Species Status Assessment Report for the Round Hickorynut Mussel (*Obovaria subrotunda*)

Photo credit: Environment Canada

July 2019
Version 1.X

U.S. Fish and Wildlife Service
Region 4
Atlanta, GA

Primary Contributors

- Andrew Henderson - Asheville Field Office, Lead Biologist (Region 4)
- Heidi Crowell - Pacific Southwest Regional Office, SAT Project Manager (Region 8)
- Mark Endries - Asheville Field Office (Region 4)

Contributors & Agency Reviewers (underlined)

- Paul Hartfield, Leroy Koch (retired), Angela Boyer, Stephanie Chance (retired), Bob Anderson, Tyler Hern, Andy Ford, Patty Morrison (retired), Bob Butler (retired) (U.S. Fish and Wildlife Service)
- Dr. Todd Morris (Fisheries & Oceans Canada)
- Chuck Howard (retired), Tim Keeling (Tennessee Valley Authority)
- Kierstin Carlson (Western Pennsylvania Conservancy)
- Steve Ahlstedt (retired) (U.S. Geological Survey)
- Dr. Arthur Bogan, Jamie Smith (North Carolina Museum of Natural Sciences)
- Jeremy Tiemann, Rachel Vinsel, Kevin Cummings (Illinois Natural History Survey)
- Heidi Dunn, Emily Grossman (Ecological Specialists, Inc.)
- Dr. Paul Johnson, Jeff Garner, Michael Buntin, Todd Fobian, Ashley Peters (Alabama Department of Conservation and Natural Resources)
- Gerry Dinkins (University of Tennessee)
- Matt Johnson, Greg Zimmermann (EnviroScience, Inc.)
- Dr. Mike Compton, Ian Horn (Kentucky State Nature Preserves Commission)
- Chad Lewis, Clarissa Lawliss (Lewis Environmental Consulting)
- Nevin Welte (Pennsylvania Boat and Fish Commission)
- Amy Mahar, Nick Conrad (New York Natural Heritage Program)
- Darran Crabtree (New York Chapter, The Nature Conservancy)
- Debbie Wolschki (Ohio Natural Heritage Program)
- Janet Clayton (West Virginia Natural Resources)
- Brant Fisher (Indiana Department of Natural Resources)
- Dr. Monte McGregor, Adam Shepard, Keith Wethington (Kentucky Department of Fish and Wildlife Resources)
- Stuart McGregor (Geological Survey of Alabama)
- Don Hubbs, Jason Wisenwski (Tennessee Wildlife Resources Agency)
- Dr. Robert (Bob) Jones (retired) (Mississippi Museum of Natural Sciences)
- John Tetzloff (Darby Creek Watershed Association)
- Peter Badra, Rebecca Rogers (Michigan Natural Features Inventory)
- Scott Hanshue (Michigan Department of Natural Resources)

SUGGESTED CITATION: U.S. Fish and Wildlife Service (Service). 2019. Species Status Assessment Report for the Round Hickorynut Mussel (*Obovaria subrotunda*), Version 1.0. Asheville Ecological Services Field Office, Asheville, North Carolina.

TABLE OF CONTENTS

ACRONYMS USED THROUGHOUT THIS DOCUMENT AND APPENDICES

ADCNR	Alabama Department of Conservation and Natural Resources
AMD	acid mine and saline drainage
ANS	aquatic nuisance species
ANSP	Academy of Natural Sciences of Philadelphia
BMP	best management practices
CBD	Center for Biological Diversity
CM	Carnegie Museum of Natural History
COSSARO	Committee on the Status of Species at Risk in Ontario
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
Corps	U.S. Army Corps of Engineers
CWA	Clean Water Act
DNA	deoxyribonucleic acid
EKU	Eastern Kentucky University Collection
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ESI	Ecological Specialists, Inc.
FMNH	Florida Museum of Natural History
FR	Federal Register
GIS	geographic information system
HUC	Hydrologic unit codes
IDEM	Indiana Department of Environmental Management
INDNR	Indiana Department of Natural Resources
INHS	Illinois Natural History Survey
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
KDEP	Kentucky Department for Environmental Protection
KYCWCS	Kentucky Comprehensive Wildife Conservation Strategy
KYDOW	Kentucky Division of Water
KYFW	Kentucky Department of Fish and Wildlife Resources
KYSNPC	Kentucky State Nature Preserves Commission
LEC	Lewis Environmental Consulting
MU	Management Unit
NCMNS	North Carolina Museum of Natural Sciences
MCZ	Museum of Comparative Zoology
MFM	Museum of Fluviatile Mollusks
MMNS	Mississippi Museum of Natural Sciences
MNFI	Michigan Natural Features Inventory
MUMC	Marshall University Museum Collection
NHP	Natural Heritage Program
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
ODNR	Ohio Department of Natural Resources
OSUM	Ohio State University Museum
PPM	parts per million
PAFBC	Pennsylvania Fish and Boat Commission
RM	river mile
Service	U.S. Fish and Wildlife Service
SSA	Species Status Assessment
SWAP	State Wildlife Action Plan
TDEC	Tennessee Department of Environment and Conservation
TVA	Tennessee Valley Authority
TWRA	Tennessee Wildlife Resources Agency
UMMZ	University of Michigan Museum of Zoology
USDA	U.S. Department of Agriculture
USNM	U.S. National Museum
USGS	U.S. Geological Survey
UTMM	University of Tennessee McClung Museum
WVDEP	West Virginia Department of Environmental Protection
WVDNR	West Virginia Division of Natural Resources

EXECUTIVE SUMMARY

The Round Hickorynut *Obovaria subrotunda* (Rafinesque, 1820) is a small- to medium-sized mussel up to 3 inches (75 millimeters) in size, which lives up to 15 years. It is found in small streams to large rivers, and prefers a mixture of sand, gravel, and cobble substrates. The Round Hickorynut mussel is a wide-ranging species, historically known from 12 states, though now occurs in 9, as well as the Canadaian Province of Ontario. It is currently found in five major basins: Great Lakes, Ohio (where it is most prevalent), Cumberland, Tennessee, and Lower Mississippi (where it is most rare). The number of known populations in the U.S. has declined by 78 percent, from 297 populations documented historically to 65 today.

The Round Hickorynut and other aquatic species have endured negative influences commonly found in the central and eastern U.S., including: habitat fragmentation from dams and other barriers; habitat loss; degraded water quality from chemical contamination and erosion from poorly managed development, agriculture, mining, and timber operations; direct mortality from dredging and harvest; and the proliferation of invasive species, such as the Zebra Mussel. Projections 20 to 30 years into the future suggest the number of populations could remain at 65 across 5 basins or drop to as low as 19 across 3 basins, depending on the variety of considerations built into potential scenarios. It is likely that the Round Hickorynut could disappear entirely from the Cumberland and Lower Mississippi River basins given current and possible future conditions in the last remaining populations within those basins.

In projecting the future viability of the Round Hickorynut, three scenarios were considered: (1) current influences remain constant 20 to 30 years into the future; (2) negative influences decrease due to elevated levels of conservation efforts over 20 to 30 years; and (3) negative influences increase in magnitude/intensity over 20 to 30 years. Historical, current, and future population projections are summarized below in Table ES-1. Our analysis articulates the ability of the species to withstand catastrophic events (redundancy), its adaptive potential across the five basins where it is extant (representation), and the capability of the population to withstand stochastic disturbance (resiliency).

Table ES-1. Overall summary of historical, current, and future conditions for Round Hickorynut populations across its range in the U.S.

- **High**—Sizable populations generally distributed over a significant and more or less contiguous length of stream (greater than or equal to 30 river miles), with evidence of recent recruitment, and multiple age classes are represented. Water quality parameters predominantly meet designated uses and habitat conditions remain optimal for species detection. Connectivity among populations is maintained within MUs such that populations are not linearly distributed (i.e., occur in tributary streams within a management unit), or habitat is available for expansion. These populations are expected to persist in 20 to 30 years and withstand stochastic events. *(Thriving; increasing population trend; capable of expanding range.)*
- **Medium**—Small, generally restricted populations with limited levels of recent recruitment and characteristics of viability, and susceptible to extirpation within 20 to 30 years. Appropriate substrates are generally maintained with flow that mimics natural conditions. Water quality and habitat degradation may occur but not at a level that negatively affects both the density and extent of a population. Individuals possibly still occur in tributary streams, such that within a MU, populations are not linearly distributed. Resiliency is less than under high conditions, but the majority (approximately 75 percent) is expected to persist beyond 20 to 30 years;

however, loss of smaller tributary populations is possible. Populations are smaller and less dense than the high condition category. *(Stable, not necessarily thriving or expanding its range.)*

- **Low**—Very small and highly restricted populations, with little to no evidence of recent recruitment, and of questionable viability and detectability. These populations may be still observable in very low numbers compared to historical conditions, but may be on the verge of extirpation in the short-term future (if not already extirpated). Population sizes may be below detectable levels despite consistent survey efforts within formerly occupied range, or may only be represented by highly isolated, or older, non-recruiting individuals. Loss of mussel habitat or water quality degradation within the formerly occupied river/stream reach has been measured or observed. Populations are linearly distributed within a management unit and are not likely to withstand stochastic events. These populations have low resiliency and are the least likely to persist in 20 to 30 years. *(Surviving, still potentially observable; population likely declining.)*

(FUTURE CONDITION ONLY)

- **Very Low**—Populations are expected to no longer occur in a river/stream or management unit in the future (20 to 30 years). Contiguous mussel habitat has been lost and water quantity or quality limits colonization potential. Previous evidence of population limited to relic or weathered dead shells only. Populations are considered extirpated or functionally extirpated within 20 to 30 years. *(No survival or survival uncertain; no longer observable; functionally extirpated.)*

	Historical	Current	Future Scenario 1	Future Scenario 2	Future Scenario 3
GREAT LAKES BASIN					
# very low populations	--	--	4	0	5
# low populations	--	5	1	0	1
# medium populations	--	1	1	5	1
# high populations	--	1	1	2	0
# total populations	32	7	3	7	2
# Management units	20	4	1	4	1
# states	4[1]	2	2	2	1
OHIO RIVER BASIN					
# very low populations	--	--	16	0	35
# low populations	--	35	24	13	15
# medium populations	--	13	10	26	0
# high populations	--	2	0	11	0
# total populations[2]	196[2]	50	34	50	15

[1] Accounts for states where the species currently resides and those states from which the species is believed to be extirpated.

[2] Total values under the three future condition scenarios exclude the very low populations counts given these populations would likely no longer exist in the future

	Historical	Current	Future Scenario 1	Future Scenario 2	Future Scenario 3
# Management units	80[2]	23	16	22	10
# states	7[3]	5	4	5	4
CUMBERLAND RIVER BASIN					
# very low populations	--	0	2	0	2
# low populations	--	2	0	0	0
# medium populations	--	0	0	2	0
# high populations	--	0	0	0	0
# total populations[1]	25[2]	2	0	2	0
# Management units	12[2]	2	0	2	0
# states	2[2]	1	0	1	0
TENNESSEE RIVER BASIN					
# very low populations	--	--	0	0	3
# low populations	--	2	2	0	1
# medium populations	--	1	2	3	1
# high populations	--	1	0	2	0
# total populations[1]	34[2]	5	5	5	2
# Management units	18[2]	5	5	5	2
# states	4[2]	2	2	2	2
LOWER MISSISSIPPI RIVER BASIN					
# very low populations	--	--	1	0	1
# low populations	--	1	0	0	0
# medium populations	--	0	0	1	0
# high populations	--	0	0	0	0
# total populations[1]	10	1	0	1	0
# Management units	8	1	0	1	0

[3] Accounts for states where the species currently resides and those states that the species is believed to be extirpated.

