BJ, Wollheim WM, Mulholland PJ, Webster JR, Meyer JL, Tank JL, Martí E, Bowden WB, Valett HM, Hershey AE, et al. 2001. Control of nitrogen export from watersheds by headwater streams. Sci 292(5514):86–90.

Peterson JT, Rabeni CF. 1996. Natural thermal refugia for temperate warmwater stream fishes. N Am J Fish Manag 16:738–746.

Petranka JW. 1998. Salamanders of the United States and Canada. Washington (DC): Smithsonian Institution Press.

Poff NL, Allan JD, Bain MB, Karr JR, Prestegaard KL, Richter BD, Sparks RE, Stromberg JC. 1997. The natural flow regime: a paradigm for river conservation and restoration. BioSci. 47(11):769–784.

Porter KM, DePerno CS, Krings A, Krachey M, Braham R. 2014. Vegetative impact of feral horses, feral pigs, and white-tailed deer on the Currituck National Wildlife Refuge, North Carolina. Castanea. 79(1):8–17.

Potter EF, Parnell JF, Teulings RP, Davis R. 2006. Birds of the Carolinas. 2nd ed. Chapel Hill (NC): University of North Carolina Press. 416 pp.

Powell C. 1999. The fight for the River of Peace. Wildl in N C. 63:72–81.

Preece RM, Jones HA. 2002. The effect of Keepit Dam on the temperature regime of the Namoi River, Australia. River Res Appl. 18:397–414.

Pritchard DW. 1967. What is an estuary: a physical viewpoint. In: Lauff GH, editor. Estuaries. Washington (DC): American Association for the Advancement of Science. p. 3–5.

Pringle CM, Freeman MC, Freeman BJ. 2000. Regional effects of hydrologic alterations on riverine macrobiota in the new world: tropical-temperate comparisons. BioSci. 50(9):807–823.

Pyle C. 1984. Pre-park disturbance in the spruce-fir forests of Great Smoky Mountains National Park. In: White PS, editor. The southern Appalachian spruce-fir ecosystem: its biology and threats. Research/Resource Management Report SER-71. Atlanta (GA): US Department of the Interior National Park Service.

Raesly RL, Gates JE. 1987. Winter habitat selection by north temperate cave bats. Am Midl Nat. 118:15–31.

Rahel FJ. 2002. Using current biogeographic limits to predict fish distributions following climate change. In: McGinn NA, editor. Fisheries in a changing climate. Symposium 32. Bethesda (MD): American Fisheries Society. p. 99–110

Rentch JS, Schuler TM, Ford WM, Nowacki GJ. 2007. Red spruce stand dynamics, simulations, and restoration opportunities in the Central Appalachians. Restor Ecol 15:440–452.

Reshetiloff K, editor. 2004. Chesapeake Bay: introduction to an ecosystem. Washington (DC): US Environmental Protection Agency for the Chesapeake Bay Program; [accessed 2012 May 2]. http://www.chesapeakebay.net/content/publications/cbp_13039.pdf.

Revenga C, Campbell I, Abell R, de Villiers P, Bryer M. 2005. Prospects for monitoring freshwater ecosystems towards the 2010 targets. Philos Trans Royal Soc. B360:397–413.

Reynolds WW, Casterline ME. 1979. Behavioral thermoregulation and the final preferendum paradigm. Am Zool. 19:211–224.

Rich TD, Beardmore CJ, Berlanga H, Blancher PJ, Bradstreet MSW, Butcher GS, Demarest DW, Dunn EH, Hunter WC, Inigo-Elias EE, et al. 2004. Partners in Flight North American landbird conservation plan. Ithaca (NY): Cornell Lab of Ornithology.

Richter BD, Braun DP, Mendelson MA, Master LL. 1997. Threats to imperiled freshwater fauna. Conserv Biol. 11(5):1081–1093.

Ricketts TH, Dinerstein E, Olson DM, Loucks C. 1999. Who's where in North America? Patterns of species richness and the utility of indicator taxa for conservation. BioSci. 49(5):369–381.

Riggs SR. 2010. North Carolina. In: Bird ECF, editor. Encyclopedia of the world's coastal landforms, volume 1. Dordrecht (Netherlands): Springer. p. 99–106.

Robbins CS, Dawson DK, Dowell BA. 1989. Habitat area requirements of breeding forest birds of the middle Atlantic states. Wildl Monogr. 103:3–34.

Rodewald AM, Yahner RH. 2001. Avian nesting success in forested landscapes: influence of landscape composition, stand and nest-patch microhabitat, and biotic interactions. Auk. 118(4):1018–1028.

Romey WL, Ascher JS, Powell DA, Yanek M. 2007. Impacts of logging on midsummer diversity of native bees (Apoidea) in northern hardwood forest. J Kans Entomol Soc. 80(4):327–338.

Roosenburg WM. 1990. The diamondback terrapin: population dynamics, habitat requirements, and opportunities for conservation. *In* New perspectives in the Chesapeake system: a research and management partnership. Proceedings of a conference. Section 3: habitat requirements. Publication no. 137. Baltimore (MD): Chesapeake Research Consortium 14 p.

Rosenbaum PA, Robertson JM, Zamudio KR. 2007. Unexpectedly low genetic divergences among populations of the threatened bog turtle (*Glyptemys muhlenbergii*). Conserv Genet. 8:331–342.

Rosenberg KV, Hames RS, Rohrbaugh Jr. RW, Barker Swarthout S, Lowe JD, Dhondt AA. 2003. A land manager's guide to improving habitat for forest thrushes. Ithaca (NY): Cornell Lab of Ornithology.

Rosgen DL. 1994. A classification of natural rivers. Catena 22:169–199.

Ross ST, Matthews WJ, Echelle AA. 1985. Persistence of stream fish assemblages: effects of environmental change. Am Nat. 126(1):24–40.

Sabine JB, Schweitzer SH, Meyers JM. 2006. Nest fate and productivity of American Oystercatchers, Cumberland Island National Seashore, Georgia. Waterbirds. 29(3):308–314.

[SAFMC] South Atlantic Fishery Management Council. 1998. Final habitat plan for the South Atlantic region: essential fish habitat requirements for fishery management plans of the South Atlantic Fishery Management Council. Charleston (SC): SAFMC; [accessed 2015 July]. http://safmc.net/ecosystem-management/safmc-habitat-plan.

Saiz-Jimenez C. 2012. Microbiological and environmental issues in show caves. World J Microbiol Biotechnol. 28:2453–2464.

[SAMAB] Southern Appalachian Man and the Biosphere. 1996. The Southern Appalachian assessment terrestrial technical report. Report 5 of 5. Atlanta (GA): US Department of Agriculture, Forest Service, Southern Region.

Sawicz K, Wagener T, Sivapalan M, Troch PA, Carrillo G. 2011. Catchment classification: empirical analysis of hydrologic similarity based on catchment function in the eastern USA. Hydrol Earth Syst Sci. 15: 2895–2911.

Schafale MP. 2012. Guide to the natural communities of North Carolina, fourth approximation. Raleigh (NC): NC Department of Environment and Natural Resources, Natural Heritage Program; [accessed 2015 July]. http://portal.ncdenr.org/c/document_library/get_file?uuid=cbaac345-aca2-4312-acca-1004f2ba59a9&groupId=61587.

Schafale MP, Weakley AS. 1990. Classification of the natural communities of North Carolina, third approximation. Raleigh (NC): NC Department of Environment and Natural Resources, Natural Heritage Program; [accessed 2015]. http://portal.ncdenr.org/c/document_library/get_file?uuid=e4d28c3d-64ef-4b83-8b8b-8c0c1afdea8d&groupId=61587.

Schlacher TA, Lucrezi S. 2010. Compression of home ranges in ghost crabs on sandy beaches impacted by vehicle traffic. Mar Biol. 157:2467–2474.

Schiesari L. 2006. Pond canopy cover: a resource gradient for anuran larvae. Freshw Biol. 51:412–423.

Schindler EE, Scheuerell MD. 2002. Habitat coupling in lake ecosystems. Oikos. 98:177–189.

Schlacher TA, Schoeman DS, Dugan J, Lastra M, Jones A, Scapini F, McLachlan A. 2008. Sandy beach ecosystems: key features, sampling issues, management challenges and climate change impacts. Mar Ecol. 29(1):70–90.

Schuster GA. 1997. Resource management of freshwater crustaceans in the southeastern United States. In: Benz GW, Collins DE, editors. Aquatic fauna in peril: the southeastern perspective. Decatur (GA): Southeast Aquatic Research Institute. p. 269–282.

[SCO] State Climate Office of North Carolina. 2014. Overview. Raleigh (NC): State Climate Office of NC; [accessed 2015]. http://www.nc-climate.ncsu.edu/climate/ncclimate.html.

Seaber PR, Kapinos FP, Knapp GL. 1987. Hydrologic unit maps. Water Supply Paper 2294. Washington (DC): US Geological Survey; [accessed 2015]. 63 p. http://pubs.usgs.gov/wsp/wsp2294/.

Seavy NE, Gardali T, Golet G, Thomas Griggs F, Howell CA, Kelsey R, Small S, Viers J, Weigand J. 2009. Why climate change makes riparian restoration more important than ever: recommendations for practice and research. Ecol Rest. 27:3.

[SEGAP] Southeast Gap Analysis Project. 2007. Land cover, North Carolina. Raleigh (NC): Southeast Gap Analysis Project; [accessed 2013]. http://www.basic.ncsu.edu/segap/.

Sherman B. 2000. Scoping options for mitigating cold water discharges from dams. CSIRO Land and Water, Consultancy Report 00/21. Canberra (Australia); [accessed 2015 July]. 46 p. http://www.researchgate.net/profile/Bradford_Sherman/publication/253447153_Scoping_Options_for_Mitigating_Cold_Water_Discharges_from_Dams/links/0deec5347621be003a000000.pdf.

Sherman B, Todd CR, Koehn JD, Ryan T. 2007. Modelling the impact and potential mitigation of cold water pollution on Murray cod populations downstream of Hume Dam, Australia. River Res Appl. 23:377–389.

Sheridan JA, Bickford D. 2011. Shrinking body size as an ecological response to climate change. Nat Clim Change. 1(8):401–406.

Simmons JW, Fraley SJ. 2010. Distribution, status, and life-history observations of crayfishes in western North Carolina. Southeast Nat. 9(sp3):79–126.

Singer E, Gangloff M. 2011. Effects of a small dam on freshwater mussel growth in an Alabama USA stream. Freshw Biol. 56(9):1904–1915.

Skelly DK. 2004. Microgeographic countergradient variation in the wood frog, *Rana sylvatica*. Evol. 58:160–165.

Skelly DK, Freidenburg LK, Kiesecker JM. 2002. Forest canopy and the performance of larval amphibians. Ecol. 83:983–992.

Skelly DK, Golon J. 2003. Assimilation of natural benthic substrate by two species of tadpoles. Herpetol. 59:37–42.

Smayda TJ. 1989. Primary production and the global epidemic of phytoplankton blooms in the sea: a linkage? In: Cosper EM, Bricelj VM, Carpenter EJ, editors. Novel phytoplankton blooms. Coastal and Estuarine Studies 35. New York (NY): Springer-Verlag. p. 449–484.

Smith DG, Chapman MJ. 2005. Hydraulic properties of the surficial aquifer at five selected sites in the Little Contentnea Creek basin, North Carolina, 2002–03. U.S. Geological Survey Scientific Investigations Report 2005–5238. 104 p.

Smith RK, Freeman PL, Higgins JV, Wheaton KS, FitzHugh TW, Ernstrom KJ, Das AA. 2002. Priority areas for freshwater conservation action: a biodiversity assessment of the southeastern United States. The Nature Conservancy; [accessed 2015 September]. http://www.conservationgateway.org/ConservationPlanning/SettingPriorities/EcoregionalReports/Documents/se_biodiv_assess.pdf.

Smith RL, Smith TM. 1998. Elements of ecology. Sydney (AU): Benjamin Cummins.

Smith VH, Tilman GD, Nekola JC. 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environ Pollut. 100(1):179–196.

Smith VH, Joye SB, Howarth RW. 2006. Eutrophication of freshwater and marine ecosystems. Limnol Oceanogr. 51(1):351–355.

Smock LA, Wright AB, Benke AC. 2005. Atlantic Coast rivers of the Southeastern United States. In: Benke AC, Cushing CE, editors. Rivers of North America. Amsterdam (Netherlands): Elsevier. p. 72–122

Somers AB, Bridle KA, Herman DW, Nelson AB. 2000. The restoration and management of small wetlands of the mountains and piedmont in the southeast: a manual emphasizing endangered and threatened species habitat with a focus on bog turtles. Washington (DC): Watershed Science and Wetland Science Institutes of the Natural Resources Conservation Service; University of North Carolina at Greensboro; and Pilot View Resource Conservation & Development, Inc.; [accessed 2015 September]. 152 p. http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/water/manage/restoration/.

Speybroeck J, Bonte D, Courtens W, Gheskiere T, Grootaert P, Maelfait J, Mathys M, Provoost S, Sabbe K, Stienen EW, et al. 2006. Beach nourishment: an ecologically sound defence alternative? A review. Aquat Conserv: Mar Freshw Ecosyst 16:419–435.

Sprandel GL, Gore JA, Cobb DT. 2000. Distribution of wintering shorebirds coastal Florida. J. Field Ornithol. 71(4):708–720.

Stefan HG, Fang X, Eaton JG. 2001. Simulated fish habitat changes in North American lakes in response to projected climate warming. Trans Am Fish Soc. 130:459–477.

Stevenson JC, Confer NM. 1978. Summary of available information on Chesapeake Bay submerged vegetation. FWS/OBS-78/66. Washington (DC): US Fish and Wildlife Service, Office of Biological Services 335p.

Stevenson R. 2015. North Carolina waterfalls. http://www.ncwaterfalls.com.

Stewart A, Komers PE, Bender DJ. 2010. Assessing landscape relationships for habitat generalists. Ecosci. 17(1):28–36.

Stone WB, McGowan EM, Hicks AP. 1993. The parasites and disease of the woodrat in New York State with special emphasis on the nematode *Baylisascaris procyonis*. Unpublished abstract from the report presented at the Allegheny Woodrat Conference; Dickenson College, PA.

Strahler AN. 1957. Quantitative analysis of watershed geomorphology. Trans Am Geophys Union. 38(6):913–920.

Street MW, Deaton AS, Chappell WS, Mooreside PD. 2005. North Carolina coastal habitat protection plan. Morehead City (NC): NC Department of Environment and Natural Resources, Division of Marine Fisheries.

Sun G, McNulty SG, Shepard JP, Amatya DM, Riekerk H, Comerford NB, Skaggs W, Swift, Jr. L. 2001. Effects of timber management on the hydrology of wetland forests in the southern United States. For Ecol Manag. 143:227–236.

Swift BL, Larson JS, DeGraaf RM. 1984. Relationship of breeding bird density and diversity to habitat variables in forested wetlands. Wilson Bull. 96(1):48–59.

Tagliapietra D, Sigovini M, Ghirardini AV. 2009. A review of terms and definitions to categorize estuaries, lagoons and associated environments. Mar Freshw Res. 60:497–509.

Taylor CA, Warren ML, Fitzpatrick JF, Hobbs HH, Jezerinac RF, Pflieger WL, Robison HW. 1996. Conservation status of crayfishes of the United States and Canada. Fish. 21:25–38.

Taylor CA, Schuster GA, Cooper JE, DiStefano RJ, Eversole AG, Hamr P, Hobbs III HH, Robison HW, Skelton CE, Thoma RF. 2007. A reassessment of the conservation status of crayfishes of the United States and Canada after 10+ years of increased awareness. Fish. 32(8):372–389.

Taylor JC, Miller JM, Pietrafesa LJ, Dickey DA, Ross SW. 2010. Winter winds and river discharge determine juvenile southern flounder (*Paralichthys lethostigma*) recruitment and distribution in North Carolina estuaries. J Sea Res. 64:15–25.

Taylor II JD, Jones JC. 2002. Quantifying amphibian richness in Southeastern forests. Proc Ann Conf Southeast Assoc Fish Wildl Agencies. 56:301–311.

Taylor JL, Kurtz R. 2008. Blue Ridge Mountains [Internet]. USGS Land Cover Trends Project [accessed 2010 January 26]. http://landcovertrends.usgs.gov/east/eco66Report.html.

Thompson FR, DeGraaf RM. 2001. Conservation approaches for woody, early successional communities in the eastern United States. Wildl Soc Bull. 29(2):483–494.

Thorp JH, editor. 2002. Aquatic ecology series. London (UK): Academic Press 551 p.

Thorp JH, Covich AP. 2001. Ecology and classification of North American freshwater invertebrates. 2nd ed. San Diego (CA): Academic Press. Chapter 2, An overview of freshwater habitats; p. 19–43.

Thurgate NY, Pechmann JHK. 2007. Canopy closure, competition, and the endangered dusky gopher frog. J Wildl Manag. 71(6):1845–1852.

Tisseuil C, Vrac M, Grenouillet G, Wade AJ, Gevrey J, Oberdorff T, Grodwohl JB, Lek S. 2012. Strengthening the link between climate, hydrological and species distribution modeling to assess the impacts of climate change on freshwater biodiversity. Sci Total Environ. 424:193–201

[TNC and SAFC] The Nature Conservancy and Southern Appalachian Forest Coalition. 2000. Southern Blue Ridge ecoregion conservation plan. Durham (NC): The Nature Conservancy.

Tockner K, Stanford JA. 2002. Review of: riverine flood plains: present state and future trends. Biological Sciences Faculty Publications. Paper 166. Cambidge (England): Cambridge University Press; [accessed 2015 February]. http://scholarworks.umt.edu/biosci_pubs/166.

Todd CR, Ryan T, Nicol SJ, Bearlin AR. 2005. The impact of cold water releases on the critical period of post-spawning survival and its implications for Murray cod (*Maccullochella peelii peelii*): a case study of the Mitta Mitta River, southeastern Australia. River Res Appl. 21:1035–1052.

Transportation Research Board, Committee on Climate Change and US Transportation. 2008. Potential impacts of climate change on US transportation. Special Report 290. Washington (DC): Transportation Research Board.

Trotter RT III, Shields KS. 2009. Variation in winter survival of the invasive hemlock woolly adelgid (Hemiptera: Adelgidae) across the eastern United States. Environ Entomol. 38(3):577–587.

Turner MG. 1987. Effects of grazing by feral horses, clipping, trampling, and burning on a Georgia salt marsh. Estuaries. 10(1):54–60.

Turner MG. 1989. Landscape ecology: the effect of pattern on process. Ann Rev Ecol Syst. 20:171–197.

Tuttle MD, Stevenson DE. 1978. Variation in the cave environment and its biological implications. In: Zuber R, Chester J, Gilbert S, Rhodes D, editors. National Cave Management Symposium Proceedings. Albuquerque (NM): Speleobooks. p. 108–120.

[TVA] Tennessee Valley Authority. n.d. Chatuge Reservoir ecological health rating. Knoxville (TN): Tennessee Valley Authority; [accessed 2015 April]. http://www.tva.com/environment/ecohealth/chatuge.htm.

Twente JW Jr. 1955. Some aspects of habitat selection and other behavior of cavern-dwelling bats. Ecol. 36:706–732.

Tyler M. 1989. Potential for long-term persistence of the red tide dinoflagellate *Ptychodiscus brevis* in North Carolina coastal waters. Final report prepared for NC Department of Natural Resources and Community Development. Project number 88-09.

[UNCW] University of North Carolina Wilmington. 2008. The potential impacts of climate change on coastal North Carolina: a report by the faculty of the University of North Carolina Wilmington. Wilmington (NC): The University of North Carolina; [accessed 2015 July]. 124 p. http://www.uncw.edu/aa/documents/UNCW%20Global%20Climate%20Change%20Final%20Report.pdf.

[USACE] US Army Corps of Engineers. 1987. Corps of Engineers wetlands delineation manual. Technical Report Y-87-1. Vicksburg (MS): Wetlands Research Program 143 p. http://el.erdc.usace.army.mil/elpubs/pdf/wlman87.pdf.

[USACE] US Army Corps of Engineers. 2003. Stream mitigation guidelines. Wilmington (NC): US Army Corps of Engineers, Wilmington district.

[USCB] US Census Bureau. 2010. 2010 Census interactive population search. Washington (DC): US Census Bureau; [accessed 2015 August]. http://www.census.gov/2010census/popmap/ipmtext.php?fl=37

[USCB] US Census Bureau. 2012. American Indian area geography, American Indian tribal subdivision (2010): Eastern Cherokee Reservation. GCS NAD83. Washington (DC): US Census Bureau, Geography Division; [accessed 2015 August]. http://www.census.gov/cgi-bin/geo/shapefiles2010/main.

[USCB] US Census Bureau. 2014. Annual estimates of resident population change for incorporated places of 50,000 or more in 2012, ranked by percent change: July 1, 2012 to July 1, 2013 U.S. Census Bureau, Population. Washington (DC): US Census Bureau; [accessed 2015 January]. http://factfinder2.census.gov/bkmk/table/1.0/en/PEP/2013/PEPANNCHG.US41PR.

[USCB] US Census Bureau. 2015. Metropolitan and micropolitan statistical area population and estimated components of change: April 1, 2010 to July 1, 2014 (CBSA-EST2014-alldata). Washington (DC): US Census Bureau; [accessed 2015 August]. http://www.census.gov/popest/data/metro/totals/2014/CBSA-EST2014-alldata.html.

[USFWS] US Fish and Wildlife Service. 2002. Endangered and threatened wildlife and plants; designation of critical habitat for the Appalachian Elktoe. Fed Regist. 67(188):188.

[USFWS] US Fish and Wildlife Services. 2013. Endangered and threatened species of North Carolina. Raleigh (NC): Raleigh Ecological Services Field Office; [accessed 2015]. http://www.fws.gov/raleigh/es_tes.html.

[USFWS] United States Fish and Wildlife Service. 2014. Imperiled Aquatic Species Conservation Strategy for the Upper Tennessee River Basin. Southwestern Virginia Field Office, Abingdon (VA). [accessed 2015 October] https://www.fws.gov/northeast/virginiafield/pdf/MISC/2014_UTRB_imperiled_aquatic_strategy.pdf. 65 p.

[USGS] US Geological Survey. n.d. National hydrography dataset [online database]. Washington (DC): US Geological Survey; [accessed 2015]. http://nhd.usgs.gov.

[USGS] US Geological Survey. 2012a. Groundwater frequently asked questions: Piedmont and Mountains aquifers. Raleigh (NC): South Atlantic Water Science Center; [accessed 2014 August]. http://nc.water.usgs.gov/about/faq_ground.html#mtns.

[USGS] US Geological Survey. 2012b. Coastal Carolina Project [web page]. [accessed 2015 August]. http://nc.water.usgs.gov/ccp.

[USGS] US Geological Survey. 2014a. USGS surface-water monthly statistics for North Carolina. National Water Information System; [accessed 2015]. http://waterdata.usgs.gov/nc/nwis/monthly/?referred_module=sw.

[USGS] US Geological Survey. 2014b. Groundwater depletion [web page]. USGS Water Science School; [updated 2014 March; accessed 2015 July]. http://water.usgs.gov/edu/gwdepletion.html.

van der Kamp G. 1995. The hydrogeology of springs in relation to the biodiversity of spring fauna: a review. J Kans Entomol Soc, Suppl: Spec Publ No. 1: Biodivers Aquat Insects Other Invertebr Springs. 68(2):4–17.

Vannote RL, Minshall GW, Cummins KW, Sedell JR, Gushing E. 1980. The river continuum concept. Can J Fish Aquat Sci. 37: 130–137.

Viola S, Hubbard D, Dugan J, Schooler N. 2013. Burrowing inhibition by fine textured beach fill: implications for recovery of beach ecosystems. Estuar Coast Shelf Sci. 150:142–148.

Vos CC, Chardon JP. 1998. Effects of habitat fragmentation and road densities on the distribution pattern of the moor frog (*Rana arvalis*). J Appl Ecol. 35:44–56.

Wagener T, Sivapalan M, Troch P, Woods R. 2007. Catchment classification and hydrologic similarity. Geogr Compass. 1(4):901–931.

Walburg CH, Novotny JF, Jacobs KE, Swink WD. 1983. Effects of reservoir releases on water quality, macroinvertebrates, and fish in tailwaters: Field study results. Technical Report E-83-6. Vicksburg (MS): U.S. Army Environmental and Water Quality Operational Studies, Army Engineer Waterways Experiment Station. 176 p.

Wang L, Lyons J, Kanehl P, Bannerman R. 2001. Impacts of urbanization on stream habitat and fish across multiple spatial scales. Environ Manag. 28(2):255–266.

Wang L, Infante D, Lyons J, Stewart J, Cooper A. 2011. Effects of dams in river networks on fish assemblages in non-impoundment sections of rivers in Michigan and Wisconsin, USA. River Res. Applic. 27:473–487.

Warren ML, Angermeier PL, Burr BM, Haag WR. 1997. Decline of a diverse fish fauna: patterns of imperilment and protection in the southeastern United States. In: Benz GW, Collins DE, editors. Aquatic fauna in peril: the southeastern perspective. Decatur (GA): Southeast Aquatic Research Institute. p. 105–164.

Warren ML, Burr BM, Walsh SJ, Bart HL, Cashner RC, Etnier DA, Freeman BJ, Kuhajda BR, Mayden RL, Robison HW, et al. 2000. Diversity, distribution, and conservation status of the native freshwater fishes of the southern United States. Fish. 25(10):7–31.

Warren RJ, Ford CF. 1997. Diets, nutrition and reproduction of feral hogs on Cumberland Island, Georgia. Proc Annu Conf Southeast Assoc Fish Wildl Agencies. 51:285–296.

Watson J, Hamilton-Smith E, Gillieson D, Kiernan K, editors. 1997. Guidelines for cave and karst protection. Gland (Switzerland): IUCN World Commission on Protected Areas, Working Group on Cave and Karst Protection. 63 p.

Wear DN, Greis JG. 2012. The Southern Forest Futures Project report. Asheville (NC): US Department of Agriculture Forest Service, Southern Research Station; [accessed 2013 June]. http://www.srs.fs.usda.gov/futures/reports/draft/Frame.htm.

Weaver DM. 2010. Effects of stocked trout on native nongame riverine fishes [thesis]. [Raleigh (NC)]: North Carolina State University.

Webbers A. 1995. Ground-water quality protection, why it's important to you [website]. Open-file report 95-376. Nashville (TN): US Geological Survey; [accessed 2015 August]. http://pubs.usgs.gov/of/1995/ofr95376/.

Weiskel PK, Vogel RM, Steeves PA, Zarriello PJ, DeSimone LA, Ries III KG. 2007. Water use regimes: characterizing direct human interaction with hydrologic streams. Water Resour Res. 43(4):1–11.

Weller MW, Stegman JL. 1977. Evaluating and maintaining habitats for fish and wildlife. In Transactions of the 42nd North American Wildlife and Natural Resources Conference. Washington (DC): Wildlife Management Institute. p. 31–41

Wenger S. 1999. A review of scientific literature on riparian buffer width, extent, and vegetation. Athens (GA): University of Georgia, Institute of Ecology.

Werner EE, Glennenmeier KS. 1999. Influence of forest canopy cover on the breeding pond distributions of several amphibian species. Copeia 1999:1–12.

Wharton CH, Kitchens WM, Pendleton EC, Sipe TW. 1982. The ecology of bottomland hardwood swamps of the southeast: a community profile. Biological Services Program FWS/OBS-81/37. 145 pp.

White PB, van de Gevel SL, Soule PT. 2012. Succession and disturbance in an endangered red spruce-Fraser fir forest in the southern Appalachian Mountains, North Carolina, USA. Endanger Species Res 18(1):17–25.

Wiens JA. 1989. Spatial scaling in ecology. Funct Ecol 3:385–397.

Wigley TB, Baughman WM, Dorcas ME, Gerwin JA, Gibbons JW, Guynn Jr. DC, Lancia RA, Leiden YA, Mitchell MS, Russell KR. 2000. Contributions of intensively managed forests to the sustainability of wildlife communities in the South. Sustaining southern forests: the science of forest assessment. Durham (NC): USDA Forest Service, Southern Forest Resource Assessment; [accessed 2015 September]. http://www.srs.fs.usda.gov/sustain/conf/abs/wigley.htm.

Wigley TB, Miller DA, Yarrow GK. 2007. Planning for bats on forest industry lands in North America. In: Lacki MJ, Hayes JP, Kurta A, editors. Bats in forests, conservation and management. Baltimore (MD): The John Hopkins University Press. p. 293–318.

Wildman RA, Pratson LF, DeLeon M, Hering JG. 2011. Physical, chemical, and mineralogical characteristics of a reservoir sediment delta (Lake Powell, USA) and implications for water quality during low water level. J Environ Qual. 40:575–586.

Williams JD, Warren ML, Cummings KS, Harris JL, Neves RJ. 1993. Conservation status of the freshwater mussels of the United States and Canada. Fish. 18:6–22.

Williams SJ, Penland S, Sallenger AH, editors. 1992. Atlas of shoreline changes in Louisiana from 1853 to 1989, Louisiana barrier island erosion study. Miscellaneous Investigations Series I-2150-A. Washington (DC): US Geological Survey, Department of the Interior. 12 p.

Winger PV. 1981. Physical and chemical characteristics of warmwater streams: a review. In: Krumholz LA, editor. The warmwater streams symposium: a national symposium on fisheries aspects of warmwater streams. Southern Division American Fisheries Society. p. 32–44. http://sdafs.org/wwstreams/wp-content/uploads/2014/04/WWS-Symposium-1981-Part-1.pdf

Winter TC, Harvey JW, Franke OL, Alley WM. 1998. Ground water and surface water, a single resource. US Geological Survey Circular 1139. Washington (DC): US Geological Survey. 87 p. http://pubs.usgs.gov/circ/circ1139/.

Wnek JP, Bien WF, Avery HW. 2013. Artificial nesting habitats as a conservation strategy for turtle populations experiencing global change. Integr Zool. 8:209–221.

Wolcott DL, Wolcott TG. 1999. High mortality of piping plovers on beaches with abundant ghost crabs: correlation, not causation. Wilson Bull. 111(3):321–329.

Wood GW, Mengak MT, Murphy M. 1987. Ecological importance of feral ungulates at Shackleford Banks, North Carolina. Amer Midl Nat. 18(2):236–244.

Yeager BL. 1993. Dams. In: Bryan CF, Rutherford DA, editors. Impacts on warmwater streams: guidelines for evaluation. Little Rock (AR): Southern Division, American Fisheries Society. p. 57–113.

Zale AV, Maughan OE, Orth DJ, Layher W. 1993. In: Bryan CF, Rutherford DA, editors. Impacts on warmwater streams: guidelines for evaluation. Little Rock (AR): Southern Division, American Fisheries Society. p. 271–285.

Zohary T, Ostrovsky I. 2011. Ecological impacts of excessive water level fluctuations in stratified freshwater lakes. Inland Waters. 1:47–59.

Threats and Emerging Concerns

5

Required Element 3

Descriptions of problems which may adversely affect species identified in Required Element 1 or their habitats, and priority research and survey efforts needed to identify factors which may assist in restoration and improved conservation of these species and habitats.

5.1 Introduction

Natural communities are subject to numerous natural processes that can trigger, reinforce, or constrain the components of an ecosystem. Today, many of the stressors that cause impacts to wildlife and their habitats can be tied to anthropogenic activities. Burning fossil fuels, overharvesting, ecosystem degradation, habitat fragmentation, and wide-spread development are human legacies that impact biodiversity and ecosystem services, not only in North Carolina, but around the world (Balmford et al. 2011).

The impacts influencing ecosystem change that are most frequently mentioned when discussing threats to wildlife and their natural habitats include many that have long existed: land-use conversion, pollution, and invasive species. More recent threats are often associated with emerging issues, especially disease and pathogens, and climate change: sea level rise and extreme changes in regional precipitation and temperature patterns (MEA 2005). The advent of new threats will drive the need for additional research and monitoring in order to make informed decisions about appropriate management and policy actions.

5.2 Threats, Stressors, and Emerging Concerns

Threats and environmental changes will affect the fitness, survival, and reproductive success of wildlife and, ultimately, the survival of populations and ecosystems. Many of the impacts will come from habitat destruction, disruption of food chains, changes in disease and pathogen loads, invasive species, increased pollution, and the direct and indirect effects of climate change (Milligan et al. 2009).

Following a best practice guide recommendation (AFWA 2012), a list of the 11 threats most likely to impact fish and wildlife are considered in this chapter. The list is based on the definitions and hierarchical classification scheme published by Salafsky et al. (2008) and adopted by the IUCN Conservation Measures Partnership (IUCN 2012), with two modifications.

First, the threat category covering geologic events (volcanic, earthquake, and avalanches) was eliminated based on an expectation these events will have little to no impact on wildlife in North Carolina over the 10-year planning horizon represented by this Plan.

Second, disease and pathogens are addressed as a separate threat category because of the serious threat they pose to fish and wildlife and ecosystems instead of considering these topics as a subset of Section 5.10 Invasive and Other Problematic Genes.

The issues discussed in the following subsections represent these threat categories that can be a source of stress to fish and wildlife species and habitat diversity in North Carolina. The list of threat categories is provided in Table 5.1. While this chapter focuses on problems likely to affect fish and wildlife species or their habitats, as outlined in Required Element 3, the discussions in this chapter address provisions outlined in each of the Eight Required Elements.

Table 5.1 Chapter section and threat category description

Threat Category	Section/Category Description
1	**5.3 Residential & Commercial Development**
	Threats are from human settlements or other nonagricultural land uses with a substantial footprint. These include housing and urban areas; commercial and industrial areas; and tourism and recreation areas.
2	**5.4 Agriculture & Aquaculture**
	Threats are from farming and ranching as a result of agricultural expansion and intensification, including silviculture, mariculture, and aquaculture. These include annual and perennial non-timber crops; wood and pulp plantations; and livestock farming and ranching.
3	**5.5 Energy Production & Mining**
	Threats are from production of non-biological resources, and exploring for, developing, and producing petroleum and other liquid hydrocarbons. These include oil and gas drilling; mining and quarrying; and renewable energy.

Threat Category	Section/Category Description
4	**5.6 Transportation & Service Corridors**
	Threats are from long, narrow transport corridors and the vehicles that use them, including associated wildlife mortality. These include roads and railroads; utility and service lines; shipping lines; and flight paths.
5	**5.7 Biological Resource Use**
	Threats are from consumptive use of "wild" biological resources, including deliberate and unintentional harvesting effects, as well as persecution or control of specific species. These include hunting and collecting terrestrial animals; gathering terrestrial plants; logging and wood harvesting; and fishing and harvesting aquatic resources.
6	**5.8 Human Intrusions & Disturbance**
	Threats are from human activities that alter, destroy, and disturb habitats and species associated with non-consumptive uses of biological resources. These include all recreational activities; military exercises; work; and other activities (research, vandalism, law enforcement, illegal activities).
7	**5.9 Natural System Modifications**
	Threats are from actions that convert or degrade habitat in service of "managing" natural or semi-natural systems, often to improve human welfare. These include fire and fire suppression; man-made dams and water management/use; and other ecosystem modifications (land reclamation; shoreline hardening; beach reconstruction, snag removal from streams, etc.).
8	**5.10 Invasive & Other Problematic Species & Genes**
	Threats are from nonnative and native plants, animals, pathogens/microbes, or genetic materials that have or are predicted to have harmful effects on biodiversity following their introduction, spread, and/or increase in abundance. These include invasive nonnative/alien species; problematic native species (e.g., beavers); introduced genetic material (e.g., genetically modified insects; hatchery or aquaculture raised species).
9	**5.11 Pollution**
	Threats are from introduction of exotic and/or excess materials or energy from point and non-point sources. These include household sewage and urban wastewater; industrial and military effluents; agricultural and forestry effluents; garbage and solid waste; airborne pollutants; and excess energy (e.g., ambient noise, sonar, cold or hot water from power plants, beach lights, etc.).
10	**5.12 Climate Change & Severe Weather**
	Threats are from long-term climatic changes that may be linked to global warming and other severe climatic or weather events outside the natural range of variation that could wipe out a vulnerable species or habitat. These include habitat shifting and alteration; droughts; temperature extremes; storms and flooding.
11	**5.13 Disease & Pathogens**
	Threats are from bacteria, viruses, protozoa, fungi, and parasites. These include exotic or introduced pathogens; prion (nonviral, nonbacterial) disease; and zoonotic diseases. Wildlife species may act as hosts or reservoirs.

Although some threats may create minor impacts when acting alone, the cumulative impact or the synergistic effects from multiple threats may lead to dramatic ecological changes (Fischlin et al. 2007), so we have included information in each threat category about expected impacts to Species of Greatest Conservation Need (SGCN) and priority species.

Information about emerging issues and concerns is also discussed in this chapter. Finding solutions to specific conservation problems will have as much to do with addressing these overarching issues as it will with addressing more immediate sources of the problems. Many categories of threats to wildlife are also general activities that can be important to the economic wellbeing of our state. It is important to work collaboratively so that ecosystem stewardship and economic goals are not mutually exclusive.

As previously noted, the threat categories addressed in this chapter are based on the definitions and hierarchical classification scheme published by Salafsky et al. (2008) with modifications. These threats were incorporated into the species evaluation and ranking process as Metrics 9 and 14 and were used by the eight Taxa Teams as part of the WAP revision process. The Taxa Teams applied Metric 9 to gauge the scope and severity of the threat impacts to fish and wildlife as part of the Conservation Concern evaluation process. Metric 14 was applied to assess and rank the importance of the threat as a research topic as part of the Knowledge Gap evaluation process. Metrics 9 and 14 are incorporated in this chapter without additional analysis beyond Taxa Team consideration. The evaluation metrics are described in a white paper provided in Appendix F. Complete results from the Taxa Team evaluations are available in Appendix G.

5.3 Residential and Commercial Development

> For this discussion, development includes housing and urban areas, commercial and industrial areas, and tourism and recreation areas that have a substantial footprint. (Salafsky et al. 2008)

The US Geological Survey (USGS) suggests that the threat to ecosystems from development patterns and current practices in the Southeast rivals threats from climate change (Terando et al. 2014). Habitat degradation and fragmentation arising from sprawling development patterns are some of the most significant causes of species imperilment in the United States (Brown and Laband 2006; Doyle et al. 2001; Ewing et al. 2005). Encroachment of major development adjacent to existing conserved lands and within high-quality wildlife corridors is of particular concern due to the need to maintain the integrity of protected habitats and the ability of wildlife and plants to disperse across the landscape.

In addition to the land use and habitat fragmentation that are common to any type of development, manufacturing and industrial facilities can also be a source of air, water, and noise pollution that can disrupt natural wildlife activities. Urbanized land can have a disproportionate effect on freshwater stream health, with estimates indicating urbanized basins can impair as much as three times the length of stream impacts when compared to stream impacts from agricultural land uses (Smoot et al. 2004).

North Carolina has been consistently among the 12 largest and fastest growing states in the country, according to recent census reports, and is now the ninth most populous state. Over one acre of land is developed for each new resident in the state and the rate of land development has been growing faster than the rate of population growth (Ouzts 2007). From 2000 to 2010, our state was the sixth fastest growing state in the nation, with over 18% population growth (Bunn and Ramirez 2011). Since 1990, housing units have increased 23%–25% per decade and the state population has grown by 1.4–1.5 million people per decade. These growth rates are projected to continue, with a 10% projected population growth rate from 2020 to 2030, when the total population is expected to be almost 11.7 million (NCOSBM 2014).

Instead of encouraging major development in or near town centers, land-use policies in our state are leading to fragmented and spread-out patterns of development in which our rural landscapes are being converted to sprawling suburban land uses with large parking lots and extensive lawn-dominated landscaping. Lack of redevelopment within town and city centers, separation of land uses instead of mixed-use development, and leapfrog development on the outskirts of towns and cities make North Carolina home to the most urban sprawl of any state (Otto et al. 2002).

Haphazard development causes negative impacts to fish and wildlife that are among the top threats, especially to those species that are identified as conservation priorities (NCWRC 2012). The encroachment of development into unfragmented habitat also causes species displacement due to competition from habitat generalist wildlife species that can thrive in urban and suburban landscapes. Nonnative invasive plant species—which reduce native insect populations—and increased predation from generalist wildlife and outdoor cats can cause local extirpation of wildlife of conservation concern. Human–wildlife conflict is another issue of particular concern that is exacerbated by spread-out development patterns. The more conflict people perceive as being caused by wildlife, the less support the public may have for wildlife conservation.

Areas of the state that are highest in biodiversity, species rarity, and endemism are experiencing the greatest rates of urban and rural sprawl. Among these areas of the state are the southeast Coastal Plain, the Sandhills, and the southeast Mountains. In addition, most priority wildlife habitats depend on the ecosystem process of fire. Some are completely fire dependent, such as the Longleaf Pine ecosystem and many small wetland community types. The ability to conduct prescribed burning is all but lost in exurban and urban areas.

The Wilmington metropolitan area and NC beach communities drive development growth on the southeast Coastal Plain. Populations in the region increased by 40% from 2000 to 2010 (USCB 2014). The Wilmington region ranks among the top 10 most diverse areas in reptiles and birds on the continent (Ricketts et al. 1999).

Fayetteville sits in the heart of the Sandhills ecoregion, which comprises the third most endangered ecosystem in the United States (Noss and Peters 1995) and communities in the region grow by 15%–30% every 10 years. From 2010 to 2025, Sandhills communities are projected to grow by 14%–32%.

Four NC cities in the Piedmont are among the top 100 fastest growing cities in the nation, with Charlotte and Raleigh listed among the top ten (City Mayors Statistics 2012). In the Charlotte region, five times more land is developed, and in Raleigh, three times more land is developed, per person, now than in the 1970s (UNCC 2009, 2012). The primary concern regarding expanding urban areas is the cumulative effect of sedimentation on rare and endangered aquatic species and the further fragmentation of habitat for fairly common terrestrial species that require large unfragmented habitats.

Land development in the southern Appalachians has outpaced population growth by a factor of 10:1 since the 1970s (RENCI 2010). The southern Appalachians of North Carolina is predicted to experience growth rates of 12%–25% through 2030 (NCOSBM 2014) and is among the most biologically diverse regions of North America, with over 400 endemic species (Ricketts et al. 1999).

Compounding this problem is the "land-use planning gap"—or the lack of effective habitat conservation strategies in land-use planning efforts. Many communities in North Carolina are not consistently using conservation data and have not had access to information on how to incorporate habitat conservation into plans, incentives, ordinances, and development design. Numerous reports have called for increased coordination between wildlife agencies and land-use planners (Azerrad and Nilon 2006; Beatley 2000; Jenkins et al. 2007; Environmental Law Institute 2007). At least ten other state wildlife agencies actively address the threat from development patterns to priority wildlife.

5.3.1 Anticipated Impacts

Fragmentation due to development and road projects makes movement between existing populations and nearby habitat more difficult. It also increases the risk of mortality from road crossings and predation by domestic pets and feral animals from nearby neighborhoods. Road impacts to amphibians and reptiles are of particular concern in the Sandhills and the southeast Coastal Plain. Conservation-based development ordinances or projects often do not address habitat fragmentation.

Lands between existing managed conservation areas are at risk, in developing counties, from major development that will impede wildlife travel and habitat corridors. Reduced ability to conduct prescribed burning and hunting can occur due to the encroachment of major development adjacent to managed conservation lands.

Bald eagles and colonial nesting waterbirds have been known to abandon their nests when development takes place during the nesting season within 330 feet or more of their nests (Rogers and Smith 1995; Carney and Sydeman 1999; USFWS 2007).

Converting pervious land surfaces to impervious surfaces such as roads, rooftops, and parking lots alters stream hydrology by increasing surface runoff during rain events and reducing infiltration. An increase in imperviousness causes streamflows to increase more rapidly following rain events and subside more quickly. With less rainfall soaking into the ground, there is less groundwater to contribute to baseflows. Altered stream hydrology can impact aquatic communities. Contamination originating from developed areas can flow into surface waters used by aquatic species and breeding and larval amphibians when stormwater runoff and other nonpoint sources carry toxic materials such as gas and oil and chemical pest control treatments from lawns and fields. Road projects and mining in areas with acidic rock types can degrade streams.

Development often encroaches on floodplains, reducing lateral connectivity and exacerbating flood damage to streams and riparian areas. Reduced or eliminated riparian buffers along streams results in increased water temperatures and less stable stream banks, leading to increased sedimentation. Increased numbers of road crossings, particularly culverts, further fragments streams and other aquatic systems, leading to reduced organism movements and gene flow.

In the Coastal Plain ecoregion, development and use of beaches increases impacts to nesting seabirds and other waterbirds, Diamondback Terrapins, and sea turtles. Lack of living shorelines along open waterbodies will increase erosion and further reduce forage, nesting areas, and cover for wildlife. Development of barrier islands, coastal forest, and wetland communities further reduces natural habitat that is already highly fragmented, which may completely isolate and threaten species with specialized life histories and limited movement ability. Examples include the Buxton Woods White-footed Deermouse, Eastern Woodrat, Eastern Coral Snake, and many amphibian species. Development of uplands adjacent to brackish wetlands impacts species such as the Diamondback Terrapin and waterbirds. Tidal swamp forests and species are also particularly threatened by development.

In the Sandhills and Coastal Plain ecoregions, impacts in landscapes surrounding upland pools, depressions and seeps, and wet and mesic pine savannas are of particular concern for winter-breeding amphibian species and seasonal wetland reptiles, such as the Chicken Turtle, Pine Barrens Treefrog, and Mabee's Salamander. Bachmann's Sparrow, Bobwhite Quail, Loggerhead Shrike, and Red-cockaded Woodpecker are also of major concern. Development in and adjacent to forested wetlands, mesic forests, and floodplains particularly impacts colonial nesting waterbirds, priority herpetofauna, and bats, among other priority wildlife.

In the Piedmont ecoregion, species that are common in other parts of the state may decline due to development of priority habitats such as forests of 75 to 500 acres or more. Floodplain and riparian forest impacts, and impacts to seasonal wetlands are of particular concern for species such as the Four-toed Salamander, Mole Salamander, and Eastern Spadefoot Toad. Early successional habitat-associated species are impacted by leapfrog development encroaching on farmland, particularly species such as Grasshopper Sparrow, Loggerhead Shrike, and Bobwhite Quail.

In the Mountains ecoregion, development that impacts unfragmented forest, rock outcrops, and seasonal wetland communities will impact species such as the Cerulean Warbler, Green Salamander, Timber Rattlesnake, and other priority amphibians and reptiles. Impacts from major and minor development to spruce–fir and northern hardwood forest are of particular concern for the Carolina Northern Flying Squirrel, small mammal species, and bats that use these habitat types. Development of early successional habitats and bogs will impact species such as the Bog Turtle, Golden-winged Warbler, and Bobolink.

5.3.2 SGCN Priority Species

The Taxa Team evaluation considered the level of threat that residential and commercial development represents to SGCN priority species. Table 5.2 provides a list of species for which this threat category is consider very high or high.

Table 5.2 SGCN at very high or high threat from residential and commercial development

Scientific Name	Common Name	Threat Level	
		Very High	High
AMPHIBIAN			
Ambystoma tigrinum tigrinum	Eastern Tiger Salamander		X
Aneides aeneus	Green Salamander		X
Hemidactylium scutatum	Four-toed Salamander		X
Rana [Lithobates] capito	Carolina Gopher Frog		X
Plethodon amplus	Blue Ridge Gray-cheeked Salamander		X
Plethodon meridianus	South Mountain Gray-cheeked Salamander		X
Plethodon richmondi	Southern Ravine Salamander		X
Plethodon ventralis	Southern Zigzag Salamander		X
Plethodon wehrlei	Wehrle's Salamander		X
Pseudotriton montanus montanus	Eastern Mud Salamander		X
Pseudotriton ruber	Red Salamander		X
BIRDS			
Aegolius acadicus	Northern Saw-whet Owl		X

Scientific Name	Common Name	Threat Level	
		Very High	High
Arenaria interpres	Ruddy Turnstone		X
Calidris canutus	Red Knot		X
Calidris pusilla	Semipalmated Sandpiper		X
Charadrius wilsonia	Wilson's Plover		X
Haematopus palliatus	American Oystercatcher		X
Hydroprogne caspia	Caspian Tern		X
Limosa fedoa	Marbled Godwit		X
Numenius phaeopus	Whimbrel		X
Vermivora chrysoptera	Golden-winged Warbler		X
CRAYFISH			
Cambarus catagius	Greensboro Burrowing Crayfish		X
Cambarus davidi	Carolina Ladle Crayfish		X
Cambarus reburrus	French Broad River Crayfish		X
FRESHWATER FISH			
Carpiodes sp. cf. cyprinus	a carpsucker		X
Heterandria formosa	Least Killifish	X	
Lampetra appendix	American Brook Lamprey		X
Noturus eleutherus	Mountain Madtom	X	
Noturus flavus	Stonecat	X	
Noturus furiosus	Carolina Madtom	X	
Percina oxyrhynchus	Sharpnose Darter		X
Percina rex	Roanoke Logperch		X
Salvelinus fontinalis	Brook Trout (Native)		X
FRESHWATER MUSSELS			
Alasmidonta heterodon	Dwarf Wedgemussel		X
Alasmidonta raveneliana	Appalachian Elktoe		X
Alasmidonta sp. 2	a freshwater bivalve		X
Alasmidonta varicosa	Brook Floater		X
Alasmidonta viridis	Slippershell Mussel		X
Elliptio dilatata	Spike		X
Elliptio steinstansana	Tar River Spinymussel		X
Lasmigona subviridis	Green Floater		X
Pegias fabula	Littlewing Pearlymussel	X	
Pleurobema oviforme	Tennessee Clubshell		X
Pleuronaia barnesiana	Tennessee Pigtoe		X
Toxolasma pullus	Savannah Lilliput		X
Villosa constricta	Notched Rainbow		X
Villosa delumbis	Eastern Creekshell		X
Villosa iris	Rainbow		X
Villosa modioliformis	Eastern Rainbow		X
Villosa vaughaniana	Carolina Creekshell		X
MAMMAL			
Peromyscus leucopus buxtoni	Buxton Woods White-footed Deermouse		X
REPTILE			
Micrurus fulvius	Coral Snake		X
SNAIL (AQUATIC)			
Helisoma eucosmium	Greenfield Rams-horn	X	

5.4 Agriculture and Aquaculture

> This category considers threats from farming and ranching as a result of agricultural expansion and intensification and includes silviculture, mariculture, and aquaculture. (Salafsky et al. 2008)

Our state has a rich agricultural heritage. North Carolina has over 8.4 million acres of farmland and ranks seventh nationally for farm profits (USDA 2014). Our state leads the nation in tobacco and sweet potato production and ranks second for Christmas trees, hogs, and turkeys (USDA 2014). In North Carolina, the state Department of Agriculture and Consumer Services (NCDACS) has responsibility for agriculture and aquaculture operations.

Livestock farming and ranching are agriculture components and involve raising terrestrial animals (e.g., cattle, swine, poultry) on farms or feed lots. Examples include dairy, chicken, horse, and cattle farms; cattle and swine feed lots; sheep and goat herds; and exotic animal herds (e.g., llamas, alpacas, ostriches). Annual and perennial non-timber crops, orchards, vineyards, and mixed agroforestry planted and harvested from traditional and industrial farms or plantations and used for food, fodder, fiber, fuel, or other uses as agricultural concerns are silviculture concerns.

Aquaculture is a fast growing source of food production throughout the world (FAO 1997; Fu et al. 2012). Freshwater and marine aquaculture (mariculture) includes aquatic animals raised in one location on farmed or nonlocal resources and hatchery fish allowed to roam in the wild. Shrimp or finfish aquaculture, fish ponds on farms, hatchery fish, seeded shellfish beds, and artificial algal beds are examples of aquaculture operations (Salafsky et al. 2008).

Freshwater aquaculture can generally be defined as the propagation and rearing of aquatic species in controlled or selected environments such as constructed ponds or lakes and hatcheries. Aquaculture facilities in the Mountain ecoregion tend to focus on cool- and coldwater production of fish using flow-through tank production. Freshwater aquaculture facilities in the Piedmont ecoregion generally use recirculating tank production, while those in the Coastal Plain ecoregion typically use warmwater ponds for production (Turano et al. 2013).

Mariculture involves propagation and rearing of marine aquatic species in controlled or selected environments such as ocean ranching, constructed ponds or lakes, hatcheries, seeded beds (shellfish), or facilities constructed in natural waters (Salafsky et al. 2008). Mariculture in North Carolina involves raising finfish species (e.g., Black Sea Bass) as well as clams, oysters, and soft crabs (Turano et al. 2013). The NC Marine Fisheries Commission is responsible for the management, protection, preservation, and enhancement of marine and estuarine resources, including mariculture operations.

5.4.1 Agriculture—Anticipated Impacts

As with all threat categories, there can be positive or negative impacts to wildlife depending on its scale and location. Potential impacts (both positive and negative) to fish and wildlife resources from agriculture are numerous. Impacts that can be harmful to wildlife include loss of habitat from conversion of forested or early successional land to cleared agricultural land, erosion of agricultural fields that leads to increased turbidity and sedimentation in surface waters, and contamination from application of pesticides and herbicides. Agricultural crops can provide an important food resource for many wildlife species; however, depredation impacts from wildlife can be significant on agricultural commodity crops. On the positive side, harvested crops within the Coastal Plain provide suitable fall and winter food supplies for waterfowl, Black Bear, White-tailed Deer, and other small wildlife species.

Clearing forested or early successional land and converting it to agriculture can displace birds and small mammals that rely on this community type and reduce the number and diversity of species inhabiting the area. The loss of forested habitats that serve as corridors for species moving among adjacent habitats can be especially harmful to wildlife as it reduces available cover for predator avoidance.

Agricultural practices also affect wetlands, streams, and groundwater in several ways. Wetlands and other similar habitats can be converted directly to agricultural land or their functions can be lost by changes to the soils or hydrology from practices such as ditching and draining. Furthermore, surface and groundwater hydrology can be affected by irrigation.

Without appropriate sedimentation and erosion control measures, rain events can lead to erosion of cleared fields resulting in increased turbidity and sedimentation of nearby surface waters. Increased turbidity and sedimentation affects foraging and reproduction in streams and lakes and can lead to changes in community composition and species extirpation. In the Coastal Plain, pumping of water during high-water events can result in sedimentation, contaminants, and large volumes of freshwater being dumped into our estuaries, which can negatively affect marine species.

Agricultural land uses that include aerial spraying of pesticides and herbicides can affect local amphibian populations when wind carries chemicals into nearby surface waters and wetlands. Little has been published about this source of contamination but research conducted in California found a significant relationship between amphibian declines in locations with known populations and pesticide drift from upwind sources of agrochemical applications (Davidson 2004).

Studies have shown that greater cattle access to wetlands contributes to a higher prevalence of *Frog Virus 3* (FV3) (Gray et al. 2007a). Pathogenic relationships between cattle and amphibians can occur when suitable hosts are present in drinking water supplies. For example, American Bullfrogs are suitable hosts of the human pathogen *Escherichia coli* (E. coli), which can provide an exposure pathway between food safety and human consumption when cattle operations contaminate waters with amphibian populations (Gray et al. 2007b; Hickling 2011). This is another reason why agricultural producers need to restrict livestock access to aquatic environments.

5.4.2 Aquaculture—Anticipated Impacts

Aquaculture operations are a potential source of accidental release of nonnative species that can become invasive in surface waters (see Section 5.10 for more information on invasive species). The aquaculture, aquarium, biological supply, and live-bait industries are potentially the most important vectors responsible for the introduction of nonnative crayfishes throughout North America (Lodge et al. 2000; Kilian et al. 2009). In Maryland, Red Swamp Crayfish has become established in streams adjacent to all aquaculture ponds where it was introduced for commercial culture or for aquaculture-related research (Killian et al. 2009). Studies in North Carolina indicate this aggressive crayfish is likely to out-compete and displace native species for shelter and other limited resources, thereby resulting in changes to the composition of aquatic communities (Cooper and Armstrong 2007; Killian et al. 2009).

Genetic contamination of wild stocks can occur by release or escape of hatchery organisms that breed with wild organisms. The traits that are beneficial in an aquaculture setting may be detrimental to wild animals. Also, a strain of fish or other aquatic organism from a particular river basin may be genetically compromised by a cultured organism whose lineage is from a different river basin. This is particularly an issue with some anadromous species, such as Striped Bass.