	Historical	Current	Future Scenario 1	Future Scenario 2	Future Scenario 3
# states	2	1	0	1	0
TOTAL					
# very low populations	--	--	23	0	46
# low populations	--	45 (69%)	28 (67%)	13 (20%)	17 (90%)
# medium populations	--	16 (25%)	13 (31%)	37 (57%)	2 (10%)
# high populations	--	4 (6%)	1 (2%)	15 (23%)	0
# total populations[1]	297	65	42	65	19
# Management units	138	34	21	34	14
# states	12	9	7	9	6

This SSA Report for the Round Hickorynut includes:

(1) An Introduction, including taxonomy (Chapter 1);
(2) A description of the SSA Framework, including Resiliency, Redundancy, and Representation (Chapter 2);
(3) A description of Round Hickorynut's ecology (Chapter 3);
(4) The resource needs of the Round Hickorynut as examined at the individual, population, and rangewide scales (Chapter 4);
(5) Characterization of the historical and current distribution, abundance, and demographic conditions of the Round Hickorynut across its range (Chapter 5);
(6) An assessment of the current factors that negatively and positively influence the Round Hickorynut, and the degree to which the various factors influence its viability (Chapter 6);
(7) Descriptions of future scenarios, including an evaluation of those factors that may influence the species in the future and a synopsis of resiliency, redundancy, and representation given the potential future condition scenarios (Chapter 7); and
(8) An overall synthesis of this report (Chapter 8).

CHAPTER 1 - INTRODUCTION

1.1 Purpose of SSA

The Species Status Assessment (SSA) framework (Service 2016, entire) guides the development of an SSA report, which is an in-depth review of a species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The SSA report is easily updated as new information becomes available. As such, the SSA report is a living document that may inform decision making under the Endangered Species Act of 1973, as amended (ESA).

The SSA report is not a decisional document; rather, it provides a review of available information strictly related to the biological status of the Round Hickorynut mussel (also referred to herein as "the Round Hickorynut"). Any decisions regarding the legal classification of the Round Hickorynut are made after reviewing this document and all relevant laws, regulations, and policies, and the results of a proposed decision will be announced in the *Federal Register*, with appropriate opportunities for public input.

1.2 Species Basics - Taxonomy and Evolution

The Round Hickorynut (*Obovaria subrotunda*; Figure 1-1) is a freshwater mussel currently found in the Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi River major river basins, within the states of Alabama, Indiana, Kentucky, Michigan, Mississippi, Ohio, Pennsylvania, Tennessee, and West Virginia (Appendix A; Figures 1-2). It is considered extirpated from Georgia, Illinois, and New York. *Obovaria subrotunda* is part of a genus that includes seven mussel species, but only three are sympatric (overlapping distribution) with the Round Hickorynut (Williams *et al.* 2017, p. 51).

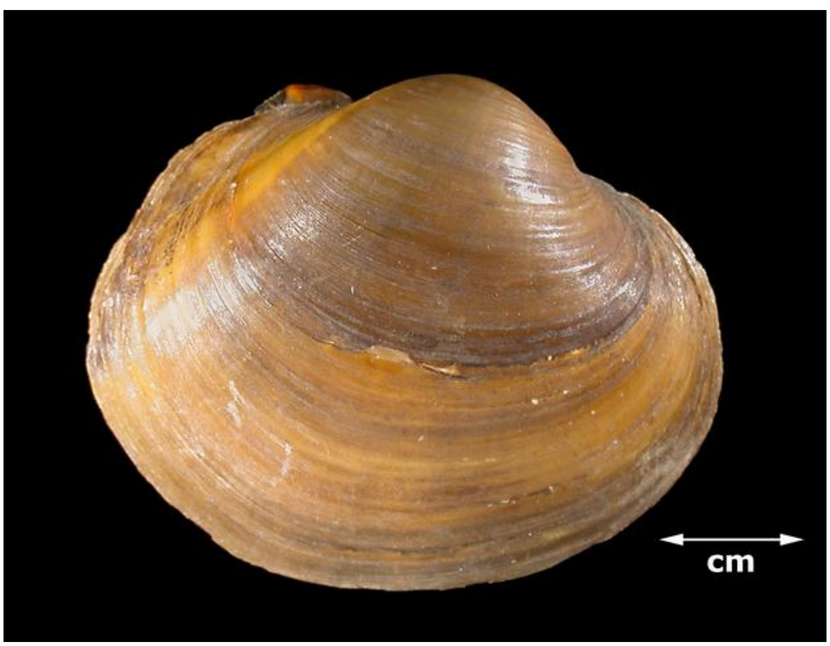

Figure 1-1. Round Hickorynut. Photo credit: Robert Warren, Illinois State Museum.

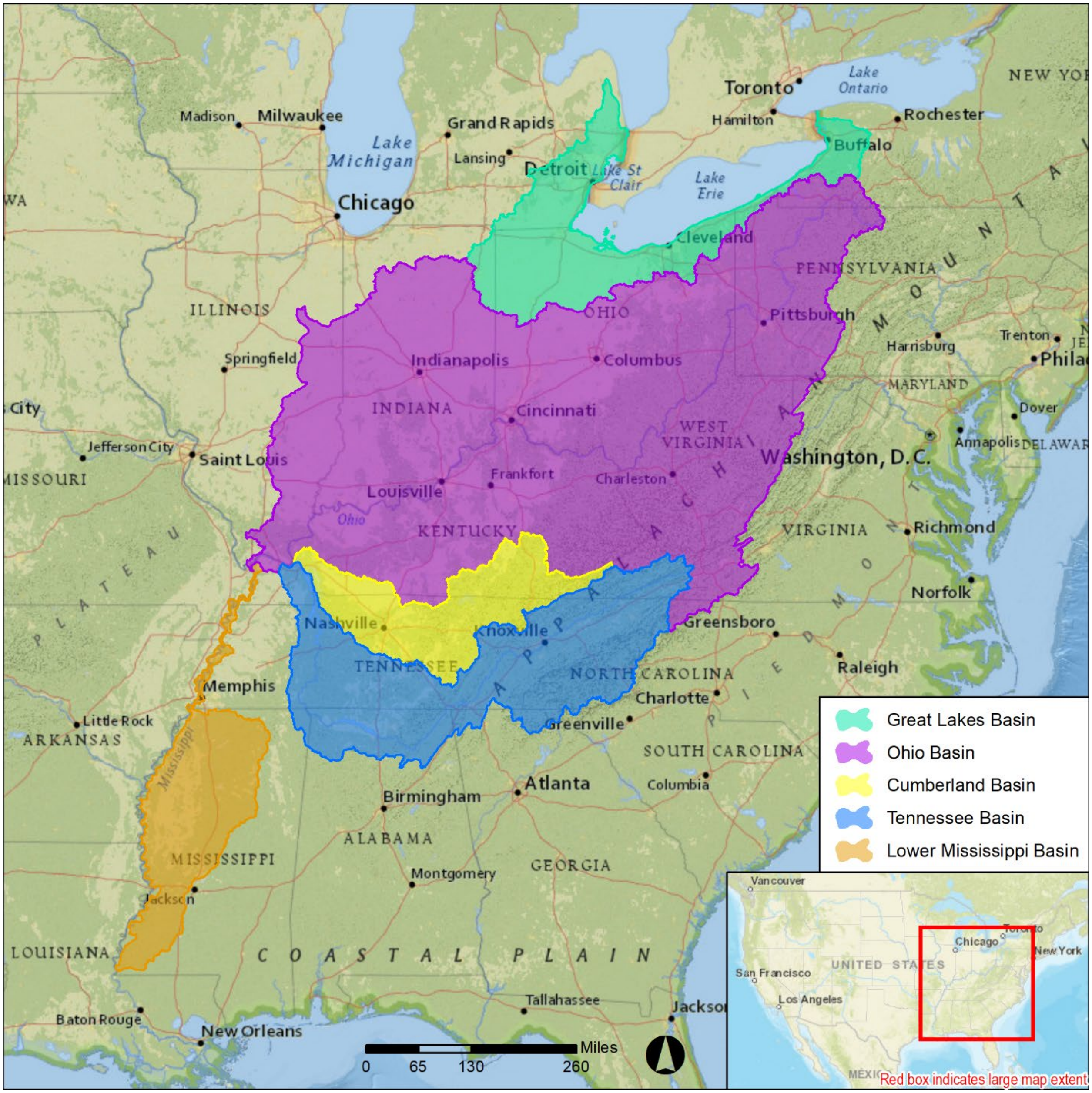

Figure 1-2. Round Hickorynut range map indicating the five major basins where it is considered extant: Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi basins. (Source: Service 2019a, unpublished data).

The five major basins that Round Hickorynut inhabits (i.e., extant) are the Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi (Figure 1-2, above). For this assessment, we used information about the mussel's historical range to partition Round Hickorynut into these five geographic units (basins). The Great Lakes basin includes portions of Michigan, Indiana, Ohio, Pennsylvania, and New York. The Ohio River basin drains portions of New York, Pennsylvania, Ohio, West Virginia, Virginia, Kentucky, Illinois, and Indiana. The Cumberland River basin drains portions of Kentucky and Tennessee. The Tennessee River basin drains portions of Alabama, Georgia, Kentucky, Mississippi, North Carolina, Tennessee, and Virginia.

The Lower Mississippi River basin includes portions of Mississippi, Tennessee, Arkansas, Missouri, and Kentucky.

The Great Lakes, Ohioan, Tennessee-Cumberland, and Mississippi Embayment (which includes the Lower Mississippi River basin) regions represent accepted patterns of faunal similarity in freshwater mussels (Haag 2009, p. 12). The Tennessee and Cumberland rivers drain into the Ohio River, and comprise the Cumberlandian Region (Ortmann 1924, p. 59). The Ohio River ultimately drains into the greater Mississippi River. Historically, the Cumberlandian Region supported the richest freshwater mussel (Bivalvia: Unionacea) fauna in the world (Johnson 1980, p. 79). Further, although the Tennessee and Cumberland River mussel faunas are very similar, the high levels of aquatic endemism in the Cumberland River basin and mussel species originating from that basin support its consideration separate from the Tennessee River basin (Gordon and Layzer 1989, p. 3; Haag and Cicerello 2016, p. 38).

1.2.1 Taxonomy

The Round Hickorynut mussel belongs to the family Unionidae, also known as the naiads or pearly mussels. This group of bivalves has existed for over 400 million years (Howells *et al.* 1996, p. 1), representing over 600 species worldwide and over 250 species in North America (Strayer *et al.* 2004, p. 429; Lopes-Lima *et al.* 2018, p. 3). This Round Hickorynut SSA report follows the most recently published and accepted taxonomic treatment of North American freshwater mussel as provided by Williams *et al.* (2017, entire).