Aquaculture operations can be a source of various pathogens and parasites that can affect wild populations (see Section 5.13 for more information on diseases and pathogens). Bacterial infection is reported as the main cause of disease-induced mortality of fish raised in aquaculture, likely because the high densities associated with fish farming increases exploitation of pathogenic bacteria (Johansen et al. 2011; Cervino et al. 2012). About 150 different bacterial pathogens associated with farmed and wild-caught fish have been identified (Austin and Austin 2012; Richards 2014), but disease transfer between farmed and wild stocks is poorly understood (Weir and Grant 2005; Cervino et al. 2012). In many cases pathogens in aquaculture can remain undetected until some stress makes the animal more susceptible to infection (Austin and Austin 2012; Richards 2014). The incidence, prevalence, and origin of diseases are difficult to measure in wild populations and the complex relationships between host, pathogen, and the environment can be influenced by many factors (McVicar 1997; Bakke and Harris 1998; Weir and

Grant 2005; Hedrick 1998; Cervino et al. 2012). Water discharges and stock escapes from aquaculture are therefore important sources of exposure for diseases and pathogens to native populations (Richards 2014).

5.4.3 Silviculture—Anticipated Impacts

Generally, silviculture is the science of managing forests or forest crops to meet diverse needs and values. For purposes of this section, the topic is focused on the management of tree plantations for wood fiber, timber, Christmas trees, or production of nonnative species for other uses (Salafsky et al. 2008). Natural forests are not included in this definition (see Sections 5.5, 5.7, and 5.9 for discussions on management and alterations to natural forests). Silvicultural operations remove various amounts of planted forest materials for processing into wood and pulp products. The mission of NC Forest Service is to protect, manage, and develop the forest resources of the state.

Converting naturally diverse forests to monocultural tree farms reduces habitat diversity, which, in turn, is a major cause of wildlife species loss (Wilcove et al. 1998; Thompson et al. 2013; Roberts and Gilliam 1995; Martin-Queller et al. 2013). At a minimum, the loss of canopy and understory vegetation diminishes availability of cover and forage for wildlife, or, in the case of clearcuts, removes these wildlife resources entirely. Sites allowed to revegetate naturally through successional growth seeded from nearby natural communities could result in poor genetic diversity from the weedy or invasive species that tend to be early colonizers on disturbed sites.

Particular forest structures and ranges of food sources may be more important than particular tree species for certain wildlife (e.g., mammals) (von Haartman 1971; Cannell 1999) or there may be life history dependence on particular species (e.g., Red-cockaded Woodpecker). The conversion of a mixed species forest to an even-aged monoculture, such as those associated with pine plantations, changes the diversity of habitats, but management options are available to improve diversity of plantation landscapes (Cannell 1999). Stand-level wildlife habitat elements such as snags, mast trees, down and coarse woody debris, den trees, and nest trees provide important perching, nesting, foraging, and displaying habitats for a wide variety of wildlife (Jones et al. 2009; Hodson et al. 2010).

In addition to the loss of vegetation, some timber operations create impacts that directly affect landscapes through changes to soil properties caused by mechanized clearing, cutting, and site preparation activities. These impacts include soil compaction, especially to organic soils, increased erosion from disturbance, nutrient loss, removal of seed resources, lost or diminished genetic diversity, changes to microtopography, and changes to hydrogeomorphic processes (FAO 1997; Carter and Grace 2012).

5.4.4 SGCN Priority Species

The Taxa Team evaluation considered the level of threat agriculture, aquaculture, and silviculture represent to SGCN priority species. Table 5.3 provides a list of species for which this threat category is consider very high or high.

Table 5.3 SGCN at very high or high threat from agriculture and aquaculture

Scientific Name	Common Name	Threat Level	
		Very High	High
AMPHIBIAN			
Aneides aeneus	Green Salamander		X
Desmognathus aeneus	Seepage Salamander		X
Eurycea quadridigitata	Dwarf Salamander		X
Hemidactylium scutatum	Four-toed Salamander		X
Plethodon richmondi	Southern Ravine Salamander		X
Plethodon ventralis	Southern Zigzag Salamander		X
Plethodon wehrlei	Wehrle's Salamander		X
Pseudotriton montanus montanus	Eastern Mud Salamander		X
Pseudotriton ruber	Red Salamander		X
BIRD			
Ammodramus henslowii	Henslow's Sparrow		X
Asio flammeus	Short-eared Owl		X
Bonasa umbellus	Ruffed Grouse	X	
Colinus virginianus	Northern Bobwhite		X
Cygnus columbianus	Tundra Swan		X
Lanius ludovicianus	Loggerhead Shrike		X
Passerculus sandwichensis	Savannah Sparrow		X
Picoides borealis	Red-cockaded Woodpecker		X
Sitta pusilla	Brown-headed Nuthatch		X
Vireo gilvus	Warbling Vireo		X
Vireo philadelphicus	Philadelphia Vireo		X
FRESHWATER FISH			
Carpiodes sp. cf. cyprinus	a carpsucker		X
Cyprinella sp.1 (cf. zanema)	Thinlip Chub		X
Exoglossum maxillingua	Cutlips Minnow		X
Fundulus cf. diaphanus	Lake Phelps Killifish		X
Hypentelium roanokense	Roanoke Hog Sucker		X
Notropis bifrenatus	Bridle Shiner		X
Notropis chalybaeus	Ironcolor Shiner		X
Noturus eleutherus	Mountain Madtom	X	
Noturus flavus	Stonecat	X	
Noturus furiosus	Carolina Madtom		X

Scientific Name	Common Name	Threat Level	
		Very High	High
Noturus gilberti	Orangefin Madtom	X	
Percina oxyrhynchus	Sharpnose Darter		X
REPTILE			
Ophisaurus attenuatus longicaudus	Eastern Slender Glass Lizard		X
Ophisaurus mimicus	Mimic Glass Lizard		X
SNAIL (TERRESTRIAL)			
Inflectarius verus	a snail		X

5.5 Energy Production and Mining

> This category addresses threats from production of nonbiological resources related to exploring for, developing, and producing energy and mining resources. Resources include oil and gas drilling on land and in ocean waters; coal and gold mines; and rock, sand, and phosphate quarries. Renewable resources also fall under this category, such as hydropower and emerging technologies associated with solar farms, windmills, tidal wave energy capture, and geothermal power production. (Salafsky et al. 2008)

Renewable energy is defined by NC General Statute (G.S.) 62-133.8(a)(7) and (8) and North Carolina has a Renewable Energy and Energy Efficiency Portfolio Standard (REPS) that was passed into law in 2007 (Session Law 2007-397, Senate Bill 3). This standard requires all investor-owned utilities to reach 12.5% renewable energy production by 2021. There is the potential for future reduction of this target. Rural electric cooperatives and municipal electric suppliers have a 10% REPS requirement (NC Renewable Energy and Energy Efficiency Portfolio Standard [REPS] 2007).

Renewable energy facilities include those that generate electric power using renewable energy resources, combined heat and power systems, and solar thermal energy facilities. Solar electric, solar thermal, wind, hydropower, geothermal, and ocean current or wave energy resources are considered renewable energy resources.

Another example of a renewable energy resource covered under the REPS includes biomass or biofuels, which use agricultural waste, animal waste, wood waste, spent pulping liquors, combustible residues, combustible liquids, combustible gases, energy crops, or landfill methane for energy production. Information about other renewable energy resources covered by the REPS is available online from the NC Utilities Commission website: http://www.ncuc.commerce.state.nc.us/reps/reps.htm.

5.5.1 Biomass and Biofuels—Anticipated Impacts

Biomass resources includes organic matter from a variety of wood materials and energy crops that can be gasified, used in combined heat and power technologies or in biochemical conversions, used to create biofuels, or used for direct combustion (Milbrant 2005; Fargione et al. 2009). There are two main types of biofuels in use today that are made from biomass resources: ethanol and biodiesel (Biofuels, n.d.).

Wood waste products include logging debris that remains from timber clearing operations, thinning of commercial forest stands, and residues left over from lumber mill production. Common energy crops are corn, soybeans, wheat, various grasses (switch grass and *Miscanthus spp.* in particular), willow, and hybrid poplar species. These resources, as well as many other similar plant and wood resources, can be used to produce biofuels such as biodiesel and ethanol for vehicles and as a replacement for coal used by utilities and industrial plants.

Biomass production often involves intensive management that uses fertilizers, pesticides, and monocultures of high-yield nonnative cultivars (Fargione et al. 2009). Grassland birds are a primary taxa group of concern because the loss of early successional and grassland habitats converted or managed for biomass production will likely impact species dependent on herbaceous communities (Fargione et al. 2009). Overall, songbird and small mammal species richness, diversity, and abundance is expected to be lower where herbaceous biomass crops are produced (Semere and Slater 2007; Sage et al. 2010; Riffell et al. 2011; Robertson et al. 2011a, 2011b; Northrup and Wittmyer 2013). The greatest concern is when biomass crops replace native forests or lands in conservation holdings (Riffell et al. 2011; Northrup and Wittmyer 2013).

Biomass crops may pose a risk of becoming invasive if exotic crop species are used, if exotic or native species are modified through breeding or genetic engineering, or if native species are used outside their home range (Raghu et al. 2006; Barney and DiTomaso 2008; Fargione et al. 2009). Breeding and genetic modification of species may make species more likely to become invasive because desirable agronomic traits such as a fast growth rate and high establishment success are also associated with successful invasive species (DiTomaso et al. 2007; Fargione et al. 2009; Buddenhagen et al. 2009; Northrup and Wittmyer 2013).

Managing for specific species is often the easiest task, especially when the ecological needs of the species are well understood (Fargione et al. 2009). Frequent harvest of vegetation will very likely favor grassland birds requiring short, sparse vegetation (e.g., Grasshopper Sparrow and Savannah Sparrow) and negatively affect those requiring tall, dense vegetation (e.g., Sedge Wren and Henslow's Sparrow) (Fargione et al. 2009). Research is needed to determine the appropriate scale and placement of habitat patches; however, the best harvest scenario is likely to be one that produces a mosaic of harvested and unharvested patches (Fargione et al. 2009). Small habitat patches may become population sinks if birds using these areas suffer higher predation rates (Fargione et al. 2009). From a wildlife perspective, having multiple harvest times throughout the year can provide a mosaic of habitat conditions that support a wider range of species (Fargione et al. 2009).

Wood product companies have expanded production in North Carolina in recent years and, along with wood chipping facilities and a deepwater berth at the Morehead City Port, the export of wood chip products from the state is likely to increase because of high demand from international markets for wood pellet exports from the United States (Fox 2012; Wood Resources International 2014). The harvest and chipping of forest vegetation infested by exotic insects (i.e., Emerald Ash Borer, Redbay Ambrosia Beetle) carries the risk of transporting pests that survive the chipping process (Spence et al. 2013) both locally (during transport and storage) and elsewhere (to domestic and international markets).

Impacts can be mitigated by using biomass sources that do not require additional land, and thus do not increase the footprint of agriculture, such as agricultural residues, cover crops, and, potentially, algae (Fargione et al. 2009). The second approach is to produce biomass with land-use practices that are compatible with wildlife, including the use of perennial biomass crops and native plants, adjusting the timing and frequency of harvest, and leaving suitable stubble height (Fargione et al. 2009). Harvest schedules should consider priority species, whether those species are migratory or resident, and the timing of the life-cycle events that have the greatest impact on populations (nesting, brood rearing, winter migrating, etc.) (Fargione et al. 2009).

5.5.2 Coal Energy—Anticipated Impacts

Coal mined from other states is used for energy production in North Carolina. Coal is burned to heat water into steam that turns turbine generators, which produce electricity. Coal-fired power plants need large amounts of water; therefore, power plants in North Carolina are typically located on large rivers or on impoundments. Burning coal produces carbon dioxide and other air pollutants such as sulfur dioxide and methylmercury. Air pollution concerns have led to improved technologies to capture air pollutants. Coal fly ash remains after coal combustion and must be properly disposed of if it is not used to manufacture other materials.

Surface impoundment of coal fly ash residues is widely practiced, despite inherent environmental hazards from leachate that can pollute groundwater and spill into surface waters in the disposal facilities fail. These facilities are also harmfully attractive to amphibians and birds for foraging or reproduction (Lemly and Skorupa 2012). Coal fly ash contains numerous elements that vary in concentration based on the source of the coal, the method of combustion, and the air pollution-control equipment installed (Patra et al. 2012; Souza et al. 2013). Coal ash is composed of oxides of silicon, aluminum, iron, and calcium and, in lower concentrations, can also include arsenic, barium, cadmium, chromium, copper, lead, selenium, and strontium (Rowe et al. 2002; Patra et al. 2012; Souza et al. 2013). In many cases, the priority for remediating spill sites is the removal of ash by dredging to prevent transport and dispersion during storm events and to prevent upstream flooding (Mathews et al. 2014).

Fish and wildlife damage from exposure to coal ash slurry ranges from physiological, developmental, and behavioral toxicity to major population and community-level changes (Lemly and Skorupa 2012). The earliest reported coal ash pond failure in North Carolina occurred in 1976 and resulted in selenium poisoning that extirpated 19 species of fish in Belews Lake (Lemly and Skorupa 2012). Following a 2008 release of coal ash in Tennessee, an assessment of effects on aquatic species found low potential exposure risk to selenium in Tree Swallows and bats; to aluminum in Mink, Killdeer, Mallard, and Raccoon; and to arsenic in Killdeer (Meyer et al. 2014).

Other studies conducted by Bryan et al. (2003, 2012) evaluated the risk to birds attracted to coal ash settling basins for nesting and the exposure of nestlings to contaminated food. Results indicate arsenic, cadmium, and selenium concentrations were elevated in feather, liver, and carcass, but only liver selenium concentrations approached levels of concern (Bryan et al. 2003, 2012). Exposure is suspected to occur from bioaccumulation concentrations in the food chain, primarily through insects consumed by insectivores and omnivores. Because selenium builds up through the food chain rather than through aqueous exposure, tissue selenium concentrations may increase gradually over a period of several years (Mathews et al. 2014).

Tissues from Raccoons exposed to coal ash showed higher levels of arsenic in hair, iron in muscle, nickel in hair, selenium in hair and muscle, strontium in hair, and vanadium in hair and liver when compared to unexposed animals (Souza et al. 2013). However, long-term monitoring is needed to understand the factors that control when coal fly ash contaminants are more likely to biomagnify (Mathews et al. 2014).

Coal-fired power plants pump large volumes of water to produce electricity. Aquatic organisms can be entrained or impinged unless measures are sufficient to keep organisms from being impacted. After water is used for electricity production, it is returned to surface waters but the temperature can be considerably higher than the temperature of the receiving waterbody. Heated discharge can create refugia for nonnative species and alter aquatic community composition.

5.5.3 Oil and Gas Extraction—Anticipated Impacts

North Carolina has limited oil and gas reserves within shale deposits in the Triassic Basin of the Piedmont ecoregion, primarily in the Durham, Sanford, and Wadesboro subbasins of the Deep River Basin and in the Dan River Basin within portions of Stokes and Rockingham counties. Offshore oil and gas exploration continues to be debated, but no offshore extraction is currently allowed because it is generally controlled by federal regulations and processes.

Two technological advances now make these oil and gas resources more accessible: horizontal drilling and hydraulic fracturing. Horizontal drilling allows access to a larger subterranean area with a single surface drilling location. This technique provides access to large subterranean areas that may be inaccessible otherwise, thereby increasing potential profits. Hydraulic fracturing, also known as fracking, is a well-stimulation technique in which pressurized water, chemicals, and sand are pumped into a well to fracture rock. This allows oil and gas to flow more freely and increases production.

In recent years, the State of North Carolina has assessed existing rules and regulations to determine what changes are necessary to allow horizontal drilling and hydraulic fracturing in our state. Rules and regulations from other states where oil and gas extraction involving horizontal drilling and hydraulic fracturing has been occurring were also assessed.

Potential impacts to wildlife from oil and gas extraction are numerous; they include water quality and water quantity impacts, terrestrial wildlife habitat fragmentation and conversion, increased sand mining, and increased road and utility corridors. Impacts can occur as a result of preparing land for oil and gas extraction, establishing travel and utility corridors, use of natural resources (primarily water and sand) for hydraulic fracturing, and handling and disposing of waste and byproducts. Additional impacts are possible from spills and unintentional discharges.

Hydraulic fracturing typically requires 4–5 million gallons of water per well, spread out over several days. The oil and gas industry typically reuses the water-based fracking fluids to fracture additional wells until the fluid is no longer effective. Even so, there is a potential to impact streamflows, especially if water is withdrawn from small streams during low flow periods. Water withdrawn from impoundments or large rivers will have less impact to streamflows, particularly if the water is withdrawn during high flow periods and the instantaneous withdrawal rate is low.

Surface water quality could be impacted by accidental spills of fracking fluid and surface runoff from well pad sites. Fracking fluids typically contain a large mix of chemicals. Increased use and transport of fracking fluids increases the probability of an accidental spill or discharge that will impact surface waters. Once fracking fluids are no longer usable, they must be treated and disposed of properly. Water treatment plants are often not equipped to treat the chemicals found in fracking fluids. Underground disposal of fracking fluids can be problematic, and inadequate treatment of fracking fluids can impact receiving surface waters. Surface runoff from well pads can contain a mix of chemicals associated with oil and gas operations, including leaked fluids associated with the operation of heavy equipment. During large rain events, polluted runoff from a well site can impact surface waters if stormwater management practices are insufficient.

While horizontal drilling allows operators to reach underground resources with fewer surface wells, impacts to wildlife habitat are likely as operators choose locations for well pad sites. Well pads are likely to be located away from houses and public properties; therefore, alterations to agricultural fields and forested areas are most likely. In addition to land conversion at the well pad, new roads may need to be constructed to access the well pad and an infrastructure of pipelines may also be constructed to transport oil and gas products from the site. These new roads and utility corridors have the potential to fragment terrestrial habitat and impact streams and wetlands at crossings.

Constituents of fracking fluids vary depending on subterranean conditions and the company conducting the hydraulic fracturing, but sand is often a component of fracking fluids. Increased demand for sand for fracking could potentially lead to increased sand mining. Increased sand mining has the potential to impact wildlife habitat (see Section 5.5.5).

Studies have shown that wildlife located in areas of unconventional oil and gas extraction tend to avoid these areas due to noise pollution from increased traffic on rural roads, drilling mud pits, building storage sites, processing plant operations, and compressing stations (Drohan et al. 2012). Drilling mud pits have been reported to entrap migratory birds and other wildlife and wastewater impoundments have been known to entrap deer and foxes (Ramirez 2009). Some species may be more sensitive to this noise pollution than others. Altered habitat selection due to wildlife avoiding these areas may have effects on reproduction and survival. Future research should consider the effects chemicals used in fracking can have on wildlife.

Many animals that have come into contact with chemicals used in fracking show signs of "shale gas syndrome" which is noted to affect the neurological, dermatological, gastrointestinal, respiratory, and vascular systems. Because studies are finding these results in livestock, we can infer that these chemicals could have the same effect on NC wildlife. As with other routes of exposure to chemicals (i.e., industry, agriculture, forestry), this poses a risk to wildlife populations as well as to humans who consume fish and wildlife because many chemicals bioaccumulate in tissue. Contaminants found in a Kentucky stream showed low pH and concentrated toxic chemicals of aluminum and iron that resulted in stressed aquatic life and gill lesions in fish (Papoulias and Velasco 2013). Fish also bioaccumulate these toxins, which can pose a risk to human consumption. In livestock, it has been documented that cattle exposed to sulfur dioxide during gestation from fracking air pollution had an increased risk of calf mortality and higher occurrence of respiratory lesions (Waldner 2008;

Waldner and Clark 2009). Further research is needed to investigate the effects chemicals used in fracking will have on wildlife.

5.5.4 Hydropower—Anticipated Impacts

Hydropower is created by harnessing the energy of falling water. In North Carolina, large rivers and high gradient streams have been dammed in the past to create impoundments for hydroelectric power production. Some reservoirs in our state were created solely for the purpose of creating hydropower. For other reservoirs, hydropower is one of several purposes of the impoundment, along with flood control or water supply creation. More recently, existing dams have been retrofitted to allow operators to generate hydropower. In recent years, some inoperable hydroelectric plants have been removed to restore streams and rivers to a free-flowing state.

Hydroelectric plants have similar impacts as other impoundments: streams and rivers impounded by dams are changed from lotic systems to lentic systems. Downstream water quality can also suffer from low dissolved oxygen (DO) levels and altered temperatures (lower water temperatures if water is released from near the bottom of the reservoir). In addition, hydropower generation can significantly change flow regimes downstream of hydropower dams.

Large hydropower facilities are typically peaking operations: they generate electricity during peak demand periods. As a result, large volumes of water are released to generate electricity during peak energy demand periods and water releases diminish during low energy demand periods so that the available water supply can be replenished for future use. This results in a flow regime that can be vastly different from the natural flow regime in terms of magnitude, frequency, duration, timing, and rate of change (Poff et al. 1997). These flow regime alterations can cause changes to the aquatic community, including local extirpation of species.

Dams also fragment habitats and disrupt the movements and migrations of fish and other aquatic organisms. Diadromous fish are those that spend part of their life in the ocean and part of their life in freshwater. They include Striped Bass, American Shad, American Eel, and Shortnose Sturgeon. These species are particularly vulnerable to blockages imposed by dams. Upstream and downstream passage facilities and strategies are often required to reconnect populations of these species to their necessary habitats.

The combined effects of barriers and altered flows can affect other important riverine processes, such as bedload and sediment transport, nutrient cycling, and woody debris transport.

5.5.5 Mining and Quarries—Anticipated Impacts

North Carolina has mines and quarries throughout most of the state that supply sand, gravel, granite, minerals, and other materials used for various development projects. Sand and gravel can be mined from open pits or sometimes directly from rivers. Recently, some exhausted granite quarries have been considered as water supply sources to augment existing water supplies. Existing mines and quarries are expected to expand and new mines and quarries created to continue to supply demand into the future.

North Carolina allows mines to operate in streams to dredge out sand and gold. Dredging in-stream incises the channel, which increases flow velocity and causes sedimentation downstream. In-stream mining also increases turbidity and stream temperatures through the loss of riparian vegetation that provides shade. These changes negatively impact aquatic species, often resulting in reduced reproductive success and survival. They can severely impact habitat and sedentary taxa like mussels at the mine site itself. Near-stream mining is also allowed in North Carolina and has similar (although often less severe) impacts. Both types of mining operations can also degrade the surrounding riparian habitat and downstream wetland habitats. Fracking activities in other parts of the state will increase the demand for sand and water (NCAFS 2002).

The primary direct impacts to wildlife resources from mining and quarries (not instream mining) relate to land conversion. Additional impacts can result if stormwater runoff is discharged offsite to surface waters. New and expanded mines and quarries may impact high-quality terrestrial uplands, wetlands, or streams. Water quality can be impacted if water from a mining site is discharged before it is appropriately treated to remove pollutants.

Instream mining removes sand and gravel directly from a stream bed, resulting in channel instability, altered habitat, increased sedimentation, and increased turbidity (Brown et al. 1998; Meador and Layher 1998). Instream mining can create pools where riffles once occurred and create headcuts that can continue upstream. These impacts to aquatic habitat can cause changes to aquatic community composition, including local extirpation of species such as freshwater mussels and other rare aquatic species (Hartfield 1993; Watters 2000).

5.5.6 Nuclear Energy—Anticipated Impacts

Nuclear power plants in North Carolina provide electricity for utility customers within our state. They require large volumes of water to ensure that nuclear reactors remain cool; therefore, they are sited near large water bodies or impoundments are created to supply cooling water. Most impacts associated with nuclear power plants revolve around the fact that they require large amounts of water to cool the nuclear reactors and the water is considerably warmer than ambient temperature after it has been used for cooling. In North

Carolina, nuclear power plants choose between two primary options for discharging heated water: discharge heated water directly into a water body or build a cooling tower that will evaporate and cool water.

Duke Energy's Brunswick Nuclear Plant near Southport transports heated water along a canal until the water is eventually discharged offshore. Duke Energy's Harris Nuclear Plant cools water with a cooling tower where most water is evaporated. The small amount of collected water that is not evaporated is returned back to Harris Reservoir.

Returning heated water directly to a water body changes the water quality of the receiving water body, particularly in the area of the discharge, and creates unnaturally warmer water conditions. Other water quality parameters such as DO, salinity, turbidity, pH, and water chemistry parameters may also differ from ambient conditions. Such modifications can affect the species inhabiting the area of the discharge. Use of cooling towers can eliminate the discharge of heated water and deleterious effects on receiving waters. However, water evaporates from cooling towers at a much faster rate than normal and that water is no longer available to contribute to downstream flows.

By withdrawing large volumes of water for cooling, aquatic organisms can be impinged or entrained, resulting in injury or death. Impinged organisms can be caught against screens used to prevent transport of larger debris. Continual water pressure against organisms can lead to eventual death or injury. Additionally, some organisms are small enough to pass through screens and will be entrained in the water transported to the nuclear reactors for cooling where they can be subjected to harsh conditions, nearly always leading to death. Water intake structures use various techniques to reduce the number of organisms that are impinged or entrained. These include slow intake velocities, fine mesh screens, and periodically backwashing screens.

In the future, there is potential for additional nuclear power plants or expansion of existing plants. In addition to the potential impacts described previously and terrestrial land conversion impacts, future nuclear plants will potentially impact river flows due to their dependence on water for cooling. Such river flow impacts could result from creating an impoundment and affecting a section of free-flowing water, pumping water from a river to maintain sufficient water in an impoundment, or expanding an existing reservoir and affecting the timing and volume of downstream flows due to increased demand for cooling water.

5.5.7 Solar Energy—Anticipated Impacts

Electricity produced from solar power has increased greatly in North Carolina in recent years. Solar electricity is produced in two primary ways: concentrated solar power (CSP) and photovoltaic (PV). CSP, not currently used in North Carolina, uses mirrors or lenses to concentrate solar energy that drives steam turbines or similar devices that in turn generate electricity. PV captures light energy using solar panels and generates electricity directly. Solar cells for PV are small but are combined into connected modules and arrays. PV systems can be installed on rooftops or on land that receives adequate sunlight.

In North Carolina, solar farms comprised of many solar arrays on open land are becoming more and more common. Solar farms produce clean, renewable energy but some sites may have impacts to terrestrial and aquatic wildlife resources. Most solar farms in North Carolina generate 5 MW of electricity or less but take up approximately 25 acres of land. However, there are also larger solar farms capable of producing up to 100 MW. Many solar farms are sited on cleared agricultural land that has been traditionally used for farming. Increasingly however, solar farms are proposed in forested areas that will require clearcutting to prepare the land for the solar farm.

Currently peer-reviewed studies are insufficient to adequately assess all the potential impacts of PV solar farms on wildlife (Lovich and Ennin 2011). The primary impact is conversion of wildlife habitat to cleared areas with solar arrays; the degree of impact depends on the quality of the habitat. Impacts will be fewer for solar farms constructed on cleared fields. Solar farms are typically enclosed with chain link fences so movement corridors for wildlife may be altered. In addition to direct impacts from the solar farm, new transmission lines may be needed to connect to the grid. New utility corridors can bisect large forest blocks or cross wetlands and streams.

5.5.8 Wind Energy—Anticipated Impacts

Wind energy uses turbines carrying rotary blades designed to capture kinetic wind energy and convert it into electricity that can be used locally, stored for later use, or provided to an energy grid. Large arrays of wind turbines are often referred to as wind power farms and they require an extensive power collection, storage, and distribution system for delivering electricity. Typical wind power farms also need some type of supervisory control and data acquisition system for two-way communications with each wind turbine as well as maintenance facilities for service equipment, spare parts, lubricants, and other supplies. These maintenance facilities can be located on- or off-site and may be combined into one building. At least one access road is needed to access the wind turbines, delivery systems, and maintenance facilities.

North Carolina has good-to-outstanding wind resource potential along the coast and mountain ridges (WINDExchange 2015). Currently, one wind energy farm is planned to be built in Perquimans and Pasquotank counties by Iberdrola Renewables and will be operational by 2016. The facility will cover 34 square miles and be able to produce 208 megawatts energy with the initial 104 turbines that are each 492 feet tall (Murawski 2015). There have been no wind farms in the state prior to this project so there is no documentation about the effects a wind farm will have on wildlife in North Carolina. There is the potential for turbines to have a greater impact on nocturnal migrating birds and bats, especially in the eastern part of the state where there is a major migratory flyway. Monitoring and research will be needed at the site and in surrounding landscapes to evaluate what impact, if any, this facility will have on wildlife and nearby habitats.

It is widely acknowledged that birds and bats suffer the most impacts from the operation of large wind turbines due to collision with the turbines' blades. In 2009, the USFWS estimated at least 440,000 birds were killed each year by the approximately 22,000 wind turbines operating in the United States at that time (ABC 2011). A 2005 Government Accountability Office (GAO) report that assessed wind energy impacts on wildlife states that over 1,000 raptors, including Golden Eagles, are killed each year at wind power farms operated in California. The report acknowledges that many wind power facilities have not been studied and much is still unknown about overall species population levels; therefore, scientists cannot draw definitive conclusions about the threat that wind power poses to wildlife in general (GAO 2005). Siting of wind farms in areas actively used by birds (e.g., flyways) was a major contributor to mortalities to birds as well as bats (Kuvlesky et al. 2007; Northrup and Wittmyer 2013). Since publication of the GAO report, wind turbine design has been modified to better address bird strike problems.

In addition to collisions with turbine structures, other impacts occur from construction and operation of the facilities, which vary by region and site, and may have greater effects on other species. These include habitat fragmentation, displacement, sedimentation and erosion from land disturbance, water quality degradation, shadowing, noise, and vibration. However, it is generally recognized that there are insufficient scientific data available about the post-construction effects of wind power facilities on all forms of wildlife (ABC 2015).

The USFWS (2012) issued voluntary guidelines for wind turbines to avoid or minimize impacts to wildlife and their habitats. The recommendations call for a tiered approach that evaluates proposed wind turbine sites, characterizes potential risks, uses field studies to identify onsite wildlife and habitats and predict impacts, and conducts post-construction studies that include mortality assessments and mitigation studies. In North Carolina, utilities are not required to comply with these voluntary guidelines nor are there any requirements from the NC Utilities Commission for the evaluation or mitigation of impacts to wildlife.

5.5.9 SGCN Priority Species

The Taxa Team evaluation considered the level of threat energy production and mining activities represents to SGCN priority species. Table 5.4 provides a list of species for which this threat category is consider very high or high.

Table 5.4 SGCN at very high or high threat from energy production and mining

Scientific Name	Common Name	Threat Level: Very High	Threat Level: High
AMPHIBIAN			
Rana [Lithobates] capito	Carolina Gopher Frog		X
Necturus lewisi	Neuse River Waterdog		X
Plethodon wehrlei	Wehrle's Salamander		X
FRESHWATER FISH			
Carpiodes sp. cf. cyprinus	a carpsucker	X	
Cottus carolinae	Banded Sculpin		X
Erimonax monachus	Spotfin Chub		X
Etheostoma inscriptum	Turquoise Darter		X
Percina nigrofasciata	Blackbanded Darter		X
Percina rex	Roanoke Logperch		X
SNAIL (TERRESTRIAL)			
Inflectarius verus	a snail		X

5.6 Transportation and Service Corridors

> Threats associated with this category relate to roads, railroads, utility and service lines, shipping lanes, and flight paths, and to the vehicles that use them, including associated wildlife mortality. (Salafsky et al. 2008)

Roads are significant features of most landscapes, covering about 1% of the United States and ecologically influencing an estimated 15%–20% of the US land area (Jochimsen et al. 2004). Land-based transportation systems include highways and secondary road networks, logging and fire access roads, causeways and bridges, and railroads and rail yards. Utility and service corridors and rights-of-way include electrical and telephone lines, oil and gas pipelines, and stormwater and sewer system lines. Coastal shipping lanes, intercoastal waterways (IWW), and canals for boat and ship transportation and utility lines are aquatic-oriented transportation and service corridors. Airport runways and flight paths between airports are another type of transportation corridor (Salafsky et al. 2008).

5.6.1 Anticipated Impacts

Potential impacts from transportation and service corridors on terrestrial wildlife species and their habitats are numerous. The characteristics of a road or service corridor will affect the degree to which it creates a barrier to species (Clark et al. 2010; Clevenger et al. 2003; Wiens 1997). Corridors consist of impervious surfaces or vegetation that is mowed or otherwise maintained periodically. New corridors have the potential to convert diverse wildlife habitat (e.g., mixed hardwood forest) to habitats that support few or no species. Maintained corridors can also serve as pathways for the spread of invasive plant species.

Habitat fragmentation is the most common impact to terrestrial environments but there are other important impacts that can negatively impact wildlife (Clark et al. 2010; Forman and Alexander 1998). The presence of roads increases the mortality of wildlife from vehicular collision, which can lead to changes in demographic and structural changes of populations (Clark et al. 2010; Mazerolle 2004; Row et al. 2007). For small animals with limited dispersal capacity (e.g., some amphibians), roads and service corridors can create a barrier to gene flow, resulting ultimately in loss of diversity and decreased population fitness (Clark et al. 2010; Frankham et al. 2002). The results of a study on the effects of roads on Timber Rattlesnakes demonstrated there was a significant effect on genetic structure and gene flow among populations (Clark et al. 2010).

Highways impact wildlife through avoidance, fragmentation, direct and indirect loss of habitat, and mortality (Ruediger 1996, 1998). Conover et al. (1995), extrapolating from a variety of sources across the United States, estimated 726,000 deer–vehicle collisions annually. Studies have also identified short-term negative impacts on Black Bears (Brody and Pelton 1989; Beringer et al. 1990), Grizzly Bears (Mattson et al. 1987), Gray Wolves (Paquet and Callaghan 1996), and other carnivores (Gibeau and Heuer 1996). North Carolina Wildlife Resources Commission (NCWRC) data indicate that a minimum of 50 to 100 Black Bears are killed in central and northeastern North Carolina by automobiles yearly. Road mortality of amphibians and reptiles is likely to correlate highly with fluctuations in water level, breeding and nesting season, dispersal of juveniles, and availability of food resources (i.e., insects attracted to street lights) (Jochimsen et al. 2004).

There is a clear need for management actions that reduce the incidence of vehicle–wildlife collisions for large mammals. For example, to help select locations for three wildlife underpasses along a new 23-km-long segment of US Highway 64 on the Albemarle/Pamlico peninsula in Washington County, track surveys were conducted to collect species crossing data (Scheick and Jones 1998). Survey results identified 1,335 tracks of seven wildlife species (Black Bear, White-tailed Deer, Bobcat, Coyote, Gray Fox, Raccoon, and Opossum). Building underpasses during road construction has several benefits including reduction of both human and animal injury and death (Scheick and Jones 1998).

Transportation corridors can also fragment aquatic habitat at stream crossings due to culverts that do not allow aquatic organism passage. Culverts must be properly sized and positioned to allow aquatic organism to move freely upstream and downstream of crossings (Kilgore et al. 2010). Failure of culverts to allow organisms to move upstream of crossings can restrict gene flow and isolate populations (Wofford et al. 2005). Poorly designed culverts can prevent upstream migration and recolonization upstream of culverts, eventually leading to extirpation above crossings (Jackson 2004). River Herring migration may also be impeded by low light levels within culverts (Moser and Terra 1999). Various groups are now working to identify culverts that are barriers to aquatic organism passage and replace them with improved crossing structures.

Utility crossings, such as aerial utility lines or underground pipes, also affect streams and wetlands at crossings because woody riparian vegetation is converted to maintained herbaceous vegetation. These utility corridor crossings create breaks in riparian vegetation that can reduce shading and lead to streambank erosion. These interruptions to riparian corridors can also impact species using forested riparian areas as travel corridors.

The National Wildlife Strike Database reported 99,411 wildlife strikes to airplanes have occurred since 1990, resulting in more than 200 human lives lost (Allan 2002; Dolbeer et al. 2010). The vast majority (97.4%) of all wildlife strikes involve birds (ACRP 2011). Bird management at airports is best considered an adaptive process of deterrence where species composition and behavior can be expected to change during the day, between seasons, and across years, even when techniques in this synthesis are actively employed. Many bird species habituate to deterrent techniques and will return to the area, particularly if the area is attractive to them. Airport managers often use repelling techniques, habitat modification, exclusion, population management, and notification to pilots as strategies to manage hazardous wildlife at or near the airport (Cleary and Dickey 2010; ACRP 2011).

5.6.2 SGCN Priority Species

The Taxa Team evaluation considered the level of threat transportation and service corridors represents to SGCN priority species. Table 5.5 provides a list of species for which this threat category is consider very high or high.

Table 5.5 SGCN at very high or high threat from transportation and service corridors

Scientific Name	Common Name	Threat Level	
		Very High	High
AMPHIBIAN			
Ambystoma mabeei	Mabee's Salamander		X
Ambystoma tigrinum tigrinum	Eastern Tiger Salamander		X

Scientific Name	Common Name	Threat Level: Very High	Threat Level: High
Aneides aeneus	Green Salamander		X
Eurycea junaluska	Junaluska Salamander		X
Rana [Lithobates] capito	Carolina Gopher Frog		X
Rana sylvatica [Lithobates sylvaticus] pop.3	Wood Frog—Coastal Plain Pop.		X
BIRD			
Catharus fuscescens	Veery	X	
Pheucticus ludovicianus	Rose-breasted Grosbeak	X	
REPTILE			
Sistrurus miliarius miliarius	Carolina Pigmy Rattlesnake		X
SNAIL (AQUATIC)			
Helisoma eucosmium	Greenfield Rams-horn	X	
SNAIL (TERRESTRIAL)			
Inflectarius verus	a snail		X

5.7 Biological Resource Use

> This threat category considers the consumptive use of wildlife biological resources that may be deliberate (e.g., hunting, harvesting) or unintentional (e.g., fisheries bycatch, accidental mortality). (Salafsky et al. 2008)

Hunting, trapping, and collecting animals, including shellfish harvesting, turtle egg collection, pest or predator control, and persecution are considered a biological resource use. Harvesting aquatic wild animals and plants for commercial, recreation, subsistence, research, or cultural purposes, and for population control are also consumptive uses (Salafsky et al. 2008). Other biological resource uses include clear-cutting of natural hardwood forests, fuel wood collection, charcoal production, and other activities related to harvesting natural stands of trees and woody vegetation for timber, fiber, or fuel uses (Salafsky et al. 2008).

Regardless of the reason, method, intentionality, or end use, this category essentially deals with the removal of plants or animals from a particular ecosystem or habitat. The removal may be selective (i.e., only certain plants or animals) or indiscriminate (e.g., clear-cutting).

5.7.1 Anticipated Impacts

Removal of plants or trees can alter habitat and disrupt food webs and energy and nutrient cycles. When the removal is limited, the impacts may be negligible or confined to a single species. Large-scale removals can result in a change of habitat type, such as from a forest to early successional habitat. Animals and other plants that rely on the removed plant species or original habitat type may be negatively impacted, while other plants and animals may take advantage of the open niche or changed conditions. For example, removal of only oak trees from a forest can be expected to affect species that rely on hard mast, such as White-tailed Deer and Wild Turkey. However, most selective vegetation harvest in North Carolina is not done at a scale to cause shifts in community composition. Shifts in habitat type from large-scale non-selective harvest will be beneficial to some species, but may offer opportunities for invasive species to become established or spread. Conversion to early successional habitat will profit certain birds and butterflies, but may also allow Kudzu to take over.

Removal of fish and wildlife may not only affect the population size and structure of the species harvested, but also can impact other species, both plants and animals, in the community by altering the food web and other species interactions. Again, certain species may benefit while others are harmed.

Removal of wild animals from terrestrial systems is generally limited to hunting, trapping, and collecting. Selective harvest of most game and furbearing species is typically not an issue. However, negative impacts can occur to nongame species, such as terrestrial, aquatic, and sea turtles, from intentional harvest of eggs or adults. Snakes are often killed for no reason other than that people are afraid of them. Bats, mice, and some birds are considered by some to be pests, and removed from human structures. The killing or removal of voles and moles is widespread. Some of these activities may be illegal because the species is protected or the harvest does not follow seasons and bag limits.

In aquatic systems, particularly freshwater ones, the overharvest of most species is not an issue, but localized poaching of species such as trout does occur. Overharvest is fairly common in marine fisheries due to the multiple gear types used, the combination of commercial and recreational fishing effort, and the multiple jurisdictions managing the fish or shellfish. Bycatch is common in marine fisheries because some harvest gear is nonselective. The bycatch may include undersized target fish, nontarget fish, and other organisms (e.g., sea turtles). The impacts of bycatch and overharvest can include reduced population size and altered population size or age structure.

Catch and release of game fish or nontarget fish can cause injury or death of individual animals, but this typically does not rise to the point of affecting the population. Holding a caught fish in a live well and releasing it a long distance from the capture location, for instance at a weigh-in site, can cause local imbalances in fish densities and increase competition for food and habitat.

5.7.2 SGCN Priority Species

The Taxa Team evaluation considered the level of threat biological resource use represents to SGCN priority species. Table 5.6 provides a list of species for which this threat category is considered very high or high.

Table 5.6 SGCN at very high or high threat from biological resource use

Scientific Name	Common Name	Threat Level	
		Very High	High
CRAYFISH			
Orconectes virginiensis	Chowanoke Crayfish		X
REPTILE			
Eretmochelys imbricata imbricata	Atlantic Hawksbill Sea Turtle		X
Chelonia mydas	Green Sea Turtle		X
Lepidochelys kempii	Kemp's Ridley Sea Turtle		X
Dermochelys coriacea	Leatherback Sea Turtle		X
Caretta caretta	Loggerhead Sea Turtle		X
Pseudemys rubriventris	Northern Red-bellied Cooter		X
SNAIL (TERRESTRIAL)			
Inflectarius verus	a snail		X

5.8 Human Intrusions and Disturbance

> Threats are from recreational activities, military exercises, civil unrest, and work and other outdoor activities (e.g., law enforcement, illegal activities, vandalism, species research). (Salafsky et al. 2008)

Human activities that may be considered non-consumptive of biological resources (those that do not take or harvest) can alter, destroy, and disturb natural habitats and species. Examples include people spending time in natural areas for recreational activities such as beach driving, driving ATVs, off-road vehicles, jet-skis, and snowmobiles, or riding mountain bikes; flying ultralight planes at low-elevations; dog-walking, bird-watching, hiking, and camping; and caving, spelunking, and rock-climbing (Salafsky et al. 2008).

Disturbance may also be related to military exercises or work activities that occur in natural environments. Training exercises can involve driving tanks and military equipment across the landscape; firing missiles onto bombing ranges; or other munitions or maneuver exercises in coastal areas. Species research often involves survey or monitoring activities that can disturb wildlife (Salafsky et al. 2008).

5.8.1 Anticipated Impacts

In one sense, human intrusion and disturbance is ubiquitous. Nearly all human interactions affect wildlife—either positively or negatively. Potential impacts from human disturbance are diverse and depend on numerous variables such as the wildlife species involved and the duration, frequency, magnitude, timing, and type of intrusion and disturbance. Human intrusion and disturbance can be particularly impactful during breeding and nesting periods (Steven et al. 2011). Impacts can be minimized by using common sense and effective management practices that limit intrusion and disturbance by restricting access on a spatial (e.g., buffer distances) or temporal (e.g., seasonal closures) basis.

North Carolina is home to many military bases with extensive acreages available for wildlife. These habitats may be relatively natural or disturbed and portions of them are used for military training, including foot and vehicular traffic, artillery and small arms fire, explosives, airplane flights, ship movements, and acoustic disturbance. As stated above, the impacts of these activities depend on many factors. Some species may avoid using otherwise suitable habitat. Disturbance can reduce breeding success, foraging and feeding efficiency, and limit population size.

While disturbance can drive some species away, the resulting open niche will often be used by another species that is tolerant of humans. A number of birds, most of which are nonnative, are able to tolerate or even take advantage of human disturbance, including Starling, Canada Geese, Rock Dove (pigeon), and House Sparrow.

An example of human intrusion and disturbance impacts on wildlife is the effect of pedestrian and vehicular traffic on nesting shorebirds and sea turtles along North Carolina's Outer Banks. Several species of shorebirds, such as Piping Plover, American Oystercatcher, Black Skimmer, and Least Tern, nest on beaches at the Outer Banks each year. Sea turtles lay eggs in nests on NC beaches each year.

Pedestrian traffic can reduce reproductive success for nesting shorebirds such as Least Terns (Kanapaux and Kiker 2013), American Oystercatchers (McGowan and Simons 2006; Sabine et al. 2008), and Piping Plovers (Doherty and Heath 2011). Nesting shorebirds can be impacted by the frequency, duration, and proximity of pedestrians. Vehicular traffic can also reduce reproductive success or reduce hatchling survival of nesting shorebirds (McGowan and Simons 2006; Tarr et al. 2010). The impact of pedestrian traffic and vehicular traffic can be mitigated by establishing buffers around nesting shorebirds and controlling the locations and timing of beach driving.

Among the features that make beach habitats suitable for sea turtle nesting are accessibility from the water, being situated high enough above the active surf zone that sand is not constantly inundated by high tides or the water table below (Mortimer 1982; Miller et al. 2003), and lack of artificial structures and visible lighting (Witherington 1992; Bouchard et al. 1998). Excessive nighttime lighting from buildings or vehicles can render nesting beaches unsuitable or unused because lighting disorients the sea turtles, thereby reducing the number of female sea turtles nesting on NC beaches (Witherington 1992). Sea turtle hatchlings generally emerge from their nests at night, and rely on visual cues for successfully finding and entering ocean waters (seafinding behavior) (Ehrenfeld 1968; Mrosovsky and Shettleworth 1969). When exposed to sources of artificial light, seafinding behavior of hatchlings will become disrupted, and often hatchlings will travel away from the sea (Peters and Verhoeven 1994; Philibosian 1976; Salmon et al. 1995a, 1995b), which increases the time they are exposed to land-based predators, reduces the amount of residual internalized yolk available to hatchlings for their initial swim offshore, and could result in desiccation/death if the hatchlings remain on land after sunrise.

Driving motorized vehicles on the beach has the potential to negatively impact sea turtles by running over nesting females, hatchlings, and stranded turtles that have washed ashore. Driving directly above incubating eggs in a sea turtle nest can cause sand compaction, which result in decreased hatching success and can kill pre-emergent hatchlings. In addition, the ruts left by motorized vehicles in the sand may prevent or impede hatchlings from reaching the ocean following their emergence from the nest (Hosier et al. 1981; Lamont et al. 2002; van de Merwe et al. 2012).

Reducing artificial lighting and nighttime beach driving can increase the number of female sea turtles nesting on our beaches. Marking sea turtle nests and creating protective buffers around nests can prevent nest disturbance. Limiting vehicular traffic during sea turtle emergence can prevent direct mortality and prevent tire ruts that can impede hatchlings as they travel to the ocean.

5.8.2 SGCN Priority Species

The Taxa Team evaluation considered the level of threat human intrusions and disturbance represents to SGCN priority species. Table 5.7 provides a list of species for which this threat category is consider very high or high.

Table 5.7 SGCN at very high or high threat from human intrusions and disturbance

Scientific Name	Common Name	Threat Level	
		Very High	High
AMPHIBIAN			
Hemidactylium scutatum	Four-toed Salamander		X
Pseudotriton montanus montanus	Eastern Mud Salamander		X
Pseudotriton ruber	Red Salamander		X

Table 5.7 SGCN at very high or high threat from human intrusions and disturbance (cont.)

Scientific Name	Common Name	Threat Level Very High	Threat Level High
BIRD			
Actitis macularia	Spotted Sandpiper		X
Charadrius wilsonia	Wilson's Plover	X	
Gavia immer	Common Loon		X
Gelochelidon nilotica	Gull-billed Tern		X
Haematopus palliatus	American Oystercatcher	X	
Hydroprogne caspia	Caspian Tern		X
Pelecanus occidentalis	Brown Pelican		X
Rynchops niger	Black Skimmer		X
Sterna antillarum	Least Tern		X
Sterna hirundo	Common Tern		X
Thalasseus maximus	Royal Tern		X
Thalasseus sandvicensis	Sandwich Tern		X
FRESHWATER FISH			
Heterandria formosa	Least Killifish	X	
SNAIL (AQUATIC)			
Helisoma eucosmium	Greenfield Rams-horn	X	
SNAIL (TERRESTRIAL)			
Inflectarius verus	a snail		X

5.9 Natural System Modifications

> Threats are from actions that convert or degrade habitat in service of "managing" natural or semi-natural systems, often to improve human welfare. This category includes suppression or increase in fire frequency and/or intensity outside natural range or variation; changing water flow patterns either deliberately or as a result of other activities; and other activities intended to 'manage' natural systems to benefit human welfare. (Salafsky et al. 2008)

5.9.1 Anticipated Impacts

When development and land-use patterns do not take the needs of wildlife into consideration, the result is a landscape with fragmented and degraded habitats that are unable to support populations of sensitive species (NCWRC 2012). Habitat degradation and fragmentation is a landscape-scale process in which patches of suitable habitat become smaller and more widely separated by a more or less unsuitable matrix (Stockwell et al. 2003). Fragmentation affects all natural areas, especially forests, and it poses increasing problems for major freshwater systems (MEA 2005). Loss of biodiversity can result when natural communities are degraded or fragmented and can lead to populations that are more susceptible to inbreeding, genetic erosion, and problematic population trends (Clark et al. 2010). Furthermore, prescribed burning as a management tool is more difficult in fragmented areas due to difficulty with smoke management and liability issues.

Destruction and degradation of habitat are widely cited as the greatest threats to aquatic species in the United States (Angermeier 1995; Warren et al. 1997; Williams et al. 1993). Physical alterations such as channelization and dredging, aquifer depletion, impoundment and dam construction, and flow modification have contributed directly to the decline of aquatic species in the South (Walsh et al. 1995; Etnier 1997). Increases in impervious surfaces, and subsequently stormwater flows, have caused changes in sediment transport and stream energy, which has led to limitations in the amount of suitable aquatic habitat and streambed material, especially near urban areas. The Nature Conservancy (TNC 2000; Smith et al. 2002) and NatureServe (TNC and NatureServe 2001) identify altered surface hydrology (i.e., flood control and hydroelectric dams, interbasin transfers of water, drainage ditches, breached levees, artificial levees, dredged inlets and river channels) and a receding water table as among the most significant sources of biological and ecological stress, especially in the Coastal Plain.

Habitat fragmentation limits movement and gene flow of area-sensitive species and can isolate species with small home ranges, which makes populations more vulnerable to disturbance, disease, disruption to gene flow between populations, and depredation. Increased amounts of road surfaces and transportation-related projects have impacted populations and natural communities in ecologically sensitive areas. Roads can separate breeding locations and provide substantial barriers to seasonal animal migration pathways. Increased human development associated with transportation development also brings an increased risk of the introduction of exotic species. Fragmentation disrupts dispersal of many species, especially those that migrate between wet lowlands and dry uplands, and can negatively affect population dynamics and reproductive success.

Fragmentation influences evolution by changing, among other things, the costs and benefits of dispersal (Stockwell et al. 2003). A decrease in population dispersal and population size can lead to a reduction in the effective population size followed by increased genetic drift, reduced genetic variation and increased inbreeding, and a decrease in the time to extinction (Marsack and Swanson 2009; Andersen et al. 2004). Inbreeding contributes to genetic mutations that decrease disease resistance and the ability of a population to adapt (Lacy 1993).

While most birds can rapidly find and colonize early successional habitat patches, some bird species (grassland birds in particular) are area sensitive and will not use small patches of habitat surrounded by forest or developed areas. Bobwhite Quail may require large (more than 5,000 acres) areas of contiguous habitat for long-term population viability (Guthery et al. 2000). Fragmentation of forests into smaller contiguous blocks is a concern for forest interior birds (like Wood Thrush, Cooper's Hawk, and Worm-eating Warbler), which may occur in lower densities or suffer lower productivity or survival in small habitat patches.

Animals with large home ranges or dispersal needs may become isolated or absent in small tracts. Fragmentation by roads and development can be particularly problematic for reptiles (particularly Timber Rattlesnake and Box Turtle), amphibians, and small mammals that suffer high mortality on roads when traveling between forest patches.

Upland changes will influence landscapes containing wetlands through changes in downstream outputs and hydrological and biogeochemical processes. Drainage and agricultural activities can degrade nearby wetlands and cause loss of vegetation diversity and ecosystem services (De Steven and Gramling 2013).

5.9.2 SGCN Priority Species

The Taxa Team evaluation considered the level of threat natural system modifications represents to SGCN priority species. Table 5.8 provides a list of species for which this threat category is considered very high or high.

Table 5.8 SGCN at very high or high threat from natural system modification

Scientific Name	Common Name	Threat Level	
		Very High	High
AMPHIBIAN			
Eurycea chamberlaini	Chamberlain's Dwarf Salamander		X
Eurycea quadridigitata	Dwarf Salamander		X
Hemidactylium scutatum	Four-toed Salamander		X
Rana [Lithobates] capito	Carolina Gopher Frog	X	
Pseudacris brimleyi	Brimley's Chorus Frog		X
Pseudacris nigrita	Southern Chorus Frog		X
Pseudacris ornata	Ornate Chorus Frog		X
Pseudotriton montanus montanus	Eastern Mud Salamander		X
Pseudotriton ruber	Red Salamander		X
BIRD			
Actitis macularia	Spotted Sandpiper		X
Ammodramus henslowii	Henslow's Sparrow	X	

Scientific Name	Common Name	Threat Level	
		Very High	High
Ammodramus maritimus	Seaside Sparrow		X
Arenaria interpres	Ruddy Turnstone		X
Butorides virescens	Green Heron		X
Calidris canutus	Red Knot		X
Calidris pusilla	Semipalmated Sandpiper		X
Charadrius melodus	Piping Plover		X
Charadrius semipalmatus	Semipalmated Plover		X
Charadrius wilsonia	Wilson's Plover	X	
Gelochelidon nilotica	Gull-billed Tern		X
Haematopus palliatus	American Oystercatcher	X	
Limnodromus griseus	Short-billed Dowitcher		X
Limosa fedoa	Marbled Godwit		X
Mycteria americana	Wood Stork	X	
Numenius phaeopus	Whimbrel		X
Pelecanus occidentalis	Brown Pelican		X
Peucaea aestivalis	Bachman's Sparrow		X
Phalacrocorax auritus	Double-crested Cormorant		X
Picoides borealis	Red-cockaded Woodpecker	X	
Pluvialis squatarola	Black-bellied Plover	X	
Rynchops niger	Black Skimmer		X
Sitta canadensis	Red-breasted Nuthatch		X
Sterna antillarum	Least Tern		X
Sterna hirundo	Common Tern		X
CRAYFISH			
Cambarus aldermanorum	Needlenose Crayfish		X
Cambarus spicatus	Broad River Spiny Crayfish		X
FRESHWATER FISH			
Acipenser brevirostrum	Shortnose Sturgeon		X
Carpiodes carpio	River Carpsucker		X
Carpiodes sp. cf. cyprinus	a carpsucker		X
Cottus caeruleomentum	Blue Ridge Sculpin		X
Cottus carolinae	Banded Sculpin		X
Erimonax monachus	Spotfin Chub		X
Etheostoma inscriptum	Turquoise Darter		X
Exoglossum maxillingua	Cutlips Minnow		X
Fundulus cf. diaphanus	Lake Phelps Killifish	X	
Heterandria formosa	Least Killifish	X	
Moxostoma ariommum	Bigeye Jumprock		X
Moxostoma breviceps	Smallmouth Redhorse		X
Moxostoma carinatum	River Redhorse		X
Moxostoma cervinum	Blacktip Jumprock		X

Table 5.8 SGCN at very high or high threat from natural system modification (cont.)

Scientific Name	Common Name	Threat Level	
		Very High	High
Moxostoma sp 2	Sicklefin Redhorse		X
Notropis mekistocholas	Cape Fear Shiner		X
Noturus eleutherus	Mountain Madtom	X	
Noturus flavus	Stonecat	X	
Noturus furiosus	Carolina Madtom	X	
Noturus gilberti	Orangefin Madtom	X	
Percina burtoni	Blotchside Logperch		X
Percina nigrofasciata	Blackbanded Darter		X
Percina rex	Roanoke Logperch		X
Thoburnia hamiltoni	Rustyside Sucker		X
FRESHWATER MUSSEL			
Alasmidonta heterodon	Dwarf Wedgemussel		X
Elliptio steinstansana	Tar River Spinymussel		X
Pleurobema collina	James Spinymussel		X
Villosa modioliformis	Eastern Rainbow		X
REPTILE			
Caretta caretta	Loggerhead Sea Turtle		X
Chelonia mydas	Green Sea Turtle		X
Dermochelys coriacea	Leatherback Sea Turtle		X
Lepidochelys kempii	Kemp's Ridley Sea Turtle		X
Ophisaurus mimicus	Mimic Glass Lizard	X	
SNAIL (AQUATIC)			
Helisoma eucosmium	Greenfield Rams-horn	X	
SNAIL (TERRESTRIAL)			
Inflectarius verus	a snail		X

5.10 Invasive and Other Problematic Species and Genes

Threats are from nonnative and native plants, animals, pathogens or microbes, or genetic materials that have or are predicted to have harmful effects on biodiversity following their introduction, spread, and/or increase in abundance. This can include feral animals (e.g., cats, swine); species introduced as biocontrol agents or as part of a management strategy (e.g., Kudzu); native species that can be problematic when populations are overabundant or concentrated (e.g., White-tailed Deer in urban areas); and introduced genetically modified organisms such as plants that can hybridize with native plants or pesticide resistant crops. (Salafsky et al. 2008)

Invasive species may be one of the most important and widespread issues in conservation biology today because once established, they are expensive to treat, are typically hard to remove, may become permanent components of the community, and have effects that can be irreversible (Reynolds and Souty-Grosset 2012). Nonnative and invasive species introductions (both plant and animal) continue to pose a threat to native wildlife in North Carolina. The spread of invasive species has been growing over the last decades, with species of all kinds moving higher in latitude and elevation as changing climate conditions facilitate range expansions.

Invasives are particularly threatening to native species with small population sizes and distribution ranges (Vose et al. 2014). Introductions of nonnative species have occurred in a number of different ways, ranging from intended stockings, to range expansions, to accidental and deliberate release of animals purchased through the pet trade. Impacts on native species are equally varied—some exotics out-compete native species (e.g., Kudzu and Japanese Stiltgrass), while others cause hybridization (e.g., Red-eared Sliders breeding with native Yellow-eared Sliders). Still others can cause direct mortalities to our native resources (e.g., red imported Fire Ants, the Hemlock Wooly Adelgid).

The most important concept to remember is that all of the components within a natural community—whether native, introduced, exotic, or invasive—will have synergistic relationships and cumulative impacts on each other, both positive and negative. The species discussed in this section do not represent an exhaustive list of all invasive or problematic species; rather, these are examples that represent widespread concerns or species that may be site-specific.

When considering invasive and other problematic species in North Carolina, it becomes clear that a discussion about one topic often leads to the need to discuss several others. Given this complexity of the topic, the information provided in this section has been organized first by landscapes (aquatic or terrestrial communities), then by category (plants or wildlife). While pathogens may be considered an invasive or problematic species, they are discussed in Section 5.13.

5.10.1 Aquatic Systems—Anticipated Impacts

Freshwater systems have a high degree of connectivity that allows invasive species to spread easily and sometimes rapidly from the source to new areas (Reynolds and Souty-Grosset 2012). Excessive aquatic plant growth can cause many types of impacts but the ones that most often involve local management efforts are habitat degradation, impaired fishing and boating, and blocked hydroelectric turbine intakes (Richardson 2008). Weed management tactics are relatively few and often have limited efficacy, various environmental impacts, and high expense. Management tools include biological, chemical, mechanical, and physical measures, and often require long-term funding commitments to control sources and new occurrences (Richardson 2008).

A partnership of state and federal agencies has developed the North Carolina Aquatic Nuisance Species Management Plan (NCANSMP), which includes an aquatic nuisance species list and policy recommendations. The list includes invasive, nuisance, and nonnative species currently known from North Carolina and those considered at risk of becoming a nuisance though they are not currently known to be in the state, including species that have commercial or recreational value in North Carolina.

Management of invasive aquatic species also needs to include outreach to the public as a means of reducing anthropogenic-related sources (e.g., bait bucket dumps, aquaria and aquaculture releases, hitchhikers on boats and trailers) and involving stakeholders in monitoring and remediation programs. A detailed risk assessment and studies on distribution, ecology, and genetics of known potential invaders can be used to develop prevention and management programs for aquatic invasive species (Reynolds and Souty-Grosset 2012).

Native species introduced into areas where they would not normally be found can create competitive pressures for food and habitat use. Blueback Herring introduced to mountain reservoirs have caused the collapse of walleye populations that now must be maintained by stocking.

The Crayfish Taxa Team identified five crayfish species considered invasive and of concern in North Carolina. In the Mountain ecoregion, the Kentucky River Crayfish has been found in large creeks and small river systems and the Coosa River Spiny Crayfish has been found in the New and Little Tennessee river basins. In the Piedmont ecoregion, Rusty Crayfish and Virile Crayfish have been found in headwater streams, small and large creeks, small and medium rivers, and reservoirs and impoundments. The Red Swamp Crawfish has the most widespread distribution and is found in all freshwater systems throughout the state. Crayfishes that are spread to habitats outside their natural range can affect the distribution of native species as well as the dynamics and biodiversity of the community (Reynolds and Souty-Grosset 2012).

The most commonly occurring groups of freshwater algae are diatoms, green algae, and blue-green algae, which are more correctly known as cyanobacteria. Cyanobacteria refer to a group of microorganisms that possess characteristics of algae (chlorophyll-a and oxygenic photosynthesis). They are found in fresh, estuarine, and marine waters in the United States and cyanobacterial blooms can produce highly potent cyanotoxins (EPA 2014). In North Carolina, two cyanobacteria—Blue-green and Black Mat Algae (*Lyngbya* spp.)—are of particular concern because they produce neurotoxins and paralytic shellfish-poisoning toxins (EPA 2014).

Invasive and nonnative aquatic plants like Watermilfoil and Hydrilla are economically damaging aquatic weeds (Richardson 2008) and can form dense mats that can clog boat motors and make swimming difficult. Propagation of Hydrilla invades via tubers, turions, plant fragments, and stolons, and is likely spread between lakes by plant fragments attached to boats (Harlan et al. 1985). In locations where Hydrilla mats do not survive winter temperatures, regrowth can occur from residual tubers and turions and germinate in the spring (Harlan et al. 1985).). Public awareness of the need to clean recreational equipment such as boats, water craft, and trailers as well as fishing tackle and gear should be a high priority. Information is available online on proper techniques for cleaning equipment to reduce or prevent the spread of aquatic invasive species (see http://www.protectyourwaters.net/prevention/prevention_user.php for specific procedures).

Exotic or invasive aquatic snails in the state include Chinese Mystery Snail, Creeping Ancylid, Giant Rams-horn, Japanese Mystery Snail, Red-rim Melania, and Savannah Elimia. The Red-rim Melania is a host for parasitic trematode worms (e.g., liver flukes and lung flukes) which allows the flukes to complete their life cycle. Trematode flukes affect waterfowl, fish, and other animals and can be transmitted to humans who eat raw or undercooked fish or crab that have been infected or who swim in waters that contain the flukes (Wingard et al. 2008).

Although not currently extant in North Carolina, Zebra Mussels, Bighead Carp, and Silver Carp occur in adjacent states and pose extremely high risks to our aquatic ecosystems. These species are known to alter community dynamics and even extirpate other species.

5.10.2 Terrestrial Systems—Anticipated Impacts

The results of some studies suggest the synergistic effects between climate warming and the presence of invasive species will negatively affect many wildlife species (Saenz et al. 2013). Some studies indicate amphibian declines may be attributed to invasive species becoming established in their habitats (Saenz et al. 2013; Doubledee et al. 2003; Brooks et al. 2004; Brown et al. 2006).

The NC Department of Transportation identifies 74 species in a guide to invasive or exotic trees, shrubs, herbaceous plants, vines, and aquatic plants that are considered a threat, moderate threat, or a watch-list concern in the state. The plant species described in this guide should be considered a priority when addressing problems caused by invasive, introduced, or exotic plants. The guide provides recommendations for management and treatment options as well as resources for additional information and is available for download as a PDF document (see Smith 2012). In addition to the ubiquitous species identified by the NCDOT Roadside Environmental Unit as invasive (Smith 2012), there are others that may not yet be as widespread but are emerging concerns because of their potential negative impacts to wildlife and habitats. These include Cogongrass, Beach Vitex, and various genetically modified organisms (GMOs).

The Emerald Ash Borer (EAB) bores in ash trees, ultimately killing them, and all four of the native ash species (White, Green, Carolina, and Pumpkin [*Fraxinus* spp.]) found in the state are susceptible to attack (NCFS 2015). Mountain Ash (*Sorbus* sp.), which is not considered a true ash, is not susceptible. When EAB is known to be present, there is a risk of long-distance dispersal through transportation of ash wood products from an infested area to an uninfested area. Treatment of infected trees requires destruction of infected wood by cutting down dead or dying trees and chipping, burning, or burying the wood on the site. Quarantines will be placed for areas where EAB has been detected (currently Granville, Person, and Vance counties). The quarantine prohibits the movement of any part of an ash tree, the insect itself, and all hardwood (deciduous) firewood from a quarantined area into an area outside the quarantine. Firewood refers to wood that is cut to less than four feet in length. Additional information is available from the NC Forest Service.

Kudzu is likely the most recognizable example of an introduced nonnative species used for biological control that has become a serious invasive problem. In the case of Kudzu, it was originally planted as a ground cover and control for erosion but is now a widespread invasive that takes extensive and repeated treatment to eradicate on a local level. A more recent example includes the release of a beetle species that specializes in an introduced exotic thistle species. In this case, the beetle has been found to spillover from its weedy invasive host plant onto multiple nontarget native species, which has ultimately resulted in impacts to native thistle populations in some areas of the United States (Louda et al. 1997; Louda 1998; Rand and Louda 2004; Blitzer et al. 2012).

The Nutria is a mammal native to South America that was introduced to North Carolina in the 1950s. Several populations became established in coastal counties by the 1970s. Their populations have grown and Nutria can now be found in Piedmont rivers and large streams. Nutria feed on numerous grasses and wetland plants and can eat approximately 25% of their body weight daily. At high densities and under certain conditions, foraging Nutria can significantly impact natural plant communities. Most damage caused by Nutria comes from overgrazing and burrowing into the banks of impoundments, earthen dams, and other waterbody foundations, which can weaken these structures. In North Carolina, they compete for food and burrows with native muskrats.

Coyotes have naturally spread to North Carolina from their native range in central and western North America. They can be found in a habitats ranging from grasslands to forests, but have also adapted to suburban and urban conditions. Coyotes prey on a variety of animals and plant materials. They will also consume carrion and hunt pets. Their adaptable nature allows them to outcompete foxes and generally replace the niche occupied by wolves. In fact, they have interbred with Red Wolves, jeopardizing efforts to reintroduce that species in eastern North Carolina (Bohling and Waits 2011).

Like Coyotes, the Nine-banded Armadillo has spread throughout much of North America over the past 100 years. The range expansion is not likely due to climate change, but rather to how the lack of predators and land-use changes provide more open conditions. Their omnivorous feeding habits and fast reproduction also contribute to their spread. They compete with other ground-dwelling species, such as skunks and ground-nesting birds. Armadillos can also carry the bacteria that cause leprosy.

Feral Swine can significantly impact plant communities and wildlife habitat because they root through the ground's surface in search of food. Feral Swine destroy agricultural crops and other property and pose a substantial disease risk for both domestic swine and other wildlife.

Invasive plants can alter the quality of breeding habitat for some species, such as songbirds, by impacting important demographic traits. For example, the loss of habitat can interfere with migratory patterns of species such as birds and fish, which can have significant impacts to the age structure and dispersal of species that tend to return to their area of natal origin (philopatry) (Ortega et al. 2014). A few research studies have found that animal behavior involving acoustic signals (e.g., birdsong) can be impacted when wildlife abundance is reduced due to habitat degradation (Laiolo and Tella 2005, 2007; Laiolo et al. 2008; Barber et al. 2010; Ortega et al. 2014). Some changes that may be subtle but will have long-term implications to local populations include increased song similarity and reduced song diversity that results from declines in the number of song models available for juveniles to learn (Laiolo and Tella 2005, 2007; Laiolo et al. 2008; Briefer et al. 2010; Ortega et al. 2014).

Single introductions of an invasive species may result in limited genetic variation to an invasive population, whereas multiple introductions of the species may result in an increase in genetic diversity and contribute to its success as an invasive species (Lucardi et al. 2014). It is also widely reported in peer-reviewed literature that integration of invasive plant species into a natural community can disrupt native plant–pollinator relationships and networks (Memmott and Waser 2002; Bjerknes et al. 2007; Morales and Traveset 2009; van Hengstum 2013).

Cogongrass is an invasive perennial grass considered a major weed of forestlands, rights-of-ways, agricultural and disturbed lands, and natural ecosystems in the southeastern United States (Lucardi et al. 2014). It is considered to be one of the top 10 worst weeds in the world and is a federal noxious weed. Rhizomes have sharply pointed tips and form a dense interwoven mat usually within the upper foot of the soil surface. The thick root mat prevents native species from establishing or growing and enables Cogon Grass to out-compete native species for water and nutrient resources.

Beach Vitex is a quickly growing coastal landscape plant tolerant of salt and drought. It can reproduce through seed production (as high as 10,000 to 20,000 seeds per square meter) or broken shoot fragments from established plants that can be washed by storms onto beaches at great distance from each other. It forms dense cover on beach dunes and can inhibit growth of the native species Seabeach Amaranth, which is federally listed as threatened. It can also cover important beach nesting habitat for shorebirds that breed in North Carolina such as the Piping Plover (federally listed as endangered), American Oystercatcher, Black Skimmer, Common Tern, and Least Tern.

Genetically modified organisms (GMOs), also referred to as novel or synthetic organisms, are those in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination (OJEU 2001; Jeschke et al. 2013). Synthetic organisms are completely synthesized by humans and are typically built by assembling short DNA sequences to create new genomes (Preston 2008; Deplazes and Huppenbauer 2009; Jeschke et al. 2013). While it is reported that there are currently no known cases of a synthetic organism becoming established in the wild, GMOs and synthetic organisms can serve as novel hosts for emerging pathogens that can become established (Jeschke et al. 2013). Less diverse ecosystems may be more susceptible to invaders, and likewise, pathogens may be transmitted more readily in ecological communities with reduced diversity (Jeschke et al. 2013). Another concern related to the development and increased cultivation of GMOs is the potential escape of transgenes into native populations and the potential change to the phenotype of an organism and the effects of transgenes on natural ecosystems (Snow et al. 2005; Stewart et al. 2003; Andow and Zwahlen 2006; van Hengstum 2013).

5.10.3 SGCN Priority Species

The Taxa Team evaluation considered the level of threat invasive and problematic species and genes represents to SGCN priority species. Table 5.9 provides a list of species for which this threat category is consider very high or high.

Table 5.9 SGCN at very high or high threat from invasives and other problematic species and genes

Scientific Name	Common Name	Threat Level	
		Very High	High
AMPHIBIAN			
Necturus lewisi	Neuse River Waterdog		X
BIRD			
Charadrius wilsonia	Wilson's Plover		X
Haematopus palliatus	American Oystercatcher		X
Vermivora chrysoptera	Golden-winged Warbler	X	

Scientific Name	Common Name	Threat Level Very High	Threat Level High
CRAYFISH			
Cambarus reburrus	French Broad River Crayfish		X
Orconectes virginiensis	Chowanoke Crayfish		X
Procambarus ancylus	Coastal Plain Crayfish		X
Procambarus blandingii	Santee Crayfish		X
Procambarus medialis	Pamlico Crayfish		X
Procambarus plumimanus	Croatan Crayfish		X
FRESHWATER FISH			
Ameiurus brunneus	Snail Bullhead		X
Ameiurus platycephalus	Flat Bullhead		X
Carpiodes sp. cf. cyprinus	a carpsucker	X	
Carpiodes sp. cf. velifer	Atlantic Highfin Carpsucker		X
Clinostomus sp.	Smoky Dace		X
Etheostoma kanawhae	Kanawha Darter		X
Etheostoma vulneratum	Wounded Darter		X
Exoglossum laurae	Tonguetied Minnow		X
Hybopsis rubifrons	Rosyface Chub		X
Menidia extensa	Waccamaw Silverside		X
Moxostoma robustum	Robust Redhorse		X
Moxostoma sp. Carolina	Carolina Redhorse		X
Nocomis platyrhynchus	Bigmouth Chub		X
Notropis lutipinnis	Yellowfin Shiner		X
Notropis rubricroceus	Saffron Shiner		X
Notropis scabriceps	New River Shiner		X
Notropis sp. cf. rubellus	Kanawha Rosyface Shiner		X
Notropis volucellus	Mimic Shiner—New River Basin pop.		X
Noturus furiosus	Carolina Madtom		X
Noturus sp. 2	Broadtail Madtom		X
Percina gymnocephala	Appalachia Darter		X
Percina oxyrhynchus	Sharpnose Darter		X
Phenacobius teretulus	Kanawha Minnow		X
Pimephales notatus	Bluntnose Minnow		X
REPTILE			
Ophisaurus mimicus	Mimic Glass Lizard		X
SNAIL (TERRESTRIAL)			
Inflectarius verus	a snail		X

5.11 Pollution and Contaminants

Threats considered in this category are from introduction of exotic and/or excess materials or energy from point (e.g., waste treatment discharge, industrial effluents) and nonpoint sources (e.g., runoff from roads, lawns, golf courses); waterborne pollutants from industrial, resource extraction, energy

> production, and military sources; agricultural and forestry effluents such as herbicide and fertilizer runoff; garbage and solid waste from landfills, construction debris, and waterborne debris that can entangle wildlife; acid rain, smog and excess nitrogen deposition, radioactive emissions, smoke from fires, and other airborne pollutants; and excess energy sources (e.g., transportation noise, submarine sonar, beach lights). (Salafsky et al. 2008)

In addition to physical alteration of aquatic habitat, sediments and contaminants delivered through point and nonpoint sources magnify the level of threats to aquatic systems (TNC 2000). Point source pollution is delivered primarily in the form of municipal wastewater and stormwater discharges. The majority of water quality problems in North Carolina, however, stem from nonpoint source pollution associated with land-use activities such as development projects, forestry and agricultural practices, and road construction (NCDWQ 2000; SAMAB 1996). Agricultural pesticides, particularly neonicotinoids and fipronil, are having direct and indirect negative nontarget impacts on aquatic invertebrates and vertebrates (Gibbons et al. 2014).

5.11.1 Sewage, Solid Wastes, and Effluents—Anticipated Impacts

The National Pollutant Discharge Elimination System (NPDES) permit program administered by the NC Department of Environment and Natural Resources (NCDENR) regulates the discharge of point source pollution in our state. Permits establish limits on pollutants that must be met before wastewater is discharged to surface waters. Wastewater treatment technologies vary among wastewater treatment plants (WWTP). There is increasing concern over contaminants that are not currently treated by WWTPs or regulated by NPDES limits, such as endocrine-disrupting chemicals (EDCs). EDCs can be found in pharmaceuticals, personal care products, and various industrial compounds.

Stormwater runoff is a nonpoint pollutant that is mostly unregulated in North Carolina except in larger cities. Stormwater best management practices (BMPs), such as detention ponds, grassed swales, filter strips, and rain gardens slow down stormwater and reduce pollutant input as it travels to surface waters from construction sites, agricultural fields, and paved areas.

Aquatic systems can be impacted by wastewater discharges when effluent fails to meet regulatory limits, accidental spills of untreated wastewater occur, stream baseflows are low and a large percentage of streamflow is comprised of treated wastewater, and WWTPs are not equipped to properly treat all contaminants within wastewater that affect aquatic organisms. EDCs have been shown to affect immune and reproductive systems in freshwater mussels (Bouchard et al. 2009; Bringolf et al. 2010; Gagné et al. 2011) and in freshwater fish (Blazer et al. 2014; Gagné et al. 2011). Contaminants can lead to population-level impacts to species, including local extirpations.

Without appropriate stormwater BMPs, stormwater runoff following rain events can lead to erosion of cleared fields and construction sites, resulting in increased turbidity and sedimentation of nearby surface waters. Increased turbidity and sedimentation affects foraging and reproduction in streams and lakes and can lead to changes in community composition and species extirpation. Stormwater runoff also affects stream hydrology because there is more surface runoff and less infiltration. As a result, water reaches surface waters quickly, causing flows to increase quickly. An increase in imperviousness causes streamflows to increase more rapidly following rain events and subside more quickly. With less rainfall soaking into the ground, there is less groundwater to contribute to baseflows. This results in a flow regime that differs from the natural flow regime (Poff et al. 1997). These flow regime alterations can cause changes to the aquatic community, including local extirpation of species.

5.11.2 Chemicals and Toxic Compounds—Anticipated Impacts

Pesticides and herbicides are widely used to control pests and unwanted vegetation. However, they can also have unwanted deleterious effects on wildlife, especially if they are used in an unapproved manner. The agricultural insecticide DDT was banned due to environmental impacts; increases in Bald Eagle and Peregrine Falcon populations are partially attributed to the ban on DDT.

Lead shot, such as that used in ammunition and fishing line sinkers, has health implications for wildlife because of the potential for acute toxicosis from ingestion of the lead (Scheuhammer and Norris 1995; Keel et al. 2002; Butler et al. 2005; Clark and Scheuhammer 2003; Samour and Naldo 2005; Fisher et al. 2006; Hunt et al. 2006; Martin et al. 2008; Stevenson et al. 2005; Strom et al. 2005; Thomas et al. 2009; Pierce et al. 2015). Hunting regulations in North Carolina prohibit the use of any shotgun shells containing lead or toxic shot while hunting on any NCWRC posted waterfowl impoundment.

Pesticides and herbicides can impact wildlife that inhabit areas treated or areas adjacent to treated areas that receive overspray or drift, or through runoff from treated areas that reaches surface waters. Pesticides and herbicides can impact wildlife in several ways, such as reducing the foraging or prey base, damaging wildlife habitat, or direct contamination (Freemark and Boutin 1995). Pollutants can have various physiological effects on birds, causing stress and mortality of young and adults (Fry 1995).

Research initially focused on the potential lead poisoning in upland game birds but has expanded to include waterbirds that eat lead pellets or ingest lead sinkers and mammals that scavenge the remains of harvested animals (Thomas 2013). There has been growing awareness and concern about human ingestion of lead fragments from harvested game animals and the potential for serious lead exposure (Dobrowolska and Melosik 2008; Kosnett 2009;

Iqbal et al. 2009; Knott et al. 2010; Pain et al. 2010; Thomas 2013). Thomas (2013) suggests that the reluctance of hunters and legislators to support use of nontoxic rifle ammunition may be based on perceptions about availability, price, and effectiveness of substitute ammunition (such as steel, copper, or copper-zinc alloy shot). However, it was reported there are as many as 48 different hunting rifle cartridges manufactured in the United States that contain lead-free ammunition, and they are readily available from national retailers (Thomas 2013).

5.11.3 Airborne Pollutants—Anticipated Impacts

Animals are exposed to air pollutants through breathing, ingestion, or absorption through the skin (in the case of amphibians). The response of an organism depends on many factors, including the type of pollutant and the magnitude and duration of exposure. There are three general pollutant types: gases (e.g., ozone), non-acidic chemicals (e.g., metals, dioxins), and acidic chemicals (e.g., nitrates and sulfates). The burning of fossil fuels releases sulfur dioxide and nitrogen oxides, which are transformed in the atmosphere and returned as acid precipitation.

Gases generally affect animal respiratory systems. Metals may affect their circulatory, respiratory, gastrointestinal, and central nervous systems, particularly the kidney, liver, and brain. Dioxins bioaccumulate, or build up in the body by concentrating in body fat, and are resistant to biological breakdown. A study of earthworms showed they accumulated dioxins up to five times the concentration found in the soil. While not lethal to the worms, it could affect many bird and small mammal species that rely on them as a food source.

Acid rain reduces soil buffering capacity and eventually results in changes to vegetation and acidification of streams and surface waters. Many studies have shown that aquatic invertebrates, fish, and other organisms are greatly affected by low pH conditions, with species composition declining as pH drops. Acid rain impacts on fish are occurring in many countries, including the United States, but evidence in North Carolina is limited. Acid deposition is a possible cause of declines in amphibian populations, particularly those that use ephemeral waterbodies that are susceptible to precipitation events. Reproduction is most vulnerable because early life stages are more sensitive to changes in water chemistry.

Air pollutants also affect wildlife indirectly by causing changes in the ecosystem. Vegetation provides cover for protection from predators and weather, provides breeding and nesting habitat, and also serves as a food source. Therefore, any change in vegetation could indirectly affect animal populations.

5.11.4 Excess Energy—Anticipated Impacts

The most common expression of excess energy is light pollution. It alters and interferes with the timing of necessary biological activities, especially for crepuscular and nocturnal species by exposing them to predators and reducing the time they have to find food, shelter, or mates, and to reproduce.

Excessive lighting has been shown to alter the nesting behavior of sea turtles, causing females to cluster nests in areas shaded from lights, which leads to competition for nesting sites and damage to previously laid eggs (Salmon et al. 1995a). Once the nestlings hatch, light pollution causes them to become disoriented and have difficulty finding their way to the ocean, thus increasing predation and mortality (Salmon et al. 1995b).

Nocturnal animals are adapted to seeing in low light conditions; consequently, lights at night can blind these animals causing disruptions to migrations and local movements. Increased mortality due to road kill at night is common for species such as Opossum and skunks. Some salamanders show reduced night foraging behavior in the presence of artificial lights.

Of course light pollution has a dramatic effect on insects, killing or affecting countless numbers. Their altered behavior, in turn, affects animals that feed on them, such as bats and birds like the Common Nighthawk and Whip-poor-will.

Light pollution can send bird migrations off course, which can cause mortality. There are instances of spring migrants such as warblers becoming disoriented by lights in a fog and flying into a building, killing hundreds of the birds.

5.11.5 SGCN Priority Species

The Taxa Team evaluation considered the level of threat pollution and contaminants represents to SGCN priority species. Table 5.10 provides a list of species for which this threat category is consider very high or high.

Table 5.10 SGCN at very high or high threat from pollution and contaminants

Scientific Name	Common Name	Threat Level	
		Very High	High
AMPHIBIAN			
Desmognathus auriculatus	Southern Dusky Salamander		X
Desmognathus imitator pop.1	Imitator Salamander—Waterrock Knob pop.		X
Hemidactylium scutatum	Four-toed Salamander		X
Necturus lewisi	Neuse River Waterdog		X

Table 5.8 SGCN at very high or high threat from pollution and contaminants (cont.)

Scientific Name	Common Name	Threat Level	
		Very High	High
Necturus punctatus	Dwarf Waterdog		X
Pseudotriton montanus montanus	Eastern Mud Salamander		X
Pseudotriton ruber	Red Salamander		X
Siren intermedia intermedia	Eastern Lesser Siren		X
Siren lacertina	Greater Siren		X
Stereochilus marginatus	Many-lined Salamander		X
BIRD			
Gavia immer	Common Loon		X
CRAYFISH			
Cambarus reburrus	French Broad River Crayfish		X
FRESHWATER FISH			
Acipenser brevirostrum	Shortnose Sturgeon		X
Aplodinotus grunniens	Freshwater Drum		X
Erimonax monachus	Spotfin Chub		X
Etheostoma thalassinum	Seagreen Darter		X
Heterandria formosa	Least Killifish	X	
Hiodon tergisus	Mooneye		X
Notropis volucellus	Mimic Shiner—French Broad River Basin pop.		X
Noturus eleutherus	Mountain Madtom	X	
Noturus flavus	Stonecat	X	
Noturus furiosus	Carolina Madtom		X
Noturus gilberti	Orangefin Madtom	X	
Percina burtoni	Blotchside Logperch		X
Percina rex	Roanoke Logperch		X
FRESHWATER MUSSEL			
Alasmidonta heterodon	Dwarf Wedgemussel		X
Alasmidonta undulata	Triangle Floater		X
Anodonta couperiana	Barrel Floater		X
Elliptio marsupiobesa	Cape Fear Spike		X
Elliptio steinstansana	Tar River Spinymussel		X
Elliptio waccamawensis	Waccamaw Spike		X
Fusconaia masoni	Atlantic Pigtoe		X
Lampsilis fullerkati	Waccamaw Fatmucket		X
Lasmigona decorata	Carolina Heelsplitter		X
Toxolasma pullus	Savannah Lilliput		X
Villosa constricta	Notched Rainbow		X
Villosa modioliformis	Eastern Rainbow		X

Scientific Name	Common Name	Threat Level Very High	Threat Level High
Villosa vaughaniana	Carolina Creekshell		X
REPTILE			
Caretta caretta	Loggerhead Sea Turtle		X
Chelonia mydas	Green Sea Turtle		X
Dermochelys coriacea	Leatherback Sea Turtle		X
Lepidochelys kempii	Kemp's Ridley Sea Turtle		X
SNAIL (AQUATIC)			
Helisoma eucosmium	Greenfield Rams-horn	X	
SNAIL (TERRESTRIAL)			
Inflectarius verus	a snail		X

5.12 Climate Change

> Long-term climatic changes that may be linked to global warming or other severe climatic or weather events outside the natural range of variation are the focus of this threat category. Related concerns are habitat shifts and alterations such as sea-level rise, coral bleaching, and desertification; droughts and sustained periods where rainfall falls below normal ranges; temperature extremes such as heat waves, cold spells, and oceanic temperature changes; and extreme weather events and shifts in seasonality of storms that cause flooding, damage, and can impact wildlife. (Salafsky et al. 2008)

The report "Understanding the impacts of climate change on fish and wildlife in North Carolina" outlines expected effects of climate change to North Carolina's wildlife (DeWan et al. 2010). An Executive Summary is provided in Appendix B and a copy of the full report is available in PDF format for download: "Understanding the impacts of climate change on fish and wildlife in North Carolina." Chapter 3 of the report provides information on temperature, precipitation, and sea level rise (sea level rise), and discusses future projections and impacts on species and habitats. Chapter 4 focuses on the interaction of climate change impacts with various other threats to habitat, such as destruction, degradation, land-use changes, pollution, and nonnative species.

Climate shapes the structure and function of natural ecosystems, and increased variability and weather extremes such as drought, heavy rain, and storm events are expected to have greater impacts than temperature alone (Vose et al. 2014). Changes to forests due to dieback, insect outbreaks, and large wildfires may be signals that rapidly changing climate conditions are amplifying ecosystem changes (Vose et al. 2014). Climate change can impact hydrologic processes and water resources directly by altering precipitation, evapotranspiration, groundwater table, soil moisture, or streamflow, and indirectly by degrading water quality or reducing the water available for irrigation.

The National Climate Assessment (NCA) was developed through a collaborative effort between numerous federal and state agencies and climate science experts and summarizes current and future impacts of climate change on the United States (Melillo et al. 2014). The report indicates the Southeast region is exceptionally vulnerable to sea level rise, extreme heat events, hurricanes, and decreased water availability associated with population growth, though the effects will not occur evenly across the landscape. Damages to infrastructure by sea level rise, heavy downpours, and extreme heat are projected to increase with continued climate change.

Climate change also directly affects biodiversity; for example, when environmental conditions change too quickly for species to adapt to them or migrate to areas with more suitable conditions if such areas still exist (Bellard et al. 2012).

The following section provides additional information about three climate change topics expected to impact wildlife: sea level rise, temperature changes, and precipitation changes.

5.12.1 Sea Level Rise—Anticipated Impacts

In simple terms, sea level is the average height of the ocean surface and it is typically measured along a coastline in relation to fixed land positions. Sea level is influenced by several factors, such as ice melt from glaciers and ice masses, and thermal expansion of sea water, which are caused by increased air and water temperatures. Given these influences, sea level naturally fluctuates to some degree on a daily basis because water inputs, ambient temperatures, evaporation, and lunar cycles will vary not only between locations but also on a global scale (NCDCM 2012).

Tide gauge stations located along the coast are used to measure local changes in water elevations and are able to measure changes in land mass that occur from subsidence, shifts, and tectonic plate movements. These types of ocean and land elevation measurements have been collected by the National Oceanic and Atmospheric Administration (NOAA) over time in several locations along North Carolina's coast (Figure 5.41).

The resulting data are used to derive relative sea level elevations along North Carolina's coast. References are provided at the end of this chapter for additional information on sea level rise and datasets that are publically available from federal and state agencies and research organizations (NOAA 2013).

According to vulnerability assessments (Boruff et al. 2005; Sallenger et al. 2012), North Carolina's coastline is one of the areas considered to have significant vulnerability to sea level rise.

Figure 5.1 **National Ocean Service Tides & Currents Stations (North Carolina)**
***Source*: http://tidesandcurrents.noaa.gov/products.html**

A report by the NC Coastal Resources Commission's Science Panel on Coastal Hazards (NCDCM 2015) notes both geological and tide gauge data provide evidence there is more land subsidence to the north of Cape Lookout than to the south. This contributes to higher measured rates of sea level rise along the state's northeastern coast (NCDCM 2015). The Science Panel's report compares the range of estimated sea level rise over a 30-year period based on three projection scenarios. The results show that the highest and lowest potential increase in mean sea level varies from 2.7 inches at Duck (northernmost area) to 4.5 inches at Southpoint (southernmost area) (NCDCM 2015). This variability is evidence of the uncertainty in predictions, especially at longer time scales, and the spatial differences along the state's coast.

Two of the greatest threats posed by sea level rise to fish and wildlife in North Carolina are loss of marsh and wetland habitats because of erosion and flooding, and the expected increase in salinity of coastal aquifers, freshwater drainage basins, and estuarine systems because of saltwater intrusion (Neumann and Hearty 1996). DeWan et al. (2010) notes that coastal habitats, such as maritime forests and shrub communities, estuarine communities, tidal swamp forests and wetlands, and beach and dune habitats, will be the most susceptible habitats to the effects of sea level rise.

Saltwater intrusion into freshwater aquifers and drainage basins can threaten the biodiversity of freshwater tidal marshes and contaminate municipal, industrial, and agricultural water supplies (Marion et al. 2014; Bear et al. 1999). Connectivity between habitats and modified landscapes will become even more important as species are forced to shift their ranges inland because vegetation is converted to open water or dies off from the influence of higher salinity of surface waters. Migratory fishes and the freshwater stream ecosystems they use for portions of their life cycle will be adversely affected by saltwater intrusion, especially if upstream freshwaters where the salt wedge has not historically been recorded becomes brackish (Roessig et al. 2004; Love et al. 2008). Movement upstream to freshwater refugia can be impeded if there are barriers to movement, such as dams and hydraulic conveyances under roadways (i.e., culverts and pipes). Sea turtles and beach-nesting shorebirds will be impacted by sea level rise through loss of nesting habitats by erosion and inundation and flooding of nests that result in egg mortality (Fuentes et al. 2010).

5.12.2 Temperature Changes—Anticipated Impacts

Higher seasonal and overall temperatures can affect the phenology (seasonal timing) of certain activities, such as migration, breeding, or leaf emergence (Leicht-Young et al. 2013). Since it can affect species differently, it can result in a mismatch between an animal and its required food source or other essential need. Some plants are producing flowers earlier due to warmer conditions, while others are blooming later because of insufficient duration of necessary cold conditions (Marchin et al. 2015). So-called false springs have been shown to damage flowers and thus affect wildlife that rely on the fruit. It is not clear, however, if phenological changes are actually damaging to a given species or an adaptation to changing conditions.

Some hunting or fishing harvest seasons have traditionally been timed to coincide with certain life stages of target fish and wildlife. Shifts in phenology can cause a mismatch of the harvest season and the size or condition of the animal (Peer and Miller 2014). Traditional hunting seasons may have to be adjusted not only to benefit the hunter, but also to avoid impacting the wildlife population. For the most part, this is not an issue for freshwater fishing because there typically are no closed fishing seasons. However, there are seasonal considerations for Striped Bass and some marine species.

Sea turtle populations will be affected by erosion of beach nesting areas; sand temperatures that influence sex determination of hatchlings toward females (no male hatchlings); temperatures that exceed the upper limit for egg incubation (34°C) to occur at all; and loss of sea grass bed and coral reef feeding grounds from warming ocean waters.

Growing seasons are becoming longer in the Southeast, nighttime air temperatures are warmer, and precipitation events are becoming more extreme (McNulty et al. 2014; Fischlin et al. 2007). Ground temperatures that are higher than normal winter seasonal ranges are associated with milder winters and may cause earlier onset of spring conditions. There is evidence that plants that have evolved to emerge annually based on persistent soil temperatures are now blooming as many as 10 days earlier than previously documented. Many wildlife species will be affected by a disconnect between availability of food resources and young produced during the spring. Birds that migrate earlier in response to warming temperatures may experience greater competition for food and cover resources when there are disconnects between occurrence and availability.

Climate-change-driven warming could expand the northern ranges for many invasive insect species (Vose et al. 2014). Climate change could also indirectly affect insect populations through impacts on natural enemies, important insect symbionts, host physiology, and host range distributions. Future warmer winter temperatures could remove existing range barriers for some native species. This could result in spread into places where hosts are currently abundant and result in competition between native and nonnative insect species.

5.12.3 Precipitation Changes—Anticipated Impacts

Climate change is expected to directly impact water resources through changes to the amount, form (fog, rain, snow, ice), and timing of precipitation (Marion et al. 2014). These changes will influence the quantity of baseflow and stormflow and the frequency of groundwater recharge and flooding (Marion et al. 2014; Karl et al. 2009). Changes in precipitation amount or storm intensity can affect soil erosion potential by changing the runoff amount, the kinetic energy of rainfall, or the vegetation cover that resists erosion (Marion et al. 2014). Models used by the Intergovernmental Panel on Climate Change (IPCC) show changes in precipitation will strongly influence future variability in wet and dry summer patterns over the southeastern United States (Li et al. 2011).

The science of predicting precipitation changes for North Carolina is still young and no clear trends are evident (NCSCO n.d.; Wootten et al. 2014). Recent changes in precipitation in some parts of the state may be related to decadal oscillation (Sayemuzzamana and Jha 2014). Some climate change models indicate that total amounts of precipitation may not change much, but the intensity and duration of events, both storms and droughts, will increase. This could mean that the extreme or infrequent conditions may be a more influential abiotic factor than these habitats and wildlife communities are accustomed to. There are more than 100 years of weather and climate observation records from several locations in the southeast, but there are typically fewer than 5 years of observation records of ecosystems (Wootten et al. 2014). There is much uncertainty in understanding the relationship between climate change and ecological response because of the lack of overlapping data sets.

With projected decreases in water availability, future population growth will increase stress over water supplies across much of the South by 2060, particularly in developing watersheds (Marion et al. 2014). Projections of water supply demand in the Raleigh–Durham metropolitan area estimate a 14% decrease in water supply from the Upper Neuse River watershed in conjunction with an estimated 21% increase in water demand (Marion et al. 2014).

The amount and timing of precipitation will affect annual amphibian reproduction because most species lay eggs in water, often seasonal and ephemeral wetland systems (Saenz et al. 2013).

Increased drought conditions and warming temperatures will contribute to the potential for increased wildfires in the Atlantic coast in summer and early autumn (Vose et al. 2014). Dynamic vegetation models indicate there will be an increase in the fuel loading in eastern areas of the South (Vose et al. 2014). Long-term drought may result in stress to vegetation.

Projected dryness is expected to influence fire season by increasing duration as much as five months longer in the Appalachian Mountains (Vose et al. 2014). Where development and population growth occur, there will be a greater potential threat to life and property from wildfires. The growing presence of people will also increase the risk of wildfire ignitions from human-ignited wildfires (Vose et al. 2014). Climate change could alter fuel loading by changing plant productivity and decomposition rates, as well as by causing shifts in species distribution. Warmer and drier conditions would result in more fuel being consumed (Liu et al. 2013).

5.12.4 SGCN Priority Species

The Taxa Team evaluation considered the level of threat climate change represents to SGCN priority species. Table 5.11 provides a list of species for which this threat category is consider very high or high.

TABLE 5.11 SGCN at very high or high threat from climate change

Scientific Name	Common Name	Threat Level: Very High	Threat Level: High
AMPHIBIAN			
Aneides aeneus	Green Salamander		X
Desmognathus imitator pop.1	Imitator Salamander—Waterrock Knob pop.		X
Rana [Lithobates] capito	Carolina Gopher Frog	X	
Rana sylvatica [Lithobates sylvaticus] pop.3	Wood Frog—Coastal Plain pop.	X	
Necturus maculosus maculosus	Common Mudpuppy		X

Scientific Name	Common Name	Threat Level	
		Very High	High
Plethodon richmondi	Southern Ravine Salamander		X
Plethodon wehrlei	Wehrle's Salamander		X
Plethodon welleri	Weller's Salamander		X
BIRD			
Ammodramus caudacutus	Saltmarsh Sharp-tailed Sparrow		X
Ammodramus leconteii	Le Conte's Sparrow		X
Ammodramus maritimus	Seaside Sparrow		X
Ammodramus nelsoni	Nelson's Sharp-tailed Sparrow		X
Anas rubripes	American Black Duck		X
Arenaria interpres	Ruddy Turnstone		X
Branta bernicla	Brant		X
Calidris alba	Sanderling		X
Calidris canutus	Red Knot		X
Calidris pusilla	Semipalmated Sandpiper		X
Charadrius semipalmatus	Semipalmated Plover		X
Charadrius wilsonia	Wilson's Plover		X
Cistothorus palustris	Marsh Wren		X
Cistothorus platensis	Sedge Wren		X
Gelochelidon nilotica	Gull-billed Tern	X	
Haematopus palliatus	American Oystercatcher		X
Hydroprogne caspia	Caspian Tern		X
Ixobrychus exilis	Least Bittern		X
Laterallus jamaicensis	Black Rail		X
Limnodromus griseus	Short-billed Dowitcher		X
Limnodromus scolopaceus	Long-billed Dowitcher		X
Limosa fedoa	Marbled Godwit		X
Numenius phaeopus	Whimbrel		X
Pelecanus occidentalis	Brown Pelican		X
Pluvialis squatarola	Black-bellied Plover	X	
Pooecetes gramineus	Vesper Sparrow		X
Rallus elegans	King Rail		X
Rallus longirostris	Clapper Rail		X
Rynchops niger	Black Skimmer	X	
Sterna antillarum	Least Tern	X	
Sterna forsteri	Forster's Tern	X	
Sterna hirundo	Common Tern	X	
Thalasseus maximus	Royal Tern		X
Thalasseus sandvicensis	Sandwich Tern		X
Tringa semipalmata	Willet		X
Vermivora chrysoptera	Golden-winged Warbler		X

Table 5.11 SGCN at very high or high threat from climate change (cont.)

Scientific Name	Common Name	Threat Level	
		Very High	High
FRESHWATER FISH			
Salvelinus fontinalis	Brook Trout (Native)		X
REPTILE			
Chelonia mydas	Green Sea Turtle		X
Lepidochelys kempii	Kemp's Ridley Sea Turtle		X
Dermochelys coriacea	Leatherback Sea Turtle		X
Caretta caretta	Loggerhead Sea Turtle		X
SNAIL (AQUATIC)			
Helisoma eucosmium	Greenfield Rams-horn	X	
SNAIL (TERRESTRIAL)			
Inflectarius verus	a snail		X

5.13 Disease and Pathogens

> This threat focuses on diseases, viruses, bacteria, prions, and other pathogens that can affect wildlife species. Some topics are wildlife-specific while others may not normally infect wildlife but can be carried over from other vectors.

All wildlife species are subject to some type of naturally occurring disease that can cause illness and death to individual animals or in some cases can significantly impact population densities (McLean 2005). It has been reported that disease resistance depends on the interaction of host, pathogens, and environment (Snieszko 1970). This subsection provides information about some of the most serious diseases or emerging concerns that can significantly impact wildlife species or create spillover effects to humans. The following information highlights some of the important concerns and identifies resources for additional information.

In many cases, the spread of disease among and between species is controlled naturally and there is little risk of extinction when mortality occurs within a population. However, management actions to control the incidence and spread of disease may be warranted when disease impacts are so severe that local populations are at risk of becoming extinct, or when mortality from diseases is so severe that it affects ecological processes and/or exceeds the social capacity for acceptance. Management may also be warranted when genetic flow will be disrupted between populations or when there is a risk of spillover to human or domestic animal populations.

Wildlife can serve as a reservoir for diseases and pathogens that naturally occur within wildlife populations with little effect on populations but which have the potential to create spillover effects that affect human health. Examples of diseases that can spillover from wildlife to humans include tickborne diseases (e.g., Lyme disease, *Ehrlichiosis*, Rocky Mountain spotted fever), leprosy, brucellosis, ebola, rabies, and hantaviruses to name a few. Newly introduced diseases can be carried by exotic nonnative species, or captive-raised animals that have been released to the wild. Unnatural high densities facilitated by wildlife feeding and baiting can lead to increased densities of wildlife species and comingling, increasing the prevalence and transmission rates of wildlife disease. When disease in wildlife is associated with human behaviors, steps to educate the public and reduce the incidence of such behaviors should be implemented in an effective way.

In some cases, wildlife may develop diseases or conditions they would not normally have but which are the result of human-induced conditions. Examples include the incidence of pancreatic cancer, diabetes, intersex malformations, and tooth decay. Black Bears have been found with tooth decay likely caused by consumption of bait foods containing high concentrations of sugar. Another example is of freshwater fish species that exhibit intersex characteristics because of exposure to EDCs and hormone-mimicking chemicals found in wastewaters discharged into surface waters.

In North Carolina, certain diseases and conditions are reportable to the Department of Health and Human Services, including diseases that affect wildlife or those for which wildlife can be a vector for human infection. A list of reportable diseases and information on each is available at http://epi.publichealth.nc.gov/cd/report.html#which. Additional information on wildlife diseases is available from the USGS National Wildlife Health Center (NWHC), which conducts research and publishes information about a number of wildlife disease issues (http://www.nwhc.usgs.gov/disease_information). The Wildlife Disease Association (www.wildlifedisease.org) is a membership organization that acquires, disseminates, and applies knowledge of the health and disease of wild animals in relation to their biology, conservation, and ecology, including interactions with humans and domestic animals.

5.13.1 Amphibians—Anticipated Impacts

Worldwide amphibian population declines have been attributed to numerous causes, primarily anthropogenic, but an increasing threat with significant impacts comes from Chytridiomycota fungus (e.g., chytrid) and Iridoviridae pathogens (e.g., ranaviruses) (Harp and Petranka 2006). Fungal diseases have been linked to the global declines and extinctions in amphibian populations because they often interfere with the animal's ability to regulate body fluids and osmotic pressure, which eventually leads to death (Briggs et al. 2010; Rollins-Smith et al. 2011; McCallum 2012). Stressors such as pollution, habitat changes, and climate change can increase the likelihood of a population being severely impacted by these pathogens. While treatment of individual populations is difficult, protocols are being investigated through various scientific research programs (Rollins-Smith et al. 2011). Current measures to prevent extinction and preserve genetic diversity primarily involve captive breeding of healthy animals for reintroduction to areas where the fungus is not present and protection of populations unaffected by disease through conservation actions.

Batrachochytrium dendrobatidis (Bd) is an infectious fungus that can be introduced to water and soils by infected animals and has been found to affect numerous amphibian species, especially Anurans, including species found in North Carolina (Parris and Beaudoin 2004). This fungus is known to kill from 50% to 80% of the individuals in infected populations, and surviving animals or other host animals can maintain the infection in the population (Gagliardo et al. 2008; Cheng et al. 2011; Blaustein et al. 2012; McMahon et al. 2012; Phillips and Puschendorf 2013; Louca et al. 2014). Some amphibian species are protected from infection by their skin mucus excretions, but exposure to pesticides can alter immune defense and lead to susceptibility to parasites and pathogens (Lannoo 2009; Rohr et al. 2008; Rollins-Smith et al. 2011).

Ranaviruses are associated with diseases in wild and cultured fishes, amphibians, and reptiles (Robert et al. 2007; Gray et al. 2007a; Brunner et al. 2015). They are reported to be most lethal to amphibian larvae with mortality rates as high as 90% or more (Harp and Petranka 2006; Gray et al. 2007). In the United States, there is a high risk of exposure for wild populations to the ranavirus Frog Virus 3 (FV3). Host reservoirs for FV3 include exotic species such as African Clawed Frogs (*Xenopus laevis*), which are commonly raised in captivity for the pet trade and sold across the United States, when they are released into the wild (intentionally or accidentally) (Robert et al. 2007). The *Regina ranavirus* is highly infectious and can be virulent to Caudata (urodela) amphibians such as the common Tiger Salamander, likely because they lack natural antimicrobial peptides associated with the more evolved immunosystems of other amphibian taxa (Froese et al. 2005; Sheafor et al. 2008). Ranaviruses present at aquaculture facilities can be 2–10 times more lethal than wild strains and can pose a particular risk to frogs in the Ranidae family, thereby contributing to their population declines (Hickling 2011).

5.13.2 Birds—Anticipated Impacts

According to the NWHC, avian vacuolar myelinopathy (AVM) is a recently discovered neurological disease affecting waterbirds, primarily Bald Eagles and American Coots, in the southern United States. AVM has also been confirmed as the cause of death in Mallards, Buffleheads, Ring-necked Ducks, Canada Geese, Killdeer, and a Great Horned Owl. Birds affected with AVM lack muscle coordination and therefore have difficulty flying and swimming. The cause of the disease is unknown, but has been linked through the food chain from plants to waterfowl to predators. A cyanobacterium is possibly the root cause.

West Nile Virus (WNV) can infect a number of animals, including humans, horses, and birds. It was first documented in the United States in 1999 and has spread throughout North America. Birds do not normally show any symptoms of WNV infection, but serve as natural reservoirs of the virus. However, some avian species, such as crows, appear to be susceptible to the virus. WNV was first documented in raptors in the summer of 2002. Since that time, this disease has been diagnosed in Bald Eagles in South Carolina as well as other states. There is some evidence that WNV has spread globally in part through transmission by migratory birds introducing the virus to other wildlife and humans (Rappole and Huba´lek 2003; Verhagen et al. 2014).

Avian influenza (bird flu) is a disease caused by any one of several influenza subtypes that can affect birds because they are a host reservoir (Alexander 2000; Kilpatrick et al. 2006; Olsen et al. 2006; Munster et al. 2007; Dugan et al. 2008; Verhagen et al. 2014). Research has documented a high prevalence for infection in migratory ducks, geese, and swans (order Anseriformes) and in gulls, terns, and shorebirds (order Characdriiformes) (Webster et al. 1992; Alexander 2000; Olsen et al. 2006; Munster et al. 2007). The prevalence of infection during fall migration may occur because of the large number of birds that occur in concentrated areas and because there are a higher number of immunologically susceptible young of the year in the population (Webster et al. 1992; Hinshaw et al. 1985; Sharp et al. 1993; Munster et al. 2007). Surveillance to detect the disease and monitoring of infected populations to determine impacts is needed before appropriate management strategies can be developed.

5.13.3 Crayfishes—Anticipated Impacts

Relatively little published research is available concerning crayfish diseases and much of the work is from Australia and Europe. Edgerton et al. (2002) provide a synopsis of crayfish diseases and pathogens. Most disease agents (viruses, bacteria, etc.) cause only limited impacts to crayfish (Longshaw 2011). Disease in freshwater crayfish can result from abiotic factors such as adverse environmental conditions, poor nutrition, and exposure to waterborne toxicants or biotic factors such as viruses, parasites, or microorganisms (Edgerton et al. 2002). Crayfish aquaculture production provides an opportunity to better monitor health status and detect pathogen and disease transmission because population densities allow efficient transfer of disease between individuals.

5.13.4 Mammals—Anticipated Impacts

White-nose syndrome (WNS) is a disease of hibernating bats that has spread from the northeastern to the central United States. Since the winter of 2007–2008, millions of insect-eating bats in 25 states and five Canadian provinces have died from this disease. The fungus *Pseudogymnoascus destructans* is known to cause WNS in hibernating and colonially roosting bat species. Current estimates of bat population declines in the northeastern United States since the emergence of WNS are approximately 80%. It is suspected that human use of caves is spreading the disease so some jurisdictions have closed or limited entry to caves. Despite these precautions, the disease continues to spread. The ecological consequences of these declines is likely to impact agricultural operations because bats are primary consumers of insects, and a recent economic analysis indicated that insect suppression services (ecosystem services) provided by bats to US agriculture are valued at between 4 and 50 billion dollars per year (USGS NWHC 2013).

Chronic Wasting Disease (CWD) is a disease of the nervous system in deer and elk (family Cervidae) that is characterized by spongy degeneration of brain tissue resulting in emaciation, abnormal behavior, loss of bodily functions, and ultimately death. There currently is no treatment for the disease and it is typically fatal for infected animals. It is not known to infect livestock or humans at the present (USGS NWHC 2013). The US Centers for Disease Control and the World Health Organization indicates there is no evidence that CWD can be transmitted to humans or linked to any neurological diseases of humans (NCWRC 2014).

According to the Chronic Wasting Disease Alliance, CWD has been confirmed in at least 19 states and in Canada, but is not yet known in North Carolina. The NCWRC has had a preventative disease management strategy since 2002, when rules were adopted to prevent the introduction of the disease into the state and to minimize the spread of disease should it be found in the state. The strategy includes implementing administrative rules (15A NCAC 10B) on holding deer and elk in captivity and monitoring activities that collect samples from harvest and road-kill deer to find evidence of the disease. In 2014, the NCWRC developed a CWD response plan (currently in draft form) that outlines management actions designed to prevent the introduction or spread of CWD in the state and increase the likelihood of detecting the disease should it occur.

Epizootic Hemorrhagic Disease (EHD) is a virus that causes fluid in the lungs of White-tailed Deer populations. Dead deer are often found by hunters near sources of water, such as lakes, swamps, and wetlands. These wet areas are breeding areas for the gnats and other small biting insects that are carriers for the virus.

Canine Distemper is a disease that occurs in foxes, coyotes, skunks, and raccoons during the spring and fall. Infection typically does not create significant impacts to populations. However, local extinctions can occur when the disease occurs in isolated or remote populations and there is a lack of natural gene flow from other areas. This disease also has a high potential for exposure and spillover to domestic animals, especially unvaccinated dogs that come into contact with infected wildlife. It has been reported that distemper and rabies infections in wildlife can be hard to visually distinguish as early symptoms appear to be similar (salivating, disorientation, lethargy or aggressiveness, aimless wandering) (Stoffregen and Dubey 1991).

Brainworm Disease affects the nervous system of deer and elk (family Cervidae). Anderson (1972) notes that White-tailed Deer are the usual host for the parasitic Meningeal Worm (*Paralaphostrongylus tenuis*) and that larvae of the parasite that are shed in fecal matter can infest terrestrial mollusks (snails and slugs). Deer and elk can become infected by accidentally ingesting gastropods containing small numbers of infective larvae. Several terrestrial snail species found in hardwood forests have been indicated as a potential vector for Meningeal Worm. In North Carolina, snails in the *Anguispira* and *Discus* genus are suspected to be a vector. Little research has been published about transmission and infection of this parasite.

5.13.5 Reptiles—Anticipated Impacts

Snake Fungal Disease (SFD) is an emerging disease in certain populations of wild snakes in the eastern and midwestern United States. The NWHC has diagnosed several species with SFD, including species found in North Carolina such as Northern Water Snake, Eastern Racer, Rat Snake, Timber Rattlesnake, Pygmy Rattlesnake, and Milk Snake. According to the NWHC, population-level impacts of the disease are not yet widely known and are difficult to assess due to the cryptic and solitary nature of snakes, and a general lack of long-term monitoring data.

5.13.6 Freshwater Fishes—Anticipated Impacts

Diseases are a significant threat to the health of free-ranging and hatchery-reared populations of fishes, including a suite of important sport and restoration species (Starliper 2008). Most of the diseases are bacterial and infection can be spread throughout the water column, making it difficult to detect and treat affected populations. Examples of bacterial disease and the species affected include *Renibacterium salmoninarum* (bacterial kidney disease in salmonids); *Aeromonas* spp. (septicemic diseases, furunculosis, in salmonids); *Edwardsiella* spp. (warmwater fishes); *Novirhabdovirus* sp. (petechial hemorrhage, exophthalmia and internal organs congestion in Muskellunge, Yellow Perch, Freshwater Drum, Smallmouth and Rock bass, Redhorse spp.) (Ellis 1997; Austin and Austin 1999; Emmerich and Weibel 1890; McCarthy and Roberts 1980; Millard and Faisal 2012; Diamanka et al. 2014).

In 2014, Brook Trout in several streams were found to be infested with Gill Lice *Salmincola edwardsii*. In 2015, Rainbow Trout in three separate river basins were found to be infected with Gill Lice *S. californiensis*. This was the first time that Gill Lice have been documented in NC waters. Gill Lice, which are actually copepods, attach to a fish's gills, which can traumatize gills and inhibit the fish's ability to breathe. While most fish are able to tolerate a moderate infestation of Gill Lice, if they are suffering from other stressors, such as drought and high water temperatures, fish kills and population impacts are more likely to occur. Relatively little research has been conducted for these two Gill Lice species. A better understanding of their distribution and life history traits will assist the determination of which fish populations may be most at risk of experiencing detrimental effects due to infestation and mitigating negative consequences of these infections (Vigil et al. 2015).