The Round Hickorynut, *Obovaria subrotunda* (Rafinesque, 1820), was originally described under in the genus *Obliquaria* (and later moved to *Obovaria*) and subgenus *Rotundaria* (which is no longer recognized). Vanatta (1915, p. 552) identified the type collection at the Academy of Natural Sciences of Philadelphia, [ANSP] 20254, as having been part of the Rafinesque collection, and Johnson and Baker (1973, p. 171) designated that shell the neotype. The neotype is from the Kentucky River, Kentucky, which makes that the type locality.

The currently accepted classification is:

- Phylum: Mollusca
- Class: Bivalvia
- Order: Unionoida
- Family: Unionidae
- Subfamily: Lampsilinae
- Tribe: Lampsilini
- Genus: *Obovaria*
- Species: *subrotunda*

The synonymy for *Obovaria subrotunda* is extensive, possibly due to the species' display of clinal variation, ranging from a smaller 'compressed headwater form' to a more 'inflated big river' form. The Round Hickorynut is an example of a mussel used to describe this law of stream position (Ortmann 1920, p. 272). Additionally, other species (i.e., *O. circulus, O. leibii*), and subspecies (i.e., *O. s. lens*), have been referred to in the literature. However, *O. subrotunda* is currently the nomenclature collectively referring to all of these forms.

1.3 Petition History

We, the U.S. Fish and Wildlife Service (Service), were petitioned by the Center for Biological Diversity (CBD), Alabama Rivers Alliance, Clinch Coalition, Dogwood Alliance, Gulf Restoration Network, Tennessee Forests Council, West Virginia Highlands Conservancy, Tierra Curry, and Noah Greenwald to list the Round Hickorynut as an endangered or threatened species under the ESA. This request was part of a 2010 petition to list 404 aquatic, riparian, and wetland species in the southeastern United States (CBD 2010, pp. 768–771). On September 27, 2011, we found that the petition presented substantial scientific or commercial information indicating that listing the Round Hickorynut may be warranted (76 FR 59836–59862); substantial findings were made for the other species in this same *Federal Register* notice, although analyses and findings for those other species are addressed separately.

1.4 State Listing Status

Of the states where Round Hickorynut is known to historically or currently occur, it is state protected by statute as endangered only in Pennsylvania. The states of Indiana, Michigan, Ohio, and West Virginia have blanket protective regulatory measures for all native freshwater mussels prohibiting take or possession without a scientific collector's permit. These regulations are associated with wildlife management agency mandates and authorities vested in their respective state governments. A variety of additional designations or status descriptions are assigned to the Round Hickorynut within other states, making it unlawful for anyone to take, possess, transport, export, process, sell or offer for sale or ship, and for any contract carrier to knowingly transport or receive for shipment. However, these designations are typically accompanied by wildlife management agency mandates and are not state statutory protections (Table 1-1).

Table 1-1. State and NatureServe conservation status of Round Hickorynut mussel throughout its historical range.

State Status	AL	IL	IN	KY	MI	MS	OH	PA	TN	WV	NY	GA	Canada
State Rank (Wildlife Action Plans) 2015	P1	NR	S1 (E)	S4 (↓ Trend)	S1 (E)	NR	NR (↓ Trend)	S1 (E)	S2S3	P1	NR	NR	E
NatureServe (as of 2010)	S2	SX	S1	S4	S1	S2	S4	S1	S2S3	S3	SH	SH	S1

KEY: P1 = highest conservation concern; NR = not ranked; E = endangered; SX = Presumed Extirpated; SH = Possibly Extirpated; S1 = Critically Imperiled; S2 = Imperiled; S3 = Vulnerable; S2S3 = Imperiled, rare within state; S4 = Apparently Secure.

The states of Alabama, Tennessee, and Kentucky all have mussel harvest sanctuaries, or designated reaches of rivers where it is unlawful to take, catch, or kill freshwater mussels, and the degradation of aquatic habitat is prohibited. These sanctuaries provide some indirect protection to the Round Hickorynut in these states, but since commercial harvest is no longer considered a primary threat to the species, in part due to its rarity, the actual protection afforded is limited without considerable enforcement effort and trained regulatory personnel.

The Round Hickorynut is listed as endangered in Canada, protected by Canadian law, and occurs only in the Ontario Province. Canadian populations have declined by 75 to 95 percent over the last 10 years, with an estimated 92 percent decline over the last 30 years and 99 percent decline overall (Committee on the Status of Species at Risk in Ontario 2013, p. 4). The Canadian government considers Round Hickorynut to be facing imminent extirpation in Canada, prompting action to list it in 2005 as an endangered species (*http://dfo-mpo.gc.ca/species-especes/profiles-profils/hickorynut-obovarie-eng.html*).

Within Ontario, the Round Hickorynut is currently found only in Lake St. Clair and the East Sydenham River, the latter of which drains into Lake St. Clair (Figure 1-3). These populations have displayed no evidence of recruitment or reproduction in the last decade (Morris 2018, pers. comm.). Under any analyses, when considered in isolation from North American populations, those in Canada have low resiliency, redundancy, and representation, and are under substantive threats, and therefore are at risk of extirpation (Committee on the Status of Species at Risk in Ontario 2013, p. 4).

However, since the Round Hickorynut was petitioned to be listed in the United States under the Endangered Species Act (see section 1.3, above), populations in Canada were not included in our analyses for this assessment. In order to evaluate the global status of the species and use the best available science for ESA listing determination, Canadian populations are listed in the appendices, and life history and demographic studies conducted on populations within Canada are referenced throughout Chapter 4. For a detailed discussion on the basis for status and recovery strategies being implemented for the species in Canada, see Fisheries and Oceans Canada (2013) and COSEWIC [Committee on the Status of Endangered Wildlife in Canada] (2003).

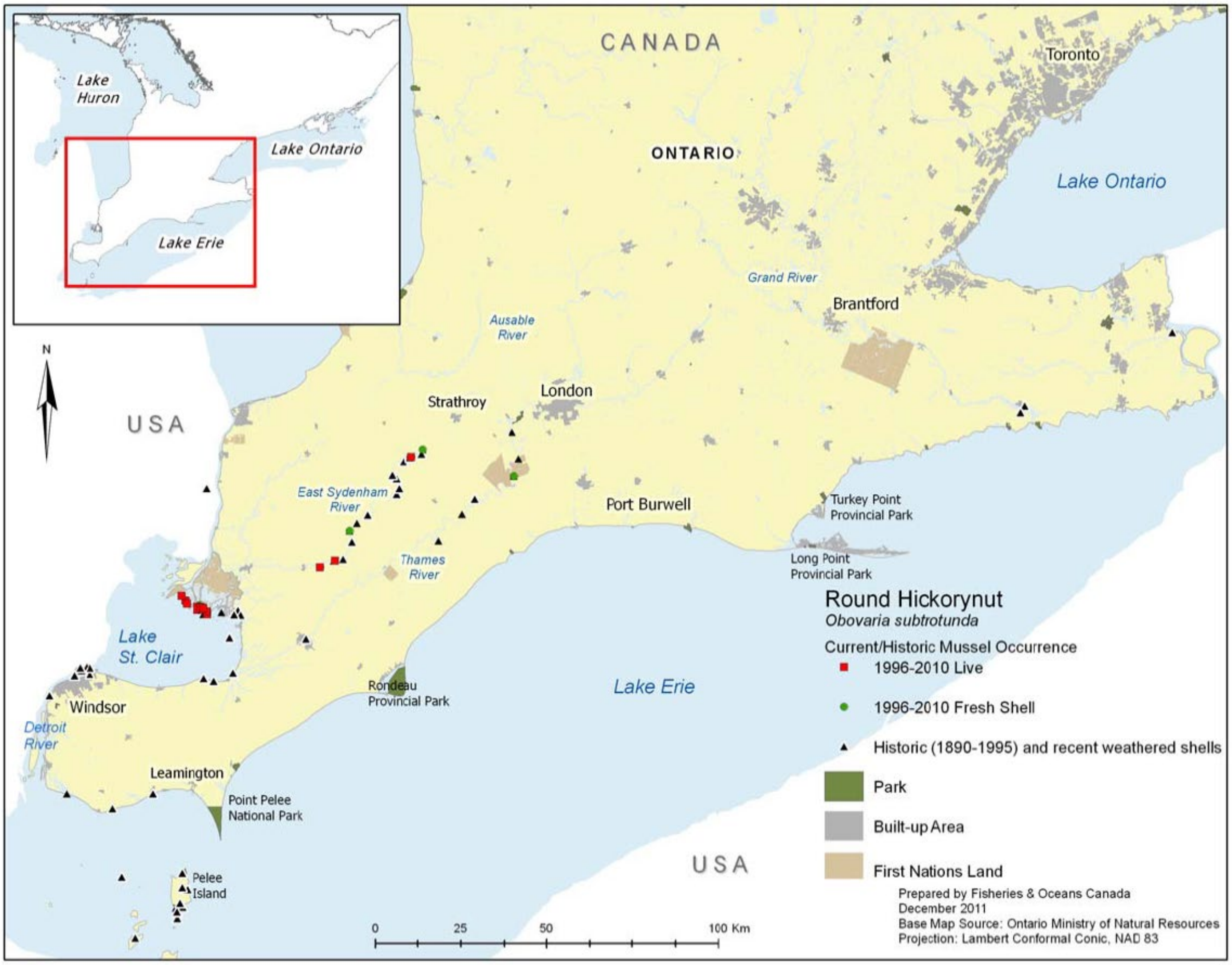

Figure 1-3. Distribution of the Round Hickorynut in Canada (From: Fisheries and Oceans Canada 2013, p. 5).

CHAPTER 2 - METHODOLOGY AND DATA

2.1 SSA Framework

This report is a summary of the SSA analysis, which entails three iterative assessment stages: species (resource) needs, current species condition, and future species condition (Figure 2-1).

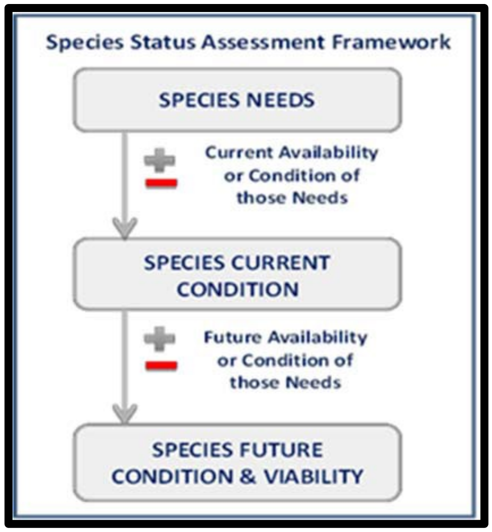

Figure 2-1. The three analysis steps in a Species Status Assessment (Service 2016, entire).

2.1.1 Species Needs

The SSA includes a compilation of the best available biological information on the species and its ecological needs at the individual, population, and rangewide levels based on how environmental factors are understood to act on the species and its habitat.

- Individual level: These resource needs are those life history characteristics that influence the successful completion of each life stage. In other words, these are survival and reproduction needs that make the species sensitive or resilient to particular natural or anthropogenic influences.