Three *Flavobacterium* species (*F.psychrophilum*, *F.columnare*, and *F.psychrophilum*) cause several diseases that result in mortality to freshwater hatchery-reared and wild fishes (Starliper 2011). These particular *Flavobacterium* pathogens are ubiquitous in temperate freshwater aquatic environments, within a wide range of water temperatures from just above freezing to 30°C (86°F) and above (Starliper 2011). *F.psychrophilum* causes bacterial coldwater disease, which is usually fatal to coldwater fishes such as trout (Starliper 2011). Chronic inflammation associated with the disease causes spiral or erratic swimming behaviors and/or spinal column deformities that are similar to symptoms associated with whirling disease.

In 2015, whirling disease was detected in the state in Rainbow Trout from the Watauga River. Whirling disease infects young salmonids (i.e., trout, salmon) and is caused by the myxosporean parasite *Myxobolus* [*Myxosoma*] *cerebralis* (Snieszko 1975; Sarker et al. 2015). This parasite causes physical deformities that cause fish to swim in circles and is particularly fatal for young Rainbow Trout (Sarker et al. 2015). The life cycle of the parasite alternates between two hosts: salmonid fishes and an aquatic oligochaete host Sludge Worms (*Tubifex tubifex*). Sludge Worms are a common oligochaete found in stream and lake sediments and are infected by feeding on sediments containing the parasite (Gilbert and Granath 2002; Sarker et al. 2015). Spores developed in the host are released into the water column where they attach and infect fishes. Infected fish can develop skeletal deformaties, may swim in circles, and ultimately will die as a result of the disease. Spores are released back into sediments when fish die, thereby repeating the cycle (Ayre et al. 2014; Sarker et al. 2015). Eutrophic impoundments and organically enriched streams are thought to contribute to the infection cycle (Thompson 2011) because density of *T.tubifex* populations are greater when organic content in sediments are high (Robbins et al. 1989; DuBey and Caldwell 2003; DuBey 2006). McGinnis and Kerans (2013) hypothesized that areas with higher residential, agricultural, and disturbed areas, higher road densities, and lower riparian cover would contribute sedimentation to trout waters that result in favorable habitat for Sludge Worms.

5.13.7 Pollinators—Anticipated Impacts

Introduced pathogens from the commercial bumble bee industry are suspected as potential contributors to significant bumble bee declines throughout North America (Cameron et al. 2011; Colla et al. 2006; Otterstatter and Thomson 2008; Murray et al. 2013). Declines in bumble bee species may be associated with the introduction of pathogens imported on a species of native bumble bee reared in Europe and reintroduced for pollination of crops in the United States (primarily for blueberry, cranberry, and greenhouse tomato production) (Cameron et al. 2011).

5.13.8 SGCN Priority Species

The Taxa Team evaluation considered the level of threat climate change represents to SGCN priority species. Table 5.12 provides a list of species for which this threat category is consider very high or high.

Table 5.12 SGCN at very high or high threat from disease and pathogens

Scientific Name	Common Name	Threat Level: Very High	Threat Level: High
AMPHIBIAN			
Rana [Lithobates] capito	Carolina Gopher Frog		X
BIRD			
Pelecanus occidentalis	Brown Pelican		X
Gavia immer	Common Loon		X
MAMMAL			
Myotis septentrionalis	Northern Bat		X
Myotis sodalis	Indiana Bat		X
Myotis lucifugus	Little Brown Bat		X

References

[ABC] American Bird Conservancy. 2011. Rulemaking petition to the U.S. Fish & Wildlife Service for regulating the impacts of wind energy projects on migratory birds. Washington (DC); [accessed 2015 July]. 109 p. http://www.jacksonkelly.com/JK/pdf/wind_rulemaking_petition.pdf.

[ABC] American Bird Conservancy. 2015. Rulemaking petition to the U.S. Fish & Wildlife Service for regulating the impacts of wind energy projects on migratory birds. Washington (DC); [accessed 2015 July]. 115 p. http://www.windaction.org/posts/42831-abc-petition-for-new-regulations-governing-wind-energy-impacts-on-birds.

[ACRP] Airport Cooperative Research Program. 2011. Bird harassment, repellent, and deterrent techniques for use on and near airports, Synthesis 23. Belant JL, Martin JA, editors. Washington (DC): Transportation Research Board of the National Academies; [accessed 2015 July]. 44 p. http://onlinepubs.trb.org/onlinepubs/acrp/acrp_syn_023.pdf.

Allan JR. 2002. The costs of bird strikes and bird strike prevention. In: Clark L, Hone J, Shivik JA, Watkins RA, Vercauteren KC, Yoder JK, editors. Human conflicts with wildlife: economic considerations. Proceedings of the National Wildlife Research Center symposium. Fort Collins (CO): National Wildlife Research Center. p. 147–155.

Alexander DJ. 2000. A review of avian influenza in different bird species. Vet Microbiol. 74:3–13.

[AFWA] Association of Fish and Wildlife Agencies. 2012. Best practices for developing state wildlife action plans. Washington (DC): Teaming With Wildlife Committee, State Wildlife Action Plan (SWAP) Best Practices Working Group; [accessed 2015 August]. 85 p. http://www.fishwildlife.org/files/SWAPBestPractices.pdf.

Andersen LW, Fog K, Damgaard C. 2004. Habitat fragmentation causes bottlenecks and inbreeding in the European tree frog (Hyla arborea). Proc. R. Soc. Lond. [accessed 2015 July];B 271:1293–1302. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1691722/pdf/15306354.pdf.

Anderson RC. 1972. The ecological relationships of meningeal worm and native cervids in North America. J Wildl Dis. 8:304–310.

Andow DA, Zwahlen C. 2006. Assessing environmental risks of transgenic plants. Ecol Lett. 9:196–214.

Angermeier PL. 1995. Ecological attributes of extinction-prone species: loss of freshwater fishes of Virginia. Conserv Biol. 9:143–158.

Austin B, Austin DA. 1999. Bacteria fish pathogens: diseases of farmed and wild fish. 3rd ed. Chichester (England): Praxis Publishing. 457 pp.

Austin B, Austin DA. 2012. Bacterial fish pathogens. 5th ed. New York (NY): Springer. 652 p.

Ayre KK, Caldwell CA, Stinson J, Landis WG. 2014. Analysis of regional scale risk of whirling disease in populations of Colorado and Rio Grand Cutthroat Trout using a Bayesian belief network model. Risk Anal. 34(9):1589–1605.

Azerrad JM, Nilon DH. 2006. An evaluation of agency conservation guidelines to better address planning efforts by local government. Landsc Urban Plan. 77:255–262.

Balmford A, Fisher B, Green R, Naidoo R, Strassburg B, Turner R, Rodrigues A. 2011. Bringing ecosystem services into the real world: an operational framework for assessing the economic consequences of losing wild nature. Environ Resour Econ. 48(2):161–75.

Bakke TA, Harris PD. 1998. Diseases and parasites in wild Atlantic Salmon (*Salmo salar*) populations. Can J Fish Aquat Sci. 55(1 Suppl):247–266.

Barber JR, Crooks KR, Fistrup KM. 2010. The costs of chronic noise exposure for terrestrial organisms. Trends Ecol Evol. 25:180–189.

Barney JN, DiTomaso JM. 2008. Nonnative species and bioenergy: are we cultivating the next invader? BioSci. [accessed 2015 July];58(1):64–70. http://bioscience.oxfordjournals.org/content/58/1/64.full.

Bear J, Cheng AHD, Sorek S, Ouazar D, Herrera I. 1999. Seawater intrusion in coastal aquifers: concepts, methods and practices. Norwell (MA): Kluwer Academic Publishers. 625 p.

Beatley T. 2000. Preserving biodiversity: challenges for planners. J Am Planning Assoc. 66(1):5–20.

Bellard C, Bertelsmeier C, Leadley P, Thuiller W, Courchamp F. 2012. Impacts of climate change on the future of biodiversity. Ecol Lett. [accessed 2015 July];15(4):365–377. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3880584/pdf/emss-54918.pdf.

Boruff BJ, Emrich C, Cutter SL. 2005. Erosion hazard vulnerability of US coastal counties. J Coast Res. [accessed 2015 July];21(5):932–942. http://www.jcronline.org/doi/pdf/10.2112/04-0172.1.

Beringer JJ, Seibert SG, Pelton MR. 1990. Incidence of road crossing by black bears on Pisgah National Forest, North Carolina. Int Conf Bear Res Manag. 8:85–92.

Biofuels [web page]. N.d. Research Triangle Park (NC): North Carolina Biotechnology Center; [accessed 2015 July]. http://www.ncbiotech.org/business-commercialization/biotech-sectors/biofuels.

Bjerknes AL, Totland O, Hegland SJ, Nielsen A. 2007. Do alien plant invasions really affect pollination success in native plant species? Biol Conserv. [accessed 2015 July];138:1-12. https://www.researchgate.net/profile/Stein_Hegland/publication/223085992_Do_alien_plant_invasions_really_affect_pollination_success_in_native_plant_species/links/02e7e5289c9e92fa6b000000.pdf.

Blaustein AR, Gervasi SS, Johnson PT, Hoverman JT, Belden LK, Bradley PW, Xie GY. 2012. Ecophysiology meets conservation: understanding the role of disease in amphibian population declines. Philos Trans R Soc B: Biol Sci. 367(1596):1688–1707.

Blazer VS, Iwanowicz DD, Walsh HL, Sperry AJ, Iwanowicz LR, Alvarez DA, Brightbill RA, Smith G, Foreman WT, Manning R. 2014. Reproductive health indicators of fishes from Pennsylvania watersheds: association with chemicals of emerging concern. Environ Monit Assess. 186(10):6471–6491.

Blitzer EJ, Dormann CF, Holzschuh A, Klein AM, Rand TA, Tscharntke T. 2012. Spillover of functionally important organisms between managed and natural habitats. US Department of Agriculture, Agricultural Research Service. Lincoln (NE): University of Nebraska; [accessed 2015 Jun]. 43 p. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1840&context=usdaarsfacpub.

Bohling JH, Waits LP. 2011. Assessing the prevalence of hybridization between sympatric *Canis* species surrounding the red wolf (*Canis rufus*) recovery area in North Carolina. Mol Ecol. 20(10):2142–2156.

Bouchard B, Gagné F, Fortier M, Fournier M. 2009. An in-situ study of the impacts of urban wastewater on the immune and reproductive systems of the freshwater mussel *Elliptio complanata*. Comp Biochem Physiol Part C: Toxicol Pharmacol. 150(2):132–140.

Bouchard S, Moran K, Tiwari M, Wood D, Bolten A, Eliazar PJ, Bjorndal KA. 1998. Effects of exposed pilings on sea turtle nesting activity at Melbourne Beach, Florida. J Coast Res. 14:1343–1347.

Briefer E, Osiejuk TS, Rybak F, Aubin T. 2010. Are bird song complexity and song sharing shaped by habitat structure? An information theory and statistical approach. J Theor Biol. 262:151–164.

Briggs CJ, Knapp RA, Vredenburg VT. 2010. Enzootic and epizootic dynamics of the chytrid fungal pathogen of amphibians. Proc Natl Acad Sci USA. 107(21):9695–9700.

Bringolf RB, Heltsley RM, Newton JT, Eads CB, Fraley SJ, Shea D, Cope WG. 2010. Environmental occurrence and reproductive effects of the pharmaceutical fluoxetine in native freshwater mussels. Environ Toxicol Chem. 29(6):1311–1318.

Brody AJ, Pelton MR. 1989. Effects of roads on black bear movements in Western North Carolina. Wildl Soc Bull. 17(1):5–10.

Brooks ML, D'Antonio CM, Richardson DM, Grace JB, Keeley JB, DiTomaso JM, Hobbs RJ, Pellant M, Pyke D. 2004. Effects of invasive alien plants on fire regimes. BioSci. 54:677–688.

Brown AV, Lyttle MM, Brown KB. 1998. Impacts of gravel mining on gravel bed streams. Trans Am Fish Soc. 127:979–994.

Brown CJ, Blossey B, Maerz JC, Joule SJ. 2006. Invasive plant and experimental venue affect tadpole performance. Biol Invasions. 8:327–338.

Brown RM, Laband DN. 2006. Species imperilment and spatial patterns of development in the United States. Conserv Biol. 20(1):239–244.

Bryan AL, Hopkins WA, Baionno JA, Jackson BP. 2003. Maternal transfer of contaminants to eggs in common grackles (*Quiscalusquiscala*) nesting on coal fly ash basins. Archiv Environ Contam Toxicol. 45(2):273–277.

Bryan AL, Hopkins WA, Parikh JH, Jackson BP, Unrine JM. 2012. Coal fly ash basins as an attractive nuisance to birds: parental provisioning exposes nestlings to harmful trace elements. Environ Pollut. 161:170–177.

Brunner JL, Storfer A, Gray MJ, Hoverman JT (editors). 2015. Ranavirus ecology and evolution: from epidemiology to extinction. Open Access Book; [accessed 2015 July]. http://link.springer.com/chapter/10.1007/978-3-319-13755-1_4.

Buddenhagen CE, Chimera C, Clifford P. 2009. Assessing biofuel crop invasiveness: a case study. PLOS ONE. 4:e5261

Bunn K, Ramirez D. 2011. North Carolina economic index. Wiener J, editor. Raleigh (NC): North Carolina Department of Commerce; [accessed 2015]. 74 p. http://www.nccommerce.com/LinkClick.aspx?fileticket=fDdSEfUsxTE%3D&tabid=41&mid=5338.

Butler DA, Sage RB, Draycott RAH, Carroll JP, Potts D. 2005. Lead exposure in ring-necked pheasants on shooting estates in Great Britain. J Wildl Manag. 33:583–589.

Cameron SA, Lozier JD, Strange JP, Koch JB, Cordes N, Solter LF, Griswold TL. 2011. Patterns of widespread decline in North American bumble bees. Proc Natl Acad Sci. 108(2):662–667.

Cannell MGR. 1999. Environmental impacts of forest monocultures: water use, acidification, wildlife conservation, and carbon storage. New For. 17:239–262.

Carney KM, Sydeman WJ. 1999. A review of human disturbance effects on nesting colonial waterbirds. Waterbirds. 22(1):68–79.

Carter EA, Grace III JM. 2012. Assessing soil impacts related to forest harvest operations. Proceedings of the 16th Biennial Southern Silvicultural Research Conference. [accessed 2015 July]. http://www.treesearch.fs.fed.us/pubs/40572.

Cervino JM, Hauff B, Haslun JA, Winiarski-Cervino K, Cavazos M, Lawther P, Wier AM, Hughen K, Strychar KB. 2012. Ulcerated yellow spot syndrome: implications of aquaculture-related pathogens associated with soft coral *Sarcophyton ehrenbergi* tissue lesions. Dis Aquat Org. 102:137–148.

Cheng TL, Rovito SM, Wake DB, Vredenburg VT. 2011. Coincident mass extirpation of neotropical amphibians with the emergence of the infectious fungal pathogen Batrachochytrium dendrobatidis. Proc Natl Acad Sci. 108(23):9502–9507.

City Mayors Statistics. 2012. The largest US cities: cities ranked 1 to 100 [website]. [accessed 2015 August]. http://www.citymayors.com/gratis/uscities_100.html.

Clark AJ, Scheuhammer AM. 2003. Lead poisoning in upland foraging birds of prey in Canada. Ecotoxicol. 12:23–30.

Clark RW, Brown WS, Stechert R, Zamudio KR. 2010. Roads, interrupted dispersal, and genetic diversity in timber rattlesnakes. Conserv Biol. [accessed 2015 July];24(4):1059–1069. http://noss.cos.ucf.edu/papers/Clark%20et%20al%202010.pdf.

Cleary EC, Dickey A. 2010. ACRP Report 32: guidebook for addressing aircraft/wildlife hazards at general aviation airports. Washington (DC): Transportation Research Board of the National.

Clevenger AP, Chruszczc B, Gunson KE. 2003. Spatial patterns and factors influencing small vertebrate fauna road-kill aggregations. Biol Conserv. 109**:**15–26.

Colla SR, Otterstatter MC, Gegear RJ, Thomson JD. 2006. Plight of the bumble bee: pathogen spillover from commercial to wild populations. Biol Conserv. 129(4):461–467.

Conover MR, Pitt WC, Kessler KK, DuBow TJ, Sanborn WA. 1995. Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. Wildl Soc Bull. 23(3):407–414.

Cooper JE, Armstrong SA. 2007. Locality records and other data for invasive crayfishes (Decapoda: Cambaridae) in North Carolina. J NC Acad Sci. 123:1–13.

Davidson C. 2004. Declining downwind: amphibian population declines in California and historical pesticide use. Ecol Appl. 14(6):1892–1902.

Deplazes A, Huppenbauer M. 2009. Synthetic organisms and living machines. Syst Synth Biol. 3(1–4):55–63.

De Steven D, Gramling JM. 2013. Multiple factors influence the vegetation composition of Southeast US wetlands restored in the Wetlands Reserve Program. J Torrey Bot Soc. [accessed 2015 September];140(4):453–464. http://www.srs.fs.usda.gov/pubs/ja/2013/ja_2013_desteven_001.pdf.

DeWan A, Dubois N, Theoharides K, Boshoven J. 2010. Understanding the impacts of climate change on fish and wildlife in North Carolina. Washington (DC): Defenders of Wildlife; [accessed 2015 July]. 218 p. www.ncwildlife.org/Portals/0/Conserving/documents/ActionPlan/Revisions/FullReportDefendersofWildlifeUnderstandingtheimpactofclimatechangeNC.pdf.

Diamanka A, Loch TP, Cipriano RC, Winters AD, Faisal M. 2014. Infection of sea lamprey with an unusual strain of Aeromonas salmonicida. J. Wildl. Dis. 50(2):159–170.

DiTomaso JM, Barney JN, Fox AM. 2007. Biofuel feedstocks: the risk of future invasions. Commentary QTA 2007-1. Ames (IA): Council for Agricultural Science and Technology; [accessed 2015 July]. http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1073&context=govdocs.

Dobrowolska A, Melosik M. 2008. Bullet-derived lead in tissues of the wild boar (*Sus scrofa*) and red deer (*Cervus elaphus*). Eur J Wildl Res. 54:231–235.

Doherty PJ, Heath JA. 2011. Factors affecting piping plover hatching success on Long Island, New York. J Wildl Manag. 75:109–15.

Dolbeer RA, Wright SE, Weller J, Begier MJ. 2010. Wildlife strikes to civil aircraft in the United States 1990–2009, Serial Report 15. Washington (DC): US Department of Transportation.

Doubledee RA, Muller EB, Nisbet RM. 2003. Bullfrogs, disturbance regimes, and the persistence of California red-legged frogs. J Wildl Manag. 67:424–438.

Doyle K, Kostyack J, McNitt B, Sugameli G, Whitaker C, Whitcomb-Blaylock K, Byrd J, Stull G. 2001. Paving Paradise: Sprawl's impact on wildlife and wildplaces in California. A Smart Growth and Wildlife Campaign California white paper. San Diego, California: National Wildlife Federation.

Drohan P, Brittingham M, Bishop J, Yoder K. 2012. Early trends in landcover change and forest fragmentation due to shale-gas development in Pennsylvania: a potential outcome for the northcentral Appalachians. Environ Manag. 49:1061–1075.

DuBey RJ. 2006. Ecology of whirling disease in arid lands with an emphasis on *Tubifex tubifex* [dissertation]. [Las Cruces (NM)]: New Mexico State University. [accessed 2015 August]. http://www.fs.fed.us/rm/pubs_other/rmrs_2006_dubey_r001.pdf.

DuBey R, Caldwell C. 2003. Ecological differentiation and survivability of *Tubifex tubifex* infested with *Myxobolus cerebralis* in the San Juan River, New Mexico Tailwater "Blue-ribbon Trout Fishery." Las Cruces (NM): Whirling Disease Symposium; [accessed 2015 July]. http://whirlingdisease.montana.edu/biblio/pdfs/WDproceedings_2003.pdf#page=49.

Edgerton BF, Evans LH, Stephens FJ, Overstreet RM. 2002. Synopsis of freshwater crayfish diseases and commensal organisms. Aquac. 206(1–2):57–135.

Ehrenfeld DW. 1968. The role of vision in the sea-finding orientation of the green turtle (*Chelonia mydas*). 2. Orientation mechanism and range of spectral sensitivity. Anim Behav. 16:281–287.

Ellis AE. 1997. The leucocytes of fish. J Fish Biol. 11:453–491.

Emmerich R, Weibel E. 1890. Uber eine durch Bakterien verursachte Infektionskrankheit der Forellen. Allg Fisch-Ztg. 15:85–92.

Environmental Law Institute. 2007. Constitutional environmental law: giving force to fundamental principles in Africa. Environmental Law Institute.

Etnier DA. 1997. Jeopardized southeastern freshwater fishes: a search for causes. In: Benz GW, Collins DE, editors. Aquatic fauna in peril: the southeastern perspective. Decatur (GA): Southeast Aquatic Research Institute. p. 87–104.

Ewing R, Kostyack J, Chen D, Stein B, Ernst M. 2005. Endangered by sprawl: how runaway development threatens America's wildlife. Washington (DC): National Wildlife Federation, Smart Growth America, and NatureServe; [accessed 2015 July]. 68 p. http://www.nwf.org/~/media/PDFs/Wildlife/EndangeredBySprawl.ashx.

[FAO] Food and Agriculture Organization, Inland Water Resources and Aquaculture Service, Fishery Resources Division. 1997. Review of the state of world aquaculture. FAO Fish Circ. No. 886(rev. 1):1–10.

Fargione JE, Cooper TR, Flaspohler DJ, Hill J, Lehman C, McCoy T, McLeod S, Nelson EJ, Oberhauser KS, Tilman D. 2009. Bioenergy and wildlife: threats and opportunities for grassland conservation. BioSci. 59:767–777.

Fischlin A, Midgley GF, Price JT, Leemans R, Gopal B, Turley C, Rounsevell MDA, Dube OP, Tarazona J, Velichko AA. 2007. Ecosystems, their properties, goods, and services. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE, editors. Climate change 2007: impacts, adaptation and vulnerability. Cambridge (England): Cambridge University Press. p 211–272.

Fisher IJ, Pain DJ, Thomas VG. 2006. A review of lead poisoning from ammunition sources in terrestrial birds. Biol Conserv. 131:421–432.

Forman RTT, Alexander LE. 1998. Roads and their major ecological effects. Annu Rev Ecol Syst. 29**:**207–257.

Fox K. 2012. Port of Morehead City supports NC logging industry with export wood chips vessel. The Inside Pages, North Carolina Ports; [accessed 2015 July]. http://www.ncports.com/insidepages/july-19-2012/#section-58.

Frankham R, Ballou JD, Briscoe DA. 2002. Introduction to conservation genetics. Cambridge (England): Cambridge University Press.

Freemark K, Boutin C. 1995. Impacts of agricultural herbicide use on terrestrial wildlife in temperate landscapes: a review with special reference to North America. Agric Ecosyst Environ. 52:67–91.

Froese JMW, Smits JEG, Wickstrom ML. 2005. Evaluation of two methods for measuring nonspecific immunity in tiger salamanders (*Ambystoma tigrinum*). J Wildl Dis. 41(1):209–217.

Fry DM. 1995. Reproductive effects in birds exposed to pesticides and industrial chemicals. Environ. Health Perspect. 103(7 Suppl):165–171.

Fu S, Shen J, Chen K, Junling T, Liu Y. 2012. A dead-end filtration method to remove particle-associated pathogens in aquaculture systems. Aquac Int. 20:657–672.

Fuentes MMPB, Limpus DJ, Hamann M, Dawson J. 2010. Potential impacts of projected sea-level rise on sea turtle rookeries. Aquat Conserv: Mar Freshw Ecosyst. 20:132–139.

Gagliardo R, Crump P, Griffith E, Mendelson J, Ross H, Zippel K. 2008. The principles of rapid response for amphibian conservation, using the programmes in Panama as an example. Int Zoo Yearb. 42(1):125–135.

Gagné F, André C, Cejka P, Hausler R, Fournier M. 2011. Evidence of neuroendocrine disruption in freshwater mussels exposed to municipal wastewaters. Sci Total Environ. 409(19):3711–3718.

[GAO] Government Accountability Office. 2005. Wind power: impacts on wildlife and government responsibilities for regulating development and protecting wildlife. GAO-05-906. Washington (DC): US Government Accountability Office; [accessed 2015 August]. http://www.gao.gov/new.items/d05906.pdf.

Gibbons D, Morrissey C, Mineau P. 2014. A review of the direct and indirect effects of neonicotinoids and fipronil on vertebrate wildlife. Environ Sci Pollut Res. 22(1):1–16.

Gibeau ML, Heuer K. 1996. Effects of transportation corridors on large carnivores in the Bow River Valley, Alberta. In: Evink GL, Garrett P, Zeigler D, Berry J, editors. Trends in addressing transportation related wildlife mortality: proceedings of the transportation related wildlife mortality seminar. Tallahassee (FL): Florida Department of Transportation. p. 67–79.

Gilbert MA, Granath Jr. WO. 2002. The role of *Tubifex tubifex* (Annelida: Aligochaeta: Tubificidae) in the transmission of *Myxobolus cerebralis* (Myxozoa: Myxosporea: Myxobolidae). In: Bartholomew JL, Wilson JC, editors. Whirling disease: reviews and current topics. Bethesda (MD): American Fisheries Society. p. 79–85.

Gray MJ, Miller DL, Schmutzer C, Baldwin CA. 2007a. Frog Virus 3 prevalence in tadpole populations inhabiting cattle-access and non-access wetlands in Tennessee, USA. Dis. Aquat. Org. 77:97–103.

Gray MJ, Rajeev S, Miller DL, Schmutzer AC, Burton EC, Rogers ED, Hickling GJ. 2007b. Preliminary evidence that american bullfrogs (*Rana catesbeiana*) are suitable hosts for *Escherichia coli* O157:H7. Appl Environ Microbiol. 73(12):4066–4068.

Guthery FS, Peterson MJ, George RR. 2000. Viability of northern bobwhite populations. J Wildl Manag. 64(3):646–662.

Harlan SM, Davis GJ, Pesacreta GJ. 1985. Hydrilla in three North Carolina lakes. J Aquat Plant Manag. 23:68–71.

Harp EM, Petranka JW. 2006. Ranavirus in wood frogs (*Rana sylvatica*): potential sources of transmission within and between ponds. J Wildl Dis. 42(2):307–318.

Hartfield P. 1993. Headcuts and their effect on freshwater mussels. In: Cummings KS, Buchanan AC, Kock LM, editors. Conservation and management of freshwater mussels. Proceedings of an Upper Mississippi River Conservation Committee symposium. Rock Island (IL): Upper Mississippi River Conservation Committee. p. 131–141.

Hedrick RP. 1998. Relationships of the host, pathogen and environment: implications for disease of cultured and wild fish populations. J Aquat Anim Health. 10:107–111.

Hickling GR. 2011. New approaches to wildlife health: monitoring and managing disease spread between free-ranging wildlife, livestock, and humans. USDA Research, Education and Economics Information System. Knoxville (TN): University of Tennessee; [accessed 2015 August]. http://portal.nifa.usda.gov/web/crisprojectpages/0209159-new-approaches-to-wildlife-health-monitoring-and-managing-disease-spread-between-free-ranging-wildlife-livestock-and-humans.html.

Hinshaw VS, Wood JM, Webster RG, Deibel R, Turner B. 1985. Circulation of influenza viruses and paramyxoviruses in waterfowl originating from two different areas of North America. Bull. World Health Organ. 63:711–719.

Hodson J, Fortin D, LeBlanc ML, Belanger L. 2010. An appraisal of the fitness consequences of forest disturbance for wildlife using habitat selection theory. Oecologia. 164:73–86.

Hosier PE, Kochhar M, Thayer V. 1981. Off-road vehicle and pedestrian track effects on the sea-approach of hatchling loggerhead turtles. Environ Conserv. 8(2):158–161.

Hunt WG, Burnham W, Parish CN, Burnham KK, Mutch B, Oaks JL. 2006. Bullet fragments in deer remains: implications for lead exposure in avian scavengers. Wildl Soc Bull. 34:167–170.

Iqbal S, Blumenthal W, Kennedy C, Yip FY, Pickard S, Flanders WD, Loringer K, Kruger K, Caldwell KL. 2009. Hunting with lead: association between blood lead levels and wild game consumption. Environ Res. 109: 952–959.

[IUCN] International Union for Conservation of Nature. 2012. Classification schemes for threats and conservation actions needed. [accessed 2015 July] http://www.iucnredlist.org/documents/Dec_2012_Guidance_Threats_Classification_Scheme.pdf and http://www.iucnredlist.org/documents/Dec_2012_Guidance_Conservation_Actions_Needed_Classification_Scheme.pdf.

Jackson SD. 2004. Design and construction of aquatic organism passage at road-stream crossings: ecological considerations in the design of river and stream crossings. In: Irwin CL, Garrett P, McDermott KP, editors. Proceedings of the 2003 international conference on ecology and transportation. Raleigh (NC): North Carolina State University. p. 20–29.

Jenkins PT, Genovese K, Ruffler H. 2007. Broken screens: the regulation of live animal importation in the United States. Washington DC: Defenders of Wildlife 2007; [accessed 2015] http://www.defenders.org/publications/broken_screens_report.pdf

Jeschke JM, Keesing F, Ostfeld RS. 2013. Novel organisms: comparing invasive species, GMOs, and emerging pathogens. R Swed Acad Sci: Ambio. 42:541–548.

Jochimsen DM, Peterson CR, Andrews KM, Gibbons JW. 2004. A literature review of the effects of roads on amphibians and reptiles and the measures used to minimize those effects. Boise (ID): Idaho Fish and Game Department; [accessed 2015 August]. 79 p. https://fishandgame.idaho.gov/public/wildlife/collisionAmphibRep.pdf.

Johansen LH, Jensen I, Mikkelsen H, Bjorn PA, Jansen PA, Bergh O. 2011. Disease interaction and pathogens exchange between wild and farmed fish populations with special reference to Norway. Aquac. 315:167–186.

Jones PD, Hanberry B, Demarais S. 2009. Stand-level wildlife habitat features and biodiversity in Southern pine forests: a review. J For. 107(8):398–404.

Kanapaux W, Kiker GA. 2013. Development and testing of an object-oriented model for adaptively managing human disturbance of least tern (*Sternula antillarum*) nesting habitat. Ecol Model. 268:64–77.

Karl TR, Mellillo JM, Peterson TC, editors. 2009. Global climate change impacts in the United States. Cambridge (England): Cambridge University Press.

Keel MK, Davidson WR, Doster GL, Lewis LA. 2002. Northern bobwhite and lead shot deposition in an upland habitat. Arch Environ Contam Toxicol. 43:318–322.

Kilgore R, Bergendahl B, Hotchkiss R. 2010. Culvert design for aquatic organism passage. FHWA-HIF-11-008-HEC-26. Lakewood (CO): Federal Highway Administration, Central Federal Lands Division. 234 p.

Kilian JV, Frentress J, Klauda RJ, Becker AJ, Stranko SA. 2009. The invasion of *Procambarus clarkii* (Decapoda: Cambaridae) into Maryland streams following its introduction to outdoor aquaculture ponds. Northeast Nat. 16(4):655–663.

Kilpatrick AM, Chmura AA, Gibbons DW, Fleischer RC, Marra PP, Daszak P. 2006. Predicting the global spread of H5N1 avian influenza. Proc Natl Acad Sci. 103(51):19368–19373.

Knott J, Gilbert J, Hoccom DG, Green RE. 2010. Implications for wildlife and humans of dietary exposure to lead from fragments of lead rifle bullets in deer shot in the UK. Sci Total Environ. 409:95–99.

Kosnett MJ. 2009. Health effects of low dose lead exposure in adults and children, and preventable risk posed by the consumption of game meat harvested with lead ammunition. In: Watson RT, Fuller M, Pokras M, Hunt WG, editors. Ingestion of spent lead ammunition: implications for wildlife and humans. Boise (ID): The Peregrine Fund. p. 24–33.

Kuvlesky Jr. WP, Brennan LA, Morrison ML, Boydston KK, Ballard BM, Bryant FC. 2007. Wind energy development and wildlife conservation: challenges and opportunities. J Wildl Manag. 71(8):2487–2498.

Lacy RC. 1993. Impacts of inbreeding in natural and captive populations of vertebrates: implications for conservation. Perspect Biol Med. 36(3):480–496.

Laiolo P. 2010. The emerging significance of bioacoustics in animal species conservation. Biol Conserv. 143:1635–1645.

Laiolo P, Tella JL. 2005. Habitat fragmentation affects cultural transmission: patterns of song matching in Dupont's Lark. J Appl Ecol. 42:1183–1193.

Laiolo P, Tella JL. 2007. Erosion of animal culture in fragmented landscapes. Front Ecol Environ. 5:68–72.

Laiolo P, Vogeli M, Serrano D, Tella JL. 2008. Song diversity predicts the viability of fragmented bird populations. PLOS ONE. 3(3):e1822.

Lamont MM, Percival HF, Colwell SV. 2002. Influence of vehicle tracks on loggerhead hatchling seaward movement along a northwest Florida beach. FL Field Nat. 30:77–109.

Lannoo MJ, Kinney VC, Heemeyer JL, Engbrecht NJ, Gallant AL, Klaver RW. 2009. Mine spoil prairies expand critical habitat for endangered and threatened amphibian and reptile species. Divers. [accessed 2015 July];1:118–132. http://pubs.er.usgs.gov/publication/70003945.

Leicht-Young SA, Enquist CAF, Weltzin JF. 2013. Observed changes in phenology across the United States—Southeast. National Phenology Network; [accessed 2015 July]. https://www.usanpn.org/files/shared/files/Changes_in_Phenology-SE.pdf.

Lemly AD, Skorupa JP. 2012. Wildlife and the coal waste policy debate: proposed rules for coal waste disposal ignore lessons from 45 years of wildlife poisoning. Environ Sci Tech. [accessed 2015 July];46:8595–8600. doi:10.1021/es301467q.

Li W, Li L, Fu R, Deng Y, Wang H. 2011. Changes to the North Atlantic subtropical high and its role in the intensification of summer rainfall variability in the southeastern United States. Am Meteorol Soc: J Clim. 24:1499–1506.

Liu Y, Prestemon JP, Goodrick SL, Holmes TP, Stanturf JA, Vose JM, Sun G. 2013. Future wildfire trends, impacts, and mitigation options in the southern United States. In: Vose JM, Klepzig KD, editors. Climate change adaptation and mitigation management options: a guide for natural resource managers in southern forest ecosystems. Boca Raton (FL): Taylor & Francis Group. p. 85–125.

Lodge DM, Taylor CA, Holdich DM, Skurdal J. 2000. Reducing impacts of exotic crayfish introductions: new policies needed. Fish. 25(89):21–23.

Longshaw M. 2011. Diseases of crayfish: a review. J Invertebr Pathol. [accessed 2015 July];106(1):54–70. doi:10.1016/j.jip.2010.09.013. http://www.researchgate.net/publication/49737432_Diseases_of_crayfish_A_review.

Louca S, Lampo M, Doebeli M. 2014. Assessing host extinction risk following exposure to *Batrachochytrium dendrobatidis*. Proceedings of the Royal Society of London B: Biological Sciences 281(1785):20132783. [accessed 2015 August] http://dx.doi.org/10.1098/rspb.2013.2783.

Louda SM. 1998. Population growth of *Rhinocyllus conicus* (Coleoptera: Curculionidae) on two species of native thistles in prairie. Environ Entomol. 27:834–841.

Louda SM, Kendall D, Connor J, Simberloff D. 1997. Ecological effects of an insect introduced for the biological control of weeds. Sci. 277:1088–1090.

Love JW, Gill J, Newhard JJ. 2008. Saltwater intrusion impacts fish diversity and distribution in the Blackwater River drainage (Chesapeake Bay Watershed). Wetl. 28(4):967–974.

Lovich JE, Ennen JR. 2011. Wildlife conservation and solar energy development in the desert southwest, United States. BioSci. 61(12):982–992.

Lucardi RD, Wallace LE, Ervin GN. 2014. Evaluating hybridization as a potential facilitator of successful Cogongrass (*Imperata cylindrical*) invasion in Florida, USA. Biol Invasions. 16(10):2147–2161.

Marchin RM, Salk CF, Hoffmann WA, Dunn RR. 2015. Temperature alone does not explain phenological variation of diverse temperate plants under experimental warming. Glob Chang Biol. [accessed 2015 July];21(8):3138–3151. doi:10.1111/gcb.12919.

Marion P, Najib K, Rosier C. 2014. Numerical simulations for a seawater intrusion problem in a free aquifer. Appl Numer Math. 75:48–60.

Martin PA, Campbell D, Hughes K, McDaniel T. 2008. Lead in the tissues of terrestrial raptors in southern Ontario, Canada, 1995–2001. Sci Total Environ. 391:96–103.

Martin-Queller E, Diez JM, Ibanez I, Saura S. 2013. Effects of silviculture on native tree species richness: interactions between management, landscape context and regional climate. J Appl Ecol. 50:775–785.

Marsack K, Swanson B. 2009. A genetic analysis of the impact of generation time and road-based habitat fragmentation on eastern box turtles (*Terrapene c. carolina*). Copeia. 2009(4):647–652.

Mathews TJ, Fortner AM, Jett RT, Morris J, Gable J, Peterson MJ, Carriker N. 2014. Selenium bioaccumulation in fish exposed to coal ash at the Tennessee Valley Authority Kingston spill site. Environ Toxicol Chem. 33(10):2273–2279.

Mattson DJ, Knight RR, Blanchard VM. 1987. The effects of development and primary roads on grizzly bear habitat use in Yellowstone National Park, Wyoming. Int Conf Bear Res Manag. 7:259–273.

Mazerolle MJ. 2004. Amphibian road mortality in response to nightly variations in traffic intensity. Herpetol. 60:45–53.

McCallum H. 2012. Disease and the dynamics of extinction. Phil Trans R Soc B. 367:2828–2839.

McCarthy DH, Roberts RJ. 1980. Furunculosis of fish—the present state of our knowledge. In: Droop MR, McCarthy DH, Jannasch HW, editors. Advances in aquatic microbiology. London (England): Academic Press. p. 293–341.

McGinnis S, Kerans BL. 2013. Land use and host community characteristics as predictors of disease risk. Landsc Ecol. 28:29–44.

McGowan CP, Simons TR. 2006. Effects of human recreation on the incubation behavior of American Oystercatchers. Wilson J Ornithol. 118:485–93.

McLean RG. 2005. Wildlife diseases and humans. Fort Collins (CO): National Center for Infectious Diseases, Centers for Disease Control and Prevention; [accessed 2015 July]. http://icwdm.org/handbook/damage/WildlifeDiseases.asp.

McMahon TA, Brannelly LA, Chatfield MWH, Johnson PTJ, Joseph MB, McKenzie VJ, Richards-Zawacki CLR, Venesky MD, Rohr JR. 2013. Chytrid fungus *Batrachochytrium dendrobatidis* has nonamphibian hosts and releases chemicals that cause pathology in the absence of infection. Proc Natl Acad Sci U S Am. [accessed 2015 September];110(1):210–215. http://www.pnas.org/cgi/doi/10.1073/pnas.1200592110.

McMahon TA, Rohr JR. 2015. Transition of chytrid fungus infection from mouthparts to hind limbs during amphibian metamorphosis. EcoHealth. 12(1):188–193.

McNulty SG, Boggs JL, Sun G. 2014. The rise of the mediocre forest: why chronically stressed trees may better survive extreme episodic climate variability. New For. 45:403–415.

McVicar AH. 1997. Disease and parasite implications of the coexistence of wild and farmed cultured Atlantic salmon populations. ICES J Mar Sci. 54:1093–1103.

[MEA] Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being. Carpenter S, Pingali P, Bennett E, Zurek M, editors. Washington, DC: Island Press; [accessed 2015 July]. Vol. 2, Scenarios. http://www.unep.org/maweb/en/Scenarios.aspx.

Meador MR, Layher AO. 1998. Instream sand and gravel mining: environmental issues and regulatory process in the United States. Fish. 23(11):6–13.

Melillo JM, Richmond TC, Yohe GW, editors. 2014. Climate change impacts in the United States: the third national climate assessment. Washington (DC): US Government Printing Office; [accessed 2015 July]. 841 p. http://nca2014.globalchange.gov/downloads.

Memmott J, Waser NM. 2002. Integration of alien plants into a native flower–pollinator visitation web. Proc R Soc Lond. [accessed 2015 July];B269:2395–2399. http://rspb.royalsocietypublishing.org/content/royprsb/269/1508/2395.full.pdf.

Meyer CB, Schlekat TH, Walls SJ, Iannuzzi J, Souza MJ. 2014. Evaluating risks to wildlife from coal fly ash incorporating, recent advances in metals and metalloids risk assessment. Integr Environ Assess Manag. 11(1):67–79.

Milbrant A. 2005. A geographic perspective on the current biomass resource availability in the United States. Technical Report NREL/TP-560-39181. Golden (CO): National Renewable Energy Laboratory; [accessed 2015 Feb 25]. http://www.nrel.gov/docs/fy06osti/39181.pdf.

Millard EV, Faisal M. 2012. Heterogeneity in levels of serum neutralizing antibodies against viral hemorrhagic septicemia virus genotype IVB among fish species in Lake St. Clair, Michigan, USA. J Wildl Dis. 48(2):405–415.

Miller JD, Limpus CL, Godfrey MH. 2003. Nest site selection, oviposition, eggs, development, hatching, and emergence of loggerhead sea turtles. In: Bolten AB, Witherington BE, editors. Ecology and conservation of loggerhead sea turtles. Washington (DC): Smithsonian Books. p. 125–143.

Milligan SR, Holt WV, Lloyd R. 2009. Impacts of climate change and environmental factors on reproduction and development in wildlife. Phil Trans R Soc B. 364:3313–3319.

Morales CL, Traveset A. 2009. A meta-analysis of impacts of alien vs. native plants on pollinator visitation and reproductive success of co-flowering native plants. Ecol Lett. 12:716–728.

Mortimer JA. 1982. Factors influencing beach selection by nesting sea turtles. In: Bjorndal KA, editor. The biology and conservation of sea turtles. Washington (DC): Smithsonian Institution Press. p. 45–51.

Moser ML, Terra ME. 1999. Low light as a possible impediment to river herring migration. Wilmington (NC): UNC-Wilmington, Center for Marine Science Research. 135 p.

Mrosovsky N, Shettleworth SJ. 1969. Wavelength preferences and brightness cues in the water finding behaviour of sea turtles. Behav. 32:211–257.

Munster VJ, Baas C, Lexmond P, Waldenstrom J, Wallensten A, Fransson T, Rimmelzwaan GF, Beyer WE, Schutten M, Olsen B, et al. 2007. Spatial, temporal, and species variation in prevalence of influenza A viruses in wild migratory birds. PLoS Pathog. [accessed 2015 September];3(5):e61. doi:10.1371/journal.ppat.0030061.

Murawski J. 2015. Amazon backs NC's 1st large-scale wind farm [Internet]. The News & Observer, Business; [accessed 2015 August]. http://www.newsobserver.com/news/business/article27125410.html#storylink=cpy.

Murray TE, Coffey MF, Kehoe E, Horgan FG. 2013. Pathogen prevalence in commercially reared bumble bees and evidence of spillover in conspecific populations. Biol Conserv. 159:269–276.

[NCAFS] NC Chapter of the American Fisheries Society. 2002. Position paper on instream sand and gravel mining activities in North Carolina. Raleigh (NC); [accessed 2015 August]. 7 p. http://www.sdafs.org/ncafs/Newsletters/March2002/InstreamMiningPosition.doc.

[NCDCM] NC Division of Coastal Management. 2012. Coastal hazards and storm information, sea level rise. Raleigh (NC): NC Department of Environment and Natural Resources.

[NCDCM] NC Division of Coastal Management. 2015. North Carolina sea level rise assessment report, 2015 update to the 2010 report and 2012 addendum. Raleigh (NC): NC Division of Coastal Management and NC Coastal Resources Commission Science Panel; [accessed 2015 July]. 43 p. http://www.rachelcarsoncouncil.org/uploads/climate%20change/2015_sea level rise_Assessment-FinalDraft-2015429.pdf.

[NCDWQ] NC Division of Water Quality. 2000. Water quality citizen's guide. Raleigh (NC): NC Department of Environment and Natural Resources.

[NCFS] NC Forest Service. 2015. Emerald ash borer frequently asked questions [web page]. [updated 2015 July 21; accessed 2015]. http://ncforestservice.gov/forest_health/fh_eabfaq.htm.

[NCGS] NC General Statute. N.d. § 62-133.8. Renewable Energy and Energy Efficiency Portfolio Standard (REPS). [accessed 2015 Feb 25]. http://www.ncga.state.nc.us/EnactedLegislation/Statutes/HTML/BySection/Chapter_62/GS_62-133.8.html.

[NCAC] NC Administrative Code. N.d. 15A NCAC 10B. Title 15A Environment and Natural Resources, Chapter 10 Wildlife Resources and Waster Safety, SubChapter B. [accessed 2015 August]. http://ncrules.state.nc.us/ncac/title%2015a%20-%20environment%20and%20natural%20resources/chapter%2010%20-%20wildlife%20resources%20and%20water%20safety/subchapter%20b/subchapter%20b%20rules.doc.

[NCOSBM] NC Office of State Budget and Management. 2014. Population estimates and projections, county population growth 2020-2030 [website]. Raleigh (NC); [accessed 2015 July] http://osbm.nc.gov/ncosbm/facts_and_figures/socioeconomic_data/population_estimates/demog/countygrowth_2030.html.

[NCSCO] NC State Climate Office. N.d. Weather and climate [web page]. [accessed 2015 May]. http://nc-climate.ncsu.edu/products/wx.

NC Renewable Energy and Energy Efficiency Portfolio Standard (REPS) [web page]. 2007. NC Utilities Commission; [accessed 2015 July]. http://www.ncuc.commerce.state.nc.us/reps/reps.htm.

[NCWRC] NC Wildlife Resources Commission. 2012. Conservation recommendations for priority terrestrial wildlife species and habitats in North Carolina. Raleigh (NC): NC Wildlife Resources Commission; [accessed 2015 July]. 96 p. http://www.ncwildlife.org/Portals/0/Conserving/documents/ConservingTerrestrialHabitatsandSpecies.pdf.

[NCWRC] NC Wildlife Resources Commission. 2014. Draft chronic wasting disease response plan. Raleigh (NC): Division of Wildlife Management. 20 p.

Neumann AC, Hearty P J. 1996. Rapid sea-level changes at the close of the last interglacial (substage 5e) recorded in Bahamian island geology. Geol. 24(9):775–778.

[NOAA] National Oceanic and Atmospheric Administration. 2013. Water level stations by state, North Carolina. National Ocean Service (NOS), Center for Operational Oceanographic Products and Services; [accessed 2015 July]. http://tidesandcurrents.noaa.gov/products.html.

Northrup JM, Wittemyer G. 2013. Characterising the impacts of emerging energy development on wildlife, with an eye towards mitigation. Ecol Lett. [accessed 2015 July];16:112–125. http://www.legassembly.gov.yk.ca/fr/pdf/rbhf_reid_Northrup_Wittemyer_2012__EcoLetters.pdf.

Noss RF, Peters RL. 1995. Endangered ecosystems: a status report on America's vanishing habitat and wildlife. Washington (DC): Defenders of Wildlife.

[OJEU] Official Journal of the European Union. 2001. Directive 2001/18/EC of the European Parliament and of the Council of 12 March 2001 on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC. Off J Europ Comm. [accessed 2015 August];L106:1–39. http://www.wipo.int/wipolex/en/details.jsp?id=10335.

Olsen B, Munster VJ, Wallensten A, Waldenstrom J, Osterhaus AD, Fouchier RA. 2006. Global patterns of influenza A virus in wild birds. Sci. 312(5772):384–388.

Ortega YK, Benson A, Greene E. 2014. Invasive plant erodes local song diversity in a migratory passerine. Ecol. 95(2):458–465.

Otterstatter MC, Thomson JD. 2008. Does pathogen spillover from commercially reared bumble bees threaten wild pollinators? PLoS ONE. [accessed 2015 August];3(7):e2771. doi:10.1371/journal.pone.0002771.

Otto B, Ransel K, Todd J, Lovass D, Stutzman H, Bailey J. 2002. Paving our way to water shortages: how sprawl aggravates the effects of drought. Washington DC: American Rivers, Natural Resources Defense Council and Smart Growth America; [accessed 2015 July]. http://www.smartgrowthamerica.org/research/paving-our-way-to-water-shortages.

Ouzts E. 2007. Losing our natural heritage: development and open space loss in North Carolina. Raleigh (NC): Environment North Carolina Research and Policy Center; [accessed 2015 August]. 29 p. http://www.environmentnorthcarolina.org/sites/environment/files/reports/Losing_Our_Natural_Heritage.pdf.

Pain DJ, Cromie RL, Newth J, Brown MJ, Crutcher E, Hardman P, Hurst L, Mateo R, Meharg AA, Moran AC, et al. 2010. Potential hazard to human health from exposure to fragments of lead bullets and shot in the tissues of game animals. PLoS ONE. 5:e10315.

Papoulias, D. M., and A. L. Velasco. 2013. Histopathological analysis of fish from Acorn Fork Creek, Kentucky, exposed to hydraulic fracturing fluid releases. Southeast Nat. 12:92–111.

Parris MJ, Beaudoin JG. 2004. Chytridiomycosis impacts predator-prey interactions in larval amphibian communities. Oecologia. 140(4):626–632

Paquet PC, Callaghan C. 1996. Effects of linear developments on winter movements of gray wolves in Bow River Valley of Banff National Park, Alberta. In: Evink GL, Garrett P, Zeigler D, Berry J, editors. Trends in addressing transportation related wildlife mortality: proceedings of the transportation related wildlife mortality seminar. Tallahassee (FL): Florida Department of Transportation. p. 46–66.

Patra KC, Rautray TR, Tripathy BB, Nayak P. 2012. Elemental analysis of coal and coal ASH by PIXE technique. Appl Radiat Isot. 70:612–616.

Peer AC, Miller TJ. 2014. Climate change, migration phenology, and fisheries management interact with unanticipated consequences. N Am J Fish Manag. 34(1):94–110.

Peters A, Verhoeven KJF. 1994. Impact of artificial lighting on the seaward orientation of hatchling loggerhead turtles. J Herpetol. 28:112–114.

Philibosian R. 1976. Disorientation of hawksbill turtle hatchlings, *Eretmochelys imbricata*, by stadium lights. Copiea. 1976:824.

Phillips BL, Puschendorf R. 2013. Do pathogens become more virulent as they spread? Evidence from the amphibian declines in Central America. Proc R Soc Lond B: Biol Sci. [accessed 2015];280(1766). http://dx.doi.org/10.1098/rspb.2013.1290.

Pierce BL, Roster TA, Frisbie MC, Mason CD, Roberson JA. 2015. A comparison of lead and steel shot loads for harvesting mourning doves. Wildl Soc Bull. [accessed 2015 July];39:103–115. doi:10.1002/wsb.504.

Poff NL, Allan JD, Bain MB, Karr JR, Prestegaard KL, Richter BD, Sparks RE, Stromberg JC. 1997. The natural flow regime, a paradigm for river conservation and restoration. BioSci. 47(11):769–784.

Preston CJ. 2008. Synthetic biology: drawing a line in Darwin's sands. Environ Values. 17(1):23–39.

Raghu S, Anderson RC, Daehler CC, Davis AS, Wiedenmann RN, Simberloff D, Mack RN. 2006. Adding biofuels to the invasive species fire? Sci. [accessed 2015 July];313:1742. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.404.4155&rep=rep1&type=pdf.

Ramirez Jr. P. 2009. Reserve pit management: risks to migratory birds. Cheyenne (WY): US Fish and Wildlife Service, Region 6; [accessed 2015 July]. http://www.fws.gov/mountain-prairie/contaminants/documents/ReservePits.pdf.

Rand TA, Louda SM. 2004. Exotic weed invasion increases the susceptibility of native plants to attack by a biocontrol herbivore. Ecol. 85:1548–1554.

Rappole JH, Huba´lek Z. 2003. Migratory birds and West Nile virus. J Appl Microbiol. [accessed 2015 August];94:47S–58S. doi:10.4269/ajtmh.2009.09-0106.

Reynolds J, Souty-Grosset C. 2012. Management of freshwater biodiversity: crayfish as bioindicators. New York (NY): Cambridge University Press. 374 p.

Richards GP. 2014. Bacteriophage remediation of bacterial pathogens in aquaculture: a review of the technology. Bacteriophage. 4(4): e975540-1–e975540-12.

Richardson RJ. 2008. Aquatic plant management and the impact of emerging herbicide resistance issues. Weed Tech. 22:8–15.

Ricketts TH, Dinerstein E, Olson DM, Loucks CJ, Eichbaum W, DellaSala D, Kavanagh K, Hedao P, Hurley PT, Carney KM, et al. 1999. Terrestrial ecoregions of North America: a conservation assessment. Washington (DC): Island Press.

Riffell SAM, Verschuyl J, Miller D, Wigley TB. 2011. A meta-analysis of bird and mammal response to short-rotation woody crops. GCB Bioenergy. 3:313–321.

Robbins JA, Keilty T, White DS, Edgington DN. 1989. Relationships among tubificid abundances, sediment composition, and accumulation rates in Lake Erie. Can J Fish Aquat Sci. 46:223–231.

Robert J, Abramowitz L, Gantress J, Morales HD. 2007. *Xenopus laevis*: a possible vector of ranavirus infection. J Wildl Dis. 43(4):645–652.

Roberts MR, Gilliam FS. 1995. Patterns and mechanisms of plant diversity in forested ecosystems: implications for forest management. Ecol Appl. 5:969–977.

Robertson BA, Doran PJ, Loomis ER, Robertson JR, Schemske DW. 2011a. Avian use of perennial biomass feedstocks as post-breeding and migratory stopover habitat. PLOS ONE. 6:e16941.

Robertson BA, Doran PJ, Loomis ER, Robertson JR, Schemske DW. 2011b. Perennial biomass feedstocks enhance avian diversity. GCB Bioenergy. 3:235–246.

Rodgers Jr. JA, Smith HT. 2000. Set-back distances to protect nesting bird colonies from human disturbance in Florida. Conserv Biol. 9(1):89–99.

Roessig JM, Woodley CM, Cech Jr. JJ, Hansen LJ. 2004. Effects of global climate change on marine and estuarine fishes and fisheries. Rev Fish Biol Fish. 14:251–75.

Rohr JR, Raffel TR, Sessions SK, Hudson PJ. 2008. Understanding the net effects of pesticides on amphibian trematode infections. Ecol Appl. 18(7):1743–1753.

Rollins-Smith LA, Ramsey JP, Pask JD, Reinert LK, Woodhams DC. 2011. Amphibian immune defenses against Chytridiomycosis: impacts of changing environments. Integr Comp Biol. [accessed 2015 August];August 3, 2011:1–11. doi:10.1093/icb/icr095.

Row JR, Blouin-Demers G, Weatherhead PJ. 2007. Demographic effects of road mortality in black ratsnakes (*Elaphe obsoleta*). Biol Conserv. 137:117–124.

Rowe CL, Hopkins WA, Congdon JD. 2002. Ecotoxicological implications of aquatic disposal of coal combustion residues in the United States: a review. Environ Monit Assess. 80:207–276.

Ruediger B. 1996. The relationship between rare carnivores and highways. In: Evink GL, Garrett P, Zeigler D, Berry J, editors. Trends in addressing transportation related wildlife mortality: proceedings of the transportation related wildlife mortality seminar. Tallahassee (FL): Florida Department of Transportation. p. 24–40.

Ruediger B. 1998. Rare carnivores and highways—moving into the 21st century. In: Evink GL, Garrett P, Zeigler D, Berry J, editors. Proceedings of the international conference on wildlife ecology and transportation. Tallahassee (FL): Florida Department of Transportation. p. 10–16.

Sabine III JB, Meyers JM, Moore CT, Schweitzer SH. 2008. Effects of human activity on behavior of breeding american oystercatchers, Cumberland Island National Seashore, Georgia, USA. Waterbirds. 31(1):70–82.

Saenz D, Fucik EM, Kwiatkowski MA. 2013. Synergistic effects of the invasive chinese tallow (*Triadica sebifera*) and climate change on aquatic amphibian survival. Ecol Evol. 3(14):4828–4840.

Sage R, Cunningham M, Haughton AJ, Mallott MD, Bohan DA, Riche A. 2010. The environmental impacts of biomass crops: use by birds of miscanthus in summer and winter in southwestern England. Ibis. 152:487–499.

Salafsky N, Salzer D, Stattersfield AJ, Hilton-Taylor C, Neugarten R, Butchart SHM, Collen B, Cox N, Master LL, O’Connor S, et al. 2008. A standard lexicon for biodiversity conservation: unified classifications of threats and actions. Conserv Biol. [accessed 2015 July];22:897–911. http://www.teaming.com/sites/default/files/A%20Standard%20Lexicon%20for%20Biodiversity%20Conservation.pdf.

Sallenger Jr. AH, Doran KS, Howd PA. 2012. Hotspot of accelerated sea-level rise on the Atlantic coast of North America. Nat Clim Change. 2(12):884–888.

Salmon M, Reiners R, Lavin C, Wyneken J. 1995a. Behavior of loggerhead sea turtles on an urban beach. I. Correlates of nest placement. J Herpetol. 29(4):560–568.

Salmon M, Tolbert MG, Painter DP, Goff M, Reiners R. 1995b. Behavior of loggerhead sea turtles on an urban beach. II. Hatchling orientation. J Herpetol. 29(4):568–576.

[SAMAB] Southern Appalachian Man and the Biosphere. 1996. The Southern Appalachian Assessment aquatic technical report. Report 2 of 5. Atlanta (GA): US Department of Agriculture, Forest Service, Southern Region; [accessed 2015 July]. http://www.samab.org/site/publications/.

Samour J, Naldo JL. 2005. Lead toxicosis in falcons: a method for lead retrieval. Semin Avian and Exot Pet Med. 14:143–148.

Sarker S, Kaller DM, Hedrick RP, El-Matbouli M. 2015. Whirling disease revisited: pathogenesis, parasite biology and disease intervention. Dis Aquat Org. 114:155–175.

Sayemuzzamana M, Jha M. 2014. Seasonal and annual precipitation time series trend analysis in North Carolina, United States. Atmosph Res. 137:183–194.

Scheick BK, Jones MD. 1998. Locating wildlife underpasses prior to expansion of Highway 64 in North Carolina. In: Evink GL, Garrett P, Zeigler D, Berry J, editors. Proceedings of the international conference on wildlife ecology and transportation. Tallahassee (FL): Florida Department of Transportation. p. 247–251.

Scheuhammer AM, Norris SL. 1995. The ecotoxicology of lead shot and lead fishing weights. Ecotoxicol. 5(5):279–295. doi: 10.1007/BF00119051.

Semere T, Slater FM. 2007. Ground flora, small mammal and bird species diversity in miscanthus (*Miscanthus giganteus*) and reed canary-grass (*Phalaris arundinacea*) fields. Biomass Bioenergy. 31:20–29.

Sharp GB, Kawaoka Y, Wright SM, Turner B, Hinshaw V, Webster RG. 1993. Wild ducks are the reservoir for only a limited number of influenza A subtypes. Epidemiol Infect. [accessed 2015 August];110(01):161–176. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2271956/pdf/epidinfect00037-0164.pdf.

Sheafor B, Davidson EW, Parr L, Rollins-Smith L. 2008. Antimicrobial peptide defenses in the salamander, *Ambystoma tigrinum*, against emerging amphibian pathogens. J. Wildl. Dis. 44(2):226-236.

Smith C. 2012. Invasive exotic plants of North Carolina [Internet]. NC Department of Transportation; [accessed 2015 July]. http://www.se-eppc.org/northcarolina/NCDOT_Invasive_Exotic_Plants.pdf.

Smith RK, Freeman PL, Higgins JV, Wheaton KS, FitzHugh TW, Ernstrom KJ, Das AA. 2002. Priority areas for freshwater conservation action: a biodiversity assessment of the Southeastern United States. Boston (MA): The Nature Conservancy.

Smoot JL, Cuffney TF, Bryant, Jr. WL. 2004. Effects of urbanization on stream ecosystems: Proceedings of the 1st annual Stormwater Management Research Symposium, Stormwater Management Academy, Orland, FL. October 12–13, 2004. pp 127–136. [accessed 2015]. http://nc.water.usgs.gov/albe/pubs/Smoot_Effects.pdf.

Snieszko SF. 1970. Immunization of fishes: a review. J Wildl Dis. 6(1):24–30.

Snieszko SF. 1975. History and present status of fish diseases. J Wildl Dis. 11:446–459.

Snow AA, Andow DA, Gepts P, Hallerman EM, Power A, Tiedje JM, Wolfenbarger LL. 2005. Genetically engineered organisms and the environment: current status and recommendations. Ecol Appl. 15(2):377–404.

Souza MJ, Ramsay EC, Donnell RL. 2013. Metal accumulation and health effects in raccoons (*Procyon lotor*) associated with coal fly ash exposure. Arch Environ Contam Toxicol. 64:529–536.

Spence DJ, Smith JA, Ploetz R, Hulcr J, Stelinksi LL. 2013. Effect of chipping on emergence of the redbay ambrosia beetle (Coleoptera: Curculionidae: Scolytinae) and recovery of the laurel wilt pathogen from infested wood chips. For Entomol. 106(5):2093–2100.

Starliper CE. 2008. General and specialized media routinely employed for primary isolation of bacterial pathogens of fishes. J Wildl Dis. 44(1):121–132.

Starliper CE. 2011. Bacterial coldwater disease of fishes caused by *Flavobacterium psychrophilum*. J Adv Res. 2:97–108.

Steven R, Pickering C, Castley JG. 2011. A review of the impacts of nature based recreation on birds. J Environ Manag. 92:2287–94.

Stevenson AL, Scheuhammer AM, Chan HM. 2005. Effects of nontoxic shot regulations on lead accumulation in ducks and American woodcock in Canada. Arch Environ Contam Toxicol. 48:405–413.

Stewart CN, Halfhill MD, Warwick SI. 2003. Transgene introgression from genetically modified crops to their wild relatives. Nat Rev Genet. 4:806–817.

Stockwell C, Hendry A, Kinnison M. 2003. Contemporary evolution meets conservation biology. Trends Ecol Evol. 18(2):94–101.

Stoffregen DA, Dubey JP. 1991. A *Sarcocystis* sp.-like protozoan and concurrent canine distemper virus infection associated with encephalitis in a raccoon (*Procyon lotor*). J Wildl Dis. 27(4):688–692.

Strom SM, Patnode KA, Langenberg JA, Bodenstein BL, Scheuhammer AM. 2005. Lead contamination in American woodcock (Scolopax minor) from Wisconsin. Arch Environ Contam Toxicol. 49:396–402.

Tarr NM, Simons TR, Pollock KH. 2010. An experimental assessment of vehicle disturbance effects on migratory shorebirds. J Wildl Manag. 74(8):1776–83.

Terando AJ, Costanza J, Belyea C, Dunn RR, McKerrow A, Collazo JA. 2014. The southern megalopolis: using the past to predict the future of urban sprawl in the southeast US. US PLoS ONE. [accessed 2015 August];9(7): e102261. doi:10.1371/journal.pone.0102261.

[TNC] The Nature Conservancy. 2000. Conservation by design: a framework for mission success. Arlington (VA): The Nature Conservancy; [updated 2015; accessed 2015 July]. http://www.nature.org/media/aboutus/conservation-by-design-20th-anniversary-edition.pdf.

[TNC and Natureserve] The Nature Conservancy and Natureserve. 2001. Mid-Atlantic Coastal Plain Ecoregion Plan. Durham (NC): The Nature Conservancy; [accessed 2015 July]. http://www.conservationgateway.org/ConservationPlanning/SettingPriorities/EcoregionalReports/Documents/BinderMACP.pdf.

Thomas VG. 2013. Lead-free hunting rifle ammunition: product availability, price, effectiveness, and role in global wildlife conservation. Ambio. 42(6):737–745.

Thomas VG, Scheuhammer AM, Bond DE. 2009. Bone lead levels and lead isotope ratios in red grouse from Scottish and Yorkshire moors. Sci Total Environ. 407:3494–3502.

Thompson ID, Kirk DA, Jastrebski C. 2013. Does postharvest silviculture improve convergence of avian communities in managed and old-growth boreal forests? Can J For Resour. 43:1050–1062.

Thompson KG. 2011. Evaluation of small-scale habitat manipulation to reduce the impact of the whirling disease parasite in streams. Aquat Ecosyst Health Manag Soc. 14(3):305–317.

Turano MJ, Gabel S, Frinsko M, Hinshaw J, Thompson K, Sloan D, Anderson P. 2013. North Carolina aquaculture update, North Carolina Aquaculture Development Conference February 8, 2013, New Bern (NC). [accessed 2015 July]. http://www.ncaquaculture.org/pdfs/2013_friday_session/turano_update2012.pdf.

[UNCC] University of NC Charlotte. 2009. Mecklenburg County Profile, Charlotte Regional Indicators Project. Charlotte (NC): UNCC Urban Institute; [accessed 2015 August]. http://ui.uncc.edu/sites/default/files/pdf/mecklenburgindicators.pdf.

[UNCC] University of NC Charlotte. 2012. Regional growth mapping and forecasting: 1976-2040. Charlotte (NC): Renaissance Computing Institute (RENCI); [accessed 2015 August]. http://ui.uncc.edu/sites/default/files/pdf/3CountyTriangleResults.pdf.

[USCB] US Census Bureau. 2014. Annual estimates of the resident population April 1, 2010 to July 1, 2014 [web page]. US Census Bureau, Population Division; [accessed 2015 August]. http://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml.

[USDA] US Department of Agriculture. 2014. 2012 census of agriculture. Washington (DC): US Department of Agriculture. 695 p.

[USGS NWHC] US Geological Society National Wildlife Health Center. 2013. Chronic wasting disease [web page]. [last updated 2013 May 21; accessed 2015 July]. http://www.nwhc.usgs.gov/disease_information/chronic_wasting_disease/index.jsp

[USFWS] US Fish & Wildlife Service. 2007. National Bald Eagle management guidelines. Pierre (SD): US Fish & Wildlife Service, South Dakota Ecological Services Field Office; [accessed 2015 September]. 25 p. http://www.fws.gov/southdakotafieldoffice/NationalBaldEagleManagementGuidelines.pdf.

[USFWS] US Fish & Wildlife Service. 2012. Land-based wind energy guidelines [Internet]. OMB Control No, 1018-0148. Washington (DC): US Fish & Wildlife Service; [accessed 2015 July]. http://www.fws.gov/ecological-services/es-library/pdfs/WEG_final.pdf.

[EPA] US Environmental Protection Agency. 2014. Nutrient policy and data: cyanobacteria/cyanotoxins [Internet]. [accessed 2015 July]. http://www2.epa.gov/nutrient-policy-data/cyanobacteriacyanotoxins.

van de Merwe JP, West EJ, Ibrahim K. 2012. Effects of off-road vehicle tyre ruts on the beach dispersal of green sea turtle *Chelonia mydas* hatchlings. Endanger Species Res. 18:27–34.

van Hengstum T. 2013. Ecological effects of plant invasions [PhD thesis]. [Amsterdam (The Netherlands)]: University of Amsterdam; [accessed 2015 July]. http://hdl.handle.net/11245/1.397535.

Verhagen JD, van Dijk JGB, Vuong O, Bestebroer T, Lexmond P, Klaassen M, Fouchier RAM. 2014. Migratory birds reinforce local circulation of avian influenza viruses. PLoS ONE. [accessed 2015 August];9(11): e112366. doi:10.1371/journal.pone.0112366.

Vigil E, Lepak JM, Dreiling D, Winkelman DL. 2015. Distribution, prevalence and intensity of gill lice *Salmincola californiensis* in Colorado. Portland (OR): American Fisheries Society.

von Haartman L. 1971. Population dynamics. In: Farner DJ, King JR, editors. Avian biology, Vol. 1. London (England): Academic Press. p. 391–459

Vose JM, Laird SG, Choice ZD, Klepzig KD. 2014. Chapter 13: Summary of findings, management options and interactions. In: Vose JM, Klepzig KD, editors. Climate change adaptation and mitigation management options: a guide for natural resource managers in southern forest ecosystems. New York (NY): CRC Press, Taylor & Francis Group.

Warren ML, Angermeier PL, Burr BM, Haag WR. 1997. Decline of a diverse fish fauna: patterns of imperilment and protection in the southeastern United States. In: Benz GW, Collins DE, editors. Aquatic fauna in peril: the southeastern perspective. Decatur (GA): Southeast Aquatic Research Institute. p. 105–164

Waldner CL. 2008. The association between exposure to the oil and gas industry and beef calf mortality in Western Canada. Arch Environ Occup Health. 63:220–240.

Waldner CL, Clark EG. 2009. Association between exposure to emissions from the oil and gas industry and pathology of the immune, nervous, and respiratory systems, and skeletal and cardiac muscle in beef calves. Arch Environ Occup Health. 64:6–27.

Walsh SJ, Burkhead NM, Williams JD. 1995. Southeastern freshwater fishes. In: LaRoe ET, Farris GS, Puckett CE, Doran PD, Mac MJ, editors. Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. Washington (DC): US Department of Interior, National Biological Service. p. 144–147.

Watters GT. 2000. Freshwater mussels and water quality: a review of the effects of hydrologic and instream habitat alterations. In: Tankersley RA, Warmolts DI, Watters GT, Armitage BJ, Butler RS, editors. Special contribution: freshwater mollusks as indicators or water quality. Freshwater Mollusk Symposia Proceedings. p. 261–274.

Webster RG, Bean WJ, Gorman OT, Chambers TM, Kawaoka Y. 1992. Evolution and ecology of influenza A viruses. Microbiol Rev. 56:152–179.

Weir LK, Grant JWA. 2005. Effects of aquaculture on wild fish populations: a synthesis of data. Environ Rev. 13:145–168.

Wiens JA. 1997. Metapopulation dynamics and landscape ecology. In: Hanski I, Gilpin ME, editors. Metapopulation biology: ecology, genetics and evolution. San Diego (CA): Academic Press. p. 43–68.

Wilcove DS, Rothstein D, Dubow J, Phillips A, Losos E. 1998. Quantifying threats to imperiled species in the United States. BioSci. 48(8):607–615.

Williams JD, Warren ML, Cummings KS, Harris JL, Neves RJ. 1993. Conservation status of the freshwater mussels of the United States and Canada. Fish. 18:6–22.

WINDExchange [website]. c. 2015. US Department of Energy; [accessed 2015 July]. http://apps2.eere.energy.gov/wind/windexchange/wind_resource_maps.asp?stateab=nc.

Wingard GL, Murray JB, Schill WB, Phillips EC. 2008. Red-rimmed Melania (Melanoides tuberculatus)—a snail in Biscayne National Park, Florida—harmful invader or just a nuisance. USGS Fact Sheet. [accessed 2015 July];3006(6). http://pubs.usgs.gov/fs/2008/3006/pdf/fs2008-3006.pdf.

Witherington BE. 1992. Behavioral responses of nesting sea turtles to artificial lighting. Herpetol. 48:31–39.

Wofford JEB, Gresswell RE, Banks MA. 2005. Influence of barriers to movement on within-watershed genetic variation of coastal cutthroat trout. Ecol Appl. 15:628–637.

Wood Resources International. 2014. Wood pellet exports from North America to Europe have doubled in two years to reach 4.7 million tons in 2013 with the US South accounting for 63% of the volume [Internet]. [accessed 2015 July]. http://www.mynewsdesk.com/se/pressreleases/wood-pellet-exports-from-north-america-to-europe-have-doubled-in-two-years-to-reach-4-7-million-tons-in-2013-with-the-us-south-accounting-for-63-992975.

Wootten A, Smith K, Boyles R, Terando A, Stefanova L, Misra V, Smith T, Blodgett D, Semazzi F. 2014. Downscaled climate projections for the Southeast United States—evaluation and use for ecological applications. Open-File Report 2014–1190. Reston (VA): US Geological Survey. 54 p.

Conservation Goals and Priorities in North Carolina

6

Required Element 4

Provide descriptions of conservation actions proposed to conserve the identified species and habitats and priorities for implementing such actions.

6.1 Introduction

Conservation needs and recommendations for specific taxonomic groups, species associations, or individual species were identified and discussed in Chapter 3. Problems affecting important aquatic, wetland, and terrestrial natural communities that provide habitat for North Carolina's wildlife were presented in Chapter 4. Current and emerging conditions that represent the threats most likely to impact fish and wildlife and their habitats were identified in Chapter 5. The information provided in these three chapters has been used to inform the programs and recommendations presented in Chapter 6. During the last decade, these programs have successfully achieved measureable benefits for wildlife and species. The recommendations are intended to be a part of the dialogue for implementing collaborative and cooperative discussions about conservation in the state.

This Chapter describes a framework used for establishing conservation goals and objectives and recommends strategies and actions that support this Plan. Examples of objectives, strategies, and priority actions that can be used to develop projects that will implement WAP goals and recommended actions are provided in Appendix K.

Section 6.2 outlines conservation incentives and programs that can be important tools in the implementation of strategic conservation plans. Program and partnership information for both private and public lands and for outreach and education efforts is outlined in this section. Section 6.3 provides information about survey, monitoring, and research strategies designed to improve conservation decisions; management practices and cooperative efforts that help partners and others implement projects; and technical guidance that can influence decisions and reduce impacts to species and habitats. Section 6.4 discusses the conservation programs and initiatives that implement WAP conservation goals and objectives. NCWRC works collaboratively with many of the federal and state agencies and conservation organizations noted in this Section and Appendix L provides more information on these efforts.

6.2 Planning and Implementing Conservation

Goals and objectives should be the founding principles that define a conservation mission. Measurable, project-specific strategies and priority actions are methods by which the conservation mission can be achieved. After conservation goals and objectives have been determined, implementation of strategies and priority actions that include adaptive management concepts can provide a framework for prioritizing actions and modifying strategies based on project results. There are several resources available that describe methods to improve the efficiency and effectiveness of goal-oriented conservation efforts.

Structured decision making is one method that includes strategies for incorporating adaptive management planning (Joseph et al. 2008; Alexander 2008; USFWS 2008; Miller et al. 2009; Newbold & Siikamaki 2009; CMP 2013). It is an iterative process that has been an integral part of the conservation dialogue between NCWRC and conservation partners, and was used throughout the WAP revision process. Figure 6.1 provides an example of an iteratively structured decision-making strategy developed by the Conservation Measures Partnership (CMP) for the Open Standards for the Practice of Conservation (CMP 2013). This graphic depicts steps in the iterative process that can be used for developing and refining goal-oriented conservation strategies.

6.2.1 Developing Conservation Goals

The 2005 WAP identified five primary conservation goals that form a conservation blueprint that is the core of that Plan (NCWRC 2005). These 2005 WAP goals focused on species and habitat conservation, fostering partnerships and cooperative efforts, supporting education and outreach efforts, and improving regulations and programs aimed at conserving species and habitats. A framework of suggested strategies and objectives was outlined in Chapter 6 of the 2005 Plan (see Tables 6.2 through 6.6, NCWRC 2005). These recommendations were the basis for efforts implemented over the last 10 and more years to address local, regional, and statewide concerns across key terrestrial and aquatic habitats.

FIGURE 6.1 **Example of an adaptive management planning cycle** (CMP 2013)

As part of the 2015 WAP revision process, a team of biologists and technical staff was tasked with evaluating the 2005 goals. The team developed recommendations that called for the WAP conservation goals to focus on species and habitat conservation efforts and to utilize objectives and strategies to address other conservation topics that support achieving these two goals. There was broad consensus that the goals should focus on two primary conservation goals that concentrate on wildlife and natural communities (which are reflected in the first two goals from the 2005 WAP). There was also agreement that efforts focused on developing partnerships, education and outreach programs, and rules, regulations, and technical guidance should be used as objectives and strategies to achieve the updated goals, rather than serve as individual goals.

6.2.2 Conservation Goals Framework

The following format represents the revised framework for the revised WAP conservation goals and the relationship between project-specific objectives, strategies, and priority actions that are used to achieve the goals.

GOAL (the overarching concept)

Objective (what we want to achieve with this goal)

Strategy (a way to achieve the objective)—these will be project-specific but examples are provided.

Priority Action (recommended actions that can be general or specific)—these will be project-specific but examples are provided.

Because projects represent many types of conservation efforts, the strategies and priority actions must be project-specific—incorporating adaptive management concepts that address the need for project modification based on results that results are measurable. The updated conservation goals and recommended objectives that focus on species and habitats, as well as example strategies and priority actions, are outlined in Tables 6.1 and 6.2 in Appendix K. The example strategies and priority actions provided in the tables are based on State Wildlife Grant (SWG) funded projects implemented by NCWRC biologists.

6.2.3 Conservation Funding Resources

In Chapter 1, we outlined how the SWG program provides matching grant funds for conservation efforts on behalf of SGCN priority species. The funds can be used for many types of conservation, such as surveys, monitoring, research, partnerships and programs, and land acquisition for habitat conservation. In addition to the SWG dollars, money from several trust-fund resources historically has been used in North Carolina to support specific types of land conservation. Successful land acquisition depends on matching site priorities with appropriate trust funds.

Federal- and state-level funding resources that have historically provided grants (as matching funds) that support landscape-level conservation programs include the following programs. However, because these resources are subject to the impacts of economic forces and legislative support, their availability varies annually.

- Land and Water Conservation Fund (LWCF)—This federal fund managed by the National Park Service supports acquisition and development of public outdoor recreation areas and facilities. The program is intended to create and maintain a nationwide legacy of quality recreation areas and facilities. The US Department of the Interior (USDOI) provides the funds and the NC Department of Environment and Natural Resources (NCDENR) administers the program in our state. Since 1965, the LWCF has provided $1.5 million on average per year in matching grants to protect land and support more than 875 state and local park projects in the state.

- Clean Water Management Trust Fund (CWMTF)—In 2013, the NC General Assembly by law (NC General Statute [G.S.] 113A, Article 18) combined the Natural Heritage Trust Fund (NHTF) with the existing CWMTF and designated that annual appropriations be used to finance projects to clean or prevent surface water pollution and for land preservation. The merged trust fund can support projects for: a) acquiring land or conservation easements for riparian buffers, conserving surface waters and enhancing drinking water supplies, high-value ecological diversity of natural features (riverine, montane, coastal, and geologic systems), and natural areas; b) coordinating with other public programs to enhance water quality protections or restoring degraded lands for water quality protection; and c) supporting other efforts related to stormwater management and pollution reduction initiatives. Since 1996, and before its merger with CWMTF, the previous NHTF had contributed more than $335 million ($18.5 million annually) through 528 grants to support the conservation of more than 300,000 acres in the state. CWMTF has provided $1 billion ($55 million annually) and partnered with communities across the state to support key local economies by funding on-the-ground water quality projects, which have leveraged an additional $500 million ($27.7 million annually) in private, local, and federal funds.

- Parks and Recreation Trust Fund (PARTF)—This fund primarily supports state and local parks and recreation projects (e.g., recreational trails, greenways, community centers) that serve the general public by providing local governments (counties, incorporated municipalities, and public authorities) with dollar-for-dollar matching grants. The program is managed by the NC Parks and Recreation Authority and administered by the NCDENR, Division of Parks and Recreation. Since 1999, more than $450 million has been awarded ($25 million annually) for 736 projects statewide.

- Agricultural Development and Farmland Preservation Trust Fund (ADFPTF)—This fund supports the preservation of NC farmland and depends on annual appropriations from the General Assembly. The fund supports farming, forestry, and horticulture communities within the $77 billion NC agribusiness industry by providing matching grants for the purchase of development rights by recording perpetual or term agricultural conservation easements (on farm, forest, and horticulture lands). The fund also provides matching grants for public and private enterprise programs that promote profitable and sustainable family farms. Grants for agricultural conservation easements give preference to lands with active production of food, fiber, and other agricultural products.

Farm and forest landowners must partner with nonprofit conservation organizations or county agencies to apply for funds. Since 2008, the trust fund has provided approximately $13 million in grant expenditures and has an additional $3.5 million under contract in support of 138 projects and easements statewide. Currently, 8,151 acres have received a recorded agricultural conservation easement and an additional 1,918 acres are under contract.

- A number of Natural Resources Conservation Service (NRCS) programs provide funds for environmental improvement and stewardship programs, staff salaries, and conservation easements. Many previous Farm Bill conservation programs were reorganized in 2014 and combine previously available funding into larger programs. Among the biggest changes and newest programs are the Regional Conservation Partnership Program (RCPP) and the Agricultural Conservation Easement Program (ACEP), which can be used to fund conservation easements. RCPP had $400 million available and ACEP had $332 million available nationwide in the 2014/15 application cycle. Visit the NRCS Conservation Programs website for a comprehensive list of programs.

- The Forest Legacy Program (FLP) is a federal program that supports state efforts to protect environmentally sensitive forest lands. In North Carolina, FLP is administered by the NC Forest Service (NCFS) to help landowners, state and local governments, and private land trusts identify and protect environmentally important forest lands that are threatened by present and future conversion to non-forest uses. The most important part of forest legacy are private landowners who want to conserve the special values of their land for future generations. Owners can do this in trust with the state government and receive a fair price for the commitment.

- NC Tax Checkoff for Nongame and Endangered Wildlife—The largest and most significant source of state funding for the NCWRC Wildlife Diversity Program. Anyone filing an NC income tax form and receiving a tax refund can designate any portion of the refund to fund the Wildlife Diversity Program. These are tax-deductible contributions for the next tax year. The deduction is generally made by checking line 31 on the form (exact line number is subject to tax form revision) and indicating the dollar amount of the contribution to be withheld from the tax refund. Since 1984, the Tax Checkoff program has provided $10,432,469 for conservation efforts. The average annual donation amount is $347,748, with the lowest in its first year in 1984 of $51,006 and the highest in 1991 of $510,269.

- NC Wildlife Diversity Endowment Fund—Interest earned from donations to this fund is spent on programs that benefit nongame species (i.e., animals not hunted or fished). Every dollar in donations given to the fund is matched with federal and other grants, so donated dollars actually count twice. Contributions are tax deductible and can be made through donations directly to the fund (including memorial contributions) or through a bequest from a will or living trust. This is a new fund designed to allow contributions toward programs benefitting nongame species. As of mid-2013, the fund had received less than $5,000 in contributions.

- NC Wildlife Endowment Fund—An investment and conservation program funded by fees paid for lifetime licenses and specified contributions. Contributions are tax deductible and can be made through donations directly to the fund (including memorial contributions) or through a bequest from a will or living trust. As of June 2013, the fund had a cash balance of nearly $99 million. The fund has been able to transfer more than $51 million to the operations of the Wildlife Resources Commission to assist in carrying out its mission.

- NC Wildlife Conservation Account—Through partnership with the NC Division of Motor Vehicles, funds are generated through purchase and renewal of a Wildlife Resources personalized license plate for a vehicle, camper, or trailer. Since 2000, the personalized license plate program has provided more than $300,000 for wildlife conservation.

- NCWRC has developed incentives for conservation-based local government land-use planning. NCWRC has established a pilot program called Partners for Green Growth to provide cost-share funding to local governments to assist them in enhancing priority wildlife habitat conservation through their land-use planning. Details about this funding can be found on the Green Growth Toolbox website.

- North Carolina has 21 local land trusts that work with landowners to ensure critical lands are protected for clean drinking water, recreation, tourism, healthy forests, and working farms that produce fresh, local foods. Land trusts range from small groups run by dedicated volunteers to large and complex organizations. These groups reflect the communities they serve—protecting a single river or open space within a town, building urban trails, or saving thousands of acres to create a new park. The one trait shared by all is a passion for protecting North Carolina's unique natural heritage. Find a land trust by visiting the Conservation Trust for North Carolina web page.

6.2.4 Conservation Tools and Data Resources

Conservation occurs across the landscape on many different scales and there currently is no single resource that maps where land conservation occurs. Several Geographic Information System (GIS) and map viewer tools representing different aspects of conservation in North Carolina are available on the internet. This Section highlights a few of the mapping tools that are beneficial to conservation planning. Some of the tools rely on others to provide spatial data, and as such, the benefits from using the tool will rely on the quality of data provided.

6.2.4.1 NC OneMap Geospatial Portal

NC OneMap is the geospatial backbone supporting NC data and map service users. It is an organized effort of numerous partners throughout North Carolina, involving local, state, and federal government agencies, the private sector, and academia. NC OneMap is an evolving initiative directed by the NC Geographic Information Coordinating Council (GICC). GICC adopted this comprehensive initiative in partnership with county, municipal, state, and federal data providers.

The program promotes a vision for geospatial data standards; data currency, maintenance, and accessibility; data documentation (i.e., metadata); and a statewide GIS inventory. Thirty-seven priority data themes were selected as the initial focus, and critical information captured in geospatial datasets includes aerial imagery, land records, transportation, regulatory data, demographics, governmental boundaries, and marine and natural resources.

6.2.4.2 NC Natural Heritage Data Explorer

The NC Natural Heritage Data Explorer provides interactive access for viewing most of the conservation data available statewide and all of the data compiled and managed by the NC Natural Heritage Program (NCNHP). The data comprise maps of the best natural areas with the highest quality habitats for rare plants and wildlife in our state. NCNHP provides training on the Data Explorer. More information is provided on the NCNHP web page.

6.2.4.3 Green Growth Toolbox (GGT)

The Green Growth Toolbox, coordinated by NCWRC, is a free technical assistance tool for communities, local governments, planners, planning-related boards, and developers. The toolbox helps plan for growth in a way that will conserve natural assets—fish, wildlife, plants, streams, forests, fields, and wetlands. A handbook and GIS datasets provide mapping data, land-use planning methods, recommendations, and case studies for conservation of priority wildlife habitats through local land use planning, policy-making, and development design. GGT is integrated with the NCNHP Data Explorer and the NC Conservation Planning Tool.

6.2.4.4 NC Gap Analysis Project (NC-GAP)

NC-GAP is the state-level representative of the National Gap Analysis Program sponsored by the Biological Resources Division of the US Geological Survey (USGS). The mission of the program is to conduct regional assessments of the conservation status of native terrestrial vertebrate species and natural land cover types, and to facilitate the application of this information to land management activities. The goal of the NC-GAP project is to assess the distribution and conservation status of biodiversity in the state under existing land ownership and management regimes. Specific objectives include:

- Map the land cover of North Carolina (Vegetation Mapping),
- Map the predicted distributions of terrestrial vertebrates that use habitat in the state during the breeding season (Vertebrate Predicted Distribution Mapping),
- Map the network of conservation lands in the state (Land Management Status),
- Assess the conservation status of both the terrestrial vertebrates and the natural vegetative communities of the state (NC GAP Final Report), and
- Provide that information to natural resource agencies so they can use it in their conservation planning efforts.

NC-GAP staff provided critical assistance in mapping species distributions and habitat types used in the 2005 WAP, especially for distribution maps in Appendix K (NCWRC 2005). More recently, staff developed the NC-GAP Geo-Data Server to provide access to species distribution, stewardship, and land cover data in an interactive map format. Data in Esri ArcInfo (www.esri.com) data format (grids and coverages) can be downloaded through the Geo-Data Download interface. In addition, all data can be viewed through the GAP Online Tool.

6.2.4.5 Data Basin

Data Basin is a science-based mapping and analysis platform that supports learning, research, and sustainable environmental stewardship. Datasets are spatial information, typically created using a GIS. Datasets contain local, regional, and global geospatial information. Biological, physical, and socioeconomic information also is available. A dataset could be coordinates where a bird species has been observed, boundaries of land managed in various ways, a thematic image of vegetation types, or the results of a model that shows changes in the habitat distribution of a species under different climate change scenarios.

The core of Data Basin is free and provides open access to thousands of scientifically grounded, biological, physical, and socioeconomic datasets. A large and continually growing body of datasets, including both raw data (e.g., monitoring data on temperature and precipitation, road networks) and analytical results (e.g., projected changes in suitability for a species or ecosystem, interpretations, or recommendations), is included.

6.2.4.6 Conservation Blueprint

The Conservation Blueprint is a spatially explicit living plan that describes the places and actions needed to meet the shared conservation objectives of the South Atlantic Landscape Conservation Cooperative (SALCC) and partners in the face of future change. As a living plan, it can be updated to respond to future changes like urban growth, sea level rise (SLR), and climate change. More than 300 people from 85 organizations were actively involved in developing the current version of the Blueprint.

The Blueprint is accessed through a simple web-based interface that informs conservation decisions through exploration of data on priority areas, recommended actions, and landscape context. The interface is a map that identifies habitats of particular concern and prioritizes them using a hierarchical system. The map uses a color matrix to depict conservation priorities in a hierarchy of highest, high, and low priorities, and indicates which areas need further investigation to understand conservation needs. The web-based Blueprint map is hosted through Data Basin (see 6.1.3.5), which facilitates uploading digital files with spatial data or downloading maps that delineate particular areas of interest.

6.3 Conservation Opportunities and Incentives

Successful wildlife habitat conservation ultimately involves effective partnerships forged among private landowners, public land managers, local governments, developers, and transportation and development planners. Strong partnerships among agencies, organizations, academics, and industries are critical to implementing these strategies and actions, both statewide and in regional settings. Examples of objectives, strategies, and priority actions to achieve the goals outlined in this Chapter are provided for these measures.

The conservation issues, strategies, and actions discussed in this Section represent only a fraction of North Carolina's conservation needs and are intended to be a starting point for discussions about how best to accomplish wildlife and habitat conservation in the state.

6.3.1 Private Lands and Conservation Incentives

Conservation programs can seem complex. Private landowners can be unaware of programs for which they are qualified, and lack information about administrators of such programs. From a programming standpoint, private land programs need to be more streamlined, better coordinated, and more effectively presented to the public. Key agencies and organizations involved in private lands programming in North Carolina should strive for better program coordination, with the goal of providing clear and consistent leadership on options and benefits to landowners.

Conservation programs, incentives, and partnerships should be utilized to the fullest extent to preserve high-quality resources and protect important natural communities. Landowners should be introduced to available cost-share programs (e.g., Farm Bill programs) and habitat improvement advice (e.g., Forest Stewardship Program, Forest Landbird Legacy Program) that fit their needs. The NC Forest Service (NCFS) and NCWRC provide technical guidance to assist private landowners with sustainable management of the natural resources on their property.

It is recommended that priority wildlife habitat management on private lands implement silvicultural management practices at appropriate locations to enhance ground forb and grass understory development; provide regeneration and habitat for disturbance-dependent species or early successional species; and enhance mature forest conditions in young to middle-aged pure stands. Quality early successional habitats should be developed and maintained through a combination of management strategies and appropriate practices (including prescribed burning, timber harvest, grazing, herbicide use, or other practices) on both public and private lands.

6.3.1.1 Incentives and Programs

Cost-share and tax incentive programs can reduce tax rates and the cost of establishing new conservation practices for private landowners, thereby encouraging them to implement better habitat and natural resource management on their lands. Examples that can benefit private landowners include the following:

- Wildlife Land Conservation Program (WLCP)—An NCWRC program that allows private landowners who have owned their property for at least five years and want to manage for protected wildlife species or priority wildlife habitats to apply for a reduced property tax assessment. A site visit by NCWRC is made to verify that the landowner has at least 20 acres of defined priority wildlife habitat. The legal framework for the program can be found in NC G.S. Section 105-277.15. These lands are assessed by the county in which they are located at a reduced value and landowners participating in WCLP can apply to their county tax office for a property tax deferment. Other present-use tax reduction programs exist in North Carolina for private lands actively managed for forestry or agriculture; however, benefits cannot be combined from multiple programs.

- Many wildlife species are declining due to a lack of properly managed early successional habitat. The Cooperative Upland habitat Restoration and Enhancement (CURE) program is designed to increase early successional habitats and improve associated wildlife populations (including small game and songbirds) on private land in North Carolina. The CURE Program aims to create enough early successional habitat on private land cooperatives (>5,000 acres) to have a measurable impact on local wildlife populations. Through the CURE program, NCWRC offers guidance, labor, and financial assistance to qualified landowners. The Farm Bill conservation incentives programs are also employed to implement CURE.

  The Commission has identified "focal areas" for early successional habitat work within the Piedmont and upper Coastal Plain for the CURE program. These focal areas contain landscapes that are considered to provide the greatest potential for early successional habitat management on private lands and should be used to prioritize and focus other early successional habitat initiatives. Furthermore, conservation efforts should be geographically clustered, to the extent possible, to create larger areas of contiguous early successional habitat.

Farm Bill programs, administered by the USDA Natural Resources Conservation Service, offer many conservation incentive cost-share funds. These programs are subject to change depending on modifications to the Farm Bill. There are numerous programs that improve management of wildlife habitat and water quality for lands in agricultural and forestry production, including:

- The Conservation Reserve Enhancement Program (CREP) and the Agriculture Cost-Share Program (ACSP). These programs are joint efforts among state and federal agencies administered by the NC Division of Soil and Water Conservation to address water quality problems. They are voluntary programs that seek to protect land currently in agricultural production along watercourses.

- One of the newest programs is the Regional Conservation Partnership Program. RCPP combines four former conservation programs, including two that were applied in North Carolina—the Agricultural Water Enhancement Program and the Cooperative Conservation Partnership Initiative (CCPI). Assistance is delivered in accordance with the rules of the Environmental Quality Incentives Program (EQIP), Conservation Stewardship Program (CSP), ACEP, and Healthy Forests Reserve Program (HFRP), and in certain areas, the Watershed Operations and Flood Prevention Program. Nearly $400 million in funding for RCPP was available in the 2014/15 cycle. Successful applicants enter into partnership agreements with NRCS under RCPP. Additionally, EQIP now contains the Wildlife Habitat Incentives Program (WHIP).

NCFS offers forest and tree conservation technical assistance and incentives for landowners. A forest management plan approved by a representative of NCFS is required. There are different qualification standards for different forest types.

- The NC Forestry and Agriculture Present-Use Value Program can reduce property taxes for qualifying farm and forest landowners.
- See the NCFS web page, Managing Your Forest, for detailed program information.
- The Forest Stewardship Program provides technical assistance to enhance wildlife habitat management on private forest lands.
- The Forest Development Program is a reforestation, afforestation, and forest stand improvement cost-sharing program run by NCFS. The goals of the program focus on timber production and the creation of the benefits associated with active forest management.
- NCFS Forester also utilizes all of the forestry programs and incentives outlined in this chapter.

The USFWS Safe Harbor and Candidate Conservation Agreements are voluntary agreements between USFWS and cooperating nonfederal (private and government) landowners. They are designed to benefit federally endangered and threatened species by giving landowners assurances that at no future time would USFWS impose restrictions on their land as a result of conservation actions on their part. In other words, these agreements essentially relieve landowners of liability under the Endangered Species Act if conservation practices on their land attract and/or perpetuate federally listed species. To date, nearly 3 million acres of land have been enrolled in Safe Harbor Agreements, benefiting a variety of listed species. In North Carolina, Safe Harbor Program agreements have been used to benefit the endangered Red-cockaded Woodpecker.

Sustainable Forestry Initiative (SFI) is an independent collaboration of individuals and organizations that work together to improve forest management and promote responsible fiber sourcing. Certification of sustainable forest management can provide a tangible incentive to timber companies to improve their natural resource management practices.

Timber Investment Management Organizations (TIMOs)—Timber investments occupy a considerable landmass in our state. Conservation ethics should be integrated into the decision-making process of the parent financial organizations through working with TIMOs, or other appropriate contracting organizations, to influence TIMO land management practices to include considerations for wildlife and habitats.

6.3.1.2 Strategies and Recommendations

The following strategies and recommended actions highlight land conservation and management considerations with a goal of conserving wildlife of conservation concern, improving hunting and fishing opportunities for all regions of the state, and improving wildlife habitat in general. These strategies can be implemented through partnerships with private land owners and should be incorporated where appropriate in management of public lands.

- Introduce private landowners to available programs that fit their needs, such as cost-share programs (e.g., Farm Bill programs) and technical guidance on habitat improvement (e.g., Forest Stewardship Program, Forest Landbird Legacy Program).
- Inform landowners about Present Use Value Programs to encourage the maintenance of working lands.
- Ensure that priority wildlife habitats are ranked appropriately in Farm Bill Incentive Programs.
- Incorporate forest habitat management that benefits priority wildlife species in Forest Stewardship Plans.
- Ensure that partners implementing CREP have access to up-to-date data and maps of priority riparian and wildlife conservation areas.
- Use agriculture cost-share programs to target protection of priority watersheds (see Chapter 4.5 River Basins).
- Assist conservation partners (including land trusts) with purchasing or acquiring easements on land with priority habitats. Rural lands around urbanizing areas are a critical priority.
- Develop large-scale incentive programs designed to improve wildlife stewardship by corporate landowners (in addition to CURE). Include measures that support prescribed burning on private and corporate timber lands.

6.3.2 Public Land Stewardship

Public lands include state and federal lands as well as municipal and local government parks and open space. Maintaining natural public lands and natural open space within urban areas will help to make cities more livable and may reduce the pressure to develop rural farms and woodlands. There is overwhelming public endorsement of conserving the land along with documentation of associated economic benefits. According to the outdoor recreation industry, more than $3.3 billion is spent annually on wildlife-related recreation in our state.

Figure 6.2 represents the expansive number of agencies and organizations with a land stewardship mission and depicts the location of lands managed for conservation. The figure illustrates a disconnect between conservation lands and nearby habitats that can pose a barrier to movement between fish and wildlife populations. There is a continuing need to protect corridors between conservation lands to provide sufficient connectivity that facilitates species movement and gene flow across the landscape. It is critical to provide corridors and protect connections in urban areas, especially in the Piedmont ecoregion where development and urbanized areas continue to expand.

6.3.2.1 State-owned Public Lands

North Carolina has more acreage of managed game lands than all states east of the Mississippi, with the exception of Florida and Michigan, both of which include lake and ocean frontage as managed land. Through cooperative agreements with federal and state agencies and private landowners, NCWRC manages over 2 million acres of land for conservation of fish and wildlife species and broad expanses of public recreational opportunities, especially public hunting, trapping, and fishing opportunities. NCWRC land conservation objectives include expanding existing game lands to connect them better with other wildlife conservation areas. This will improve connectivity of priority habitats and buffer natural communities from encroaching development and land uses that could limit use of prescribed fire as a conservation tool. Other objectives are to provide public hunting and fishing access and wildlife observation opportunities that benefit all regions of the state, and to preserve wildlife migration and movement corridors.

These state game lands are managed using science-based practices and are critical to the preservation of endangered, threatened, and rare species. Currently, there are 64 game lands representing over 812,000 acres of state-owned land. There are another 40 game lands representing over 1.2 million acres owned by others (e.g., national forest and park lands, conservation easements) that are managed by NCWRC. Several game lands have management plans that implement conservation actions for the endangered, threatened, and rare species that occur in the landscape. For example, in the Coastal Plain ecoregion, Holly Shelter Game Land (Pender County) is home to 13 endangered, threatened, or rare species, including the federally endangered Red-cockaded Woodpecker, Golden Sedge, and Rough-leaf Loosestrife, and several state-listed species, including the Carolina Gopher Frog, Cooley's Meadowrue, and Venus Flytrap. The Sandhills Game Land (Hoke, Moore, Richmond, Scotland counties) contains one of the largest and most intact remnants of Longleaf Pine ecosystems in the state and has several state and federal listed species such as Red-cockaded Woodpecker, Michaux's Sumac, Rough-leaf Loosestrife, and Sandhill's

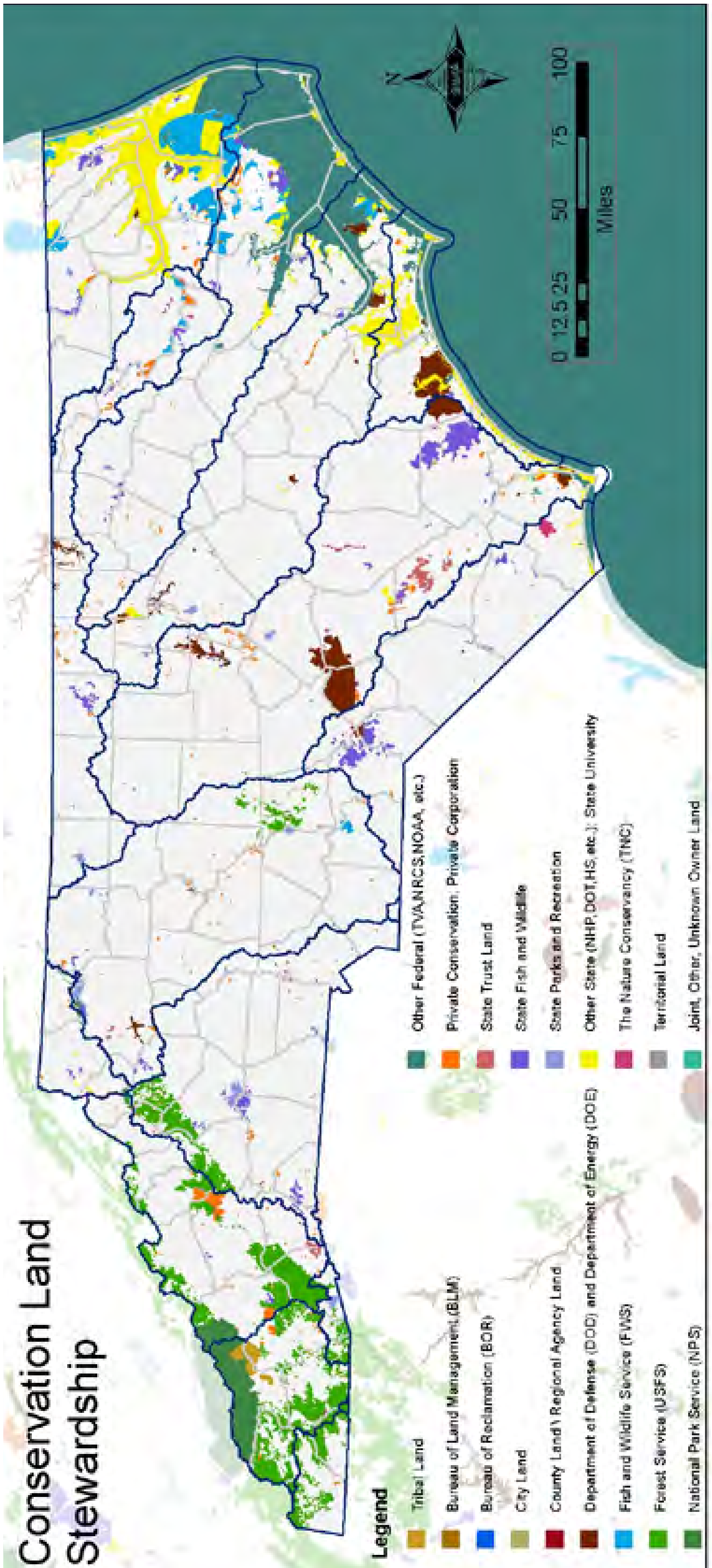


FIGURE 6.2 Conservation Land Stewardship

Lily. In the Mountain ecoregion, prescribed fire is a management tool used on these game lands to maintain the understory of the Longleaf Pine and wet pine savanna communities essential for Red-cockaded Woodpeckers.

Game lands include the largest intact and least disturbed bottomland forest ecosystem in the mid-Atlantic Region and some of the oldest Cypress-tupelo trees on the East Coast—many at least 800 years old. Other benefits include:

- One of the largest, most intact remnants of Longleaf Pine ecosystems in North Carolina, a high-priority wildlife habitat in the Lands Management program. Among the species dependent upon this type of habitat are Northern Bobwhite Quail, a variety of songbirds, Eastern Fox Squirrels and the federally endangered Red-cockaded Woodpecker;

- The densest populations of Black Bear, White-tailed Deer, and Turkey, and the highest density of nesting birds in the state. Most of our 32 Black Bear sanctuaries are on game lands;

- A system of floating waterfowl blinds, 19 public hunting blinds for disabled sportsmen, 32 public boating access areas, 33 public fishing areas, 6 wildlife observation platforms, and 4 public WRC shooting ranges with plans to build and manage more as opportunities occur; and

- Some of the finest examples of multiple conservation collaborations in the country.

NCFS manages the 10,400-acre DuPont State Recreational Forest in Henderson and Transylvania Counties. This forest also is found in the NCWRC game lands program. NCFS operates a system of six Educational State Forests (ESFs) designed to teach the public—especially school children—about forest environments. In some cases, forest restoration projects are used to promote the importance of the state's unique natural communities. For example, the Clemmons ESF (Johnston County) is restoring the original Longleaf Pine stands, which will eventually cover as much as 400 acres of the forest and benefit many species that rely on this type of habitat. Turnbull Creek (Bladen County) is located amongst natural Carolina bays and natural Longleaf Pine savannah habitat is being restored on the site.

North Carolina Division of Parks and Recreation (NCDPR), a part of NCDENR, works to conserve and protect representative examples of the natural beauty, ecological features, and recreational resources of statewide significance; to provide outdoor recreational opportunities in a safe and healthy environment; and to provide environmental education opportunities that promote stewardship of the state's natural heritage. Numerous state parks are notable for their natural resources:

- Grandfather Mountain State Park in the Mountain ecoregion is home to 70 known rare and endangered species and 16 distinct natural communities.
- Eno River State Park in the Piedmont ecoregion is home to several state and federally protected species. The park is a scenic wilderness corridor encompassing 14 miles of river, and featuring multiple cultural history sites.
- The Longleaf Pine forests of Weymouth Woods Sandhills Nature Preserve in the Sandhills ecoregion are home to rare and endangered species including the Red-cockaded Woodpecker and Pine Barrens Tree Frog.
- Lake Waccamaw State Park in the Coastal Plain ecoregion features one of the largest natural Carolina bays in the state, which is home to several unique plants and animals—some of which exist only at this location.

6.3.2.2 Federally Owned Public Lands

USFWS manages the National Wildlife Refuge System, a national network of lands and waters for the conservation, management, and where appropriate, restoration of fish, wildlife, and plant resources and their habitats. Managing these habitats is a complex process of controlling or eradicating invasive species, using fire in a prescribed manner, assuring adequate water resources, and assessing external threats such as development or contamination.

National wildlife refuges are home to more than 380 of the nation's 1,311 endangered or threatened species. So far, 11 of those species have been removed from the list due to their recovery, and conservation efforts have resulted in 17 others being downlisted from endangered to threatened status. More than 500 listed species are now stable or improving. Fifty-nine national wildlife refuges have been created specifically to help imperiled species. North Carolina has 11 national wildlife refuges, including one of the newest, Mountain Bogs National Wildlife Refuge.

USFS manages public lands in national forests and grasslands. North Carolina falls within the Southern Region of the Forest Service (Region 8). There are four National Forests in North Carolina: Croatan, Uwharrie, Nantahala, and Pisgah. Each has its own Land and Resource Management Plan (LRMP), a document that provides direction for the future management of the forest and its resources.

The National Park Service (NPS) manages several public lands scattered across the state. Cape Hatteras and Cape Lookout national seashores protect more coastal acreage, including beaches, maritime grasslands, and maritime forests, than do any other managed areas in the state. The Great Smoky Mountains National Park and the Blue Ridge Parkway protect several hundred thousand acres of mature forests in the Mountain ecoregion, including some of the best examples of spruce-fir forests.

6.3.2.3 Municipal Parks and Open Space

The Statewide Comprehensive Outdoor Recreation Plan suggests a link between access to open space and the overall mental and physical health of nearby residents (NCDPR 2015). Many city and county parks in North Carolina have been developed with human recreation as the top priority, but opportunities also exist to improve habitat management and wildlife-related recreation and education on these public lands. An urban wildlife program can serve to maximize biodiversity within urban areas, build critical public support for conservation efforts, and assist in guiding development pressures to help ensure the conservation of species and habitats in presently rural areas. Technical guidance assistance is available from state and federal agency partners to help develop appropriate management options.

The Mecklenburg County Parks and Recreation Department is a prime example of a parks system that has made natural resources management a priority by conserving habitat integrity and educating the public by offering guided hikes and programs about the environment. It serves as a model for other parks and recreation programs that wish to better integrate natural resources management into traditional programming methods.

Recommendations for conservation and management of both private and public lands that will benefit fish and wildlife resources and their habitats and education and outreach opportunities that will connect natural resource agencies and organizations to the broader conservation community are provided in the next section.

6.3.2.4 Strategies and Recommendations

The following strategies and recommended actions highlight land stewardship strategies that can be implemented through partnerships with federal, state, and local government land owners and should be incorporated where appropriate in management of public lands.

- Improve management for wildlife on existing public lands through technical assistance programs. Many city and county parks in North Carolina have been developed with human recreation as the top priority, but opportunities also exist to improve habitat management and wildlife-related recreation and education on these public lands.

- Promote conservation of open space and coordinate with regional open space and land-use planning initiatives.

- Promote development and management of greenways as natural areas that are not landscaped and manicured, especially in urban areas. Studies suggest greenways between 100 and 300 meters wide (roughly between 330 and 985 feet) provide the best wildlife habitat and corridors for dispersal when maintained in native vegetation and adjacent to canopy cover (NCWRC 2012).
- Provide technical guidance that supports preserving intermediate canopy layers and understory vegetation to benefit wildlife species that utilize open space in urban settings. Wide trails that are frequently maintained to remove vegetation and canopy cover may disrupt sensitive species or habitats by creating breaks in the forest cover as well as introducing human intrusion.
- Protect and adequately buffer high priority habitats, especially riparian forests, floodplains, isolated wetlands, and sites with known sensitive or listed species occurrences located in urban settings or areas subject to development.
- Support stream restoration in priority watersheds and in areas with sensitive species or significant aquatic resources (e.g., trout waters).

6.3.3 Education and Outreach

Effective conservation can only be an integral feature of human society when it is a priority for most of its citizens. As North Carolina's population centers become increasingly urban, there appears to be a growing disconnect between people and the outdoors, nature, and wildlife, which can lead to misconceptions, distrust, and fear. Education, outreach, and recreation opportunities are important tools to engage citizens in conservation and improve understanding of our wildlife resources among the general public and conservation stakeholders.

Limited funding, personnel, and resources are challenges when trying to meet education, outreach, and associated recreation needs, especially when there are more imminent needs associated with species and habitat protection. Some may view these types of activities as more expendable when balancing limited budgets and manpower. There is a critical link to be made between education, outreach, and recreation initiatives that can help address conservation problems.

Developing appropriate education and outreach efforts requires identifying different target audiences and understanding their respective attitudes and needs in the context of wildlife and natural community conservation. Human dimensions surveys should be used to collect information on attitudes toward wildlife and open space, conservation issues and management options. Further, human dimensions surveys need to identify actions that different audiences are willing to take or have their governments take on behalf of wildlife conservation. In light of the state's population growth and changing demographics, the perceived needs and desires of the public for wildlife education programs must be evaluated at regular intervals to ensure that needs are being met.

The Commission-published magazine, *Wildlife in North Carolina*, is an important outlet for information dissemination about fish and wildlife conservation projects and initiatives across the state. The WRC offers other publications such as a Wildlife Diversity newsletter, news releases, photos, species fact sheets, and technical, conservation, and management guides. Education and outreach needs specific to particular species groups (see Chapter 3) or habitats (see Chapter 4) are addressed within the appropriate natural community or river basin sections.

6.3.3.1 Public Education

Education, outreach, and recreation initiatives are components of successful wildlife conservation because they provide a way to connect natural resource agencies and organizations to citizens that comprise the broader conservation community. This community includes students and educators, public and private landowners, urban and rural residents, special interest and user groups (e.g., birders, hikers, paddlers, sportsmen and women), as well as local governments, corporations, and other natural resource stakeholders. State fish and wildlife agencies have a mandate to manage shared public wildlife resources for this broad constituency.

The NCWRC Division of Wildlife Education provides publications and programs through which the general public and educators can learn about wildlife, natural history, and outdoor skills. The NCWRC runs four education centers across the state and provides educator training, distance learning opportunities, and in-service training opportunities for professional educators and civic groups, who in turn, can carry what they learn to larger audiences. Programs for students of all ages can provide opportunities for hands-on learning outside the classroom as well as connect students to education programs through the use of current technologies. These programs include:

- Growing Up WILD, an early childhood program that builds on children's sense of wonder about nature and invites them to explore wildlife and their habitats, with an emphasis on promoting aquatic resource appreciation and stewardship. Through a wide range of activities and experiences, Growing Up WILD provides an early foundation for developing positive impressions about nature and lifelong social and academic skills. These six-hour workshops are primarily oriented toward formal and non-formal educators who work with children ages three to seven. They include early childhood and classroom educators, homeschool teachers, and park rangers.

- The Triangle Chapter of the Safari Club International and NCWRC sponsor the Sensory Safari trailer, a mobile, kid-friendly exhibit that encourages conservation of our native wildlife, promotes hunter education, and enables students to see and touch some of the game and nongame species found in North Carolina.