- Population level: These components of the Round Hickorynut's life history profile describe the resources, circumstances, and demographics that most influence **resiliency** of the populations.

- Rangewide level: This is an exploration of what influences **redundancy** and **representation** for the Round Hickorynut. This requires an examination of the mussel's evolutionary history and historical distribution to understand how the species functions across its range.

To assess the biological status of the Round Hickorynut across its range, we used the best available information, including peer-reviewed scientific literature and academic reports, and survey data provided by state and Federal agencies, as well as non-governmental organizations. Additionally, we consulted with several species experts who provided important information and comments on Round Hickorynut distribution, life history, and habitat.

We researched and evaluated the best available scientific and commercial information on the Round Hickorynut's life history. To identify population-level needs, we used published literature, unpublished reports, information from partners, consultants, and data from current agency survey and taxonomic research projects. Host fish identification, population demographics, as well as age and growth information is available from life history studies conducted on the species. Information on Round Hickorynut reproduction was published as part of comprehensive studies of regional mussel faunas in the early 1900s (Ortmann 1909a; 1913; 1919; 1921). Glochidia of the Round Hickorynut were described as early as 1915 by Surber (1915, p. 7) and illustrated with measurements in Hoggarth (1999, p. 73).

2.1.2 Current Species Condition

The SSA describes the current known condition of the Round Hickorynut's habitat and demographics, and the probable explanations for past and ongoing changes in abundance and distribution within areas representative of the geographic, genetic, or life history variation across the species range.

We considered the Round Hickorynut's distribution, abundance, and factors currently influencing the viability of the species. We identified known historical and current distribution and abundance, and examined factors that negatively and positively influence the species. Scale, intensity, and duration of threats were considered for their impacts on the populations and habitat across life history stages. The magnitude and scale of potential impacts to the Round Hickorynut or its habitat by a given threat are described using a High/Moderate/Low category scale.

How Populations Were Evaluated For Current Conditions

For the current condition analyses, the Round Hickorynut was considered extant if a live individual or fresh dead specimen was collected since 2000[4], or collections of the species have been made since 1990 with no available negative mussel survey data from the stream to dispute that the species still occurs there. Given the timing and frequency of mussel surveys conducted throughout the species range, collections or observations of live individuals or fresh dead specimens since 2000 likely indicate the continued presence of a species within a river or stream (Stodola *et al.* 2014, p. 1).

The Round Hickorynut is not generally considered a dominant component of mussel assemblages in rivers and streams that it is known to occur (Watters *et al.* 2009, p. 211; Haag and Cicerello 2016, p. 179). For large water bodies such as the Ohio River, or for streams that have not received consistent survey effort, it is difficult to determine whether a lack of occurrence since 1990 relative to pre-1990 reflects a lack of sampling or a decline in abundance or distribution (Haag and Cicerello 2016, pp. 65–66).

Presumed extirpation was determined by documentation in literature, reports, or from communications with state malacologists and aquatic biologists. General reference texts on regional freshwater mussel fauna, such as Gordon and Layzer (1989), Cummings and Mayer (1992), Strayer and Jirka (1997), Parmalee and Bogan (1998), Williams *et al.* (2008), Watters *et*

[4] We used the year 2000 in this analysis for consistency, due to the potential for incomplete survey detection, highly variable recent survey information across the range of the Round Hickorynut, and available state heritage databases and information support for the likelihood of the species continued presence within this timeframe.

al. (2009), and Haag and Cicerello (2016) provided substantial information on species status and distribution, both past and present.

There is no systematic sampling regime to monitor the Round Hickorynut's distribution and status across its range. We gathered information from a large body of published and unpublished survey work rangewide since the late 1800s and early 1900s. More recent published and unpublished distribution and status information was provided by biologists from State Natural Heritage Programs (NHP), natural resource programs, other state and Federal agencies, or academia. Museum collections are a valuable source of information on the past and present range of mussel species, and extensive documentation of collection records from major museum collections of the Round Hickorynut are presented in Appendix B.

All information was compiled into a Microsoft Excel spreadsheet for reference and current and future condition analysis. Occurrence data were grouped by named stream and state, then organized by 8-digit hydrologic unit code watershed (HUC 8)[5]. All records were also added to a Geographic Information System (GIS) database to facilitate spatial analyses. Additional detail on the current condition analysis methodology is presented in Chapter 5. The compilation of distributional information herein indicates a reduction in the range of the Round Hickorynut, and an accelerated loss of resiliency since the 1960s, resulting in the extirpation of 232 populations. Long-term collection histories (e.g., Ohio State University Museum [OSUM] collection records in the Scioto River system, Ohio Basin) depict this downward trend and indicate approximate time spans when the Round Hickorynut became extirpated.

The Round Hickorynut is especially vulnerable to extirpation from the Cumberland basin, where only two populations remain in the upper portion of the basin, and the Lower Mississippi basin, where only one severely isolated population remains. The state of West Virginia currently contains 25 populations of the Round Hickorynut, comparatively more than any other state, but there are numerous threats affecting these populations (Appendix D).

Defining Management Units

The smallest measure of the Round Hickorynut occurrence is at the river or stream reach, which varies in length and width. Occasional or regular interaction among individuals in different reaches not interrupted by a barrier likely occurs, but in general, interaction is strongly influenced by distance between occupied river or stream reaches, and habitat fragmentation. Once released from their fish host, freshwater mussels are benthic, generally sedentary aquatic organisms and closely associated with appropriate habitat patches within a river or stream (Strayer 2008, p. 48). In situations where Round Hickorynut populations are close in proximity

---

[5] Hydrologic unit codes (HUC) are two to twelve-digit codes based on the four levels of classification in a hydrologic unit system, as described in Seaber *et al.* (1987) and United States Geological Survey (USGS) (2018). In summary, the United States is divided into successively smaller hydrologic units arranged or nested within each other. Each successively smaller hydrologic unit/code contains successively smaller drainage areas, river reaches, tributaries, etc. HUC 8 is the fourth-level (cataloguing unit) that maps the subbasin level, which is analogous to medium-sized river basins across the United States.

with little or no fragmentation, multiple river or stream reaches may constitute a single metapopulation. Examples include multiple tributaries to the Little Kanawha River, West Virginia, and Big Darby and Big Walnut Creek, tributaries to Walnut Creek in Ohio. Available data were organized by named river or stream that was subsequently used as the unit to delineate an individual population. In this context, "river or stream" and "population" are used synonymously herein.

Management units were defined as a HUC 8, which were identified as most appropriate for assessing population-level resiliency, and are used for illustrative purposes in Chapter 5. Range-wide species occurrence data were used to create maps indicating the historical and current distribution of Round Hickorynut among 34 Management Units (MUs) for each of 65 populations currently known to be extant (Appendix C). The HUC 8 MU approach has been used for other wide-ranging aquatic species for the purposes of an SSA (e.g., the Longsolid mussel (*Fusconaia subrotunda*), Service 2018b, entire; the Eastern Hellbender (*Cryptobranchus alleganiensis*) (Service 2018c, entire)).

2.1.3 Future Species Condition

The SSA forecasts a species' response to probable future scenarios of environmental conditions and conservation efforts. As a result, the SSA characterizes the species' ability to sustain populations in the wild over time (viability) based on the best scientific understanding of current and future abundance and distribution within the species habitat.

To examine the potential future condition of the Round Hickorynut, we developed three future scenarios that focus on a range of conditions based on projections for habitat degradation or loss, invasive or nonnative species, harvest and overutilization, and genetic isolation and displacement; beneficial conservation actions and public lands were also considered. The range of what may happen in each scenario is described based on the current condition and how resilience, representation, and redundancy may change. We chose a time frame of 20 to 30 years for our analysis based on the availability of trend information, planning documents, and climate modeling that helps inform future conditions. This time frame should capture at least two generations of this species, which lives on average 12–13 years (Shepard 2006, p. 7; Ehlo and Layzer 2014, p. 11). The scenarios considered the most probable threats with the potential to influence the species at the population or rangewide scales, including potential cumulative impacts if applicable.

For this assessment, we define viability as the ability of the Round Hickorynut to sustain resilient populations in the wild over time. Adaptive potential and population genomic data are lacking for the Round Hickorynut, but given the documented maximum age (16 years) and age-at-maturity (1–3 years), we can make estimates of the predicted response to known environmental stressors within timeframes relevant to extinction risk for the species (Funk *et al*. 2018, p. 117). Using the SSA framework (Figure 2-1, above), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Wolf *et al.* 2015, entire; Service 2016, entire).

- ***Resiliency*** is assessed at the level of populations and reflects a species' ability to withstand stochastic events (events arising from random factors). Demographic measures that reflect population health, such as fecundity, survival, and population size, are the metrics used to evaluate resiliency. Resilient populations are better able to withstand disturbances such as random fluctuations in reproductive rates and fecundity (demographic stochasticity), variations in rainfall (environmental stochasticity), and the effects of anthropogenic activities.

- ***Representation*** is assessed at the species level and characterizes the ability of a species to adapt to changing environmental conditions. Metrics that speak to a species' adaptive potential, such as genetic and ecological variability, can be used to assess representation. Representation is directly correlated to a species' ability to adapt to changes (natural or human-caused) in its environment.

- ***Redundancy*** is also assessed at the species level and reflects a species' ability to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk of such an event across multiple, resilient populations. As such, redundancy can be measured by the number and distribution of resilient populations across the range of the species.

To evaluate the current and future viability of the Round Hickorynut, we assessed a range of conditions to characterize the species' resiliency, representation, and redundancy.

CHAPTER 3 - SPECIES BACKGROUND AND ECOLOGY

3.1 Physical Description

Mollusks are mostly aquatic and are named from the Latin *molluscus*, meaning "soft." Their soft bodies are often enclosed in a hard shell made of calcium carbonate ($CaCO_3$), which functions as an exoskeleton. This shell is secreted by a thin sheet of tissue called the mantle, which encloses the internal organs (Figure 3-1). The shell morphologies of freshwater bivalves are highly variable, provide a record of growth as well as other life events, and influence how the mussel interacts with its environment (Haag 2012, p. 8).

Round Hickorynut adult mussels are greenish-olive to dark or chestnut brown, sometimes blackish in older individuals, and may have a yellowish band dorsally (Parmalee and Bogan 1998, p. 168). There is variability in the inflation of the shell depending on population and latitudinal location (Ortmann 1920, p. 272; Williams *et al.* 2008, p. 474). The shell is thick, solid, and up to 3 inches (in) (75 millimeters (mm) in length, but usually is less than 2.4 in. (60 mm) (Williams *et al.* 2008, p. 473; Watters *et al.* 2009, p. 209). A distinctive characteristic is that the shell is round in shape, nearly circular, and the umbo (the raised portion of the dorsal margin of a shell), is centrally located (Figure 1-1).

The umbo cavity is moderately deep and wide, with a typically silvery white nacre (the lustrous interior layer of the shell) (Watters *et al.* 2009, p. 209). The maximum shell width is 1.6 in (40 mm) (Zanatta 2000, p. 130). The foot can be pale tan to pale pinkish orange (Williams *et al.*

2008, p. 473). The species is sexually dimorphic, with character traits visible to differentiate individuals within 1–5 years, and males average slightly longer maximum ages (up to 16 years) (Shepard 2006, p. 7; Watters *et al.* 2009, p. 211; Ehlo and Layzer 2014, p. 11). Differences in shells are not pronounced, but in females the posterior margin of the shell is truncated, and females are generally smaller than males (Ortmann 1920, p. 307; Ehlo and Layzer 2014, p. 1).