- NCWRC's mobile aquarium provides students with an opportunity to learn about different aquatic communities. The mobile aquarium features two 300-gallon tanks that display coldwater fish such as trout in one tank and warmwater fish such as sunfish in the other tank. The twin tanks are permanently mounted inside a trailer where artificial habitat insets have been made for the tanks to provide natural-looking settings for different fish assemblages.

- Project WILD workshops are for adults interested in teaching young people about wildlife. Participants receive the Project WILD K–12 educator guide along with materials specifically about NC wildlife. The educator guide contains more than 150 hands-on activities that focus on wildlife and natural resources. A similar program, Aquatic WILD, uses the format of Project WILD activities and professional training workshops but with an emphasis on aquatic wildlife and aquatic ecology. Both Project WILD and Aquatic WILD provide correlations to the NC K–5 Science Essential Standards for education.

- Other student education programs include the CATCH (Caring for Aquatics Through Conservation Habits) workshop. CATCH provides a curriculum guide to explore ways to teach about aquatic environments through fish biology, outdoor ethics, water safety, and fishing skills. Techniques and activities are geared for children ages 8–15. Other opportunities utilize technology by connecting classroom students with wildlife educators using distance-learning videoconferencing technology.

- Flying WILD workshops provide activities to teach middle school students about birds, their migration, and what people can do to help birds and their habitats. The activities can be used to teach classroom lessons or to set up service-learning projects about birds and their habitats.

Outdoor skill experiences are hands-on, participatory training that increase a person's ability to enjoy and experience wildlife resources (e.g., orienteering, fly fishing, cooking game). Women who are interested in connecting with the outdoors can take advantage of the Becoming an Outdoors Woman (BOW) program. BOW is an international program that provides women age 18 and older the opportunity to learn outdoor skills through hands-on experiences. In North Carolina, BOW workshops are usually sponsored through partnerships with wildlife clubs. Workshops are held in many locations across the state, offering learning opportunities on a variety of outdoor skills, including fishing, boating, hunter safety, target shooting, archery, canoeing, motorboat safety, outdoor cooking, tracking, and map-and-compass orienteering.

A goal of public education and outreach in urban and suburban areas is to increase awareness of and appreciation for wildlife-related issues in the urban landscape and to inspire people to take action toward protecting their local environment. Some citizens want to learn more about the impacts their homes and yards have on wildlife and how to create backyard oases for species. These programs can increase awareness of and appreciation for local wildlife species and habitats and create a connection between urbanites and nature. Local connections can be emphasized by promoting to the audience an awareness of where they live in their watershed and how their actions affect the world around them.

Pets are exotic predators in the environment and when allowed to roam freely they can significantly reduce small animal populations, especially birds, amphibians, and reptiles, by disrupting nesting and reproduction behavior or by killing wildlife. Educating pet owners about the importance of keeping their domesticated animals on a leash or within a fenced yard, or in the case of house cats, keeping them inside to help minimize impacts to wildlife is an ongoing need. Dogs allowed to run off-leash impact disturbance-sensitive species such as ground-nesting birds and small mammals and are subject to conflicts and injury from interaction with wild animals. Cats are exotic predators and efficient killers that prey on wild animals. Even well-fed cats will kill small mammals, insects, birds, amphibians, and reptiles—some of which may be species of conservation concern. Exposure to rabies and distemper is a health threat to both dogs and cats when vaccinations are not kept up to date and the animals are allowed to roam freely outside. Support of feral cat colonies should be discouraged, because the number of cats can significantly multiply and impact local wildlife populations.

Improved public education is critical to reducing human-induced threats and impacts to sensitive species and habitats. Humans have great influence and impact on sensitive environments such as coastal beaches, dunes, and estuarine habitats. Residential development in coastal areas can create impacts such as beach lighting and beach management practices (e.g., fencing, dredging, beach renourishment) that affect beach-nesting sea turtles and birds. Commercial and recreational activities such as boating and fishing (which can cause collisions, ghost line impacts, by-catch concerns) disturb and threaten coastal wildlife such as Diamondback Terrapins, sea turtles, and marine mammals. Education about human impacts on other sensitive environments such as isolated wetlands, bogs, caves and mines, and rock outcrops will be critical for the continued protection of these sites.

Prescribed burning is used as a forest management tool to reduce fuels and the risk of wildfire, and for ecosystem restoration, oak regeneration, understory control, and wildlife conservation. The importance of continued use and reintroduction of prescribed fire as a habitat management tool is critical to several natural communities. Public attitudes about fire have been greatly influenced by decades of Smokey Bear's effective fire prevention messages that emphasize the destructiveness of wildfire. Although anti-wildfire messages did not extend to prescribed burning, many people are unable to distinguish between "good" and "bad" fire (NCCES n.d.). Support for prescribed fire practices will require effective education and outreach to the communities and private landowners affected by this management practice.

6.3.3.2 Citizen Science Outreach

Citizen science projects help to involve the public in a hands-on way and create a sense of ownership and accomplishment among participants. Continued expansion of citizen science projects involving water quality monitoring, watershed restoration, wildlife conservation, and cleanup efforts are important in North Carolina. These efforts do a great deal to connect citizens to natural resource and water quality conservation, and help them understand human impacts on these resources at the local level.

In the western part of the state, the Hiwassee River Watershed Coalition sponsors volunteer water quality monitoring programs and supports local watershed restoration work that protects water quality. In the densely urbanized central Piedmont, the Lake Norman Wildlife Conservationists (an NC Wildlife Federation Teaming With Wildlife partner) actively works toward protection and enhancement of wildlife habitats in the Lake Norman area.

Other programs provide citizens with the opportunity to contribute to the base of scientific knowledge about wildlife. For example, the NC Calling Amphibian Survey Program (CASP) is a volunteer-based monitoring program administered by NCWRC. CASP coordinates with the North American Amphibian Monitoring Program (NAAMP), which maintains an online database administered by the USGS. The CASP survey data will contribute to information on the distribution and relative abundance of frogs and toads in North Carolina over time. This NC data will also be pooled with data from other states to investigate regional and national trends in frog distribution and changes in frog populations. Understanding these trends will provide us with a better understanding of the status and health of our frog and toad populations, and will enable us to protect critical habitats for our frog and toad species.

The National Audubon Society sponsors an annual Christmas Bird Count (CBC) that engages tens of thousands of birders in three weeks of organized group spotting events. The goal of CBC is to collect the most complete and accurate picture of bird populations across the world. This volunteer-driven citizen science event has been conducted for more than 100 years and is the most complete historic record of our bird populations over time. A less formal version of CBC, the Great Backyard Bird Count (GBBC) is held each February while many birds are on their wintering grounds. Participants can count birds for as few as 15 minutes and record species they observe in the international eBird database. The event began in 1998 as a way to collect data and display citizen science results in real time through digital reporting.

During spring and fall migration, millions of birds pass through North Carolina, often flying at night. Because they are attracted to the lights of tall buildings, birds like the Wood Thrush are at risk of becoming fatigued and suffering window collisions. The Lights Out North Carolina initiative provides citizen science opportunities in Winston-Salem, Charlotte, and Raleigh that include monitoring for injured birds or working with local officials and building owners to turn off lights during peak migration times.

6.3.3.3 Connecting with Wildlife

Although promoting some outdoor activities, such as birding or canoeing, may not directly result in species delisting or reverse habitat loss trends, these types of activities can create strong supporters for broader conservation goals. These initiatives are often the only opportunity for members of an urbanized area to make a personal connection with the natural environment.

Some species have adapted to coexist with humans and even prosper in their presence while others need additional assistance as their natural habitat is altered. Loss of natural habitats can result in wildlife adapting to use human structures, such as Chimney Swifts roosting in smokestacks and chimneys, bats roosting in house attics, Barn Owls nesting in sheds and barns, or Purple Martins using hanging gourds for nests. Local populations can be impacted as man-made structures are removed or wildlife viewed by residents as a nuisance is removed.

Conservation organizations such as the Chimney Swift Conservation Association and Bat Conservation International encourage construction of artificial roost habitats. Other activities to benefit wildlife species using man-made and urban structures include preserving old chimneys for Chimney Swifts; identifying buildings used by Peregrine Falcons for nesting and foraging and protecting these areas from disturbance; identifying, enhancing and protecting structures used for bat roosts; and promoting installation of bird boxes of various sizes and shapes for Eastern Bluebirds, American Kestrels, Wood Ducks, Purple Martins, Barn Owls, and other cavity nesters.

Wildlife conservation in urban areas necessarily relates to managing human–wildlife interactions. Wildlife disturbance by people can cause wildlife to abandon habitats and is more common in developed and developing areas.

Nuisance wildlife problems can occur when wildlife is attracted to human dwellings for food or shelter, when wildlife populations are enhanced by the presence of humans, and when wildlife is displaced by human development. Wildlife species that can be compatible with human development include some bats, foxes, Raccoons, Opossums, squirrels, deer, pigeons, European Starlings, House Sparrows, Canada Geese, and Chimney Swifts, among others. Many wildlife damage problems can be addressed by changing the perceptions and expectations of homeowners with regards to living with wildlife.

Many human-wildlife conflicts can be addressed by changing the perceptions and expectations of homeowners who live with wildlife. Though most nuisance wildlife issues may not relate directly to a conservation concern (e.g., a listed species or an endangered habitat), our efforts to solve nuisance wildlife problems are critical to improving the perception of urban wildlife issues in general. The Commission has developed nuisance wildlife recommendations and guidelines on some issues (e.g., resident Canada Geese, Black Bear).

Nuisance guidelines developed by the US Department of Agriculture (Hygnstrom et al. 1994) are another key source of information used by Commission outreach specialists for wildlife damage-related inquiries. Certified damage control agent programs should be supported and periodic reevaluation of the methods used for the removal of sensitive or tracked species (such as bats and some snakes) may be necessary to ensure the most appropriate handling of these sensitive species.

Wild animals can be reservoirs or hosts for diseases that can be transmitted to humans and domestic animals, such as rabies, distemper, tuberculosis, and leprosy. When there is contact between humans, domestic animals, and wildlife, there will be more risk for transmission of some zoonotic diseases (Bosch et al. 2013; Sharma et al. 2013; Schrenzel 2012; Calver et al. 2011; Loughry et al. 2009; Infectious Disease News 2008). Outdoor pets are at increased risk of contracting diseases from infected wildlife. Public service announcements, wildlife and hunter education programs, and coordination with local public health agencies are important avenues for sharing information about safety practices and local pet vaccination programs.

The NCWRC, NCSU Cooperative Extension Service, USDA Wildlife Services, and county and local wildlife control officers all play a role in responding to wildlife damage problems (e.g., crop depredation, flooding). Continued coordination and improved sharing of resources among these entities will make response efforts more effective.

6.3.3.4 Strategies and Recommendations

There are many conservation, management, education, outreach, and recreation programs. Substantial progress has been made towards meeting many of the program priorities identified in the 2005 Plan (e.g., the Commission now has wildlife education and nature centers in each region of the state). Still, some have not been fully realized to-date and where possible, priorities should be addressed within the context of other recommendations identified within this Plan. Continuing efforts should develop and foster partnerships that incorporate targeted conservation topics into existing programs. As unmet needs are identified, new projects should be developed and implemented through cooperative efforts. Emphasis should be on local programs, where individuals have the opportunity to have personal experiences that may foster greater appreciation and concern for local or regional conservation issues. Important needs for NCWRC and our partners include the following topics.

Wildlife Nature Centers

- Continue support of Commission-owned wildlife nature and education centers in each physiographic region and support projects at existing centers.
- Develop materials and traveling displays for use across the state at schools, universities, science museums, and aquariums to increase awareness of wildlife concerns.
- Expand delivery of wildlife-related programs and field trips to key audiences (e.g., schools, civic groups, watershed associations, planning boards).
- Establish demonstration areas for backyard wildlife habitat improvements and promote schoolyard habitat programs.
- Provide funding for regional education staff to develop and conduct training and outreach programs.

Wildlife Education Programs

- Improve the Commission's capabilities to provide instructor training in Project Wildand CATCH and coordinate support for other state environmental education programs.
- Develop and improve guides for construction/development of outdoor classrooms.
- Develop demonstration projects for wildlife education programs.
- Develop citizen education programs about impacts from homes on wildlife, coexisting with wildlife, and having a wildlife-friendly landscape.
- Work with developers, local government staff, and elected officials on ways to minimize impacts (e.g., impervious surface effects on stormwater drainage).

- Develop programs and involve the public through volunteer and citizen science opportunities; support existing programs such as NC Wildlife Federation's Backyard Habitat Program or Wildlife Federation's Wildlife and Industry Together.
- Improve coordination among biologists and educators to develop effective education and outreach materials for endangered/rare species and implement workshops that highlight high priority species, species groups, and habitats.
- Promote and expand cooperative projects between partners and other organizations with an aim to improve efficiency and effectiveness at reaching shared goals.

Wildlife Educational Materials

- Develop and distribute wildlife educational materials to public school systems.
- Develop public informational materials on wildlife species, management programs, and habitat conservation.
- Distribute educational materials about reducing homeowner impacts to natural communities. Topic examples include: reducing the use of fertilizers and herbicides/pesticides on lawns; washing vehicles away from waterways and storm drains; properly disposing of oils, antifreeze, and other household chemicals as well as pet waste and yard waste; removing invasive exotic plants; and keeping pets indoors.
- Incorporate education/outreach goals, priorities, and ideas from existing conservation plans, such as North American Bat Conservation Partnership Strategic plan, The Bird Conservation Plan for North Carolina (an NC Partners in Flight Bird plan; Johns et al. 2005), and the Southeast United States Regional Waterbird Conservation Plan (Hunter et al. 2006).
- Distribute materials that address critical conservation issues (e.g., endangered species, invasive species) to retail partners and at special interest functions (e.g., boat shows, Dixie Deer Classic).

Engaging the Public

- Conduct human dimension surveys to understand attitudes toward wildlife better and to use information to develop appropriate education and outreach programs and materials for the public.
- Promote the North Carolina Watchable Wildlife Viewing Program through development of highway map guides and informational materials for significant public sites.

- Develop guides, informational materials, and workshops on wildlife photography.
- Develop structures and stations for fish and wildlife viewing and photography.
- Encourage commercial guided trips through development of training programs and informational materials.
- Use media relations to highlight conservation issues and success stories and make a local connection with the public through media outlets.
- Use agency's website, magazine, and social media platforms to engage the public directly on various conservation issues and success stories.
- Participate in and support citizen science and wildlife monitoring programs that offer hands-on opportunities to learn about wildlife while helping these programs accomplish their conservation objectives. Examples include the Box Turtle Project; statewide amphibian calling surveys; Backyard Bird Survey, Christmas Bird Count, and other bird survey programs; Carolina Herp Atlas; and the Sea Turtle Stranding Network.

Connecting Recreation and Wildlife

- Develop and maintain access points (at piers, docks, etc.) to accommodate kayaks, canoes, and other paddle (non-motorized) boats accessing aquatic systems.
- Develop and maintain marked canoe trails along major streams and rivers.
- Support and assist with maintenance to the Mountain-to-Sea Trails and the Rails-to-Trails systems as well as connections to local greenway systems.
- Develop and maintain hiking trails on state-owned game lands and provide interpretive materials to educate users about local wildlife and conservation needs.
- Develop and maintain hiking trails and viewing sites associated with state-maintained campgrounds, picnicking areas, and visitor centers.
- Develop wildlife-related displays and educational materials at state-owned campgrounds, picnicking areas, and visitor centers.
- Produce wildlife-related educational programs at state-owned campgrounds, picnicking areas, and visitor centers.

- Develop and maintain Coastal, Piedmont, and Mountain Birding Trails development projects that support and promote the North Carolina Bird Trail initiative (www.ncbirdingtrail.org).
- Assist with the organization, promotion, and operation of local birding or wildlife festivals.
- Develop Birding Guides to North Carolina species and Birding Lists for significant public-owned properties.
- Continue to support programs such as Becoming an Outdoors Woman (BOW).
- Establish demonstration areas for backyard wildlife habitat improvements and promote schoolyard habitat programs.
- Educate the public about human impacts on sensitive sites, such as isolated wetlands, bogs, caves and mines, and rock outcrops.

Education and Training Opportunities

- Support NC Division of Parks and Recreation educational opportunities provided through the Environmental Education Learning Experiences (EELE), which include workshops for educators and information for student activities.
- Support the Environmental Education Certification Program offered by the Office of Environmental Education. This program provides teacher guides, state curriculum guides, guides to environmental education centers around the state, and adult education programming.
- Support courses on plant identification, native plant propagation, and maintenance as well as wildlife identification, ecology, and habitat protection/creation. Examples include programs offered by the NC State University Cooperative Extension Service.

6.3.4 Technical Guidance, Rules, and Regulations

The availability of technical guidance can be a limiting factor, both in the amount of initial guidance available and in the ability to follow up on management efforts. There is a significant need for increased and targeted outreach and technical guidance to private landowners to help them understand the different types of assistance and management practices available and to encourage participation in conservation programs. There is also a need for interagency cooperation to serve the needs of landowners better with multiple or varying objectives (e.g., for landowners wishing to manage their property for wildlife, wildlife biologists should be on hand to provide advice, in addition to foresters or agricultural extension agents). Protection measures that utilize existing regulatory frameworks to protect habitats and species should be incorporated where applicable.

Wildlife species that can adapt to human development (e.g., foxes, some bats, Raccoons, Opossums, squirrels, deer, Canada Geese, Chimney Swifts, some snakes, and small rodents) are often the source of human-wildlife conflicts. NCWRC has developed wildlife recommendations and guidelines on avoiding and controlling nuisance issues. Evaluation of the methods used for the removal of sensitive or tracked species (such as bats and some snakes) may be necessary to ensure the most appropriate handling of these species. Nuisance guidelines developed by USDA are a key source of information used by Commission outreach specialists handling wildlife damage-related inquiries (Hygnstrom et al. 1994).

Currently, North Carolina considers venomous reptiles, large constricting snakes, or crocodilians to be dangerous animals (see NCGS 14). Regulations require owners to have a written safety protocol and escape recovery plan that includes emergency contact information, identification of the local animal control office, and first aid procedures. Escapes must be reported to local law enforcement immediately. Specialized training is needed for law enforcement personnel, first responders, and animal handlers who may encounter dangerous or venomous animals as part of their work (e.g., animals that have escaped, are part of personal property seizures, or have been abandoned by the owners). Resources to support and coordinate emergency medical services, such as distribution and type of antivenom available, resources for exotic species identification, and facilities for temporary or long-term handling need to be identified and funded.

NCWRC offers free education programs for hunters and anglers that cover ethics and responsibilities as well as conservation and wildlife management information. Wildlife enforcement officials work with local law enforcement, federal and state agencies, wildlife biologists, and others to investigate and prosecute illegal activities. Illegal activities can range from hunting outside of season limits or taking a larger harvest than allowed by bag or creel limits; holding wild animals in captivity without permits; capturing wild animals without appropriate collection permits; harassing or harming protected species; or setting artificial lures or baits for animals and other unapproved harvest methods.

6.3.4.1 Strategies and Recommendations

Outreach

- Target outreach and technical guidance to private landowners to help them understand the different types of assistance and management practices available, to get participants enrolled, and to provide initial and ongoing management guidance. Work with key landowners and groups who are influential in their communities and are likely to influence participation by other landowners.

- Develop and offer incentives for corporate landowners to effect positive on-the-ground changes on the considerable corporate landholdings in the state.
- Coordinate with partner agencies that work with private landowners to increase awareness and interest in programs that benefit species and habitats on private lands.

Land Management

- Identify resources and take action when appropriate to implement programs that control, suppress, or eradicate invasive species threats.
- Facilitate conservation of large, contiguous tracts of land under multiple ownerships as a means to conserve wildlife and habitat on a landscape scale.
- Continue to coordinate placement of dredge materials to benefit beach-nesting birds, foraging shorebirds, and sea turtles.
- Increase the number and availability of private contractors available to conduct prescribed burns on private and corporate lands.
- Highlight and support opportunities for ongoing land management and restoration efforts on protected lands through coordination, protection, management assistance programs, and stewardship funding.
- Provide information and implementation guidance about land management practices that effectively maintain suitable habitat for species.
- Assist in the planning, development, and management of greenways.
- Promote the use of native plants in landscaping, publicizing native plant nurseries and partnering with UNC Botanical Garden and North Carolina Exotic Pest Plant Council.

Development

- Expand technical guidance to promote site design techniques that minimize impacts and maximize benefits to wildlife and habitat (e.g., development, roads, utilities).

- Ensure that Best Management Practices (BMPs) are robust enough to protect aquatic habitats and water quality.
- Encourage adoption of BMPs by landowners by demonstrating benefits and linking use with eligibility to other landowner assistance programs.
- Implement NCWRC (2002, 2012) recommendations to minimize cumulative and secondary impacts during initial site design and environmental review process.
- Develop local government ordinances to streamline the environmental review process through reduction of development impacts.
- Support the EPA's Low Impact Development approaches (US EPA 2002).
- Encourage higher density development within existing urban boundaries and around existing infrastructure; discouraged development on urban fringes and in high diversity or ecologically sensitive areas.
- Work with home builders and developers to adopt voluntary conservation guidelines; promote the principles of "conservation design" outlined in the Green Growth Toolbox and Wildlife Friendly Development Certification programs.

Rules and Regulations

- Coordinate with partners to develop policies and programs that address the presence and movement of nonnative and exotic invasive species.
- Work with local municipalities (commissions, planning boards, and other government entities) to promote ordinances that protect natural resources and improve water quality.
- Continue coordination with regulatory agencies that enforce wetlands regulations, Migratory Bird Treaty Act, and the Endangered Species Act.
- Support and encourage public comment to local officials or commissioners to voice their opinions on natural resources issues.

6.3.5 Partnerships and Cooperative Efforts

Partnerships and cooperative efforts among natural resource agencies, organizations, academia, private industry, and landowners that focus on common goals and objectives are key to reducing redundant efforts. These partnerships provide the basis for programs and projects that implement species, habitat, and ecosystem conservation and provide public recreation opportunities, preserve open space, protect water quality, and buffer military activities.

Sections 6.4 through 6.9 highlight federal and state agencies, organizations, and initiatives that are key partners for implementing the conservation goals of this Plan. Appendices L and M provide additional information about important programs and initiatives that implement this Plan.

6.4 Federal Conservation Partners

6.4.1 US Fish and Wildlife Service (USFWS)

The mission of USFWS is working with others to conserve, protect, and enhance fish, wildlife, plants, and their habitats for the continuing benefit of the American people. In 2006, USFWS leadership endorsed Strategic Habitat Conservation (SHC) as the conservation approach the agency would use to achieve its mission in the 21st Century. The SHC approach is built on five main components (biological planning, conservation design, conservation delivery, outcome-based monitoring, and assumption driven research) that compel USFSW to align expertise, capability, and operations across programs in a unified effort to achieve mutually aspired biological outcomes.

USFWS includes National Wildlife Refuges, National Fish Hatcheries, Law Enforcement, Ecological Services offices, and Migratory Birds offices. In North Carolina, there are two Ecological Services offices, located in Asheville and Raleigh, that oversee listing and recovery of federally endangered and threatened species in the state. They also provide fish and wildlife expertise to large-scale planning efforts in the areas of energy, transportation, and water and coastal development. Ecological Services offices host the Coastal Partners for Fish and Wildlife Programs, which focus on habitat restoration. There are 11 wildlife refuges across the state, each with Comprehensive Conservation Plans. These refuges are Alligator River, Cedar Island, Currituck, Mackay Island, Mattamuskeet, Mountain Bogs, Pea Island, Pee Dee, Pocosin Lakes, Roanoke River, and Swanquarter.

Landscape Conservation Cooperatives (LCCs) are public-private partnerships initiated by USFWS that provide the expertise needed to support conservation planning, implementation, and evaluation on landscape scales. These LCCs are generating the tools, methods, and data that managers need to carry out conservation using the SHC approach. They also promote collaboration among their members in defining shared conservation goals. These LCCs consider landscape-scale stressors, including climate change, habitat fragmentation, invasive species, and water scarcity as partners work to support landscapes capable of sustaining healthy populations of fish, wildlife, plants, and cultural resources.

The South Atlantic LCC, which crosses 6 states from southern Virginia to northern Florida, covers the Piedmont and Coastal Plain of North Carolina and is headquartered in Raleigh. The westernmost part of North Carolina is located within the Appalachian LCC, which spans 15 states, from New York to Alabama and westward to central Tennessee, Kentucky, and parts of Indiana and Illinois.

USFWS faces the greatest challenges to fish and wildlife conservation in its history: the Earth's climate is changing at an accelerating rate that has the potential to cause abrupt changes in ecosystems and contribute to widespread species extinctions. In response, the USFWS's Climate Change Strategic Plan was developed as a blueprint for action in a time of uncertainty. It calls for the agency and the larger conservation community to employ adaptation, mitigation, and engagement to conserve our nation's fish and wildlife resources in the years to come. The Southeast Climate Science Center (SECSC) was established by DOI in 2010 to address the needs of natural and cultural partners for climate science in the southeastern United States. Hosted by North Carolina State University (NCSU), SECSC is one of eight Climate Science Centers managed by the National Climate Change and Wildlife Science Center (NCCWSC) under USGS.

The USFWS conservation priorities in the Southeast region are listed below. Information about various programs and resources that support these USFWS priorities are described in Appendix L (page 1227).

- Threatened and Endangered Species: Achieving Recovery and Preventing Extinction
- National Wildlife Refuge System: Conserving Our Lands and Resources
- Landscape Conservation: Working with Others
- Migratory Birds: Conservation and Management
- Aquatic Species: National Fish Habitat Initiative and Trust Species
- Connecting People with Nature: Ensuring the Future of Conservation

6.4.2 US Forest Service (USFS)

USFS, an agency within USDA, manages public lands in national forests and grasslands. The mission of USFS is to sustain the health, diversity, and productivity of the nation's forests and grasslands to meet the needs of present and future generations. There are nine geographical regions and North Carolina falls within USFS Southern Region 8.

The Croatan, Uwharrie, Nantahala, and Pisgah National Forests provide 1.25 million acres of public lands from the mountains and the coast. Each has its own LRMP, a document that provides direction for the management of the forest and its resources over a 10- to 15-year planning period. The Croatan National Forest underwent an LRMP revision in 2003 and the Uwharrie LRMP was revised in 2012. The current Nantahala Pisgah LRMP was published in 1994 and is currently in the process of revision.

Conservation priorities of USFS in North Carolina are highlighted below and information about programs and resources that support these priorities are described in Appendix L (see page 1229).

- Protect drinking water and fish habitat
- Conserve land for future generations
- Manage land through collaborative planning
- Enhance fish and wildlife habitat
- Improve recreational opportunities and services
- Improve forest health and protect residents through use of prescribed fire

6.4.3 National Park Service (NPS)

The National Park Service (NPS) is a bureau within US DOI. As of 2012, NPS managed 12 sites in North Carolina: Appalachian National Scenic Trail, Blue Ridge Parkway, Cape Hatteras National Seashore, Cape Lookout National Seashore, Carl Sandburg Home National Historic Site, Fort Raleigh National Historic Site, Great Smoky Mountains National Park, Guilford Courthouse National Military Park, Moores Creek National Battlefield, Overmountain Victory National Historic Trail, Trail of Tears National Historic Trail, and Wright Brothers National Memorial.

The mission of NPS is to preserve, unimpaired, the natural and cultural resources and values of the national park system for the enjoyment, education, and inspiration of this and future generations. NPS cooperates with partners to extend the benefits of natural and cultural resource conservation and outdoor recreation throughout this country and the world. Information about programs and resources that support the NPS mission are described in Appendix L (page 1230).

6.4.4 Natural Resources Conservation Service (NRCS)

The NRCS is an agency within USDA that provides assistance to land users for developing and implementing conservation plans on their lands. To complete its mission, NRCS offers a variety of programs aimed at species and habitat conservation, including the Longleaf Pine Initiative and Farm Bill programs like the Wetlands Reserve Program, Wildlife Habitat Incentives Program, and Conservation Reserve Program, among others (NRCS 2013).

The National Resources Inventory (NRI), a nationwide survey conducted annually by NRCS, is the federal government's principal source of information on the status, condition, and trends of soil, water, and related resources in the United States. The NRCS conservation priorities in North Carolina are highlighted below and information about programs and resources that support these priorities are described in Appendix L (page 1232).

- Provide leadership in a partnership effort to conserve, maintain, and improve our natural resources and environment.
- Provide conservation planning and technical consultation about natural resource management.
- Support conservation implementation through installation of conservation practices and systems that meet established technical standards and specifications.
- Conduct natural resource inventories and assessments by collecting, analyzing, and providing natural resource data.
- Develop and distribute a wide array of technology pertaining to resource assessment, conservation planning, and conservation system installation and evaluation.
- Provide financial assistance to encourage the adoption of beneficial land-treatment practices that conserve and protect our nation's valuable natural resources.

6.4.5 National Oceanic and Atmospheric Administration (NOAA) Fisheries

The National Oceanic and Atmospheric Administration (NOAA) Fisheries unit (formerly known as the National Marine Fisheries Service) is the federal agency responsible for the stewardship of the nation's living marine resources and their habitat. NOAA Fisheries is responsible for the management, conservation, and protection of living marine resources within the United States' Exclusive Economic Zone (waters 3 to 200 miles offshore). North Carolina is part of the Southeast Region, which operates a research lab in Beaufort.

NOAA Fisheries works to promote sustainable fisheries and to prevent lost economic potential associated with overfishing, declining species, and degraded habitats. NOAA

Fisheries strives to balance competing public needs and interest in the use and enjoyment of our oceans' resources. Using the tools provided by the Magnuson-Stevens Act, NOAA Fisheries assesses and predicts the status of fish stocks, ensures compliance with fisheries regulations and works to reduce wasteful fishing practices. Under the Marine Mammal Protection Act and the Endangered Species Act, NOAA Fisheries recovers protected marine species (e.g., whales, sea turtles) without unnecessarily impeding economic and recreational opportunities.

The NOAA Fisheries research and conservation priorities in North Carolina are highlighted below and information about programs and resources that support these priorities are described in Appendix L (page 1233).

- Collect and analyze data describing the individual and population biology of living marine resources, with emphasis on exploited fish species (e.g., snappers and groupers), coral reefs (e.g., fish spawning aggregations), and protected resources (e.g., marine mammals and sea turtles).
- Conduct research to understand the structure and function of the southeast US continental shelf large marine ecosystem.
- Assess fish stocks, primarily in the Atlantic.
- Work to understand fisheries' ecosystems, primarily in the Atlantic.
- Assess population and health of sea turtles and dolphins, primarily in the Atlantic.
- Conduct aging of reef fishes.
- Collect data and samples and conduct assessments with commercial menhaden fisheries and recreational headboat fisheries in the Atlantic and Gulf of Mexico.

6.4.6 US Environmental Protection Agency (USEPA)

North Carolina is part of USEPA Region 4, which encompasses eight southeastern states and six Native American tribes. The mission of USEPA is to protect human health and the environment and is accomplished through the following activities:

- Development and Enforcement of Regulations
- Awarding of Grants
- Study of Environmental Issues

- Sponsorship of Partners
- Teaching People About the Environment and
- Publishing of Information

The agency's strategic plan identifies seven priorities:

- Taking Action On Climate Change
- Improving Air Quality
- Assuring the Safety of Chemicals
- Cleaning Up Our Communities
- Protecting America's Waters
- Expanding the Conversation on Environmentalism and Working for Environmental Justice
- Building Strong State and Tribal Partnerships

USEPA Region 4 is committed to operating an effective Environmental Management System (EMS) as part of an integrated framework for sustainable environmental stewardship. An EMS is a continual cycle of planning, implementing, reviewing, and improving the processes and actions that an organization undertakes to meet its operational and environmental goals. It is a set of processes and practices that enable an organization to reduce its environmental impacts. This includes nonregulated environmental impacts like energy use, carbon dioxide emissions, and purchase and use of products that have less impact on the environment.

With an EMS, the organization's environmental impacts become the responsibility of all employees and managers. EMS is integrated with EPA's mission and is accomplished through the setting targets for environmental stewardship, reducing or preventing pollution, and preserving environmental resources and enforcing environmental protection in conjunction with other governmental agencies. The USEPA initiatives in North Carolina are accomplished through the actions identified above. Key programs and resources that support conservation priorities are described throughout this Plan and are summarized in Appendix L (page 1234).

6.4.7 US Geological Survey (USGS)

As the sole science agency for DOI, USGS provides natural science expertise and shares earth and biological data holdings with partners and customers. It is the largest water, earth, and biological science and civilian mapping agency and is responsible for collecting, monitoring, analyzing, and providing scientific understanding about natural resource conditions, issues, and problems. The diversity of scientific expertise enables USGS to carry out large-scale, multidisciplinary investigations, and provide impartial scientific information to resource managers, planners, and other customers. The mission of USGS is to:

- provide reliable scientific information to describe and understand the Earth;
- minimize loss of life and property from natural disasters;
- manage water, biological, energy, and mineral resources; and
- enhance and protect our quality of life.

This mission is accomplished through various types of programs, partnerships, and cooperative agreements with other agencies and organizations. The USGS Water Science Center works cooperatively with other agencies and organizations to collect and interpret water-resource information in North Carolina. The NC Cooperative Fish and Wildlife Research Unit is jointly sponsored by USGS, NCWRC, NCSU, and the Wildlife Management Institute. The Cooperative Unit focuses on the identification, assessment, interpretation, and alleviation of the effects of current or potential environmental changes or perturbations on fish and wildlife resources. Key USGS programs and resources that support conservation priorities described throughout this Plan are summarized in Appendix L (page 1237).

6.4.8 US Army Corps of Engineers (USACE)—Wilmington District

As the nation's environmental engineer, USACE (or Corps) manages one of the largest federal environmental missions: restoring degraded ecosystems; constructing sustainable facilities; regulating waterways; managing natural resources; and cleaning contaminated sites affected by past military activities. There are two main federal laws that grant the Corps the authority to regulate the nation's waterways: Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act of 1899.

The Wilmington District is responsible for two deepwater ports and more than 300 miles of federal navigation projects along the Atlantic coast stretching from Norfolk, Virginia, to Little River, South Carolina; coastal storm damage reduction; water management and multi-purpose reservoirs; Section 404 and Section 10 regulatory permit programs for waters and wetlands in North Carolina; and ecosystem restoration programs, as well as other responsibilities. Materials from dredging projects are used to create and maintain dredge spoil islands that provide nesting and roosting habitat for shorebirds. Examples include South Pelican, Ferry Slip, Goat, and Bird islands.

The Wilmington District has four field offices (Wilmington, Washington, Raleigh, Asheville) and several district lake and dam facility offices located around the state. USACE works in partnership with other federal and state agencies, nongovernmental organizations (NGOs), and academic institutions to find innovative solutions to challenges such as sustainability, climate change, endangered species, environmental cleanup, ecosystem restoration, and more.

The mission of USACE is to deliver vital public and military engineering services, partner in peace and war to strengthen our nation's security, energize the economy, and reduce risks from disasters. Environmental Operating Principles were developed to ensure that the Corps' missions include totally integrated sustainable environmental practices and provide corporate direction to ensure responsibility for sustainable use, stewardship, and restoration of natural resources across the nation and through the international reach of its support missions. The Environmental Operating Principles are:

- Foster sustainability as a way of life throughout the organization.
- Proactively consider environmental consequences of all Corps activities and act accordingly.
- Create mutually supporting economic and environmentally sustainable solutions.
- Continue to meet corporate responsibility and accountability under the law for activities undertaken by the Corps, which may impact human and natural environments.
- Consider the environment in employing a risk management and systems approach throughout the life cycles of projects and programs.
- Leverage scientific, economic, and social knowledge to understand the environmental context and effects of Corps actions in a collaborative manner.
- Employ an open, transparent process that respects views of individuals and groups interested in Corps activities.

Programs and resources in North Carolina that support conservation priorities described throughout this Plan are summarized in Appendix L (page 1238).

6.4.9 Department of Defense (DOD)

The Department of Defense's (DOD) Natural Resources Conservation Compliance Program (NR Program) supports the military's testing and training mission by protecting its biological resources. The NR Program provides policy, guidance, and oversight for management of natural resources on approximately 28 million acres nationwide of military land, air, and water resources owned or operated by DOD. North Carolina DOD facilities include:

- Marine Corps Installation East
  - Marine Corps Base Camp Lejeune
  - Marine Corps Air Station Cherry Point
  - Marine Corps Air Station New River
- Fort Bragg Army Base
  - Pope Army Airfield
  - Camp Mackall Army training facility
- Seymour Johnson Air Force Base
- Sunny Point Military Ocean Terminal
- Harvey Point Defense Testing Activity

The NR Program's goal is to support the military's combat readiness mission by ensuring continued access to realistic habitat conditions, while simultaneously working to ensure the long-term sustainability of our nation's priceless natural heritage. The NR Program's primary responsibilities are to:

- Oversee development and implementation of natural resource-related policy, guidance, procedures, and metrics;
- Ensure military service compliance with policies, Executive Orders, and legislative obligations;
- Respond to Congressional inquiries;
- Manage natural resources allocation programs; and
- Coordinate with external stakeholders, including NGOs, states, and other federal agencies.

The DOD's NR Program implements several initiatives and management strategies to conserve and protect federally listed species, provide climate change tools and workshops, address invasive species, and conserve and protect pollinators found on military installations. The North Carolina Sandhills Conservation Partnership and the Onslow Bight Conservation Forum (described in Section 6.8) support NR Program conservation initiatives. Key DOD programs and resources that support conservation priorities described throughout this Plan are summarized in Appendix L (page 1239).

6.5 State Conservation Partners

Since the 1800s, North Carolina has taken steps to protect the state's natural resources through science-based stewardship and management programs that address not only land and water quality issues but also agricultural and forestry functions. In addition to NCWRC efforts, the mission of NCDENR is to protect North Carolina's environment and natural resources. This mission is accomplished through collaboration among agency partners and stakeholders across the state and through legislation enacted by the NC General Assembly. Several divisions and organizational units within the NCDENR organization focus on management and protection of wildlife and natural habitats. Key programs for these units are highlighted in this section.

The NC Department of Agriculture and Consumer Services (NCDACS) divisions have responsibilities in regulatory and service areas covering agronomy; animal health; crop and livestock statistics; USDA commodity distribution; state farm operations; research station operations; nursery and plant pest eradication activities; agricultural environmental issues; soil and water conservation; forest management and protection; and many other related topics. The agency's mission is to provide services that promote and improve agriculture, agribusiness and forests; protect consumers and businesses; and conserve farmland and natural resources for the prosperity of all North Carolinians.

6.5.1 NC Wildlife Resources Commission (NCWRC)

NCWRC (or Commission) has a much broader regulatory responsibility than just the recreational activities of hunting, trapping, fishing, and management of game lands. General Statutes charge the Commission with stewardship of all wildlife resources (see Chapter 1). As a result, the Commission enforces other rules—many pertaining to nongame wildlife. Nongame animals are defined in the General Statutes as all wild animals except game and fur-bearing animals (see Glossary for definitions). The mission of NCWRC is to conserve, protect, manage, restore, and regulate the wildlife resources of the state.

Toward this mission, Commission biologists conduct a variety of management and conservation activities, ranging from surveys and inventories, to habitat management, to land acquisition. The Division of Inland Fisheries oversees the Commission's Aquatic Wildlife Diversity Program for aquatic nongame species. The Division of Wildlife Management oversees the Wildlife Diversity Program for terrestrial nongame species. A standing Nongame Wildlife Advisory Committee (NWAC) provides external support and assistance to the NCWRC's nongame activities.

The NCWRC Habitat Conservation Program works to protect, manage, and conserve aquatic, wetland, and upland habitats for the benefit of fish and wildlife populations through technical guidance. The program assesses impacts and provides recommendations to avoid or minimize those impacts through permit and environmental document review; provides technical guidance regarding habitat conservation to governmental and private agencies and to individuals; and encourages adequate mitigation for losses of fish, wildlife, their habitats, and uses thereof resulting from land and water developments.

The Wildlife Friendly Development Certification was developed through collaboration between NCWRC, NCWF, and the NC Chapter of the American Society of Landscape Architects, and was designed to recognize residential land developers who promote the conservation of wildlife habitat while using environmentally sound construction practices. The program benefits wildlife by protecting existing habitats onsite that provide food, water, cover, and places to raise young—the four components of suitable wildlife habitat.

In 2011, science-based recommendations for conservation of priority wildlife habitats were developed and published in the guide *Conservation Recommendations for Priority Terrestrial Wildlife Species and Habitats in North Carolina*. The recommendations were developed to assist local governments, developers, and other stakeholders in conserving and managing terrestrial wildlife habitats and species for future generations, particularly in North Carolina's urbanizing landscapes. The recommendations, if implemented, should increase the probability that these habitats will support most of the priority species associated with them. The priority habitats described in the document are wetland habitats, riparian and floodplain habitats, upland forests, early successional habitats, and rock outcrops, caves, and mines.

The programs and resources that support conservation priorities are described throughout this Plan and are summarized in Appendix M (page 1245).

6.5.2 NC Museum of Natural Sciences (NCMNS)

The NC Museum of Natural Sciences (NCMNS) is a division within NCDENR. The mission of NCMNS is to enhance the public's understanding and appreciation of the environment in ways that emphasize the natural diversity of North Carolina and the southeastern United States and relate the region to the world as a whole. In support of this mission, the NCMNS scientific staff maintains the state's extensive natural sciences research collections, conducts primary research in the natural sciences, collaborates on research projects with area universities, state and federal agencies, and international organizations, and interprets natural history to the public through a variety of outreach initiatives and programs.

In addition to the paleontology and geology collections, zoological collections are maintained for terrestrial and aquatic invertebrates, crustaceans, fishes, amphibians, reptiles, birds, and mammals. These extensive Research Collections, and the data associated with them, are invaluable sources of information, are available to the larger scientific community for academic research, and often serve to inform policy makers on environmental issues. NCMNS offers online access to certain collections on its website (collections.naturalsciences.org). Key programs and resources that support conservation priorities are summarized in Appendix M (page 1247).

6.5.3 NC Natural Heritage Program (NCNHP)

North Carolina's Natural Heritage Program (NCNHP), established in 1976, is a unit of the Office of Land and Water Stewardship within NCDENR. Its mission is to provide the scientific knowledge and motivation for appropriate stewardship of the significant natural areas in North Carolina. The office is an integral part of the state's conservation efforts, and seeks to maintain a positive relationship with communities through partnerships with local, state, and federal agencies, industries, and organizations, and private citizens.

The NCNHP inventories, catalogues and facilitates protection of rare and outstanding elements of the natural diversity of North Carolina. These elements of natural diversity include plants and animals which are so rare, or natural communities which are so significant, that they merit special consideration as land-use decisions are made.

NCNHP follows methodology developed by The Nature Conservancy and shared by the Natural Heritage Network and NatureServe. By consolidating information about hundreds of rare species and natural communities, the program is able to ensure that the public is able to get the information needed to weigh the ecological significance of various sites, and to evaluate the likelihood and extent of ecological impacts resulting from land-use activities. This information supports informed evaluations of the trade-offs associated with biological diversity and development projects.

Finally, NCNHP data can be used to help set priorities for the protection of North Carolina's most important natural areas. The NCNHP information database is easily reached online and can be used to produce reports about rare species, high-quality natural communities, and areas managed for conservation. Written reports, including rare plant and animal lists, are also available from the NCNHP website (http://www.ncnhp.org/). Key programs and resources that support conservation priorities are summarized in Appendix M (page 1248).

6.5.4 NC Division of Marine Fisheries (NCDMF)

NCDMF is dedicated to ensuring sustainable marine and estuarine fisheries and habitats for the benefit and health of the people of North Carolina. The NCDMF jurisdiction encompasses all coastal waters and extends to 3 miles offshore. NCDMF is a part of NCDENR and is composed of nine sections that collectively carry out this mandate.

Agency policies are established by the ninemember Marine Fisheries Commission (MFC) and the Secretary of NCDENR. North Carolina is a member of the Atlantic States Marine Fisheries Commission, the Mid-Atlantic Fishery Management Council, and the South Atlantic Fishery Management Council. Key components of the DMF mission include:

- Enforcing marine fisheries statutes and rules fairly and consistently,
- Ensuring healthy, sustainable marine and estuarine fisheries and habitats through management decisions based on sound data and objective analyses, and
- Monitoring and evaluating coastal waters for the safe harvest of molluscan shellfish and recreational uses to safeguard the public health of shellfish consumers and recreational bathers.

The NC General Assembly charged NCDENR to develop, adopt, and implement plans and strategies to protect and restore fisheries habitats (see NCGS 143B). The plans are to be drafted by the agencies responsible for managing fisheries, water quality, and coastal management, with DMF as the lead agency for development of the plans. These strategies and supporting scientific background information are reported in the Coastal Habitat Protection Plan (CHPP), which is organized across six key estuarine and marine fisheries habitats. Each Chapter includes a characterization of the habitat, its distribution, fish use, ecological benefits, status, trends, and threats, as well as management and research needs.

CHPP is reviewed and approved by the CHPP Steering Committee, which consists of two members of the Environmental Management Commission, Coastal Resources Commission, and MFC. After the CHPP Steering Committee approves of the plan, each associated full commission has the opportunity to review and approve. The CHPP Steering Committee also meets regularly to enhance communication and discussion of cross-cutting and emerging coastal habitat issues, review the CHPP biennial implementation plans, and discuss progress on implementation actions. The plan was initially completed and then approved in late 2004 and 2010, respectively, and will continue to be updated in five-year cycles. NCWRC voluntarily joined as a participating commission in 2006 due to common issues regarding migrating fish species that utilize both coastal and inland waters.

Key programs and resources that support conservation priorities are described throughout this Plan and are summarized in Appendix M (page 1250).

6.5.5 NC Division of Coastal Management (NCDCM)

NCDCM works to protect, conserve, and manage North Carolina's coastal resources through an integrated program of planning, permitting, education, and research. North Carolina's coastal zone includes 20 coastal counties that in whole or in part are adjacent to, adjoining, intersected, or bounded by the Atlantic Ocean or any coastal sound. NCDCM carries out the state's Coastal Area Management Act (CAMA), the Dredge and Fill Law, and the federal Coastal Zone Management Act of 1972 in the 20 coastal counties using rules and policies established by the Coastal Resources Commission (CRC).

NCDCM is home to the NC Coastal Reserve (NCCR) and NC National Estuarine Research Reserve (NCNERR), a network of 10 protected sites established for long-term research, education, and stewardship. NCCR and NCNERR together protect more than 42,000 acres of estuarine land and water, which provide essential habitat for wildlife, offer educational opportunities, and serve as living laboratories for scientists.

While NCDCM is part of NCDENR, it also receives oversight and part of its funding from the Office for Coastal Management, part of NOAA. Additionally, NOAA administers the Federal Coastal and Estuarine Land Conservation Program (CELCP) that offers coastal states cost sharing for land conservation efforts, with the funds provided through an annual competitive process among eligible states. The NC Coastal and Estuarine Land Conservation Plan provides an assessment of priority conservation needs and guidance for nominating and selecting land conservation projects. North Carolina received $3 million in federal CELCP funding to purchase 6,500 acres of land in Gates County, which has been added to the Chowan Swamp Game Land.

NCDCM is responsible for several programs, including permitting and enforcement, CAMA land-use planning, public beach and waterfront access, North Carolina Coastal Reserves, and Clean Marinas and Pump-out grants program. Staff of NCDCM also collect and analyze data for oceanfront erosion rates and recently completed an inventory of the state's entire estuarine shoreline.

NCDCM is preparing a Living Shorelines Strategy to advance alternatives to vertical erosion control structures to minimize erosion, improve water quality, and provide wildlife habitat. The Coastal Nonpoint Pollution Control Program seeks to improve coordination between state coastal zone managers and water quality experts to reduce polluted runoff in the coastal zone. These are just a few of the several programs designed to protect and conserve North Carolina's coastal resources. Programs and resources that support NCDMF conservation priorities are summarized in Appendix M (page 1252).

6.5.6 NC Division of Water Resources (NCDWR)

In August 2013, the NCDENR Division of Water Quality (NCDWQ) merged programs with the Division of Water Resources (NCDWR) and responsibilities of the NCDWQ Stormwater Section were merged into the Division of Energy, Mineral and Land Resources (NCDEMLR). The resulting NCDWR is the agency responsible for statewide regulatory programs in surface water and groundwater protection. The mission of NCDWR is implemented through water quality monitoring programs, efficient permitting, responsible management, fair and effective enforcement, and excellence in public service. NCDWR accomplishes these goals by collaborating with other agencies to develop appropriate management strategies, assuring equitable distribution of waste assimilative capacity, evaluating the cumulative effects of pollution, and improving public awareness and involvement.

The new integrated NCDWR planning group is responsible for producing an integrated basinwide water quality and water quantity plan, which is a nonregulatory, basin- and watershed-based approach to identifying, quantifying, restoring, and protecting North Carolina's water resources. Basinwide water resource plans will be prepared for each of the 17 major river basins and are proposed to be presented in a dynamic online format. Implementation of the plan protection and restoration recommendations requires the coordinated efforts of many agencies, local governments, and stakeholder groups in the state. These cooperative efforts help achieve the goals of basinwide planning, which are to:

- identify and quantify the state's water resources,
- evaluate the current, near-term (20 years into the future), and long-term (50 years into the future) basinwide water use needs,
- identify sites where ecological integrity for planning purposes may not be met,
- identify water quality problems and restore full use to impaired waters,
- identify and protect high value resource waters, and
- protect unimpaired waters while allowing for reasonable economic growth.

NCDWR is also responsible for monitoring aquatic toxicology through support of the USEPA National Pollutant Discharge Elimination System (NPDES) program; evaluating water quality of streams and rivers using the fish and benthic macroinvertebrate communities as a measure of environmental condition to assign bioclassifications to surface waters; and collecting and analyzing biological, chemical, and physical data from a variety of surface waters using a statewide network of sampling sites. Key programs and resources that support conservation priorities are described and summarized in Appendix M (page 1255).

6.5.7 NC Division of Mitigation Services (NCDMS)

NC Ecosystem Enhancement Program (NCEEP) was created in 2003 out of a Memorandum of Agreement (MOA) between USACE, NCDENR, and the NC Department of Transportation (NCDOT), effectively merging the NCDENR Wetlands Restoration Program with resources from the NCDOT Office of Natural Environment. In spring 2015, the agency was renamed NC Division of Mitigation Services (NCDMS), but continues to be recognized as NCEEP.

The mission of NCEEP is to restore, enhance, and protect the state's wetlands, streams, and streamside buffers, with an aim to improve the state's compensatory mitigation process for unavoidable impacts to wetlands and streams. NCEEP will identify and implement projects within the context of a watershed approach based on multiple scales of planning, provide functional replacement based on watershed needs through stream, buffer, and wetlands projects, and provide watershed planning and project implementation in advance of impacts.

The existing Watershed Restoration Plans, developed by the Wetlands Restoration Program in cooperation with, and on the same five-year planning cycle as the NCDWQ Basinwide Planning Program, are key to NCEEP efforts. Key programs and resources that support conservation priorities are described and summarized in Appendix M (page 1256).

6.5.8 NC Division of Energy, Mineral and Land Resources (NCDEMLR)

In 2013, the NCDENR Division of Land Resources was reorganized. A new Energy Section was established and sediment and erosion control and stormwater management responsibilities, previously part of the Division of Water Quality and Division of Water Resources, were merged with the Land Quality Section and the new organization became the Division of Energy, Mineral and Land Resources. The NCDEMLR Land Quality Section regulates and provides technical assistance related to mining, dams, sediment and erosion control, and stormwater management. The Energy Section is responsible for oil and shale gas management, transportation, renewables, and the implementation of the

State Energy Program and Weatherization Assistance Program. The NC Geological Survey is part of the Division and is responsible for performing scientific investigations, providing technical assistance and maps of the state's geological resources. The Division as a whole supports public geoscience education. Information about conservation efforts can be found on the NCDEMLR web page.

6.5.9 NC Division of Parks and Recreation (NCDPR)

The North Carolina State Parks System exists for the enjoyment, education, health, and inspiration of all our citizens and visitors. The mission of the state parks system is to conserve and protect representative examples of the natural beauty, ecological features, and recreational resources of statewide significance; to provide outdoor recreational opportunities in a safe and healthy environment; and to provide environmental education opportunities that promote stewardship of the state's natural heritage. The ecosystems and cultural features protected by the state parks system often represent the highest quality examples of the state's natural landscape cultural heritage. In many cases, these ecosystems and cultural features are also among the most threatened.

The division's Natural Resources Program provides field staff, planning staff, and construction staff with technical expertise on issues such as resource stewardship, scientific research, environmental review and compliance, and landscape planning. The primary goal of natural resource management is to minimize human impacts on the natural environment and to ensure the long-term protection of state parks as intact, naturally evolving ecosystems. The primary goal of cultural resource management is to protect and preserve historically significant features. The program is currently working with a number of agencies, universities and cooperative extension program to control exotic species in the state park system. Exotic species are seen as one of the greatest threats to rare species, high-quality communities, and biodiversity. Over the past several years the Natural Resources Program has been working with field staff to develop a natural resources database. The database contains a number of projects that will need to be accomplished to ensure resource protection in the park system. In addition, the database will assist in setting priorities for the Natural Resources Program.

6.5.10 North Carolina Aquariums

The NC Aquariums were established in 1976 to promote an awareness, understanding, appreciation, and conservation of the diverse natural and cultural resources of North Carolina's ocean, estuaries, rivers, streams, and other aquatic environments. They incorporate conservation into daily activities and long-term programs. This is also integral to maintaining accreditation with the Association of Zoos and Aquariums. Collections conservation ensures the health of our captive population. North Carolina has three aquariums: Roanoke Island, Pine Knoll Shores, and Fort Fisher.

The aquarium setting provides a unique opportunity for scientific research aimed at sustaining and restoring native aquatic animals, plants, and their habitats. Veterinary research is carried out in partnership with the NCSU College of Veterinary Medicine, our partner in caring for aquarium animals. Applied research projects are often done in coordination with research institutions. Key programs and resources that support conservation priorities are summarized in Appendix M (page 1257).

6.5.11 NC Zoological Park (Zoo)

The NC Zoo is a 1,500-acre tract of land in the Uwharrie Mountains. Approximately 500 acres of this property have been developed into one of the largest "natural habitat" zoos in the United States. The Zoo's conservation mission includes initiatives and programs to improve the quality of our environment and the health of our state and participation in international efforts to protect animal habitats and help people understand the value of wild animals and wild places. The Zoo is active in a number of regional initiatives to protect plants and wildlife in the central Piedmont, preserve the state's resources, and minimize negative impacts throughout the southeastern United States.

The Valerie H. Schindler Wildlife Rehabilitation Center at the Zoological Park was established for the care and husbandry of injured and orphaned native wildlife, until they are ready for release back into the wild, as well as caring for education animals housed at the park. Programs and resources that support conservation priorities are described and summarized in Appendix M (page 1259).

6.5.12 Office of Environmental Education and Public Affairs

The Office of Environmental Education and Public Affairs (Environmental Education) was established in 1993 to balance NCDENR's regulatory functions with a commitment to environmental literacy and environmental education outreach. The mission of the Office of Environmental Education is to encourage, support, and promote environmental education programs, facilities, and resources in North Carolina for the purpose of improving the public's environmental literacy and stewardship of natural resources through planning, policy development, community involvement, innovative partnerships, and collaboration.

The Environmental Education Section works to increase environmental literacy and natural resource stewardship in North Carolina by encouraging, promoting, and supporting environmental education programs, facilities, and resources throughout the state. It serves as the clearinghouse for all of the environmental education resources in the state. The office also manages a nationally recognized professional development program that certifies educators in environmental education. The NC Environmental Educator Certification Program provides enrollees with outdoor teaching skills, science and nature content knowledge, and environmental education methods.

Since 2005, the Office of Environmental Education has been a key partner in a 10-state consortium that has developed an interactive, web-based database that allows us to share resources and opportunities. This greatly increases the capacity for environmental education in North Carolina and allows sharing of grants, resources, and job opportunities with the people of the state. Appendix M provides more information on Environmental Education Programs in the state (page 1260).

6.5.13 NC Forest Service (NCFS)

The NC Forest Service (NCFS) is a division with NCDACS. The mission of NCFS is to protect, manage, and promote forest resources for the citizens of North Carolina. NCFS accomplishes its mission through management of existing resources, development and creation of new and better forests, and protection of these valuable resources. NCFS is directly involved with forest management assistance to private landowners, reforestation services, forest fire prevention and suppression, and insect- and disease-control programs.