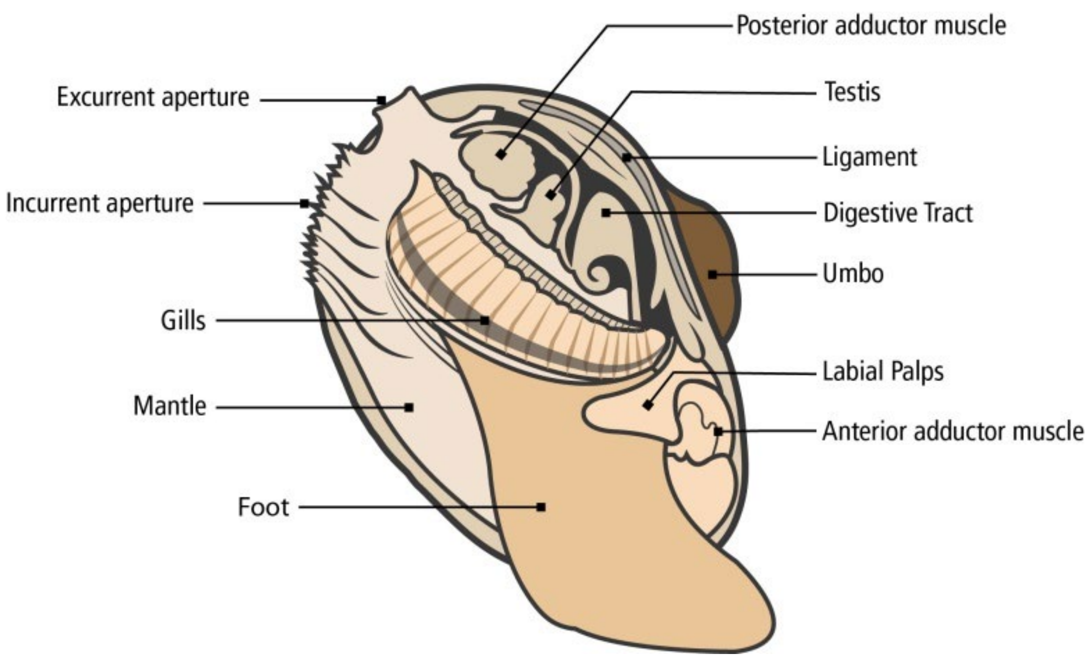

Figure 3-1. Generalized internal anatomy of a freshwater mussel. (Image courtesy of Matthew Patterson, Service).

3.2 Genetics

To our knowledge, there are no comprehensive studies that thoroughly address intraspecific divergence in genetic diversity across the range of the Round Hickorynut. There is some taxonomic uncertainty regarding the Lower Mississippi River basin population; it may represent a disjunct population, or the closely related *Obovaria arkansensis,* or an undescribed species (Inoue *et al.* 2013, p. 2,670; Haag and Cicerello 2016, p. 178). The remaining population in the Lower Mississippi River basin in the Big Black River, Mississippi, is isolated from populations in other basins (Figure 5-1). Recent examination of archeological material indicates the Round Hickorynut formerly had a much more widespread distribution and was abundant within the Big Black River and the Lower Mississippi basin (Peacock and James 2002, p. 123; Mitchell and Peacock 2014, p. 629; Peacock *et al*. 2016, p. 125).

Mitochondrial genes COI and ND1 indicate that the genus *Obovaria* forms a well-supported clade with *Epioblasma* and *Venustaconcha;* however, their lure morphologies differ, leading to the conclusion that the lure used to attract a host fish may have been secondarily lost in *Obovaria* (Zanatta and Murphy 2006, pp. 198, 206). The synonymy of the Round Hickorynut is extensive due to the species' display of clinal variation with a smaller 'compressed headwater form' and ‘inflated big river’ form, to which taxonomists and malacologists often refer. This ecophenotypic variation is well documented in the species (Ortmann 1920, p. 272). Additionally, several subspecies and varieties are referred to in the literature; however, these are typically based on identification of this species based on morphological characters alone. Support for recognition of all forms of the Round Hickorynut as a singular species is maintained (Williams *et al.* 2017, p. 41).

3.3 Life History

The Round Hickorynut has been the subject of two recent life history studies: one on a population in the Duck River, Tennessee, and another on a population in Buck Creek, Kentucky (Shepard 2006, entire; Ehlo and Layzer 2014, entire). These studies provide valuable information on age, growth rates, sex ratios, population demographics, and fecundity of the species in these populations within two basins (Tennessee and Cumberland, respectively), and were the primary references for this and following sections of this report. Additionally, descriptive information on Round Hickorynut glochidia from the Great Lakes and Ohio basins can be found in Ortmann (1911), Surber (1915), Hoggarth (1999), and Watters *et al.* (2009) (Table 3-1). Both Williams *et al.* (2008) and Watters *et al.* (2009) contain summarized life history information from Tennessee, Great Lakes, and Ohio River basin populations as well.

Sex ratios and length-frequency distribution calculations (Figure 3-2) were determined from examining 165 individuals (74 males, 75 females, and 16 juveniles) from the Duck River, Tennessee (Ehlo and Layzer 2014, pp. 6–7). The overall sex ratio was not significantly different from 1:1. A length-frequency distribution showed that 90 percent of females were between 0.8 and 1.2 in (20 and 31 mm) long. Based on the length-age relationship calculated using the von Bertalanffy growth equation, these females were 1 to 5 years old. Seventy percent of males were between 0.9 and 1.5 in (22 and 39 mm) long and 1 to 5 years old. Juveniles (greater than 1-year old) accounted for 10 percent of all *O. subrotunda* examined. Males grow faster and attain a greater average size than females (Figure 3-2a).

Round Hickorynut reached sexual maturity (i.e., change in shell growth) in 3 to 5 years, with males living up to 16 years and females up to 13 years in Buck Creek, Kentucky, within the Cumberland basin (Shepard 2006, p. 16; Figure 3-2b). In comparison, the species reached sexual maturity at 1 year in the Duck River, Tennessee, and maximum age was 14 for males and 13 for females ([n = 100 individuals] Ehlo and Layzer 2014, p. 8; Figure 3-2c). Additional information from the Ohio and Great Lakes basins indicate “few individuals live longer than 12 years” (Watters *et al*. 2009, pp. 210–211). Overall, longevity and age-at-maturity data from 4 of the 5 basins (Great Lakes, Ohio, Cumberland, and Tennessee) where the species occurs suggests the maximum life span of Round Hickorynut is between 10 and 16 years (avg. 12 to 13), and the species reaches sexual maturity between 1 to 5 years (avg. 2 to 3).

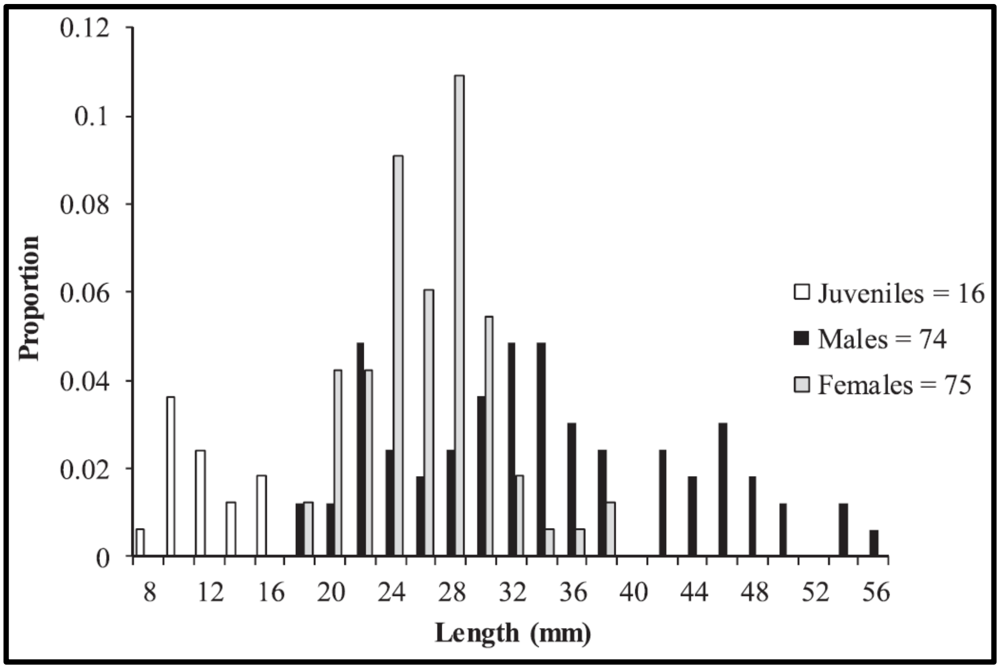

Figure 3-2a. Length frequency distributions for male, female, and juvenile *Obovaria subrotunda* collected from the Duck River, Tennessee. (From Ehlo and Layzer 2014, p. 10).

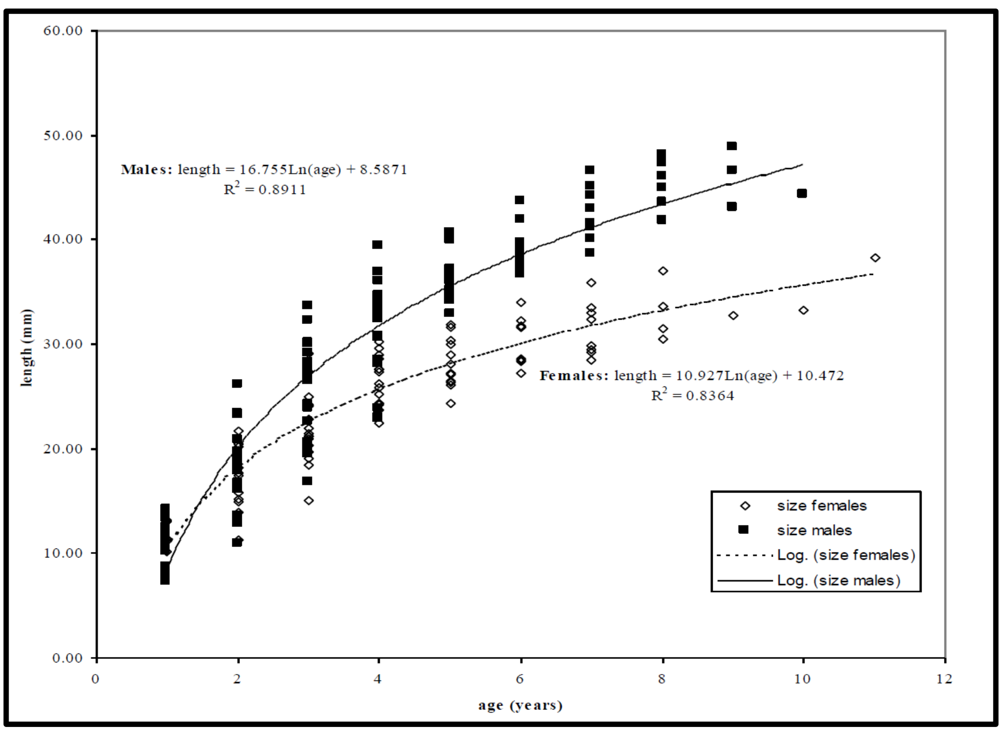

Figure 3-2b. Length (mm) at age regressions for male and female *Obovaria subrotunda* determined from external annuli from Buck Creek, Kentucky (From Shepard 2006, p. 18.).

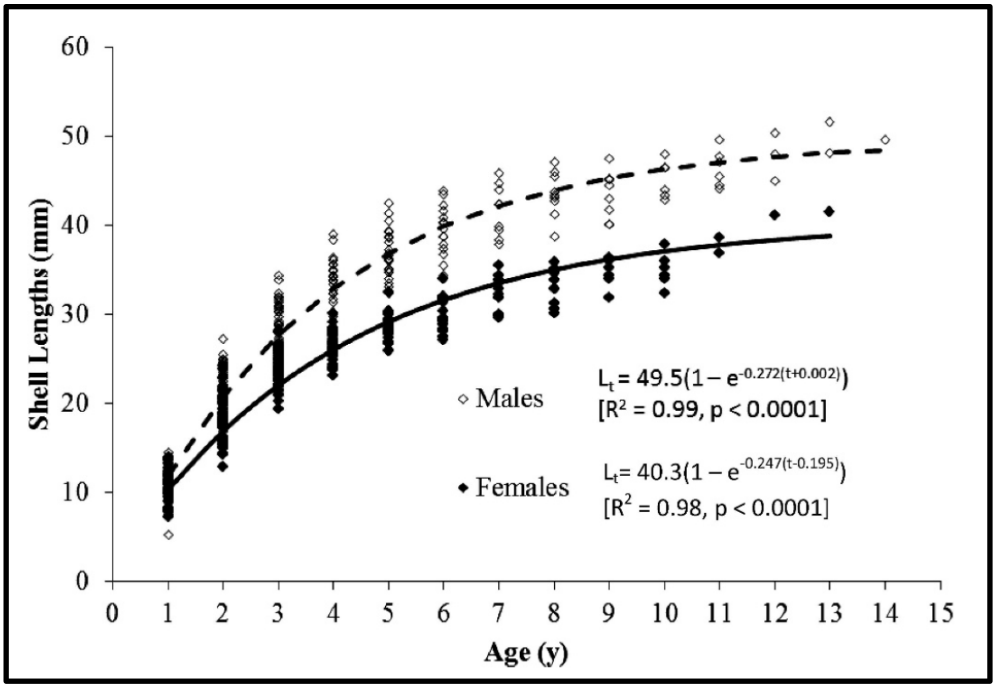

Figure 3-2c. Estimated von Bertalanffy growth curves for male and female shells collected and thin-sectioned from the Duck River, Tennessee (From Ehlo and Layzer 2014, p. 8).

The expected general growth rate for Round Hickorynut averages 0.02–0.03 in (0.56–0.86 mm) per year, similar to growth rates of other freshwater Lampsiline mussels (Haag and Rypel 2011, p. 248). However, variation in mussel growth and longevity is likely related to site-specific factors and response to changes in environmental conditions, such as water quality and habitat conditions present at a given location (Haag and Rypel 2011, p. 243). Specimens from Lake Erie and Lake St. Clair in Canada appear to attain much smaller maximum sizes than more southerly populations (COSEWIC 2003, p. 13). As expected, the growth rate slows as individuals age. Depending on water quality and other environmental conditions, negative growth is possible, or could even be expected as the individuals age and the shell erodes.

A variety of river and stream habitat conditions are necessary for the species. The Round Hickorynut exhibits a preference for sand and gravel in riffle, run, and pool habitats in streams and rivers, but also may be found in sandy mud (Watters *et al.* 2009, p. 211). They can be found in shallow habitats with gentle flows at less than 1 foot (ft) (30 centimeters (cm)) with abundant American water-willow (*Justicia americana*) (Henderson 2015, pers. obs.), but in larger rivers are commonly found up to depths of 6.5 ft (2 meters (m)) (Gordon and Layzer 1989, p. 28).

The Round Hickorynut and other adult freshwater mussels within the genus *Obovaria* are suspension-feeders that consume nutrients filtered from the water to feed. Mussels may shift to deposit feeding, though reasons for this are not well understood at this time, but may depend on flow conditions or temperature. Ciliary tracks on the adult foot apparently facilitate this feeding behavior. Their diet consists of a mixture of algae, bacteria, detritus, and microscopic animals (Gatenby *et al.* 1996, p. 606; Strayer *et al.* 2004, p. 430).

Available information suggests that dissolved organic matter may be significant source of nutrition for mussels (Strayer *et al.* 2004, p. 431). Such an array of foods, containing essential long-chain fatty acids, sterols, amino acids, and/or other biochemical compounds, may be necessary to supply total nutritional needs (Strayer *et al.* 2004, p. 431). For their first several months, juvenile mussels likely use their foot to contact food particles and send them to their mouth via cilia, and are thus deposit feeders, although they may also filter interstitial pore water and soft sediments (Yeager *et al.* 1994, p. 221; Haag 2012, p. 26). Additionally, recent evidence emphasizes the importance to riverine mussels of the uptake and assimilation of detritus and bacteria over that of algae (Nichols and Garling 2000, p. 881). Due to the mechanism by which food and nutrients are taken in, freshwater mussels collect and absorb toxins and contaminants (see section 6.1.3, below).

3.4 Reproduction

The Round Hickorynut has a complex life cycle (see Figure 3-3) that relies on fish hosts for successful reproduction, similar to other mussels. In general, mussels are either male or female (Haag 2012, p. 54). Males release sperm into the water column, which is taken in by the female through the incurrent aperture, where water enters the mantle cavity. The sperm fertilize eggs in the suprabranchial chamber (located above the gills) as ova are passed from the gonad to the marsupia (Yokely 1972, p. 357). The developing larvae remain in the gill chamber until they mature (called glochidia) and are ready for release.

The Round Hickorynut is a long-term brooder, gravid year-round in some southern populations in the Tennessee River basin, but with gravid period potentially more contracted in the northernmost portions of its range. For example, in the Great Lakes basin, the species has been found gravid from September through the following June (Clarke 1981, p. 326; Gordon and Layzer 1989, p. 51). An orange-brown coloration has been observed on the outer edge of the mantle during gravidity, which appears slightly lamellar and crenulated in the Round Hickorynut (Ortmann 1911, p. 315; Shepard 2006, p. 15). Age and size affect fecundity, and while length is positively related to fecundity in other mussels, overall size (shell length, width, and height), is important for this relatively small species (Haag and Staton 2003, p. 2,118; Ehlo and Layzer 2014, p. 11). Localized habitat and environmental conditions are also a factor in fecundity of individuals (Moles and Layzer 2008, p. 220).

The number of glochidia extracted from one female Round Hickorynut used during fish/host infestation trials was approximately 5,725 from Buck Creek in the Cumberland River basin (Shepard 2006, p. 15). Mean fecundity was estimated as 5,366 +/- 1,843 per female, as reported from three females examined in Lake St. Clair, Canada. Juveniles reached metamorphosis and dropped off host fishes within 4 to 40 days (McNichols 2007, p. 51). Fecundity did not vary in left versus right gills, and mean fecundity estimates were much higher in the Tennessee River basin: 36,101 and ranged from 7,122 to 76,584 (n = 30; Duck River; Ehlo and Layzer 2014, p. 171). Only a few glochidia reach the free-living juvenile stage, and mortality rates for the glochidial stage have been estimated at 99 percent, making this a critical phase in the life history of freshwater mussels (Jansen *et al.* 2001, p. 211).

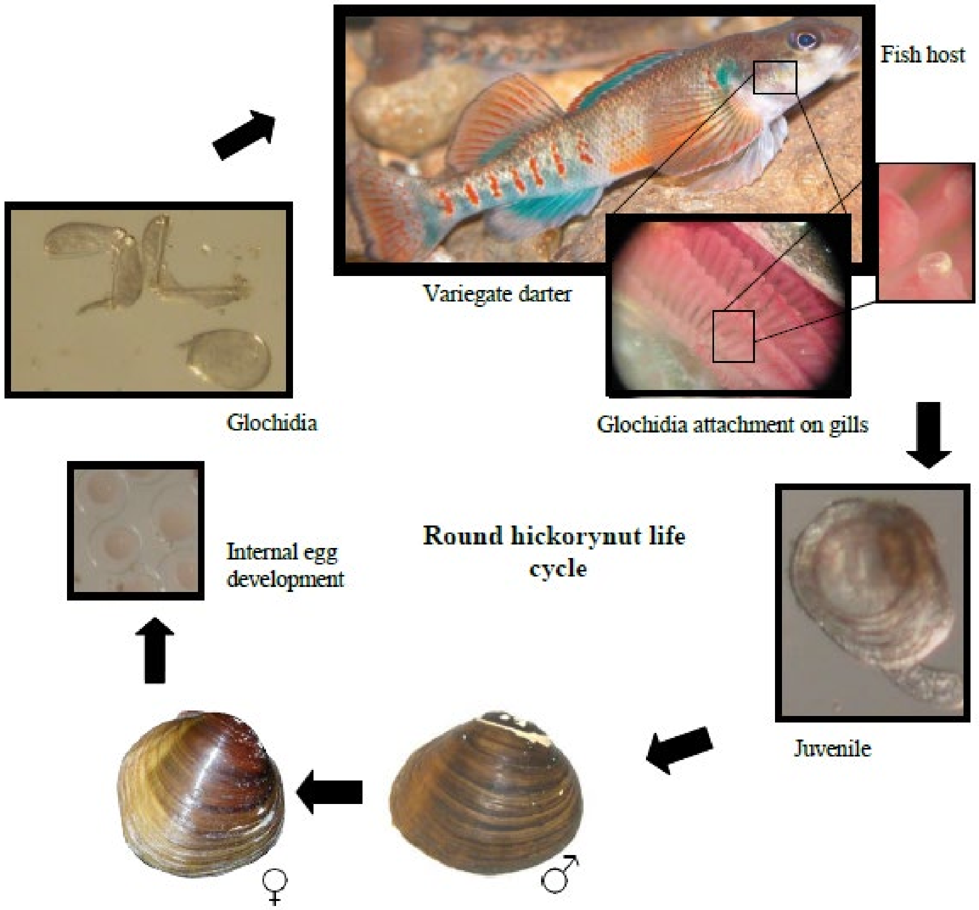

Figure 3-3. Life cycle of the Round Hickorynut. Freshwater mussels such as the Round Hickorynut have a complex life history involving an obligate parasitic larval life stage, called glochidia, which are wholly dependent on host fish. (From Shepard 2006, p. 9).