The NCFS Forest Action Plan is a strategic plan that defines the goals and objectives that guide the agency's efforts in meeting its mission. It is a complementary plan to the WAP. The NCFS is also involved in the operation of tree seedling nurseries, long-range forestry planning and technical development, water quality controls, urban forestry assistance, training and support to volunteer fire departments, and forestry education. The primary emphasis in conducting the programs under these objectives is directed at the 664,000 forest landowners who collectively own nearly 70% of more than 16 million acres of the state's privately owned forest land. Information about programs and resources that support these priorities are described in Appendix M (page 1261).

6.5.14 Plant Conservation Program (PCP)

The mission of the NCDACS Plant Conservation Program (PCP) is to conserve the native plant species of North Carolina in their natural habitats, now and for future generations. To accomplish its mission, PCP develops regulations, voluntary programs, and cooperative partnerships to help protect imperiled species and their habitats. PCP's responsibilities include maintaining the list of imperiled species and the development of conservation programs to protect these species permanently.

PCP's conservation goal is to ensure protection of the two best populations of each of the more than 400 imperiled species where they naturally occur. To meet this goal, the program has determined that there are 134 of the best imperiled-plant locations (about 51,000 acres) in need of protection. An additional 120 locations (about 245,000 acres) are partially protected and/or lack appropriate conservation-oriented management. PCP employs a host of methods and procedures to perpetuate native plants and their ecosystems, including the acquisition and management of important plant sites and habitats. PCP works with various partners to identify the most important sites for protecting imperiled plant species and with local land trusts and landowners to protect these sites as Plant Conservation Preserves in perpetuity. The most significant funding source for these preserves has been the Natural Heritage Trust Fund (now part of the Clean Water Management Trust Fund, see Section 6.1).

PCP's regulatory activities involve administering the state's Ginseng (*Panax quinquefolius*) harvest monitoring system to comply with federal and international mandates related to the trade of this species. Other regulatory activities involve permitting actions affecting the listed imperiled species and investigating violations of relevant portions of the Plant Protection and Conservation Act. In addition to laws specific to ginseng, there are rules and regulations protecting the listed imperiled plant species. Staff at PCP issues permits for a variety of matters involving imperiled plants. Scholars, plant enthusiasts, and NCDOT have worked with PCP to minimize impacts of activities on imperiled plants. Information about programs and resources that support these priorities are described in Appendix M (page 1264).

6.5.15 Division of Soil and Water Conservation (S&WC)

A seven-member Soil and Water Conservation (S&WC) Commission provides oversight, rules, and policy for the state soil and water conservation programs. These programs are voluntary and emphasize a locally led approach to improving and protecting water quality and natural resources for a wide range of land uses. The S&WC mission is to foster voluntary, incentive-driven management of soil, water, and related natural resources for the benefit of the environment, economy, and all citizens. This division provides programs, technical services, and educational outreach promoting voluntary natural resource management and conservation on the private lands of the state through a nonregulatory, incentive-driven approach.

S&WC cooperates with federal and local partners to administer a comprehensive statewide program to protect and conserve the state's soil and water resources. It is recognized as having one of the nation's top soil and water conservation programs for private lands. This effort is achieved through a conservation partnership composed of the state division, local soil and water conservation districts, and NRCS, as well as private and nonprofit entities.

Cost-share programs offer BMPs targeted to meet specific program goals to address agricultural, rural, and urban water resource issues. Information about programs and resources that support these priorities are described in Appendix M (page 1264).

6.5.16 Plant Industry Division, Apiary Program

The mission of the NC Department of Agriculture and Consumer Services Plant Industry Division is to ensure seed and fertilizer and other soil additives offered for sale in North Carolina meet prescribed standards and are truthfully labeled; to protect the state's agriculture and natural environment from introduced plant pests, including insects, diseases, and noxious weeds; and to enhance and protect the state's endangered and threatened plants. To meet this mission, the division regulates the movement of agricultural or related items capable of spreading harmful insects, diseases, and other pests.

The mission of the Apiary Program is to promote and protect the state's beekeeping industry. The Apiary Program provides disease and disorder inspections and fumigation services to control diseases and pests of the beekeeping industry. Additionally, the Apiary Program provides educational workshops to educate the state's beekeepers on the biology and treatment of mite and disease pests of honey bees and Africanized bees. The division works in partnership with the NCSU Apiculture Program to promote bee conservation by combating the spread of pathogens, mites, and other hive pests and to promote bee pollination services.

6.5.17 NC Department of Transportation (NCDOT)

NCDOT's mission is to connect people and places in North Carolina safely and efficiently, with accountability and environmental sensitivity. To fulfill this mission, NCDOT adopted an Environmental Stewardship Policy that calls for a safe and well-maintained transportation system that meets the needs of the traveling public and supports the development of sustainable, vibrant communities while striving to preserve and enhance the state's natural and cultural resources. NCDOT has the responsibility to comply with all rules and regulations described in the Sedimentation Pollution Control Act and all requirements stipulated in the program delegation from NCDENR.

The NC Board of Transportation, which has oversight of NCDOT, formed an Environmental Planning and Policy Committee (EPPC). NCDOT and EPPC are working to integrate environmental stewardship into decision making; engage the public and resource agencies early in the project-development process; build trust and effective working relationships; develop mutual goals related to transportation and the environment with local, state and federal partners; use context-sensitive design and maintenance strategies; and continually improve processes, among other initiatives.

It is the intent of NCDOT to forge more effective and efficient working relationships through partnerships with agencies and organizations. NCDOT and its partners strive to serve as a national model for interagency partnerships for environmental stewardship and streamlining. Information about programs and resources that support these priorities are described in Appendix M (page 1265).

6.6 Native American Indian Lands

Native American Indian lands are not federal public lands or part of the public domain. They were retained by Indian tribes or were set aside for tribal use pursuant to treaties, statutes, judicial decisions, or executive orders or agreements. These lands are managed by the tribes in accordance with tribal goals and objectives, within the framework of applicable laws. Many locations have remained untouched by conventional land-use practices and therefore are islands of high-quality ecosystems, attracting many sensitive species (USFWS 2013).

The Eastern Band of Cherokee Indians (EBCI) is the only Native American tribe in North Carolina that is currently recognized by the federal government. The EBCI's primary lands are known as the Qualla Boundary and are located in western North Carolina. The Qualla Boundary is not a reservation, but rather a land trust supervised by the US Bureau of Indian Affairs (BIA). EBCI also owns, holds, or maintains additional lands in the vicinity, and as far away as 100 miles from the Qualla Boundary.

Present day EBCI lands and waters continue to support diverse wildlife communities. This biological diversity is intricately tied to Cherokee culture with thousands of species playing critical roles in subsistence, arts, medicine, ceremonies, and stories. Conserving fish and wildlife populations and their interrelationships with the environment in a changing world is an integral part of maintaining Cherokee livelihood. Tribal programs responsible for the management of fish and wildlife resources include EBCI Fisheries and Wildlife Management, EBCI Office of Environment and Natural Resources, and EBCI Natural Resource Enforcement. Legal guidelines relating to fisheries and wildlife conservation include codified EBCI hunting, fishing, and water quality protection ordinances, BIA Forest Management Plan regulations, and the Endangered Species Act of 1973. The EBCI works collaboratively with many external natural resource agencies to maximize conservation opportunities while maintaining sovereign interests.

EBCI wildlife management actions are focused on species of greatest conservation need and species of significant cultural importance. These include, but are not limited to, migratory and game birds, fishes, rare small mammals, and large game mammals. Conservation strategies include habitat enhancement and protection, inventory and monitoring, native species restoration, and outreach. Comprehensive planning and implementation efforts are documented in the Tribal Wildlife Action Plan (unpublished).

6.7 Land Trusts and Private Conservation Organizations

6.7.1 Audubon North Carolina

The mission of the National Audubon Society's NC state office is to conserve and restore natural ecosystems, focusing on birds, other wildlife, and their habitats for the benefit of humanity and North Carolina's biological diversity. The Important Bird Areas (IBA) program is key to this mission. The IBA program operates under two objectives:

- To identify places that are essential to sustaining the diversity and abundance of naturally occurring populations of birds in North Carolina; and
- To protect or ensure the appropriate management of these sites for the long-term conservation of birds and their habitats.

Audubon North Carolina is a key partner for beach-nesting bird and colonial waterbird conservation efforts in the state. As of 2015, 96 sites have been approved as IBAs across the state. There are several regional Audubon Chapters across the state. For more information about their conservation efforts visit the website (http://nc.audubon.org). Additional information about IBAs and other bird conservation regions can be found in Appendix I.

6.7.2 North Carolina Wildlife Federation (NCWF)

The mission of NCWF is to be the leading advocate for all NC wildlife and its habitat. The goals of NCWF are:

- To advocate the conservation and enhancement of all wildlife and its habitat;
- To advocate ethical and biologically sound hunting, fishing, and other outdoor activities;
- To advocate education, for children and adults, that increases public awareness of wildlife, its dependence on habitat, and the importance of both to human existence;
- In affiliation with member organizations, to communicate, cooperate, and partner with the NC General Assembly, state resource agencies, corporations, and other interested groups to advance the well-being of wildlife and its habitat; and
- In affiliation with the National Wildlife Federation, to support national and international issues of mutual interest.

NCWF was instrumental in the creation of the Wildlife Resources Commission in the mid-1940s and it continues to be a key advocate for wildlife and wildlife-related policy in North Carolina. Additional information is available from its website (www.ncwf.org).

6.7.3 The Conservation Trust for North Carolina (CTNC)

CTNC was created to help protect North Carolina's land and water resources, both by direct action and by assisting private, local land trusts, other community groups, and private landowners. CTNC is the statewide land trust working with communities, landowners, local land trusts, and other conservation organizations to protect North Carolina's natural and cultural resources. It serves as the resource center for North Carolina's 24 local and regional land trusts, and acts as a hub for information exchange, coordination, public policy representation, and financial assistance. CTNC works cooperatively with land trusts across the state to help landowners protect natural resources through voluntary conservation methods. Visit its website to learn more (www.ctnc.org).

6.7.4 The Nature Conservancy (TNC)

The Nature Conservancy's mission is to conserve the lands and waters on which all life depends. This mission is carried out through partnerships, alliances, and collaborations with a variety of state and federal agencies, land trusts, and conservation groups. North Carolina falls within three of The Nature Conservancy's defined ecoregions (the Mid-Atlantic Coastal Plain, the Piedmont, and the Southern Blue Ridge)—each with its own ecoregional plan that identifies priority conservation areas within the ecoregion.

The Nature Conservancy has developed a strategic, science-based planning process, called "Conservation by Design," which is used to help identify the highest-priority places—landscapes and seascapes that, if conserved, promise to ensure biodiversity over the long term. Visit the TNC website for more information about their work in North Carolina (www.nature.org/ourinitiatives/regions/northamerica/unitedstates/northcarolina).

6.8 Local and Municipal Programs

There are 100 counties in North Carolina and hundreds of municipal and local governments that range from large cities like Charlotte and Raleigh to small communities such as Banner Elk and Navassa. Local government programs can participate in Open Space Funding Programs funded through the PARTF and CWMTF programs (see Section 6.2.3).

Currently, 92 counties across North Carolina are involved in 14 local and regional open space planning efforts. Local and regional open space planning efforts provide invaluable new information to add to the statewide conservation plan. Data from each of these regional plans are incorporated into the Conservation Planning Tool and GGT programs (see Section 6.2.4.3).

Some local government programs have implemented their own riparian buffer and floodplain protection programs in compliance with National Flood Insurance Programs and as a means to protect nutrient-sensitive waters. Other programs work with landowners, nonprofit agencies, public agencies, and other stakeholders in the protection of important farmlands, natural resources, and waterways.

An example is the Charlotte-Mecklenburg County Division of Nature Preserves and Natural Resources, which is responsible for the protection and conservation of Mecklenburg County's parks designated as nature preserves. Nature preserves protect the county's biological resources and natural areas, while providing opportunities for environmental education, nature-based programs, and outdoor recreation.

Durham County's Farmland Protection Program represents a collaboration among Durham's Soil and Water Conservation District, Open Space and Real Estate Division, City-County Planning, the Farmland Protection Advisory Board, County Manager, and the Board of County Commissioners to protect farmland. This collaboration has succeeded in communicating with landowners on farmland preservation options and in leveraging significant state and federal funds to match local dollars for the purchase of agricultural conservation easements.

Another example of local conservation efforts is Orange County's Lands Legacy Program. This program works with landowners, land trusts, and other conservation partners to leverage local funds and state and federal dollars for the acquisition and protection of important natural and cultural resource lands in the county. Since 2000, the program has helped to protect more than 3,000 acres that include natural areas, prime farmlands, and watershed riparian buffer lands. In Wake County, the Open Space Program protects valuable open space by purchasing land or conservation easements in areas targeted for protection. The Wake County Consolidated Open Space Plan was developed to guide decisions about protection and conservation of county land and water for current residents and future generations. The Open Space Program also provides matching funds to partners for purchase of land or conservation easements.

The Community Conservation Assistance Program (CCAP) works at the county level with urban, suburban, and rural landowners interested in reducing their contributions to nonpoint source pollution. Both Durham County CCAP and Rockingham County CCAP provide assistance for installation of qualifying BMPs (e.g., rain gardens, riparian buffers, stormwater wetlands, stream restoration, permeable pavement, and other conservation measures).

6.9 Other Statewide Conservation Partners and Initiatives

North Carolina is home to several esteemed university and research colleges that are important partners in accomplishing the conservation goals outlined in this Plan. Research projects often involve partnerships with universities and organizations located outside the state. Some of the notable partnerships and initiatives are outlined in the following sections.

6.9.1 Albemarle-Pamlico National Estuary Partnership (APNEP)

APNEP is a cooperative effort jointly sponsored by NCDENR and USEPA, in partnership with the Virginia Department of Environmental Quality. The mission of APNEP is to identify, protect, and restore the significant resources of the Albemarle-Pamlico estuarine system. APNEP pursues this mission with guidance and support from its overarching Comprehensive Conservation and Management Plan (CCMP), advisory bodies, and regional partners. The program area extends across most of the Albemarle-Pamlico watershed, including the Neuse, Tar-Pamlico, Roanoke, Chowan, lower Roanoke, and parts of the White Oak River basins.

In collaboration with partners, APNEP supports implementation of CCMP, which has a 10-year planning horizon, through development and implementation of annual work plans. APNEP also supports several important initiatives, including a brownwater rivers floodplain inventory conducted in cooperation with NCNHP; the Defense Coastal and Estuarine Research Program conducted in cooperation with the DOD; peatland restoration projects with TNC and the North Carolina Coastal Federation; and the submerged aquatic vegetation (SAV) partnership that operates under an MOA between numerous federal and state agencies, universities, and conservation organizations. NCWRC and APNEP partner in a statewide SAV signage program. Additional information about APNEP is available from its website (www.apnep.org).

6.9.2 Albemarle-Pamlico Conservation and Communities Collaborative (AP3C)

AP3C was formed in 2007 through a Memorandum of Understanding (MOU) among regional conservation groups and aims to develop approaches that integrate economic and ecological resilience for the lands, waters, and communities of the Albemarle-Pamlico region. Additional information about AP3C is available from its website (http://portal.ncdenr.org/web/apnep/ap3c).

6.9.3 Appalachian Mountains Joint Venture (AMJV)

AMJV is one of 18 habitat joint-venture partnerships in the United States. It comprises state and federal government agencies, NGOs, universities, and industries that work together to prioritize and coordinate bird conservation activities using an adaptive management framework that builds upon the best available science. AMJV is a self-directed partnership governed by a management board representing its partners, with NCWRC having a seat on the board.

AMJV's mission is to restore and sustain viable populations of native birds and their habitats in the Appalachian Mountains. It does so by coordinating and assisting partners in prioritizing which species and habitats to conserve, working with researchers and resource managers to design and implement effective conservation projects for native bird species throughout their annual life cycles, and capitalizing on funding opportunities relevant to partnership priorities.

Their work in the Appalachian Region of western North Carolina focuses on enhancing and maintaining young forest habitat for Golden-winged Warblers and other young forest species, improving mature forest habitat for forest interior species such as Cerulean Warblers and Wood Thrush, and restoring high elevation spruce-fir forests. AMJV has released "Golden-winged Warbler Habitat: Best Management Practices for Forestlands in Maryland and Pennsylvania" by Drs. Jeff Larkin and Marja Bakermans at Indiana University of Pennsylvania.

Key partners to AMJV in North Carolina include NCWRC, USFS, USFWS, NRCS, NPS, Audubon NC, National Wild Turkey Federation, and Southern Appalachian Highlands Conservancy. Additional information about AMJV is available from its website (www.amjv.org).

6.9.4 Atlantic Coast Joint Venture (ACJV)

The mission of ACJV is to provide a forum for federal, state, regional, and local partners to coordinate and improve the effectiveness of bird conservation planning and implementation. ACJV is one of 18 habitat joint-venture partnerships in the United States and brings together partners focused on the conservation of habitat for native birds in the Atlantic Flyway, from Maine south to Puerto Rico.

ACJV was originally formed as a regional partnership focused on the conservation of waterfowl and wetlands under the North American Waterfowl Management Plan (NAWMP) in 1988 and has since broadened its focus to the conservation of habitats for all birds consistent with major national and continental bird conservation plans under the framework of the North American Bird Conservation Initiative formed in 1999.

Under the framework of NAWMP and NABCI, ACJV plans and implements bird conservation in the Atlantic Flyway through these major initiatives and planning efforts:

- **Waterfowl**: North American Waterfowl Management Plan; ACJV Waterfowl Implementation Plan
- **Waterbirds**: Waterbird Conservation for the Americas; Southeast US Region Waterbird Conservation Plan; Northwestern Atlantic Marine Bird Conservation Cooperative; Integrated Waterbird Management and Monitoring Plan;
- **Shorebirds**: US Shorebird Conservation Plan; Northern Atlantic Regional Shorebird Plan; Western Hemisphere Shorebird Reserve Network; Atlantic Flyway Shorebird Business Strategy
- **Landbirds**: Partners In Flight Bird Conservation Plans
- **NABCI Bird Conservation Plans** (BCR Plans); South Atlantic Migratory Bird Initiative (eastern portion of BCR 27 – Southeastern Coastal Plain), New England/Mid-Atlantic Coast (BCR 30), Atlantic Northern Forest (BCR 14), Lower Great Lakes-St. Lawrence Plain (BCR 13), Piedmont (BCR 29), Peninsular Florida (BCR 31).*
- **Single Species Planning efforts**: National Bobwhite Conservation Initiative, North American Grouse Management Strategy, Woodcock Management Plan, Atlantic Brant Management Plan

**Note*: BCR Plans synthesize information of all these planning efforts for each bird initiative on an ecoregional scale, integrating the planning and implementation vision for all of these species/initiatives into a single BCR plan.

Additional information about ACJV is available from its website (www.acjv.org).

6.9.5 Blue Ridge Forever

Blue Ridge Forever is a collective campaign led by 10 land conservation organizations to engage the public and raise financial resources to safeguard land and water in the southern Blue Ridge for present and future generations. A region-wide conservation vision guides the connection of protected lands on a landscape scale with attention to places containing important wildlife habitat, water quality, scenic value, and cultural, economic, and agricultural significance. Additional information about Blue Ridge Forever is available from its website (www.blueridgeforever.info).

6.9.6 Cape Fear Arch Conservation Collaborative (CFACC)

The Cape Fear Arch is a region distinguished by unusual geology and the greatest biological diversity along the Atlantic Coast north of Florida. It is located between Cape Lookout in North Carolina and Cape Romain in South Carolina, and extends inland beyond Fayetteville to the Sandhills region of the Carolinas. In North Carolina, the Cape Fear Arch includes the watersheds of the lower Cape Fear and Waccamaw rivers. The area is under great development pressure, which requires infrastructure that often eliminates habitat for important wildlife species.

CFACC is a nonprofit partnership of organizations and individuals created in 2006 to enhance cooperation and communication regarding regional conservation issues within the CFA landscape. The participating organizations represent a broad spectrum of land managers and land conservation advocates with differing missions. All are dedicated to sustainable natural resource management, providing for human needs while retaining the natural heritage of the region.

A conservation plan was developed in 2009 that identifies, evaluates, and prioritizes an interconnected network of essential core ecosystems in the Cape Fear Arch region and identifies gaps in the existing network for protection and restoration priorities. The Cape Fear Arch Conservation Plan was published in 2009 and is a tool for informing planning at regional and local levels. Additional information about CFACC is available from its website (http://capefeararch.org).

6.9.7 Cape Fear River Partnership (CFRP)

The Cape Fear River Partnership was formed in 2011 to restore and demonstrate the value of robust, productive, and self-sustaining stocks of migratory fish in the Cape Fear River. The partnership includes key federal, state, local, academic, and other organizations in the region that are working together on a multi-year action plan to provide long-term, habitat-based solutions for the most pressing challenges for migratory fish. The Cape Fear River Basin Action Plan for Migratory Fish, published in 2013, outlines problems related to the health of migratory fish stocks and recommends actions to restore fish passage and improve habitat and water quality to revitalize fish populations and improve overall condition of the river.

The partnership evaluates its efforts through goals and objectives associated with: increased fish populations (as measured by catch-per-unit efforts, improved age structure, and other techniques); increased recreational fishing success for Shad, Striped Bass, and River Herring (as measured by creel surveys); and a reopened native Striped Bass and River Herring harvest in the Cape Fear River. The partnership successfully got underway through the US Army Corps of Engineers' construction of a new fish passage structure at Lock and Dam 1 on the Cape Fear River near Wilmington. Additional information about CFRP is available from its website (www.capefearriverwatch.org/about-us/the-cape-fear-river-partnership).

6.9.8 Chatham Conservation Partnership (CCP)

The mission of CCP is to develop and implement strategies for a community conservation vision that builds awareness, protection, and stewardship of Chatham County's natural resources. CCP is a partnership of government agencies, local land trusts, local conservation organizations, colleges, private businesses, and landowners who share the common interest of developing a sustainable county focused on the preservation of its natural resources and rural and agricultural heritage.

To achieve its goals, CCP provides a forum for public discourse on sustainable land use, serves as an educational resource on land conservation and management tools, facilitates collaborative efforts among members to achieve common conservation objectives, and promotes the role science plays in responsible sustainable land use. CCP has created an innovative tool, the Comprehensive Conservation Plan, to help with land protection and development decisions in Chatham County. Additional information about CCP is available from its website (http://chathamconservation.wikispaces.com).

6.9.9 Eastern Brook Trout Joint Venture (EBTJV)

This fish habitat partnership includes state fish and wildlife agencies, federal resource agencies, academic institutions, and private sector conservation organizations that have adopted a formal management structure and signed an MOU. The partnership works to conserve Eastern Brook Trout and their habitats and has produced a range-wide population assessment of brook trout; completed extensive work that identifies key threats to brook trout and their habitats; and developed conservation strategies to protect, enhance, and restore brook trout.

A conservation strategy, which was published in 2011, is a goal-oriented, science-based action plan that explicitly states EBTJV principal goals, presents guidance for decision making, and provides methods for evaluating success. In addition, there are 12 state-level conservation action plans that prioritize the specific strategies needed for brook trout conservation within each state. Additional information about EBTJV is available from its website (http://easternbrooktrout.org).

6.9.10 Eastern North Carolina/Southeastern Virginia (ENC/SEVA) Strategic Habitat Conservation Team

The ENC/SEVA Strategic Habitat Conservation (SHC) Team is a partnership of DOI agencies (USGS, USFWS, and NPS) working together and with other partners to promote strategic landscape-level conservation in the ENC/SEVA ecoregion. The mission is to accomplish priority landscape-level conservation collaboratively by utilizing the Strategic Habitat Conservation framework to develop a comprehensive Strategic Habitat Conservation Plan (Plan). The Plan provides guidance for members, partners, and collaborators by establishing mutual conservation goals, objectives, strategies, and metrics to gauge the success of conservation efforts. In this way, conservation actions can help recover and sustain species' populations as part of whole communities and systems, together with their ecological functions and processes.

The planning vision is to establish a network of public and private lands and waters in the ENC/SEVA ecoregion that sustain resilient populations of priority fish, wildlife, and plants, and the habitats on which they depend, for the benefit and appreciation of current and future generations. This includes adaptively identifying conservation needs and priorities; mutually establishing annual conservation goals and objectives; identifying challenges and opportunities for strategic habitat conservation implementation and developing remedies; establishing and fostering partnerships to accomplish conservation goals and objectives; and implementing strategies to accomplish them. Efforts include compiling data to establish baseline conditions for targets, integrating an assessment of climate change vulnerability, and developing appropriate monitoring plans and securing capacity to implement them collaboratively with partners.

6.9.11 Greater Uwharrie Conservation Partnership (GUCP)

GUCP is a collaboration of diverse partners that works cooperatively to conserve wildlife, habitats, and associated natural resources in the Greater Uwharries region of the south-central Piedmont in North Carolina. Partner organizations are: NHP, NCPCP, NCWRC, NCMNS, NC Zoological Park, Piedmont Land Conservancy, USFS, NRCS, USFWS, Central Park NC, Environmental Defense Fund, The Land Trust for Central NC, and The Nature Conservancy.

Since its founding in 2006, the partnership has permanently conserved more than 6,500 acres and enhanced habitat on more than 3,400 acres for high-priority wildlife and rare plant habitat. Other work includes biological surveys on 230 sites leading to the discovery of a 1,000-acre significant natural heritage area in Anson County with the largest population in the world of river sedge, a rare plant. Partners have contacted more than 200 private landowners in the region's most valuable natural areas, to offer technical guidance about conservation options and cost-share programs, resulting in cooperative working relationships with 64 of these landowners.

In 2013, GUCP developed a conservation plan for the region that identifies priority species and natural communities for conservation and defines conservation strategies for the partnership to implement over the next five years. Additional information about GUCP is available from its website (http://centralparknc.org/component/content/article/45/98-conservation.html).

6.9.12 NC Longleaf Coalition

The mission of the NC Longleaf Coalition is to promote the maintenance and restoration of North Carolina's Longleaf Pine ecosystem, including its cultural and economic values, by forming a collaborative network of diverse stakeholders to provide strategic leadership across the historic range while also supporting local restoration activities. The Coalition was formalized in 2010 and aims to provide the state/local level leadership called for in the regional plan.

Participants in the Coalition include multiple state agencies (NCFR, NCWRC, and NCNHP) and federal agencies (USFWS, USFS, NRCS, and the NC Commander's Council, representing multiple military services). The Coalition is rounded out by multiple nonprofits, consulting foresters/landowners, academics, and other Longleaf proponents. The Coalition coordinates closely with on-the-ground restoration efforts including the NC Sandhills Conservation Partnership, the Onslow Bight Conservation Forum, and the CFA. Additional information is available from its website (http://nclongleaf.org).

6.9.13 NC Partners in Amphibian and Reptile Conservation (NCPARC)

NCPARC is North Carolina's Chapter of Partners in Amphibian and Reptile Conservation, which has the mission of conserving amphibians and reptiles and their habitats. Members include academia, state and federal agencies, research facilities, nature education centers, land trusts, municipalities, zoos, veterinary fields, forest products industries, energy cooperatives, conservation organizations, herpetological societies, pet trade industries, museums, and even communities and neighborhoods.

NCPARC believes that the successful conservation of amphibians and reptiles can only be accomplished by joining forces to combine the expertise and resources of a multitude of individuals and organizations. This effort includes technical working groups that facilitate herpetological conservation by addressing research, inventory and monitoring needs, policy, regulation and trade issues, and education and outreach objectives.

NCPARC is a unique conservation network because it includes conservation of all reptiles and amphibians; is focused on conserving the habitats required for survival; includes all individuals, organizations, and agencies that have an interest in reptile and amphibian conservation; and focuses not only on endangered and threatened species but also on keeping common native species common. Additional information is available from its website (www.ncparc.org/about/about.htm).

6.9.14 NC Partners In Flight (NCPIF)

NCPIF is North Carolina's Chapter of Partners In Flight, a cooperative effort involving partnerships among federal, state, and local government agencies, philanthropic foundations, professional organizations, conservation groups, industry, the academic community, and private individuals. NCPIF is a statewide initiative that brings together government, private, and public organizations, and individuals in an effort to further migratory bird conservation through habitat protection, management, monitoring, professional training, and education. NCPIF is also part of the Southeast PIF Work Group. Additional information is available from its website (http://ncpartnersinflight.org).

6.9.15 NC Prescribed Fire Council

Fire is a natural part of North Carolina's ecosystem. Low-intensity fire historically occurred across the state to maintain some ecosystems. Today, prescribed burning is essential to the perpetuation, restoration, and management of many plant and animal communities.

The mission of the NC Prescribed Fire Council is to foster cooperation among all parties in North Carolina with an interest or stake in prescribed fire. The goal is to optimize burning opportunities for the benefit of natural ecosystems and wildlife and to reduce the risk of damage from wildfires. This will be accomplished by encouraging the exchange of information, techniques, and experiences among practitioners of prescribed fire in North Carolina. Another goal is to promote public understanding of the regional importance and benefits of prescribed fire. Goals and objectives are described in the Council's 2013–2018 Strategic Plan.

Council members represent federal and state agencies, organizations, corporations, institutions, or private landowners with an interest in prescribed fire and whose goals are consistent with the Council's mission. The Council advocates for increased expertise in prescribed fire through the sharing of technical and biological information; promotes safety, training, and research in the art and science of prescribed fire; reviews prescribed fire practices, regulations, and policies, and suggests improvements; and promotes BMPs that minimize smoke and air quality impacts from prescribed fires. The Council is affiliated with the Coalition of Prescribed Fire Councils. Additional information is available from its website (http://ncprescribedfirecouncil.org).

6.9.16 NC Sandhills Conservation Partnership (NCSCP)

The NCSCP was created in 2000 with the mission to protect, enhance, and restore the unique Sandhills environment. The Partnership facilitates collaboration between various federal, state, and nonprofit conservation groups for the purposes of conserving the vanishing Longleaf Pine ecosystem and recovering the endangered Red-cockaded Woodpecker in the NC Sandhills. The NCSCP seeks input from more than 18 stakeholder organizations and has developed a landscape-level strategic conservation plan for the Sandhills. In addition to traditional natural resource and land conservation organizations, the Partnership includes the US Army, a key partner in the region.

Examples of successes that have been achieved as a result of the NCSCP include: more than 20,000 acres protected through collaborative land conservation efforts and leveraging of funds; the development of GIS data layers identifying the lands and waterways most important to natural resource conservation and management; the expansion and sharing of resources to improve land management including prescribed burning and invasive plant control; the development of a strategic plan that includes threat assessments, implementation strategies, and monitoring; increased communication and collaboration between partners; the training of several local government land-use planning staff in the use of conservation data; and the recovery of the NC Sandhills population of the endangered Red-cockaded Woodpecker to levels identified in the national recovery plan.

In addition, results compiled through a 10-year review conducted in 2010 indicate that NCSCP provides partners with invaluable opportunities to build their personal and professional networks, to bolster internal capacity and support for accomplishing conservation objectives, and to demonstrate the success of the collaborative approach to conservation. Additional information is available from its website (www.ncscp.org).

6.9.17 Onslow Bight Conservation Forum

The Onslow Bight is a unique geographic landform located along the mid-coast region of North Carolina and includes all or portions of 13 coastal counties. The landscape stretches from the lower Northeast Cape Fear River to the Pamlico River and from offshore waters to approximately 40 miles inland. The Onslow Bight contains large federal- and state-managed areas including three Marine Corps installations, the Croatan National Forest, and the Holly Shelter and Angola Bay state game lands. The landscape contains rare and unusual animal and plant life such as the Red-cockaded Woodpecker, Venus Flytrap, and Carolina Gopher Frog. The region includes barrier islands, marshes, riverine wetlands, pocosins, Longleaf Pine savannas, and many other Coastal Plain and coastal habitats.

The Onslow Bight Conservation Forum facilitates collaborative partnership between organizations and individuals dedicated to conservation within the Onslow Bight landscape while helping to preserve mission-compatible land use adjacent to the military installations. The Forum fosters a strong collaborative relationship among regional military installations, federal, state, and local agencies, and a wide array of environmental groups.

The mission of the Onslow Bight Conservation Forum is to allow open communication between the collaborating partners to achieve forum goals for the conservation, protection, and restoration of the Onslow Bight landscape.

6.9.18 Piedmont Prairie Partnership

The Piedmont Prairie Partnership is a group of natural resource professionals and landowners who joined forces to explore opportunities and techniques for the restoration and enhancement of native prairies throughout North Carolina. Piedmont Prairies, also known as grasslands, early successional habitat, savannas, or xeric hardpan forests contain a whole suite of native bird and rare plant species such as Schweinitz's Sunflower and Smooth Coneflower, which are both federally listed endangered species.

The Partnership implemented the Piedmont Prairie Restoration Program, which began with collaboration between Mecklenburg County, USFWS, NCDOT, and University of North Carolina at Charlotte faculty. Since it was first organized in 1994, several Piedmont prairie restoration projects have been implemented, including Mecklenburg County's McDowell Nature Preserve prairie restoration (150 acres), Latta Plantation Nature Preserve prairie restoration (40 acres), Gar Creek Nature Preserve (36 acres), Shuffletown Prairie Nature Preserve (18 acres), and the City of Greensboro's Meadowlark Sanctuary Piedmont Prairie (23 acres) at Price Park.

6.9.19 Robust Redhorse Conservation Committee (RRCC)

The Robust Redhorse Conservation Committee (RRCC) was created in 1995 to improve the status of the Robust Redhorse throughout its former range. RRCC is a cooperative, voluntary partnership formed under an MOU between state and federal resource agencies, private industry, and the conservation community. Members of the RRCC MOU are working collaboratively to conserve an imperiled species and its habitat in lieu of listing the species for protection under the Endangered Species Act. Current RRCC members include: Georgia Department of Natural Resources, NCWRC, South Carolina Department of Natural

Resources, USFWS, USGS, USFS, Duke Energy, Georgia Power Company, South Carolina Electric and Gas Company, Georgia Wildlife Federation, and the South Carolina Aquarium.

The Robust Redhorse is a large, long-lived species that occurs in Atlantic Slope rivers from the Altamaha River drainage in Georgia to the Yadkin-Pee Dee River drainage in North and South Carolina. The RRCC is facilitating the recovery efforts and conservation measures by conducting research to answer scientific questions and address management needs including habitat use and movement, early life history, population dynamics, and genetics. Work has also focused on discovery of additional populations, supplemental stocking of existing populations, reestablishment of historical populations, and public education.

The RRCC's Conservation Strategy, which establishes short- and long-term conservation goals and management actions, was adopted in 1999 and revised in 2003. We are currently very close to meeting the goal of establishing or maintaining at least six self-sustaining populations distributed within a significant portion of its historic range. Wild populations exist in the Oconee River (Georgia), Savannah River (Georgia and South Carolina), and Pee Dee River (North and South Carolina). Successful stockings in the Broad, Ogeechee, and Ocmulgee rivers in Georgia, and the Broad and Wateree rivers of South Carolina, have reestablished historical populations. Detailed information, reports, and publications on the Robust Redhorse are updated online at www.robustredhorse.com.

6.9.20 Southeast Aquatic Resources Partnership (SARP)

SARP is a regional collaboration of natural resource and science agencies, conservation organizations, and private interests developed to strengthen the management and conservation of aquatic resources in the southeastern United States. The mission is to work with partners to protect, conserve, and restore aquatic resources including habitats throughout the Southeast for the continuing benefit, use, and enjoyment of the American people. This mission is achieved through the support and facilitation of on-the-ground and in-the-water science-based action to improve and protect aquatic habitats and resources. Efforts are focused on habitat assessments, restoration actions, monitoring, and evaluation of some of the nation's most economically and socially significant aquatic habitats. Additional information is available from the SARP website (http://southeastaquatics.net).

6.9.21 Upper Neuse River Basin Association (UNRBA)

This association was formed in 1996 to provide a forum for cooperation on water quality protection and water resource planning and management within the 770-square-mile watershed. Seven (of the eight) municipalities, six counties, and local Soil and Water Conservation Districts in the watershed voluntarily formed UNRBA.

The mission of UNRBA is to preserve the water quality of the Upper Neuse River Basin through innovative and cost-effective pollution reduction strategies, and to create a forum to cooperate on water supply issues within the basin by forming a coalition of units of local government, public and private agencies, and other interested and affected communities, organizations, businesses, and individuals to secure and pool financial resources and expertise; collecting and analyzing information and data, and developing, evaluating, and implementing strategies to reduce, control, and manage pollutant discharge; and providing accurate technical, management, regulatory, and legal recommendations regarding the implementation of strategies and appropriate effluent limitations on discharges into the Upper Neuse River Basin. Visit the UNRBA website for more information (http://unrba.org).

6.9.22 Upper Tar Collaboration

Anchored by the Tar River Land Conservancy (TRLC), the Upper Tar Collaboration includes a multitude of corporate, agency, nonprofit, and private partners dedicated to preserving and managing riparian buffers and wetlands to help protect the incredible aquatic biodiversity that resides in the Upper Tar River Basin. This basin is nationally recognized as one of the most important watersheds along the East Coast because it harbors 14 federal and state rare and endangered species, including the federally endangered Tar Spinymussel and Dwarf Wedgemussel.

6.9.23 WakeNature Preserves Partnership

The WakeNature Preserves Partnership brings together natural resource professionals from local governments, NCSU, state agencies, and nonprofit organizations to build capacity among Wake County's local governments to identify the most valuable natural resources areas they own and improve environmental stewardship of these areas.

The mission of the Partnership is to organize and provide resources to identify ecologically valuable, publicly owned open spaces within Wake County, and to build capacity for appropriate management and long-term stewardship of those areas. WakeNature encourages a coordinated approach to classifying and managing the most ecologically valuable natural areas in Wake County, as well as better public education about our local natural heritage. More information is available from its website (http://wakenature.org).

References

Alexander M. 2008. Management planning for nature conservation, a theoretical basis and practical guide. Barmouth (UK): Springer Science. 429 p.

Bosch SA, Musgrave K, Wong D. 2013. Zoonotic disease risk and prevention practices among biologists and other wildlife workers – results from a national survey, US National Park Service, 2009. J Wildl Dis. 49(3):475–485.

Brunell PA. 2008. Rabies: when to worry. Infectious Disease News; [accessed 2015 August]. http://www.healio.com/infectious-disease/news/print/infectious-disease-news/%7B8f6fd3d6-8306-4863-97c5-74957ffd8aa6%7D/rabies-when-to-worry.

Calver MC, Grayson J, Lilith M, Dickman CR. 2011. Applying the precautionary principle to the issue of impacts by pet cats on urban wildlife. Biol Cons. 144:1895–1901.

[CMP] Conservation Measures Partnership. 2013. Open standards for the practice of conservtion. Version 3.0. [web page]; [accessed 2015 August] http://cmp-openstandards.org/wp-content/uploads/2014/03/CMP-OS-V3-0-Final.pdf.

Hygnstrom SE, Timm RB, Larson G (eds). 1994. Prevention and control of wildlife damage (Vol. 1 & 2). Washington (DC): Animal and Plant Health Inspection Service, US Department of Agriculture; Lincoln (NE): University of Nebraska Cooperative Extension, Great Plains Agriculture Council Wildlife Committee, Animal Damage Control; [accessed 2015 August]. http://digitalcommons.unl.edu/icwdmhandbook/?utm_source=digitalcommons.unl.edu%2Ficwdmhandbook%2F1&utm_medium=PDF&utm_campaign=PDFCoverPages.

Joseph LN, Maloney RF, Possingham HP. 2008. Optimal allocation of resources among threatened species: a project prioritization protocol. Conserv Biol. 23(2):328–338.

Loughry WJ, Truman RW, McDonough CM, Tilak M, Garnier S, Delsuc F. 2009. Is leprosy spreading among Nine-banded Armadillos in the southeastern United States? J Wildl Dis. 45(1):144–152.

Miller JR, Snyder SA, Skibbe AM, Haight RG. 2009. Prioritizing conservation targets in a rapidly urbanizing landscape. Landsc Urban Plan. 93:123–131.

[NCCES] NC Cooperative Extension Service. n.d. Using fire to improve wildlife habitat. Raleigh (NC): NC State University; [accessed 2015 August]. http://content.ces.ncsu.edu/using-fire-to-improve-wildlife-habitat.pdf.

[NCDPR] NC Division of Parks and Recreation. 2015. North Carolina Outdoor Recreation Plan 2015-2020. Raleigh (NC); [accessed 2015 August]. http://www.ncparks.gov/About/plans/scorp/main.php.

[NCGS 14] NC General Statutes. n.d. Chapter 14 Criminal Law, Article 55 Regulation of Certain Reptiles. Raleigh (NC); [accessed 2015 August]. http://www.ncga.state.nc.us/EnactedLegislation/Statutes/PDF/ByArticle/Chapter_14/Article_55.pdf.

[NCGS 113] NC General Statutes. Chapter 113 Conservation and Development. Raleigh (NC); [accessed 2015 August]. http://www.ncga.state.nc.us/gascripts/Statutes/StatutesTOC.pl?Chapter=0113.

[NCGS 113A] NC General Statutes. Chapter 113A Pollution Control and Environment, Article 18 Clean Water Management Trust Fund. Raleigh (NC) [web page]; [accessed 2015 August]. http://www.ncga.state.nc.us/EnactedLegislation/Statutes/pdf/ByArticle/Chapter_113A/Article_18.pdf. 7 p.

[NCGS 143B] NC General Statutes. Chapter 143B Executive Organization Act of 1973, Article 7 Department of Environment and Natural Resources, Section 279.8 Coastal Habitat Protection Plans. Raleigh (NC); [accessed 2015 August]. http://www.ncga.state.nc.us/EnactedLegislation/Statutes/PDF/BySection/Chapter_143B/GS_143B-279.8.pdf.

[NCWRC] NC Wildlife Resources Commission. 2005. North Carolina Wildlife Action Plan. Raleigh (NC): NC Wildlife Resources Commission; [accessed 2015 August]. 700 p. http://www.ncwildlife.org/plan.asp.

[NCWRC] NC Wildlife Resources Commission. 2012. Conservation recommendations for priority terrestrial wildlife species and habitats in North Carolina. Raleigh (NC): NC Wildlife Resources Commission; [accessed 2015 July]. http://www.ncwildlife.org/Portals/0/Conserving/documents/ConservingTerrestrialHabitatsandSpecies.pdf. 96 p.

Newbold SC, Siikamaki J. 2009. Prioritizing conservation activities using reserve site selection methods and population viability analysis. Ecol Appl. 19(7):1774–1790.

[NRCS] Natural Resources Conservation Service. 2013. Farmland Protection Policy Act. Washington (DC): US Department of Agriculture; [accessed 2015 August]. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/landuse/fppa/?cid=nrcs143_008275.

Schrenzel MD. 2012. Molecular epidemiology of mycobacteriosis in wildlife and pet animals. Vet Clin N Am-Exot Anim Pract. 15(1):1.

Sharma R, Lahiri R, Scollard DM, Pena M, Williams DL, Adams LB, Figarola J, Truman RW. 2013. The armadillo: a model for the neuropathy of leprosy and potentially other neurodegenerative diseases. Dis Model Mech. 6(1):19–24.

Tribal Wildlife Action Plan. Unpublished. Eastern Band of Cherokee Indians. Cherokee, North Carolina.

[USFWS] US Fish and Wildlife Service. 2008. Strategic habitat conservation handbook, a guide to implementing the technical elements of strategic habitat conservation (Version 1.0). [web page]; [accessed 2015 August]. http://www.fws.gov/science/doc/SHCTechnicalHandbook.pdf. 24 p.

[USFWS] US Fish and Wildlife Service. 2013. Endangered species program: working with tribes overview. [web page]; [updated 2013 Jul 15]. http://www.fws.gov/endangered/what-we-do/tribes-overview.html.

7

Monitoring

Required Element 5

Proposed plans for monitoring species (as identified in Required Element 1) and their habitats (as described in Required Element 2), for monitoring the effectiveness of the conservation actions proposed in Required Element 4, and for adapting these conservation actions to respond appropriately to new information or changing conditions.

7.1 Introduction

Monitoring and evaluation are tools that scientists can use to measure change over time in species populations, habitat status, or the effects of activities. These tools also provide information for the interpretation of those measured changes. Monitoring and evaluation are especially important to examining whether there has been a response to applied conservation actions, and are necessarily linked to conservation and management objectives. Monitoring conducted at multiple levels (e.g., species, guilds, or natural communities) and across multiple scales (e.g., local, statewide, and regional) is required to assess changes that occur in populations and habitats over time:

- Species-specific monitoring is an important component of any conservation program and allows an agency or organization to assess topics such as wildlife population trends, estimated population size, relative abundance, or shifts in distribution or range. Monitoring of individual species, when coordinated at the appropriate level, contributes to the conservation of species beyond local populations and at scales far beyond individual state boundaries.

- Guild-level monitoring (e.g., ephemeral pond amphibians, colonial waterbirds) is essential for tracking and assessing habitat-level impacts over time. It allows us to assess habitat availability, use, and condition over time, and can be used to measure the effectiveness of habitat-based management activities. Habitat and natural community monitoring is necessary to track landscape-level trends and to anticipate future needs as threats change.

- Implementation monitoring is needed to measure project success and advancement toward achieving project goals. It allows us to adapt conservation actions to respond appropriately to new information or to changing conditions.

Monitoring needs for particular species or guilds are detailed in other sections of this Plan: Chapters 3 (Species), Chapter 4 (Habitats), and Chapter 5 (Threats) .This chapter provides information about monitoring activities conducted by NC Wildlife Resources Commission (NCWRC) and conservation partners. These activities implement the recommendations made in previous chapters and are accomplished through the planning process and collaboration and cooperation among the agencies, organizations, and initiatives discussed in Chapter 6.

Section 7.2 provides information about species-specific and guild-level monitoring activities, while Section 7.3 addresses habitat and natural community monitoring. A list of Species of Greatest Conservation Need (SGCN) can be found in Appendix G and their habitat associations are provided in Appendix H. Lists of monitoring activities and programs conducted by NCWRC and partners is available in Appendix O.

7.1.1 Monitoring on Public Lands

In North Carolina, the largest acreages of publicly owned land are managed by state and federal agencies, and there are many smaller tracts owned by local municipalities and conservation organizations. Species and habitat monitoring is part of routine monitoring conducted on state and federal public lands. NCWRC coordinates with other agencies and organizations to identify shared priorities and to facilitate efficient monitoring and data synthesis. Table 7.1 provides examples of large tracts of public lands monitored by federal and state agencies. More information about the management programs on these lands can be found in Chapter 6.

7.1.2 Monitoring Coordination and Data Sharing

Coordinated monitoring efforts are critical to achieving efficient and effective conservation. Local efforts help to sustain and strengthen monitoring programs that benefit sea turtles, Bog Turtles, and colonial nesting waterbirds in North Carolina. Initiatives such as the South American Migratory Bird Initiative (SAMBI), Partners In Flight (PIF), and the Robust Redhorse Conservation Committee (RRCC), and cooperative agreements such as

Table 7.1 Examples of large public land tracts with monitoring programs

Agency	Land Tracts with Monitoring Programs
Department of Defense (DOD) Integrated Natural Resource Management Plans stipulate monitoring needs for each installation (DOD 2013).	• Camp Lejeune Marine Base • Cherry Point Marine Air Station • Fort Bragg Army Base • Seymour Johnson Air Force Base • Pope Air Force Base
US Forest Service (USFS) Land and Resource Management Plans identify monitoring needs related to each forest's Management Indicator Species and communities. (As of 2014, these plans are being updated.)	• Croatan National Forest • Uwharrie National Forest • Nantahala and Pisgah National Forests
US Fish and Wildlife Service (USFWS) Comprehensive National Wildlife Refuge (NWR) Plans outline the programs and corresponding resource needs for managing each wildlife refuge over a 15-year period.	• Alligator River NWR (2008) • Cedar Island NWR (2006) • Currituck NWR (2008) • Mackay Island NWR (2005) • Mattamuskeet NWR (2008) • Pea Island NWR (2006) • Pee Dee NWR (2008) • Pocosin Lakes NWR (2008) • Roanoke River NWR (2005) • Swanquarter NWR (2008)
NC Wildlife Resources Commission (NCWRC) Game Land Management Plans (GLMPs) outline science-based land management goals and describe measures needed to support sustainable natural resources through implementation of comprehensive conservation programs.	• Green River GLMP (2014 Draft) • Holly Shelter GLMP (2014 Draft) • Lower Roanoke River Wetlands GLMP (2014 Draft) • R. Wayne Bailey-Caswell GLMP (2014 Draft) • Sandhills GLMP (2014 Draft) • Sandy Mush GLMP (2015 Draft) • Suggs Mill Pond GLMP (2015 Draft)
NC Division of Parks & Recreation (NCDPR) General management plans (GMPs) for individual parks provide a comprehensive evaluation of park resources, outline management actions to conserve important ecosystem functions, and are combined and used with the Statewide Comprehensive Outdoor Recreation Plan.	• Carolina Beach State Park GMP (2007) • Cliffs of the Neuse State Park GMP (2005) • Eno River State Park GMP (2005) • Fort Fisher State Park GMP (2007) • Gorges State Park GMP (2005) • Hanging Rock State Park GMP (2012) • Jones Lake State Park GMP (2005) • Lake Waccamaw State Park GMP (2007) • Lumber River State Park GMP (2005) • Mount Jefferson State Natural Area GMP (2012) • Raven Rock State Park GMP (2007)

the NC Colonial Waterbird Cooperative Agreement (with 12 state and federal agency and nonprofit signatories) implement efforts at regional levels. The North American Breeding Bird Survey (NABBS) is an example of a long-term, large-scale, international monitoring program that tracks bird populations and provides an index of avian status and trends at various geographic scales. The conservation achieved through these programs and others demonstrates the success and importance of such collaborations.

The US Forest Service (USFS) provides technical guidance on how to monitor populations and habitats in one integrated design for multiple species (USFS 2006). The efforts of the various North American Bird Conservation Initiative (NABCI) programs provide models on which to build coordinated monitoring efforts for other taxa, and recommendations from NABCI plans have been incorporated into NCWRC monitoring programs. Monitoring infrastructures developed by various programs (see Table 7.2) support specific monitoring goals for birds in North Carolina and contributes to regional, national, and even international bird conservation efforts.

There is an ongoing need for collaborative monitoring efforts for all SGCN and for wide-ranging species (e.g., pelagic seabirds, neotropical migratory birds). Strong data standards and a centralized system for housing and managing data and analyzing results are critical to the success of monitoring programs. Standardized protocols are needed to ensure that data collected are compatible with similar programs and can be integrated with regional, national, or international data sets. Population units relevant to conservation planning and research must be defined and standards or protocols developed where none presently exist. Reliable and reproducible techniques should be used and new population-monitoring techniques should be evaluated as needed.

Emerging technologies, research methods, and wildlife issues will require more genetics research and DNA analysis in order to better understand disease, conduct forensic analysis, and improve taxonomic identification and classification. These new opportunities for generating datasets need protocols and methods that will minimize problems with sharing data (Taberlet and Luikart 1999; Bonin et al. 2004; Waits and Paetkau 2005; Lukacs and Burnham 2005; Schwartz et al. 2007). Participation in a clearinghouse could facilitate sharing data among partners.

Regional and national coordination is needed to evaluate the capacity of existing state programs to combine and monitor populations across their range. One effort is the US Geological Survey's (USGS) Status and Trends Program, which supports and provides collection and analysis of biological data for local, regional, and national assessment of biological resources and the ecosystems that support them.

Table 7.2 Examples of cooperative monitoring efforts

Initiative	Plan Year and Name
Atlantic Coast Joint Venture (ACJV)	• 2002 Atlantic Brant Management Plan • 2005 ACJV Waterfowl Implementation Plan • 2008–13 Black Duck Joint Venture Strategic Plan • 2010 Implementing the American Woodcock Conservation Plan • 2011 National Bobwhite Conservation Initiative
North American Waterfowl Management Plan (2012)	• 2004 Strategic Guide • 2012 NAWMP Action Plan
South Atlantic Migratory Bird Initiative (SAMBI) (Watson et al. 2005) and Implementation Plan (Watson and Malloy 2006)	• 2004 Pelagic Bird Conservation Plan (SAMBI 2004) • 2005 Southeastern Coastal Plain Bird Conservation Region 27 Conservation Design • 2014 Piedmont Bird Conservation Region 29 Conservation Design
U.S. Shorebird Conservation Plan (Brown et al. 2001)	• 2002 Southeastern Coastal Plains-Caribbean Regional Shorebird Plan (Hunter et al. 2002)
North American Waterbird Conservation Plan (Kushlan et al. 2002)	• 2006 Southeast United States Regional Waterbird Conservation Plan (Hunter et al. 2006)
PIF North American Landbird Conservation Plan (Rich et al. 2004)	• 1999 Southern Blue Ridge (Hunter et al. 1999) • 1999 Piedmont (Cooper and Demarest 1999) • 2001 South Atlantic Coastal Plain (Hunter et al. 2001) • 2004 Partners In Flight Continental Priorities and Objectives Defined at the State and Bird Conservation Region Levels (Rosenberg 2004) • Bird Conservation Plan for North Carolina (Johns 2005)
Department of Defense (DOD)	• 2005 Monitoring Avian Winter Survival (MAWS) Program on four DOD Installations in Southeastern United States • 2008 Conserving Biodiversity on Military Lands • 2010 Legacy Resource Management Program, Species at Risk on Department of Defense Installations in the Carolinas • 2012 Coordinated Bird Monitoring Technical Recommendations for Military Lands

7.1.3 Indicators and Targets

The South Atlantic Landscape Conservation Cooperative (SALCC) worked collaboratively with numerous agencies and organizations to develop natural resource indicators and targets based on ecological, practical, and social criteria (SALCC 2013). The ecological criteria focus on how well indicators capture key ecosystem elements and major landscape threats. The practical criteria focus on the ability to monitor and model the indicators based on current resources and efforts. The social criteria focus on how well the indicators resonate with a wide variety of audiences capable of changing the landscape. Table 7.3 provides examples of common performance indicators and measurement targets.

The number of agencies and organizations tracking trends associated with particular habitat types or regions of the state can make coordination and statewide assessments difficult. There is variability in terms of what is actually monitored, the indicators and criteria that are measured, and methods used to measure those indicators. A key improvement should be the establishment of a statewide clearinghouse of information for assessing habitat status and environmental trends information across North Carolina.

7.2 Monitoring Protocols

In addition to the species and habitat monitoring protocols recommended in this Plan, scientific literature is another resource for methodologies appropriate for monitoring various wildlife species. A brief list of examples includes the following resources:

7.2.1 Amphibians and Reptiles

- Greenberg CH, Neary DG, Harris LD. 1994. A comparison of herpetofaunal sampling effectiveness of pitfall, single-ended, and double-ended funnel traps used with drift fences. J Herpetol. 28(3):319–324. An assessment of relative effectiveness of pitfalls, single-ended, and double-ended funnel traps at 12 replicate sites in sand pine scrub using drift fence arrays. All three trap types yielded similar estimates of relative abundance of lizards and frogs but not snakes.

- Crouch WB, Paton WC. 2000. Using egg-mass counts to monitor wood frog populations. Wildl Soc Bull. 28(4):895–901. Assessment of the efficacy of using egg-mass counts to monitor wood frog population because they may not be detectable using calling surveys at breeding ponds.

- Welsh Jr. HH, Droege S. 2001. A case for using plethodontid salamanders for monitoring biodiversity and ecosystem integrity of North American forests. Conserv Biol. 15(3):558–569. Considers variability associated with sampling for plethodontid salamanders as indicators of biodiversity and ecosystem integrity in forested habitats by estimating the coefficient of variation from available time-series data in comparison and comparison results with lepidoptera, passerine birds, small mammals, and other amphibians.

- Acevedo MA, Villanueva-Rivera LJ. 2006. Using automated digital recording systems as effective tools for the monitoring of birds and amphibians. Wildl Soc Bull. 34(1):211–214.

Table 7.3 Examples of common performance indicators and measurement targets

Target	Indicators and measurement targets
Beaches and Dunes	Productivity of Loggerhead Sea Turtles Index of beach birds Miles of altered beach
Forested Wetlands	Acres of forested wetlands Index of forest wetland birds Acres of natural habitat near isolated wetlands
Freshwater Aquatic	Percent of natural habitat near rivers and streams Percent of impervious cover Index of biotic integrity
Upland Hardwood Forests	Acres of biodiversity hotspots in natural condition Abundance of big trees Index of upland hardwood birds

A comparison of an automated digital recording system (ADRS) with traditional methods (point-counts and transects) for the assessment of birds and amphibians.