Several host fish species have been documented for the Round Hickorynut, but the dominant host fishes appear to be darters of the genera *Ammocrypta*, *Etheostoma*, and *Percina* (see section 4.2.3, below). Similar to other species in the tribe Lampsilini, the Round Hickorynut targets darter species by releasing glochidia contained in packets called conglutinates (Haag 2012, p. 163). The Round Hickorynut holds glochidia in ovisacs, and conglutinates are released into the water column (McNichols 2007), then sink following release by the female (Shepard 2006, p. 15). Conglutinates appear to be formed only near the end of the brooding cycle and released in late spring or early summer, or even as late as August in southern populations, and most females synchronously expel their broods (Ehlo and Layzer 2014, p. 10).

Following release from the female mussel, the conglutinates are targeted by sight-feeding darters, and burst when bitten by the fish (Figure 3-4). The glochidia snap shut in contact with fish and attach to its gills, head, or fins (Vaughn and Taylor 1999, p. 913). For most mussels, the glochidia will die if they do not attach to a fish within a short period. Once on the fish, the glochidia are engulfed by the host's tissue that forms a cyst. The cyst protects the glochidia and aids in their maturation. The larvae draw nutrients from the fish and develop into juvenile mussels, days to weeks after initial attachment.

The most descriptive information on the glochidium of the Round Hickorynut is from Ohio (n = 10) by Hoggarth (1999, p. 73): dorsal margin slightly curved at 85–95 µm in length, posterior margin straight, oblique dorsally, ventral portion of posterior margin curved. Central ligament 40–43 µm, micropoints lanceolate, arranged in broken vertical rows on ventral rim and on short ventral flange (Figure 3-4). Several studies have measured the maximum height and length of glochidia of the Round Hickorynut. Measurements from the Great Lakes, Ohio, and Cumberland basins are located in Table 3.1.

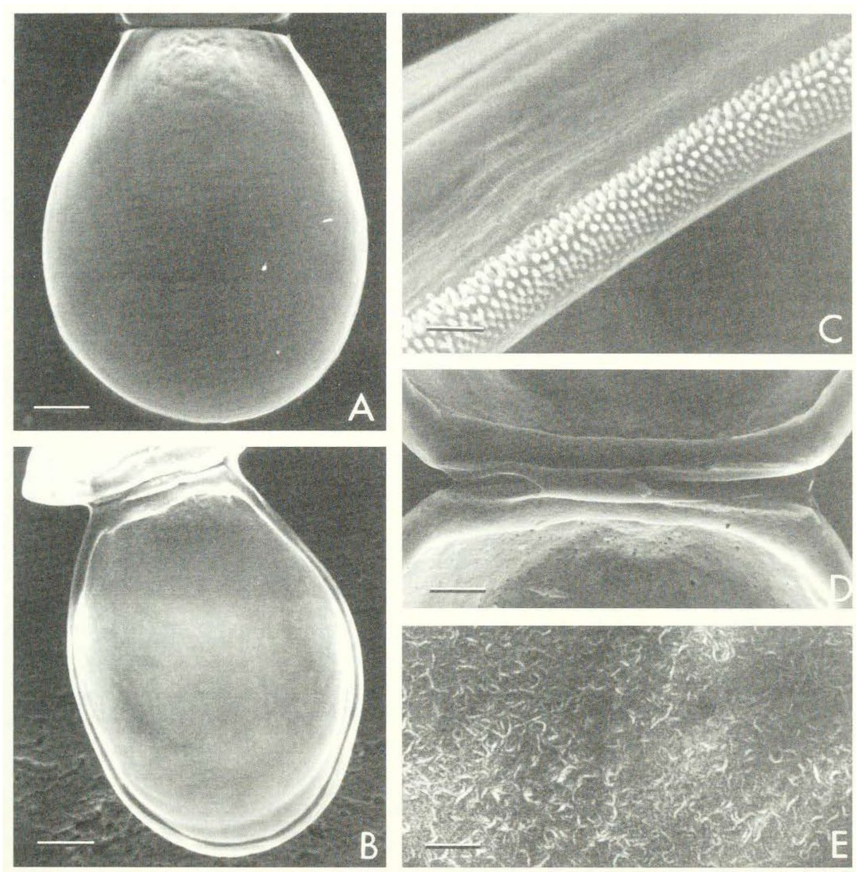

Figure 3-4. Glochidium of the Round Hickorynut (From Hoggarth 1999, p. 73). A. exterior valve, B. interior valve, C. micropoints along margin, D. hinge, and E. exterior valve sculpture.

Table 3.1. Glochidia dimensions reported for the Round Hickorynut.

State (Basin)	Height (µm)	Length (µm)	Source
Pennsylvania (Ohio)	200	230	Ortmann 1911, p. 347
Indiana (Ohio)	215	170	Surber 1915, p. 7
Kentucky (Cumberland)	223	182	Shepard 2006, p. 7
Ohio (Ohio & Great Lakes)	210	180	Hoggarth 1999, p. 73

Lampsiline mussels exhibit some of the most sophisticated mantle lures and brooding strategies of all freshwater mussels, and can expel fragile or more durable conglutinates that are white, leaflike, broad, and several egg layers thick, and that break up readily or with difficulty (Barnhart *et al.* 2004, p. 380). These fascinating strategies have been effective at exploitation of predator-prey relationships and feeding guilds of host fish, thus colonizing a wide array of suitable habitats (Zanatta and Murphy 2006, p. 206). However, the Round Hickorynut, like other members of the genus *Obovaria*, has no demonstrated movement or use of water currents to attract a potential host fish, and lures appear to have been secondarily lost (Zanatta and Murphy 2006, p. 207). Thus, the ancestral state of lure strategies in the genus are unknown.

CHAPTER 4 - RESOURCE NEEDS

As discussed in Chapter 3, the Round Hickorynut has a multi-staged life cycle: fertilized eggs to glochidia to juveniles to adults. The life cycle represents several stages that have specific requirements (resource needs) that must be met (Table 4-1) for the mussel to progress to the next stage.

Table 4-1. Requirements for each life stage of the Round Hickorynut mussel.

Life Stage	Resources Needed to Complete Life Stage[6]	Source
Fertilized eggs - late spring to summer	● Clear, flowing water ● Sexually mature males upstream from sexually mature females ● Appropriate spawning temperatures	Berg *et al.* 2008, p. 397; Haag 2012, pp. 38–39
Glochidia - late summer, fall to early spring	● Clear, flowing water ● Enough flow to keep glochidia or conglutinates adrift and to attract drift-feeding host fish ● Presence of host fish for attachment	Strayer 2008, p. 65; Haag 2012, pp. 41–42

[6] These resource needs are common among North American freshwater mussels; however, due to lack of species-specific research, parameters specific to Round Hickorynut are unavailable.

Life Stage	Resources Needed to Complete Life Stage[6]	Source
Juveniles - excystment from host fish to approx. 0.8 in (~20 mm) shell length	● Clear, flowing water ● Host fish dispersal ● Appropriate interstitial chemistry; low salinity, low ammonia, low copper and other contaminants, high dissolved oxygen ● Appropriate substrate (clean gravel/sand/cobble) for settlement	Dimmock and Wright 1993, pp. 188–190; Sparks and Strayer 1998, p. 132; Augspurger *et al.* 2003, p. 2,574; Augspurger *et al.* 2007, p. 2,025; Strayer and Malcom 2012, pp. 1,787–1,788
Adults - greater than 0.8 in (20 mm) shell length	● Clear, flowing water ● Appropriate substrate (stable gravel and coarse sand free from excessive silt) ● Adequate food availability (phytoplankton and detritus) ● High dissolved oxygen ● Appropriate water temperature	Yeager *et al.* 1994, p. 221; Nichols and Garling 2000, p. 881; Chen *et al.* 2001, p. 214; Spooner and Vaughn 2008, p. 308

4.1 Individual-level Resource Needs

In the following subsections, we outline the resource needs of individuals including biotic and abiotic habitat, physical habitat, host fishes, and diet.

4.1.1 Clean, Flowing Water

Generally speaking, Round Hickorynut habitat is in rivers and streams with natural flow regimes. While mussels can survive seasonally low flows and (random) short-term, periodic drying events, intermittent stream habitats generally cannot support mussel populations. Because a lotic (i.e., flowing water) environment is a critical need for the Round Hickorynut, perturbations that disrupt natural flow patterns (e.g., dams) may negatively influence Round Hickorynut resilience metrics.

Round Hickorynut habitat must have adequate flow to deliver oxygen, enable passive reproduction, and deliver food to filter-feeding mussels (see Table 4-1, above). Further, flowing water reduces contaminants and fine sediments from interstitial spaces, preventing mussel suffocation. Mussels may also shift to deposit feeding, underlying the importance of clean-swept substrates and interstitial spaces. Stream velocity is not static over time, and variations may be attributed to seasonal changes (with higher flows in winter/spring and lower flows in summer/fall), extreme weather events (e.g., drought or floods), or anthropogenic influence (e.g., flow regulation via impoundments). The Round Hickorynut relies on sight-feeding fishes as part of its life cycle; therefore, turbidity and high levels of suspended solids during critical reproductive periods may impact glochidial attachment and ultimately decrease recruitment in any given population (McLeod *et al.* 2017, p. 348).

While mussels have evolved in habitats that experience seasonal fluctuations in discharge, global weather patterns can have an impact on the normal regimes (e.g., El Niño or La Niña). Even during naturally occurring low flow events, mussels can become stressed because either they exert significant energy to move to deeper waters or they may succumb to desiccation (Haag

2012, p. 109). Droughts during the late summer and early fall may be especially stress-inducing because streams are already at their naturally occurring lowest flow rate during this time. Hydrologic and thermal modification through other factors, such as irrigation, may result in reduced water availability during these periods (Golladay *et al*. 2004, p. 494). Conversely, prolonged or sustained flooding can result in dislocation of mussels that are unable to burrow completely and isolation when water levels recede (Hastie *et al*. 2001, p. 111). Areas of high shear stress and scour do not support stable substrates and affect juvenile and adult mussel settlement and occupation (Layzer and Madison 1995, p. 329).

4.1.2 Appropriate Water Quality and Temperatures

Freshwater mussels, as a group, are particularly sensitive to changes in water quality parameters, including (but not limited to): dissolved oxygen (generally below 2–3 parts per million (ppm)), salinity (generally above 2–4 ppm), ammonia (generally above 0.5 ppm total ammonia-nitrogen), elevated temperature (generally above 86 °Fahrenheit (°F) (30 °Celsius (°C)), excessive total suspended solids, and other pollutants (see discussion in Chapter 6). Habitats with appropriate levels of these parameters are considered suitable, while those habitats with levels outside of the appropriate ranges are considered less than suitable.

Appropriate water temperature thresholds for the Round Hickorynut are unknown; thus, we must rely on the best available information for other mussel species, which primarily focuses on temperatures necessary for reproduction. The temperatures at which glochidia are released in the wild is undocumented, but one 2010 study documented that all females were gravid in July, most females released all of their glochidia within a 3-day period in early August, and subsequently recharged their gills within 2 weeks (Ehlo and Layzer 2014, p. 6). By August 26, researchers found only eggs in the marsupial gills at 79 °F (26 °C), but fully developed glochidia were present 19 days later on September 14 at 72 °F (22 °C) (Ehlo and Layzer 2014, p. 6).