- McDiarmid RW, Foster MS, Guyer C, Gibbons JW, Chernoff N, editors. 2011. Reptile biodiversity, standard methods for inventory and monitoring. Los Angeles (CA): University of California Press. 424 p. A comprehensive guide to the best methods for carrying out standardized quantitative and qualitative surveys of reptiles, while maximizing comparability of data between sites, across habitats and taxa, and over time. The contributors discuss each method, provide detailed protocols for its implementation, and suggest ways to analyze the data.

- Walls SC. 2014. Identifying monitoring gaps for amphibian populations in a North American biodiversity hotspot, the southeastern USA. Biodivers Conserv. 23:3341–3357. A review of primary literature to ascertain the status of amphibian monitoring efforts in the southeastern USA.

7.2.2 Aquatic Species

- Thompson WL, editor. 2004. Sampling rare or elusive species: concepts, designs, and techniques for estimating population parameters. Washington (DC): Island Press. 428 p. Descriptions of sampling designs and counting (estimation) techniques for reliably estimating occupancy, abundance, and other population parameters of rare or elusive plants and animals.

- Drew CA, Wiersma YF, Huettmann F, editors. 2011. Predictive species and habitat modeling in landscape ecology, concepts and applications. New York (NY): Springer. The ecological theory and an assessment of the relevant assumptions that underlie predictive landscape-scale species and habitat modeling.

- Fischer JR, Neebling TE, Quist MC. 2012. Development and evaluation of a boat-mounted RFID antenna for monitoring freshwater mussels. Freshw Sci. 31(1):148–153. Design, construction, and evaluation of a boat-mounted RFID antenna to detect individually PIT-tagged benthic aquatic organisms (mussels) and evaluation of the effects of tag orientation on detection distances in water with a 32-mm half-duplex PIT tag.

- Fischer JR, Quist MC. 2014. Characterizing lentic freshwater fish assemblages using multiple sampling methods. Environ Monit Assess. 186(7):4461–4474. Six lakes and impoundments (48–1,557 ha surface area) were sampled seasonally with seven gear types to evaluate the combined influence of sampling methods and timing on the number of species and individuals sampled.

- Machler E, Deiner K, Steinmann P, Altermatt F. 2014. Utility of environmental DNA for monitoring rare and indicator macroinvertebrate species. Freshw Sci. 33(4):1174–1183. eDNA techniques were used for a broad taxonomic array of macroinvertebrate species in river and lake systems in parallel to the conventional kicknet-sampling method commonly applied in aquatic habitats. The eDNA method showed medium to very high consistency with the data from kicknet-sampling and was able to detect both indicator and nonnative macroinvertebrates.

7.2.3 Birds

- Nur N, Jones SL, Geupel GR. 1999. Statistical guide to data analysis of avian monitoring programs. Biological Technical Publication BTP-R6001-1999. Washington (DC): US Fish and Wildlife Service. A guide for designing monitoring programs for landbirds and analyzing data collected on terrestrial bird populations.

- Ralph DJ, Geupel GR, Pyle P, Martin TE, DeSante DF. 1993. Handbook of field methods for monitoring landbirds. Albany (CA): US Forest Service, Pacific Southwest Research Station. A compilation of methods for determining population size, demographics, and status of various birds and habitats. Methods include censuses, mist-netting, nest searches, and general observations. (http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1104&context=usdafsfacpub.).

- Martin TE, Geupel GR. 1993. Nest-monitoring plots: methods for locating nests and monitoring success. J Field Ornithol. 64(4):507–519. Standardized methods and cues are described that aid in locating and monitoring nests of neotropical migratory birds to allow comparisons across studies in space and time.

- Ralph CJ, Droege S, Sauer JR. 1995. Managing and monitoring birds using point counts: standards and applications. General Technical Report PSW-GTR-149. Arcata (CA): US Forest Service. A summary of suggested standards for consistency between studies using point counts during the breeding season to track population trends or determine associations between birds and their habitats. (http://www.fs.fed.us/psw/publications/documents/psw_gtr149/psw_gtr149_pg161_168.pdf)

- Ralph CJ, Sauer JR, Droege S, editors. 1997. Monitoring bird populations by point counts. General Technical Report PSW-GTR-149. Albany (CA): US Forest Service, Pacific Southwest Research Station. Contains in part papers presented at the Symposium on Monitoring Bird Population Trends by Point Counts, which was held November 6–7, 1991, in Beltsville, MD, in response to the need for standardization of methods to monitor bird populations by point counts. (http://www.fs.fed.us/psw/publications/documents/psw_gtr149/psw_gtr149.pdf).

7.2.4 Mammals

- Boddicker J, Rodriguez JJ, Amanzo J. 2002. Indices for assessment and monitoring of large mammals within an adaptive management framework. Environ Monit Assess. 76:105–123. Examines the design, applicability and effectiveness of two indices applied within a framework of adaptive management. An occurrence index assesses the composition and distribution of large mammals at a site, and an abundance index monitors the abundance of large mammals over time in relation to development.

- Meyer J. 2006. Field methods for studying nutria. Wildl Soc Bull. 34(3):850–852. Methods used for live-trapping, handling, and marking animals strongly depend on the species considered and the circumstances at particular study sites. This paper provides a short overview on methods used for capturing and marking Nutrias, which may be appropriate for other aquatic mammals, and relates field experiences of the author.

- Yack TM, Barlow J, Rankin S, Gillespie D. 2009. Integration of automated detection methods into NOAA Southwest Fisheries Science Center (SWFSC) acoustic marine mammal monitoring protocol. J Acoust Soc Am. 125(4):2588–2588. PAMGUARD 1.0 CORE software is evaluated for use in automated detection of cetacean acoustic signals. Three different detector configurations of PAMGUARD are evaluated.

- Lesmeister DB, Nielsen CK. 2011. Protocol for large-scale monitoring of riparian mammals. Wildl Biol Pract. 7(2):55–70. A large-scale monitoring protocol for populations of Beaver, American Mink, Muskrat, and North American River Otter. (http://socpvs.org/journals/index.php/wbp/article/view/10.2461-wbp.2011.7.15/257).

- Glen AS, Cockburn S, Nichols M, Ekanayake J, Warburton B. 2013. Optimizing camera traps for monitoring small mammals. PLoS ONE. 8(6):e67940. doi:10.1371/ journal.pone.0067940. Optimal specifications for a low-cost camera trap for small mammals. The factors tested were 1.) trigger speed, 2.) passive infrared vs. microwave sensor, 3.) white vs. infrared flash, and 4.) still photographs vs. video. A new approach was tested to standardize each camera's field of view success rates were compared of four camera trap designs in detecting and taking recognizable photographs.

7.3 Species Monitoring

Some populations are naturally dynamic because of life history strategies (*r*- versus *k*-reproductive strategies) while others may fluctuate on a generational, seasonal, or periodic basis depending on various environmental or biodiversity factors. Multiple investigation strategies may be needed to understand the dynamics of a species' population size. Surveys, monitoring, and research to facilitate appropriate conservation actions must be conducted to determine vulnerability of priority species to specific threats and studies should provide recommendations for mitigation and restoration. In North Carolina, birds and sea turtles are the only vertebrate groups for which there are historically established, standardized, long-term monitoring efforts. Recent efforts have incorporated national protocols for acoustic bat monitoring at a regional landscape level. It is important to continue implementing established monitoring programs to further strengthen trend and population estimates, and, as baseline inventory and survey data allow, to establish new monitoring efforts across all other taxa groups.

In addition to the work conducted by NCWRC, the Commission coordinates a great deal of species status and population monitoring conducted by others and manages a collection permit system to regulate the collection of nongame fauna. The data from annual collection permit reports submitted by permit holders is reviewed by NCWRC and added to a statewide database. Voucher specimens collected during priority aquatic species surveys and monitoring efforts are archived at the NC Museum of Natural Sciences (NCMNS) to identify and document where species occur; this information is included in datasets managed by the Museum. All of the data collected by NCWRC becomes part of a database managed by the North Carolina Natural Heritage Program (NCNHP) and available for public use through the NC Natural Heritage Data Explorer (https://ncnhde.natureserve.org).

Monitoring is also a standard component of many other agency planning efforts, such as the NCDWR's Stream Fish Community Assessment Program, the USFS Land and Resource Management Plans, and DOD Integrated Natural Resource Management Plans (see Section 7.2.1). The data collected for the stream fish community assessment program is shared with NCWRC, NCMNS, and NCNHP, and any nonnative species records collected by the program are shared with the USGS Nonindigenous Aquatic Species Program. Future monitoring efforts need to build on and utilize these existing systems. There are other monitoring efforts conducted in the state on smaller scales or at levels focused on specific wildlife needs and as part of research by universities or private organizations such as special interest groups (especially for birds) (NCDPR 2000; Mitchell 2002; Smyth et al. 2010).

As bird monitoring efforts are by far the most advanced and established of any species group, the establishment of protocol for other species groups (e.g., small mammals, amphibians, reptiles) should be developed with strong consideration of the lessons learned through the various monitoring efforts of NABCI. Assessments must be conducted to document status trends following completion of baseline survey work.

As stipulated in recovery plans for federally listed endangered and threatened species, regular monitoring is coordinated through efforts among state and federal agencies (e.g., NCWRC, NCDENR, USFWS, NCDMF, and NOAA Fisheries). Many of these recovery plans are available for download from the internet (see Appendix N for a list of species recovery plans).

The following sections outline monitoring needs for taxa groups and provide information about protocols that can be used. Appendix O summarizes activities conducted in the state that are representative of collaborative efforts implementing local, regional, and state-wide monitoring activities. In some cases, there may be multiple lead agencies involved in a given effort depending on location (e.g., Red-cockaded Woodpeckers on state- and federally owned public lands), but for simplicity, all agencies and organizations involved with the monitoring effort are listed.

7.3.1 Amphibians and Reptiles

Monitoring protocols for amphibians (especially wetland breeding anurans and salamanders) and reptiles (especially secretive snakes, priority turtles, and terrapins) developed by Partners in Amphibian and Reptile Conservation (PARC) need to be applied statewide. The North Carolina Partners in Amphibian and Reptile Conservation (NC PARC) can serve as the umbrella program in North Carolina for monitoring activities and data sharing. Coordinated nesting and stranding monitoring of sea turtles is critical and collaboration with partners (NOAA-Fisheries, USFWS) must be continued.

Habitats that should be included in amphibian and reptile monitoring efforts are rock outcrops, early successional habitats, Longleaf Pine forests, dry coniferous woodlands, pocosins, wet pine savannas, floodplain forests, all wetlands (including isolated wetlands, riparian corridors, and bogs), maritime forests, and estuarine systems (Mitchell 2002).

7.3.2 Aquatic Species

Many aquatic species in North Carolina (especially crayfishes and snail species) lack distribution, survey, and inventory data on which to build long-term monitoring efforts. For these groups, established monitoring priorities may not be attainable in the near term. For those taxa and species with adequate baseline data, there is strong need to improve long-term monitoring across species groups, habitats, and management actions. Important partners (statewide) to engage in aquatic species and habitat monitoring include the NC Division of Water Resources (NCDWR), NCMNS, and USFWS.

Three fundamental monitoring needs include:

- Long-term monitoring to identify population trends of SGCN and other priority species.
- Working with partners to establish appropriate protocols, schedules, and sites for long-term population monitoring.
- Monitoring for selected fishes and mussel species in western region river basins.

Special-purpose monitoring is needed to assess the performance of specific conservation actions, including stream restoration projects, hydropower remediation, and species enhancement and restoration projects. Nonnative species impacts need to be monitored, especially impacts by populations of potentially injurious nonnative species, and impacts to SGCN when specific nonnative species are identified within river basins.

7.3.3 Birds

It is important to continue ongoing monitoring coordination and adhere to recommendations developed by national and regional entities of NABCI, which includes PIF regional and state plans, Southeastern Migratory Bird Conservation Initiative, the North American Waterbird Conservation Plan, and Audubon NC. Coordination with the Continental Bird Monitoring Workgroup of the International Association of Fish and Wildlife Agencies (IAFWA) to strengthen the coordination of bird monitoring efforts is another priority.

Other strategies include:

- Continuing to participate in ongoing monitoring research that NC State University (NCSU) and the USGS Patuxent Wildlife Research Center are conducting to evaluate monitoring protocols for standard point counts and the Breeding Bird Survey (estimation of detectability).

- Expanding current bird monitoring across the state, especially Monitoring Avian Productivity and Survivorship (MAPS) and migration banding stations, as training opportunities and technical assistance allow, in order to improve population status information for birds not adequately sampled under existing protocol (e.g., Breeding Bird Survey).

- Establishing 'surrogate' species where possible—species that may be representative of the habitat needs of a particular guild of species and are widespread enough to allow for population-level monitoring.

- Continuing established shorebird and waterbird monitoring efforts along all coastal and estuarine habitats, and expanding monitoring efforts for secretive marshbirds along estuarine, lake, and tidal swamp habitats using established protocol (Conway 2004).

- Continuing to monitor recovering species such as Bald Eagles and Peregrine Falcons in their key habitats.

Key species (or species groups) include Swainson's Warbler, Cerulean Warbler, Henslow's Sparrow, Bachman's Sparrow, other grassland specialists, Wayne's Black-throated Green Warbler, Painted Bunting, hawks, ground-nesters, cavity-nesters, and owls.

Key habitats include Longleaf Pine forests, floodplain forests, early successional habitats, high-elevation forests, pocosins, nonalluvial wetlands, and maritime forests. Ideally, monitoring should continue expanding across all habitats in order to strengthen trend data for all species.

7.3.4 Mammals

Standards and protocols for surveys and monitoring exist for some mammals and should be use to improve data matching with regional datasets. Establish and monitor bat numbers and species composition using reliable, reproducible techniques (Keeley et al. 2003). Conservation recommendations for monitoring Rafinesque's Big-eared Bat and Southeastern Bat include protocols for short- and long-term monitoring (BCI and SBDN 2013).

The North American Bat Monitoring Program (NABat) is an international, multiagency program to monitor bats at local to range-wide scales that will provide reliable data to promote effective conservation decision making and the long-term viability of bat populations (Loeb et al. 2015). Bat monitoring efforts in North Carolina (and throughout the southeast) need to be coordinated and data shared through a unifying body (e.g., SBDN, USFS, or USGS).

There is also a need for long-term survey and monitoring programs for all small mammals in North Carolina. Key habitats to focus monitoring efforts for small mammals are early successional habitats, dry coniferous woodlands, floodplain forests, and mesic and oak forests. For bats, key habitats for monitoring are caves, floodplain forests, mesic forests, and dry coniferous woodlands.

7.4 Habitat Monitoring

Given the varied habitat monitoring efforts ongoing across North Carolina, it is impossible to use a single trend to make a gross assessment of changes in habitat quality and quantity. A variety of indicators used in combination, however, could provide an indication of habitat and ecosystem conditions, such as forest conversion rates, land development rates, wetland losses, percent of impervious surface changes by watershed or river basin, and/or Impaired Waters listings. Monitoring needs for particular habitats are detailed throughout the natural community descriptions in Chapter 4 (Habitats).

Ongoing habitat monitoring conducted by NCWRC is largely associated with habitat restoration activities in order to gauge success in pre- vs. post-restoration treatments. Other efforts coincide with regular species monitoring (e.g., habitat monitoring is a component of biennial colonial waterbird monitoring). Habitat monitoring is a critical component of NCWRC projects such as:

- Game lands management activities
- Watershed enhancement program activities
- Waterfowl management areas/impoundments
- Hydropower remediation/Federal Energy Regulatory Commission (FERC) relicensing efforts
- CURE program areas (areas that are being restored to quality early successional habitat).

The North Carolina Division of Parks and Recreation (NCDPR) has developed guidelines for natural resource inventory and monitoring in state parks and provides an example of data collection, management, and reporting (NCDPR 2000). The guidelines have been used for baseline inventories of park resources, long-term monitoring studies, and cooperative research agreements with the agency.

Land in North Carolina is primarily in private ownership, which emphasizes the importance of refining and strengthening remote sensing techniques when direct access to lands may not be feasible. Satellite imagery Light Detection and Ranging (LIDAR) and digital elevation models, and geo-spatial data analysis tools have become more accessible and digital resources for statewide, regional, and national coverage are generally available through numerous sources. High-quality GIS data sets and imagery are available online from the NCDOT Business Partner Resources web page.

7.4.1 Terrestrial Habitat Monitoring Programs

NCNHP Natural Heritage Program Natural Areas (NHPNA) identifies terrestrial and aquatic sites that are of special biodiversity significance. A survey-based approach and indicator species are used to determine what habitat units constitute core areas and what priority rank they should receive. Indicator species are selected based on their sensitivity to the integrity and fragmentation of specific types of habitat. Landscape/Habitat Indicator Guilds are used for analysis and to monitor, as well as compare, the relative quality of these high-quality habitats and natural communities through time. Comprehensive natural areas surveys have been conducted for 92 counties in the state. Landscape Habitat Guild and county Natural Areas Inventory reports are available online from the NCNHP web page.

Coastal wetlands inventories and functional assessments as well as beach erosion rates are conducted by the NC Division of Coastal Management (NCDCM). Annual wetland and stream buffer losses and gains are tracked by NCDWR. Wetlands mitigation site monitoring is conducted by the NC Ecosystem Enhancement Program (NCEEP; a joint effort between the NCDOT, the US Army Corps of Engineers [USACE], and the NC Department of Environment and Natural Resources [NCDENR]).

The USFS Southern Research Station's Forest Inventory and Analysis (FIA) Work Unit conducts periodic forest surveys in North Carolina (and nationwide) to provide statistics for measuring changes and trends in the extent and condition of forest land, associated timber volumes, and rates of timber growth, mortality, and removals. North Carolina contains four forest survey regions: the Mountains, Piedmont, Northern Coastal Plain, and Southern Coastal Plain.

The most recent forest survey in the state compares 2007 data to 2002 data and highlights changes in forest land area, ownership, forest type, stand size, stand treatment, softwood volume, hardwood volume, growth, mortality, and removals. Recent changes in methods, plot design, and sampling intensity were made to increase national consistency between FIA Research Work Units. These changes complicate the comparison of historic data with recent surveys and make detection of genuine resource trends difficult, but will improve consistency in future analyses.

The Natural Resources Conservation Service's (NRCS) National Resources Inventory (NRI) program collects and disseminates information on a state, regional, and national level about the status, condition, and trends of soil, water, and related resources in the United States, including land use, erosion, nonfederal and federal lands inventory, cropland use, prime farmland, and wetlands and deepwater habitats. NRI was conducted every five years between 1977 and 1997, but since 1997, it has been conducted annually.

Regional and statewide Gap Analysis Project (GAP) land cover data provides a potential source with which to assess land cover trends over time. Regional GAP efforts across the southeast (http://www.basic.ncsu.edu/segap/) do present potential opportunities for land cover change detection analyses in the future.

NatureServe provides a national assessment of ecological landscape condition to model the effects of landscape fragmentation on biodiversity. The NatureServe Modeling Landscape Condition tool produces a remote assessment index of ecological condition using available spatial data and user applied knowledge and assumptions about stressors and relative ecological condition for sites of interest.

Data Basin is a science-based mapping and analysis platform that provides collaborative information for sharing and analyzing data and information. An example for North Carolina is the Southeast Aquatic Resources Partnership (SARP) Riparian Assessment (2013) data set that assesses the current condition of riparian habitat within a 30-meter buffer along streams and rivers throughout the SARP region and provides a baseline against which to measure future progress toward achieving riparian habitat conservation and restoration goals. Another example is the series of Sea Level Affecting Marshes Model (SLAMM) data sets that illustrate potential changes in marsh and coastal environments due to long-term sea level rise (SLR). Data Basin is also a resource for indicator species models being developed by SALCC.

LANDFIRE is a program that provides over 20 national geo-spatial data sets for vegetation type and cover, fuel loads, and land disturbance. Vegetation is mapped using predictive landscape models based on extensive field-referenced data, satellite imagery, and biophysical gradient layers using classification and regression trees. LANDFIRE uses vegetation products (i.e., NatureServe's Ecological Systems classification) to create fuel and fire regimes data. The NatureServe Explorer provides descriptions for each ecological system including species, distribution and classification information.

7.4.2 Aquatic Habitats Monitoring

Strategies for monitoring various community types include expanding monitoring efforts on public lands, initiating monitoring protocols on key private lands (especially industrial forest land), and collaborating with key partners (e.g., USFS, DOD, USFWS) and private timber companies.

NCDWR conducts extensive Index of Biotic Integrity (IBI) monitoring for their basin-wide planning efforts, including lake assessments, phytoplankton monitoring, physical and chemical water quality monitoring, and aquatic toxicity monitoring (as well as fish and benthic macroinvertebrate monitoring). NCDWR also designates and maintains a list of impaired waters (305(b) and 303(d) Reports) and tracks percent impervious surfaces by basin.

Where dams regulate stream flow, long-term monitoring and research are needed to determine if existing minimum flow requirements are adequate to support aquatic communities and not just available habitat. The data generated from monitoring can be used to establish thresholds for flow requirements (i.e., ecological flows) necessary to sustain all riverine and riparian processes. This is especially important where there is a lack of biological and hydrological data and knowledge about synergistic influences such as water velocities, water quality, salinity, temperature, and DO.

NOAA Fisheries conducts submerged aquatic vegetation (SAV) mapping and monitoring in coordination with EPA and NCDWR. According to the Coastal Habitat Protection Plan (CHPP) (Deaton et al. 2010), however, no quantified trends analysis is available for the state, as currently there is only one complete SAV mapping dataset (1983–91) (Street et al. 2004). CHPP (Deaton et al. 2010) includes a broad recommendation to coordinate and enhance water quality, physical habitat, and fisheries resource monitoring from headwaters to the nearshore ocean (key partners include NCDMF, NCDWR, NCDCM, NCWRC).

Recommendations in CHPP call for a site-specific, compound-specific monitoring program to assess potential impacts of endocrine-disrupting chemicals (EDCs) in North Carolina's estuaries. Estuarine monitoring of the concentration and prevalence of priority chemicals of concern, with a possible focus on the Neuse River system and research on the effects of EDCs on fishery species, particularly blue crab, oysters, and fish, should be a priority. Analysis and monitoring of long-term trends in estuarine salinity and temperature is needed to evaluate the impact of SLR and climate change on fishery resources in North Carolina. It is also important to quantify the episodic and chronic effects of trawling on nursery functions in different estuarine settings. CHPP also identifies a number of key monitoring needs across specific coastal fisheries habitats. These are:

Water column

- Conduct stream flow monitoring and research to assess the impact of freshwater withdrawals on water column habitat and fish populations in affected river basins.
- Continue coastal research and monitoring in order to improve our understanding of the processes of hypoxia and anoxia and the effect on fish populations.
- Implement more-detailed monitoring to assess the extent oceanfront septic systems are causing degradation to nearshore coastal waters.
- Identify basic water quality parameters (flow, temperature, pH, and DO) for wastewater permit applicants to monitor. If the data indicate the presence of pollutants in the discharge water, toxic chemical monitoring and toxicity testing should be required. Nutrients and ammonia should be monitored if a mass balance approach indicates excess nutrients. Biological monitoring of the macrobenthic community should be required in facilities discharging more than 0.5 million gallons per day.
- Monitor port waters for algal blooms and exotic species until treatment of ballast water is required and implemented in order to minimize risks of introduction elsewhere.

Submerged aquatic vegetation (SAV)

- Make certain portions of the Neuse and White Oak river basins high priorities for SAV and water clarity monitoring. Since some SAV is present in the shallow portions of the Neuse and portions of the White Oak river basins, and water quality data indicate some level of eutrophication exists, nutrient levels may be limiting survival or expansion of SAV in these areas.
- Monitor submerged grasses on a regular basis to assess the status of wasting disease and its association with human-induced stresses.
- Evaluate whether current sampling locations and methods are sufficient in estuarine waters to monitor the suitability of water quality conditions for SAV survival and growth.
- Verify recovery and determine if there is a spatial pattern of that recovery in areas where SAV restoration and enhancement projects have been implemented. If there is a pattern, special monitoring and protection should be afforded to those core areas from which SAV begins its recolonization.

Wetlands

- Implement additional monitoring to better assess impacts where extensive areas of wetlands were drained.
- Given a limited time to monitor for restoration success, criteria should focus on identifying trajectories of functional development that include wetland soil development.
- Conduct a study to quantify the cumulative impact of shoreline hardening on wetland vegetation and habitat-mediated predator–prey interactions in NC estuarine waters.

Soft bottom

- Gather more information to understand the consequences on the estuarine food web and to what extent anoxia is impacting the soft bottom community.
- Implement adequate monitoring of the effects of beach nourishment on the soft bottom community and associated surf fish populations as the number of beach nourishment projects increase. This should be required for all large-scale or long-term nourishment projects.
- Conduct long-term monitoring in combination with management actions that reduce discharge concentrations to determine effectiveness and future management needs.

Hard bottom

- Monitor hard bottom communities to assess the level of impact from trawling activity, particularly shrimp trawls in the southern portion of the coast.
- Initiate monitoring of hard bottom communities and coordinate with UNC-Wilmington or other ocean water quality monitoring programs to determine the effects of estuarine water quality, particularly nutrient and sediment loading, on hard bottom communities.

References

[BCI and SBDN] Bat Conservation International and Southeastern Bat Diversity Network. 2013. A conservation strategy for Rafinesque's Big-eared Bat (*Corynorhinus rafinesquii*) and Southeastern Myotis (*Myotis austroriparius*). Austin (TX): Bat Conservation International; [accessed 2015 June]. 101 p. http://sbdn.org/wp-content/uploads/2014/12/ConservationPlanforCORAandMYAU_2014.pdf.

Bonin A, Bellemain E, Eidesen PB, Pompanon F, Brochmann C, Taberlet P. 2004. How to track and assess genotyping errors in population genetics studies. Mol Ecol. 13(11):3261–3273.

Brown S, Hickey C, Harrington B, Gill R. 2001. US shorebird conservation plan. 2nd ed. Manomet (MA): Manomet Center for Conservation Sciences.

Conway CJ. 2004. Standardized North American marsh bird monitoring protocols. Waterbirds. [accessed 2015 July];34(3):319–346. 29 p. http://www.bioone.org/doi/pdf/10.1675/063.034.0307.

Cooper RJ, Demarest D. 1999. Partners In Flight bird conservation plan for the Southern Piedmont [internet]. Partners In Flight; [accessed 2015 July]. http://www.partnersinflight.org/bcps/pl_11sum.htm.

Deaton AS, Chappell WS, Hart K, O'Neal J, Boutin B. 2010. North Carolina Coastal Habitat Protection Plan. Morehead City (NC): NC Division of Marine Fisheries; [accessed 2015 June]. 659 p. http://portal.ncdenr.org/c/document_library/get_file?uuid=4cb3ec6a-a5d8-4851-bef0-314ab0d8787c&groupId=38337.

[DOD] Department of Defense. 2013. Integrated Natural Resources Management Plan (INRMP) implementation manual. Department of Defense Manual Number 4715.03. Washington (DC); [accessed 2015 June]. 31 p. http://www.dtic.mil/whs/directives/corres/pdf/471503m.pdf.

Hunter WC, Collazo J, Noffsinger B, Winn B, Allen D, Harrington B, Epstein M, Saliva J. 2002. Southeastern Coastal Plain–Caribbean regional shorebird plan. Atlanta (GA): US Fish and Wildlife Service; [accessed 2015 June]. http://www.shorebirdplan.org/wp-content/uploads/2013/01/SECPCRRev02.pdf.

Hunter WC, Golder W, Melvin S, Wheeler J. 2006. Southeast United States regional waterbird conservation plan. Atlanta (GA); [accessed 2015 June]. 131 p. http://www.waterbirdconservation.org/pdfs/regional/seusplanfinal906.pdf.

Hunter WC, Katz R, Pashley D, Ford B. 1999. Partners In Flight bird conservation plan for the Southern Blue Ridge (Physiographic Area 23). Atlanta (GA): American Bird Conservancy; [accessed 2015 July]. 101 p. http://www.partnersinflight.org/bcps/plan/pl_23_10.pdf.

Hunter WC, Peoples L, Collazo J. 2001. Partners In Flight bird conservation plan for the South Atlantic Coastal Plain (Physiographic Area 03). Atlanta (GA): American Bird Conservancy; [accessed 2015 July]. 166 p. http://www.partnersinflight.org/bcps/plan/pl_03_10.pdf.

Johns M. 2005. A bird conservation plan for North Carolina; a bird conservation strategy by NC Partners in Flight. Raleigh (NC): Partners In Flight; [accessed 2015 September]. 23 p. http://static1.1.sqspcdn.com/static/f/1319779/22228911/1363729075077/NCPIF_Bird_Conservation_Plan.pdf?token=G%2BnC5J3ZH5NeE5wGA4jr9qe5A7U%3D.

Keeley BW, Fenton MB, Arnett E. 2003. A North American partnership for advancing research, education, and management for the conservation of bats and their habitats. Wildl Soc Bull. 31(1):80–86.

Kushlan JA, Steinkamp MJ, Parsons KC, Capp J, Cruz MA, Coulter M, Davidson I, Dickson L, Edelson N, Elliot R, et al. 2002. Waterbird Conservation for the Americas: The North American waterbird conservation plan, Version 1. Washington (DC): Waterbird Conservation for the Americas; [accessed 2015 July]. 84 p. http://www.waterbirdconservation.org/pdfs/plan_files/complete.pdf.

Loeb SC, Rodhouse TJ, Ellison LE, Lausen CL, Reichard JD, Irvine KM, Ingersoll TE, Coleman JTH, Thogmartin WE, Sauer JR, et al. 2015. A plan for the North American Bat Monitoring Program (NABat). General Technical Report SRS-208. Asheville (NC): Southern Research Station; [accessed 2015 June]. 112 p. http://www.srs.fs.usda.gov/pubs/gtr/gtr_srs208.pdf.

Lukacs PM, Burnham KP. 2005. Review of capture–recapture methods applicable to noninvasive genetic sampling. Mol Ecol. 14(13):3909–3919.

Mitchell JC. 2002. Guide to inventory and monitoring of amphibians on Dare County Bombing Range, Cherry Point Marine Corps Air Station, and Marine Corps Base Camp Lejeune, North Carolina. Camp Lejeune (NC): Department of Defense; [accessed 2015 June]. 91 p. http://www.denix.osd.mil/nr/upload/GuidetInventoryMonitoringAmphibianCampLejeuneNC.pdf.

[NCDPR] NC Department of Parks and Recreation. 2000. Natural Resource Inventory and Monitoring. Raleigh (NC): NC Department of Environment and Natural Resources; [accessed 2015 June]. 36 p. http://www.ncparks.gov/About/docs/monitor_guide.pdf.

Rich TD, Beardmore CJ, Berlanga H, Blancher PJ, Bradstreet MSW, Butcher GS, Demarest DW, Dunn EH, Hunter WC, Iñigo-Elias EE, et al. 2004. Partners In Flight North American Landbird Conservation Plan. Ithaca (NY): Cornell Lab of Ornithology; [accessed 2015 June]. http://www.partnersinflight.org/cont_plan/.

Rosenberg KV. 2004. Partners in Flight continental priorities and objectives defined at the state and bird conservation region levels. Ithaca (NY): Cornell Lab of Ornithology; [accessed 2015 June]. 30 p. http://www.fishwildlife.org/files/NC_PIF_OBJ_PRIO.pdf.

Schwartz MK, Luikart G, Waples RS. 2007. Genetic monitoring as a promising tool for conservation and management. Trends Ecol Evol. 22(1):25–33.

Smyth R, Smart L, Pyne M. 2010. Species at risk on Department of Defense installations in the Carolinas, final report. Durham (NC): NatureServe; [accessed 2015 June]. 103 p. http://www.denix.osd.mil/nr/upload/Carolina_SAR_report-2.pdf.

[SALCC] South Atlantic Landscape Conservation Cooperative. 2013. Natural resource indicators and targets. Raleigh (NC): South Atlantic Landscape Conservation Cooperative; [accessed 2015 June]. 16 p. http://data.southatlanticlcc.org/SALCC_indicators_and_targets.pdf.

[SAMBI] South Atlantic Migratory Bird Initiative. 2004. South Atlantic Migratory Bird Initiative pelagic conservation plan [draft]. Charleston (SC): US Fish and Wildlife Service.

Street MW, Deaton AS, Chappell WS, Mooreside PD. 2004. Coastal habitat protection plan. Morehead City (NC): NC Department of Environment and Natural Resources, Division of Marine Fisheries.

Taberlet P, Luikart G. 1999. Non-invasive genetic sampling and individual identification. Biol J Linn Soc. 68(1-2):41–55.

[USFS] US Forest Service. 2006. Multiple species inventory and monitoring technical guidance. General Technical Report WO-73. Washington (DC): US Department of Agriculture, Forest Service; [accessed 2015 June]. 216 p. http://www.fs.fed.us/rm/pubs_other/wo_gtr073.pdf.

Waits LP, Paetkau D. 2005. Noninvasive genetic sampling tools for wildlife biologists: a review of applications and recommendations for accurate data collection. J Wildl Manag. 69(4):1419–1433.

Watson C, Hayes C, McCauley J, Milliken A. 2005. The South Atlantic Migratory Bird Initiative. An integrated approach to conservation of all birds across all habitats. General Technical Report PSW-GTR-191. Charleston (SC): US Forest Service. [accessed 2015 June]. 11 p. http://www.fs.fed.us/psw/publications/documents/psw_gtr191/psw_gtr191_0266-0276_watson.pdf.

Watson C, Malloy K. 2006. The South Atlantic Migratory Bird Initiative implementation Plan. Version 3.1. Charleston (SC): South Atlantic Migratory Bird Initiative; [accessed 2015 June]. 99 p. http://www.acjv.org/documents/SAMBI_Plan3.2.pdf.

Review, Coordination, Revision, and Next Steps

8

Required Element 6

Descriptions of procedures to review the WAP at intervals not to exceed 10 years.

Required Element 7

Plans for coordinating the development, implementation, review, and revision of the WAP with federal, state, and local agencies and Indian tribes that manage significant land and water areas within the State or administer programs that significantly affect the conservation of identified species and habitats.

Required Element 8

Congress has affirmed through the World Climate Research Program (WCRP) and State the Wildlife Grant, and other guidance to states and partners, that broad public participation is an essential element of developing and implementing these Plans, the projects that are carried out while these Plans are developed, and the Species of Greatest Conservation Need (SGCN) and Congress has indicated that such programs and projects are intended to emphasize.

8.1 Introduction

The 2005 Wildlife Action Plan (WAP) outlined steps for implementation and monitoring of its priorities as well as recommendations and measures for review and revision of the document (see Chapters 6 and 8) (NCWRC 2005). Since publication of that Plan, new guidance has been provided by the US Fish and Wildlife Service (USFWS) and the Association of Fish and Wildlife Agencies (AFWA) concerning its review, coordination, revision, and content. The 2007 Administrative guidelines (USFWS 2006) and subsequent review and revision guidance (USFWS 2007) from USFWS outlined steps and requirements for a mandatory 10-year comprehensive review (and revision), but allowed for intermediate minor or major updates or revisions. Other guidance has been described in Chapter 1 of this document, including a recommendation to incorporate climate change during this revision process. The 2015 WAP revision is in compliance with the requirement to conduct a comprehensive review and revision at an interval not to exceed 10 years.

Using recommendations from various workshops, several committees and teams were organized and tasked with guiding the revision process. The Revision Steering Committee, Technical Team, Taxa Teams, *ad hoc* Stakeholder Advisory Committees, and other special topic workgroups are key components, and their membership reflects several agency and organization partners as well as private citizens (stakeholders). The 2015 WAP revision was accomplished through the efforts of numerous individuals participating in meetings held statewide as well as various regional locations and virtual (technology-based) venues. A list of key members, participating agencies, and the structure of the committees and workgroups involved in the revision process and letters of support from partners are provided in Appendix C.

8.2 Required 10-Year Comprehensive Review and Revision

North Carolina's comprehensive review and revision began in 2009, when the WAP Stakeholders Workshop Steering Committee (Committee) was convened by the NC Wildlife Resources Commission (NCWRC or Commission). The Committee was composed of members from federal and state agencies and partner organizations and was tasked with organizing a forum for NCWRC and partners to strategically address climate change impacts to priority wildlife and habitats. A goal of the Committee was to incorporate the results into the Wildlife Action Plan. To achieve this goal, the Committee worked collaboratively with climate scientists and scientific experts to develop the report "Understanding the impacts of climate change to fish and wildlife in North Carolina" (DeWan et al. 2010), which outlines likely impacts and provides recommendations for addressing them. An Executive Summary and the full report are available for download in PDF format from the WAP webpage: www.ncwildlife.org/plan.

8.2.1 Climate Change Workshop (2010)

A two-day workshop organized by the Committee was held in September 2010 as an early step in starting the WAP revision process. The workshop goals were to engage partners and stakeholders on the issue of potential climate change impacts to fish and wildlife, to collect input on revision of the WAP, and to garner support for using the Plan as a framework for addressing climate change as it relates to fish and wildlife.

Stakeholders were asked during breakout sessions to identify the top three climate change impacts to wildlife. Results from these sessions indicate that sea level rise, habitat changes (e.g., species range and habitat biodiversity), and weather pattern changes (e.g., temperature and precipitation) are the most significant concerns in North Carolina. It was also recommended to use an iterative approach in the revision process rather than a linear approach, with climate change, habitat, and species information being developed in parallel rather than sequentially. Other feedback from participants included recommendations on how to proceed with revision of the WAP, including:

- organization structure to accomplish the revision (leadership, committees, and teams);
- cooperative development of the technical content with incorporation of climate change;
- prioritization of conservation measures and ongoing research needs; and
- solicitation for review of the completed draft document.

It was also recommended to use an iterative approach to the revision instead of a linear approach, with climate change, habitat, and species information being developed in parallel rather than sequentially.

About 140 individuals, representing 36 different federal, state, and local agencies, conservation organizations, and private companies, attended the workshop. A summary of the workshop and recommendations were developed by the University of North Carolina at the Charlotte Urban Institute and published in a report available on the NC WAP webpage: www.ncwildlife.org/Plan/Revision/September2010Workshop.

8.2.2 Regional Workshops (2011)

Five additional workshops were held from January through May 2011 in regional settings to accommodate partners and stakeholders unable to attend the Climate Change Workshop. These regional workshops were designed to introduce the report on climate change impacts to fish and wildlife in North Carolina; to provide a forum to discuss adaptation and mitigation measures; to provide information about conservation programs; to introduce a NCWRC Conservation Registry portal designed for partners to share and manage conservation data and needs; and to solicit feedback about implementation of 2005 priorities and collect input on priorities for the revision.

Over 190 individuals representing 66 different agencies, organizations, companies, and individuals participated in the workshops. Meeting handouts and presentations are available on the NC WAP webpage: www.ncwildlife.org/Plan/Revision/Spring2011RegionalWorkshops.

8.2.3 Incorporating Best Practice Recommendations (2012)

In 2012, the WAP Revision Technical Team adopted several recommendations from AFWA's Best Practice Guide (AFWA 2012), which were endorsed by the Revision Steering Committee and implemented during the revision process. Many of the recommendations in the Guide are already integral components of North Carolina's State Wildlife Grant program and are part of NCWRC's daily implementation of the 2005 WAP priorities and recommendations. Briefly, new recommendations that have been incorporated into this plan include

- developing evaluation procedures to characterize risk of extinction and extirpation of species based on a suite of variables such as population size, trend, geographic range, and threats (including climate change) and using this information to determine Species of Greatest Conservation Need (SGCN);

- prioritizing conservation, research, and management concerns and needs using a structured ranking system that considers taxonomic status, endemism, geographical range, threat status, and other factors that measured risk of extinction;

- evaluating the anticipated impacts of threats based on the hierarchical classification system described by Salafsky et al. (2008);

- incorporating climate vulnerability assessments of effects and adaptation measures, developed by the NC Natural Heritage Program (NCNHP) and presented during the September 2010 Climate Change Workshop, into natural community descriptions in the revised WAP;

- applying models to analyze existing and new Geographic Information System (GIS) data, using it to identify potential Conservation Opportunity Areas (COAs), and making associated datasets available to partners through an online map interface and data downloads;

- working regionally to collaboratively apply North American Bat Monitoring Program (NABat) monitoring protocols in collection of occurrence data for multiple bat species and using a citizen science component for outreach and education;

- systematically addressing the Eight Required Elements in sequential chapters and identifying in the table of contents where to find the information; and

- publishing the 2015 WAP in an electronic format that uses dynamic links to referenced materials, can be accessed through multiple electronic document formats, and can be distributed digitally through the WAP webpage.

8.2.4 Technical Review and Revision (2012–2015)

In 2012 and 2013, the Technical Team, along with NCWRC biologists, partners, and stakeholder volunteers, collaboratively reviewed draft copies of NCNHP's climate vulnerability assessment reports (NCNHP 2010) using onsite workgroup meetings, virtual meetings, and data sharing via multiple web-based tools (e.g., online meeting rooms, Microsoft OneNote, electronic comment forms). The NCNHP vulnerability assessments describe how climate change and other impacts are expected to affect fish and wildlife species and compare and rank climate change against other categories of threats. Recommendations developed during the collaborative review identify needs for survey, monitoring, research, management, programs, and partnerships to address the impacts. These recommendations have been incorporated into natural community descriptions for aquatic, wetland, and terrestrial systems (see Chapter 4 of this Plan).

In 2013 and 2014, the vulnerability assessments were revised to incorporate technical review comments and were published as draft natural community descriptions for public review on the NCWAP web page. An announcement requesting review assistance was distributed to a list of over 700 partner and stakeholder email addresses and was prominently featured on the NCWAP web page for nearly eight months. A sign-up form was also made available online for the public to participate on an *ad hoc* Stakeholder Review Team to assist with reviewing the draft descriptions. The draft documents were available in PDF format, which could be viewed in a number of ways: online in a web browser using a variety of electronic devices (computer, mobile phone, tablet, e-reader); after downloading to a local storage device for offline viewing on an electronic device; or by downloading and then printing the pages. Each PDF document contained a URL link to automatically submit comments through the internet to NCWRC. The web page included telephone and email contact information to request additional information, report problems or difficulties accessing the draft Plan, or ask questions. Comments received were evaluated and incorporated as appropriate; approximately 20 comments were received during this review process. The information developed during this review has been incorporated into Chapter 4 Habitats.

A workgroup formed in 2013 by the WAP Revision Technical Team was tasked with developing new evaluation metrics and ranking criteria for identifying SGCN and other priority species (see Appendix F for more information). To help facilitate the evaluation process, NCWRC created a database interface to collect evaluation input and made it accessible through a secured internet portal for Taxa Team members to submit evaluation data. The database was designed to reduce reviewer bias by standardizing the review process, consolidate data, calculate ranking scores, track revisions, and provide a consistent information collection method. Reports compiled from database entries were provided to Taxa Team members and peer review volunteers. Three email announcements were sent to a list of species experts to request peer review assistance. A sign-up form was also available on the NCWAP web page for individuals with knowledge about any species evaluated by the Taxa Teams to volunteer as peer reviewers. Data sets and reviewer instructions were provided to any person who responded with interest in the peer review.

Teams of taxonomic and species experts from numerous federal and state agencies and partner organizations were convened in 2013 to form Taxa Teams. The Teams were asked to use the new evaluation and ranking process to identify SGCN and other priority species. Training workshops were held for Team members to become familiar with the new evaluation process and learn how to use the internet based database portal. Each Taxa Team held numerous onsite and virtual meetings in 2013 and 2014 that focused on evaluating species and developing the SGCN and priority species list. Potential peer reviewers were identified and invited to review evaluation results; peer review comments were reviewed by the appropriate Taxa Team and incorporated as determined by the Team. The final evaluation results have been incorporated into Chapter 3 Species and are available in Appendix G.

Online document sharing was used by the Revision Technical Team, other NCWRC biologists, and numerous federal, state, and stakeholder partners to consider the threat categories defined in Salafsky et al. (2008). Information developed about anticipated impacts from these threats in North Carolina has been incorporated into Chapter 5 Threats. Updated or new information provided by partners about their conservation priorities and programs and monitoring efforts was collected between 2013 and 2014 and has been incorporated into Chapter 6 Conservation Priorities and Chapter 7 Monitoring Efforts.

8.2.5 Public Review and Comment (2014–2015)

Public-review and peer-review comment opportunities were provided in 2014 and 2015. Peer review and technical assistance was sought from species and technical experts on the proposed taxa evaluation process developed by the Ranking Criteria Work Group. Appendix F provides more information about the review and comment opportunity and participants who provided feedback. Another opportunity involved peer review of the Taxa Teams' evaluation results. Numerous species experts from federal and state agencies, universities, museums, and stakeholder groups (e.g., corporations, conservation organizations) were invited to review, comment, or provide research data. Comments and research data were reviewed by the Taxa Teams and incorporated into the evaluation results as appropriate. The evaluation results were available to the public on the NCWRC website during the peer-review process.

The draft revised WAP was made available for public review in electronic format and comments were received from July 20 to August 18, 2015. The public review was intended to offer private citizens and those individuals from organizations not otherwise involved in the revision process an opportunity to review and provide comments and to offer new information for consideration. An announcement requesting the public's assistance was distributed statewide to news media outlets and was prominently featured on the NCWRC website. The draft document was available in PDF format, which could be viewed in a number of ways: online in a web browser using a variety of electronic devices (computer, mobile phone, tablet, e-reader); after downloading to a local storage device for offline viewing on an electronic device; or by downloading and then printing the pages. The electronic version of the announcement provided a hyperlink to the NCWRC public review website and the print version of the announcement provided a URL address to the website. Both versions included telephone and email contact information to request additional information, report problems or difficulties accessing the draft Plan, or ask questions. During the public review period, numerous newspapers and local news agencies published the request for public review and comments. A copy of the media announcement is provided in Appendix C.

Google Analytics was used to track the number of times the public review website was visited during the comment period. According to a Google Analytics analysis, there were 4,175 visits to the WAP public review web page, including both first-time and repeat viewers. The website provided a link to an electronic form that automatically submitted comments to NCWRC. Each electronic submission received an automatic email response with a message thanking the individual for their participation and comments and providing them with a record of their comment(s). Software was used to compile a report of all electronic submissions made from the public review website. Most comments were submitted using the electronic form, but comments were also received through emails and letters. A total of 11 commenters responded during the public review process. A summary of the public review comments and actions taken to address the comments is provided in Table 8.1.

Some public comments concerned topics in the Plan that were developed through coordination with other partners and stakeholders. There was not sufficient time from when they were received to adequately consider and address them or to complete additional coordination with the partners and stakeholders originally involved in developing content concerning those topics. The NCWRC will coordinate with appropriate partners and stakeholders to determine what action(s) to take for comments identified as needing further consideration. These topics can be included in a future revision of the Plan.

All public review comments in their entirety and the actions taken to address the comments were presented to the NCWRC Commissioners during a Committee of the Whole meeting on August 26, 2015. Afterward, Commissioners approved a resolution to endorse the draft plan and submission of the document to the USFWS Regional Review Team to meet the required 10-year comprehensive review and revision. The endorsement resolution can be found in the preface of this Plan. The public review comments are included in Commission meeting archives and are available as public records from the NCWRC web page: http://www.ncwildlife.org/Portals/0/About/documents/Agenda_Package/2015/2015-08-27-NCWRC-Commission-Meeting-Agenda-Package.pdf.

Table 8.1 Summary of public review participation and disposition of comments

Number Received	Group Represented	Action Taken to Address Comments
4	Private Citizens	Commenter 1: the WAP already addresses the topic; no action needed.
		Commenter 2: general in nature; no action needed.
		Commenter 3: regards game land management plans handled through a separate public review process; no action taken.
		Commenter 4: general in nature; no action needed.
3	State Agency	Commenter 5: hunting concerns handled through the rules and regulations process; no action needed.
		Commenter 6: regarding wind energy development; incorporated as new information in Chapter 5 Threats.
		Commenter 7: from agency partner concerned updated website information and was incorporated as needed.
4	Special Interest Groups	Commenter 8: the WAP already addresses the topic; no action taken.
		Commenter 9: the WAP already addresses the topic or the WAP is not the appropriate forum to comment on proposed rules; no action needed.
		Commenter 10: general in nature and the WAP already contains information about the topic; no action needed.
		Commenter 11: for most, the WAP already addresses the topic and no action needed. Some comments will require further consideration to determine how best to address the topic; information may be incorporated during future revision.

8.3 Future Review and Revision

Review, revision and maintenance of the WAP will require the continuation of all the activities that went into development of the document (e.g., communication and coordination with partners, database updates), as well as the management of new activities (e.g., website updates, project implementation, evaluation, monitoring, adaptive management process). Maintenance activities will be primarily coordinated by NCWRC but will require regular communication with partners and stakeholders. Considering the electronic format of the Plan, it is anticipated that future revision will be a straightforward and streamlined process.

Semi-annual reporting on projects and annual evaluation of project accomplishments by program supervisors are used to assess adaptive management needs on a project-by-project basis. Commission program supervisors and administration will assess individual project performance to determine if they are meeting program-level strategies on par with the conservation actions called for in the Plan. Program supervisors will work with staff and partners to review the results of individual projects and, as needed, will use the adaptive management process to revise projects. Project descriptions and updates will be entered into the USFWS database for Tracking and Reporting on Actions for Conservation of Species (Wildlife TRACS) and shared with partners through news media releases, magazine articles, report summaries, or other methods to keep them abreast of project progression and highlights. Currently, quarterly summaries for NCWRC projects funded through the SWG program for 2012–2015 are available in PDF format online: http://www.ncwildlife.org/Conserving/Programs/WildlifeDiversityProgram/WDPQuarterlyReports.aspx. Annual reports for NCWRC projects funded through the SWG program for 2007–2011 are available in PDF format online: http://www.ncwildlife.org/Conserving/Programs/WildlifeDiversityProgram.aspx.

When any type of WAP revision is to occur, the Steering and Technical committees will assemble appropriate teams to complete the effort. Draft material developed for WAP revisions will be peer reviewed for technical content, made available for public review and comment, and approved by the Revision Steering Committee for incorporation into the Plan before submittal to USFWS for approval.

8.3.1 Short-term Revisions

There are any numbers of issues that can result in a need to revise the document in the short-term and these are expected to be handled as either a minor or major revision to the WAP. Examples include

- updating the scientific name of a putative species when identification is confirmed and a species description has been published;
- changes to the federal or state listing status of a species;
- gaining new information through surveys, research, and monitoring that will influence management actions;
- reprioritization of activities following accomplished tasks;
- flaws in how the Plan serves to guide implementation activities that need to be eliminated; or
- correcting typographical errors in the text or editing images and graphics to correct errors.

A short-term revision of the WAP is planned in 2017 to incorporate new information about COAs and to incorporate the associated decision support tool (DST) that identifies potential COAs. Using a 2013 State Wildlife Grant competitive award, NCWRC has partnered with the Biodiversity and Spatial Information Center (BaSIC) at the NC Cooperative Fisheries and Wildlife Research Unit (NC State University) to develop a GIS model to evaluate climate change and other threats to species and habitats. The resulting datasets will be incorporated into an online web-based map and DST that can be used to identify potential COAs. The DST will allow users to explore individual threat/risk components in a spatial environment as well as combine and weigh components in user-defined configurations to highlight specific threats and develop specific scenarios of future trends. This revision to the WAP will be submitted to the USFWS Regional Review Team as a major revision.

8.3.2 Planned Interim and Comprehensive Revision

A comprehensive review and revision will occur within the required 10-year interval based on the publication date of the last comprehensive review and revision. Based on current USFWS requirements and the submittal of this WAP revision, the next comprehensive revision will be due in 2025.

Interim review and revision of the WAP will occur as needed but is expected at no more than three- to five-year intervals. Interim revisions will depend on the completion and results of significant projects and as determined by the Revision Steering Committee and Technical Team. These types of revisions are expected to be submitted to the USFWS as major revisions to the Plan. Other projects that may be included during an interim revision in order to integrate project results or critical information include (but are not limited to) the following:

- Ecosystem indicators developed by the South Atlantic Landscape Conservation Cooperation (SALCC) to assist with design and evaluation and to measure success of the South Atlantic Conservation Blueprint.
- A freshwater resilience analysis for the rivers and streams of North Carolina conducted by The Nature Conservancy (TNC) that classifies waterways by their degree of resilience or vulnerability (Benner et al. 2014).
- Southeast region landscapes were analyzed by TNC to identify key areas for conservation based on land characteristics that increase diversity and resilience (Anderson et al. 2014).
- The Southeast Aquatic Connectivity Assessment Project (SEACAP) assessed dams in the Southeast to identify opportunities to improve aquatic connectivity by prioritizing

dams based on their potential ecological benefits if removed or bypassed within watersheds that intersect the SALCC area (Martin et al. 2014).

- Research that incorporates North American Bat Conservation Partnership (NABCP) monitoring recommendations into regional bat monitoring efforts to accurately document populations of priority bat species so better estimates can be determined.
- New or improved approaches to internal supporting processes (e.g., species prioritization, threat assessment) that are worth the investment of revision before an unwieldy process becomes tradition.
- Expansion of the Plan to include species or groups (e.g., insects) that were secondarily addressed and revision will make a more truly comprehensive document.

Since it takes considerable time to assess changes related to the implementation of conservation activities and to collect and analyze new information useful in making management decisions, reevaluation of SGCN and priority species is planned to be part of the interim review and revision process, based on recommendations from the Revision Technical Team or the Taxa Teams. However, should immediate declines (e.g., white-nose syndrome and bat population trends) become apparent for any species, taxonomic group, or species guild the Revision Steering Committee can convene a Taxa Team to conduct an immediate reevaluation. Revision of any SGCN and priority species list will be submitted to the USFWS as a major revision of the WAP.

References

[AFWA] Association of Fish and Wildlife Agencies. 2012. Best practices for developing state wildlife action plans: voluntary guidance to states for revision and implementation. Washington (DC): Association of Fish and Wildlife Agencies; [accessed 2015 August]. 85 p. www.fishwildlife.org/files/SWAPBestPractices.pdf.

Anderson MG, Barnett A, Clark M, Ferree C, Sheldon AO, Prince J. 2014. Resilient sites for terrestrial conservation in the southeast region. N.p.: The Nature Conservancy, Eastern Conservation Science; [accessed 2015]. 127 p. www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/resilience/se/Pages/default.aspx.

Benner R, Barnett A, Sheldon AO, Hoenke K, Meitzen K, Fields M. 2014. North Carolina's freshwater resilience. Durham (NC): The Nature Conservancy. 33 p.

DeWan AN, Dubois N, Theoharides K, Boshoven J. 2010. Understanding the impacts of climate change on fish and wildlife in North Carolina. Washington (DC): Defenders of Wildlife; [accessed 2015 August]. 209 p. www.ncwildlife.org/Portals/0/Conserving/documents/ActionPlan/Revisions/FullReportDefendersofWildlifeUnderstandingtheimpactofclimatechangeNC.pdf.

Martin EH, Hoenke K, Granstaff E, Barnett A, Kauffman J, Robinson S, Apse CD. 2014. SEACAP: Southeast Aquatic Connectivity Assessment Project: Assessing the ecological impact of dams on southeastern rivers. N.p.: The Nature Conservancy, Eastern Division Conservation Science, Southeast Aquatic Resources Partnership.

[NCNHP] NC Natural Heritage Program. 2010. North Carolina climate change ecosystem assessment, draft. North Carolina ecosystem response to climate change: NCDENR assessment of effects and adaptation measures. Raleigh (NC): NC Natural Heritage Program.

[NCWRC] NC Wildlife Resources Commission. 2005. North Carolina wildlife action plan. Raleigh (NC): NC Wildlife Resources Commission; [accessed 2015 August]. 700 p. www.ncwildlife.org/plan.

Salafsky N, Salzer D, Stattersfield AJ, Hilton-Taylor C, Neugarten R, Butchart SHM, Collen B, Cox N, Master LL, O'Connor S, et al. 2008. A standard lexicon for biodiversity conservation: unified classifications of threats and actions. Conserv Biol. [accessed December 2014];22(4): 897–911. www.teaming.com/sites/default/files/A%20Standard%20Lexicon%20for%20Biodiversity%20Conservation.pdf.

[USFWS] US Fish and Wildlife Service. 2006. Administrative guidelines for state wildlife grants (2007). FWS/AWSR-FA: 027804. Letter addressed to state fish and wildlife agencies and territory governors dated October 18, 2006. 14p.

[USFWS] US Fish and Wildlife Service. 2007. Guidance for wildlife action plan (comprehensive wildlife conservation strategy) review and revision. Letter addressed to state fish and wildlife agencies and territory governors dated July 11, 2007. 8 p.