Individuals have been collected gravid during July–February in Tennessee, May in Pennsylvania, March-November in Kentucky, and September–June in Canada. In host fish studies of the Round Hickorynut (using individuals collected from Buck Creek in Kentucky, the Duck River in Tennessee, and Lake St. Clair in Ontario), infested fishes were held in recirculating systems at 66–77 °F (19–25 °C), and transformation of glochidia occurred (Shepard 2006, p. 5; McNichols 2007, p. 21; Ehlo and Layzer 2014, p. 4). This temperature range is a reasonable estimate of required thermal regimes for species of the genus *Obovaria* during their reproductive cycle.

4.1.3 In-Stream Sedimentation

Optimal substrate for the Round Hickorynut is predominantly stable sand and gravel, but may include mud without excessive accumulation of silt and detritus. Riparian condition strongly influences the composition and stability of substrates that mussels inhabit (Allan *et al.* 1997, p. 149). Streams with urbanized or agriculturally dominated riparian corridors are subject to increased sediment loading as soil erodes from banks that do not have dense networks of roots holding soil in place, or from the landscape in general in areas without sufficient ground cover. Streams in urban areas may be subject to excessive runoff from impervious surfaces, which can overwhelm a stream channel's capacity to carry the water, resulting in increased stream bed and bank erosion (see discussion in section 6.1.3, below). Excess sediment in streams settles to the stream bottom, filling spaces required by juvenile mussels and host fish eggs. The result is a less suitable in-stream habitat for mussels compared to habitat with forested corridors (Allan *et al.* 1997, p. 156).

4.1.4 Food and Nutrients

Adult freshwater mussels, including the Round Hickorynut, are filter-feeders, drawing in suspended phytoplankton, zooplankton, rotifers, protozoans, detritus, and dissolved organic matter from the water column or sediments (Strayer *et al.* 2004, p. 430). Juvenile mussels are capable of pedal and deposit feeding to collect food items from sediments (Vaughn *et al.* 2008, pp. 409–411). Glochidia can derive what nutrition they need from their obligate fish hosts (Barnhart *et al.* 2008, p. 372). Freshwater mussels must keep their shells open, or gaped, to obtain food and facilitate gas exchange, but they often respond to water quality impairments by closing their shells (Bonner *et al.* 2018, p. 141).

Food supply is not generally considered limiting in environments inhabited by the Round Hickorynut. However, food limitation may be important during times of elevated water temperature, as both metabolic demand and incidence of valve closure increases concomitantly, resulting in reduced growth and reproduction (Bonner *et al.* 2018, p. 6). In addition, in areas where nonnative species (e.g., Zebra Mussel and Asian Clam) attain high densities, such as the Great Lakes, Ohio, Tennessee, and Cumberland basins, competition for food resources may affect overall food availability for the Round Hickorynut (Strayer 1999, p. 90).

4.2 Population- and Species-level Needs

In order to assess the viability of a species, the needs of individuals are only one aspect. This section examines the larger-scale population- and species-level needs of the Round Hickorynut.

4.2.1 Connectivity of Aquatic Habitat

River systems are a hierarchical network of aquatic habitats, and lotic, or flowing, landscapes are naturally dynamic and heterogeneous. Dendritic, or branched, orientation can enhance metapopulation persistence compared to linear or two-dimensional systems (Fagan 2002, p. 3,243). Tributary connection to river mainstems allows movement of fishes, and helps facilitate dispersal and colonization of appropriate habitat patches by mussels. A high degree of connection between habitat patches and occupied reaches is necessary for mussel populations to persist, because mussels are heavily dependent on gene exchange and host fish movement and dispersal within river and stream corridors to maintain viable populations (Newton *et al.* 2008, p. 425). Connectivity to a larger ‘parent’ water body can also have positive effects in that it may combine with other local factors to discourage the settlement and survival of nonnative species, such as Zebra Mussel (Zanatta *et al*. 2002, p. 487).

Latitudinal shifts in distributions may occur in response to a warming climate, underscoring the importance of longitudinal and dendritic connectivity (Evans 2010, p. 18; Inoue and Berg 2016, p. 2). Fragmentation can reduce the potential for recolonization, increasing the likelihood, and compounding the significance of, local extirpation events (Fagan 2002, p. 3,248). In the case of mussels, fragmentation results in barriers to host fish movement, which in turn, influences mussel distributions. Mussels that use small host fishes, such as darters (family Percidae) and sculpins (family Cottidae), are more susceptible to impacts from habitat fragmentation. This is due to increasing distance between suitable habitat patches and low likelihood of small host fish swimming over that distance as compared to large host fishes (Vaughn 2012, p. 7). Barriers to movement can cause isolated or patchy distributions of mussels, which may limit both genetic exchange and recolonization (Jones *et al.* 2006, p. 528).

The fragmentation of river habitat by dams and other aquatic barriers, such as perched or undersized culverts, is one of the primary threats to aquatic species in the U.S. (Martin and Apse 2014, p. 7). Dams, whether man-made or natural (e.g., from beavers [*Castor canadensis*]), have a profound impact on in-stream habitat as they can change lotic systems to lentic systems (non-flowing water). Moreover, fragmentation by dams or culverts generally involves loss of access to quality habitat for one or more life stages of freshwater species, such as spawning runs of migratory fishes.

4.2.2 Dispersal-Adult Abundance and Distribution

Mussel abundance in a given stream reach is a product of the number of mussel beds (aggregations of freshwater mussels) and the density of mussels within those beds. For populations of Round Hickorynut to be healthy, individuals must be numerous with multiple age classes, and populations show evidence of recruitment. For Round Hickorynut populations to be resilient, there must be multiple mussel beds of sufficient density such that local stochastic events do not eliminate the bed(s), allowing mussel beds and the overall local population within a stream reach to recover from any one event.

A non-linear distribution over a large area (occurrence in tributaries, in addition to the mainstem) also helps buffer against stochastic events that may affect populations. Additionally, mussel abundance facilitates reproduction; mussels do not actively seek mates, rather males release sperm into the water column, where it drifts until a female takes it in (Moles and Layzer 2008, p. 212). Therefore, successful individual reproduction and population viability require sufficient numbers of female mussels downstream of sufficient numbers of male mussels (Figure 3-4).

Mussel abundance is estimated by the number of individuals found during a sampling event. Mussel surveys rarely are a complete census of the population, and detection of mussels can be difficult since they bury in the substrate. Water level and clarity, which influence visibility, and other factors, such as the experience of the searcher during the survey period, can strongly influence capture rates. Density is estimated by the number found during a survey event using various statistical techniques.

In many situations, only catch per unit effort is available for a given survey. To our knowledge, no surveys have singularly specifically targeted the Round Hickorynut, and the species is usually a small component of the larger mussel assemblage within a river or stream in which it occurs. Detection is highly variable, especially in situations where the species may be in decline. In Lake St. Clair, where a formerly large population of Round Hickorynut occurred, less than two

Round Hickorynut were found per person-hour of effort, and the species was encountered at only 50 percent of sites surveyed for mussels (Zanatta 2000, pp. 74–75).

Because population estimates for most populations of Round Hickorynut are not available, and techniques are not directly comparable (i.e., same area size searched, similar search time, same individuals searching), we used the number of individuals captured as an index over time. While we cannot precisely determine population abundances at these sites using these numbers, we are able to determine if the species is abundant or rare at the site, and examine this over time if those data are available.

4.2.3 Host Fish

As mentioned previously, the Round Hickorynut has been the subject of two recent life history studies, one on individuals collected from the Duck River, Tennessee (Ehlo and Layzer 2014, entire) and another on individuals collected from Buck Creek, Kentucky (Shepard 2006, entire). These studies provide valuable life history information in these populations within the Tennessee and Cumberland basins, respectively, and, in addition, identified host fishes for the Round Hickorynut. Also, McNichols (2007, entire) conducted fish host trials for the Round Hickorynut collected from Lake St. Clair in Canada. The results of these studies, in which glochidial encystment and transformation occurred, with juvenile mussels documented to drop-off, are listed in Table 4-2.

Host fishes confirmed for the Round Hickorynut are primarily darters of the genera *Ammocrypta, Percina,* and *Etheostoma*. Optimal host fish identified to date include the Variegate Darter (*Etheostoma variatum*) in the Cumberland River basin (Shepard 2006, p. 25), the Iowa Darter (*Etheostoma exile*) in the Great Lakes basin (McNichols 2007, p. 77), and the Spangled Darter in the Tennessee River basin (Ehlo and Layzer 2014, p. 12). Other darter species and the Banded Sculpin (*Cottus carolinae*) are also confirmed as host fish for Round Hickorynut (Shepard 2006, p. 25; McNichols 2007, p. 77; Ehlo and Layzer 2014, p. 12) (Table 4-2).

There was some overlap in suitability of the Fantail Darter (*Etheostoma flabellare*) in the Ohio and Great Lakes basin studies (McNichols 2007, p. 77), but these were considered marginal host fishes, having a much lower transformation rate. Interestingly, the Round Hickorynut did not transform on Greenside Darter (*Etheostoma blennioides*) in the Lake St. Clair host fish trials, despite commonly occurring in the Great Lakes basin (McNichols 2007, p. 77); however, they were a confirmed host in the Duck River host study in the Tennessee River basin (Ehlo and Layzer 2014, p. 7). This indicates that, despite selecting for darters within these genera, similar to other mussel species, the Round Hickorynut may be flexible in its host selectivity at the fish species level, which may be more driven by localized distribution and abundance of available darter hosts.

A closely related mussel species, the Alabama Hickorynut (*Obovaria unicolor*), had the most successful transformation rate on the Naked Sand Darter (*Ammocrypta beani*) (Haag and Warren 2003, p. 85). In more recent captive culture studies in Kentucky, the closely related Eastern Sand Darter (*Ammocrypta pellucida*) had comparatively high successful transformation rates on Round Hickorynut (Shepard 2017, pers. comm.). This mussel host fish relationship was suggested by Clark (1977, p. 34), Metcalfe-Smith *et al.* (2003, p. 46), and Shepard (2006, p. 26). It is noteworthy because the Eastern Sand Darter has suffered steady decline in distribution and abundance in some portions of the species' native range in the Great Lakes and Ohio basins, including Canada (Metcalfe-Smith *et al.* 2003, p. 46; Grandmaison *et al.* 2004, p. 9). However, in contrast to the Round Hickorynut, the Eastern Sand Darter has lost only a few populations in Indiana, and is potentially expanding its range within the state (Fisher 2019, pers. comm.). Numerous surveyors have indicated there is a direct correlation with locations and habitats, such as sandy riffles and runs, from which the Eastern Sand Darter and Round Hickorynut are collected.

There are likely some other secondary hosts capable of transforming juvenile Round Hickorynut at a low rate, potentially in large rivers such as the Ohio and Tennessee River mainstems. Darters, the preferred hosts in all studies, are small benthic fishes of the family Percidae. They are typically diurnal sight feeders that feed on aquatic insects (Etnier and Starnes 1993, p. 440). Darters of the genus *Ammocrypta* commonly bury in the substrate to conserve energy and to avoid predators. Members of the genera *Etheostoma* and *Percina* require clean substrates for feeding and spawning and are generally intolerant of pollution and siltation (Etnier and Starnes 1993, p. 441).

Table 4-2. Host fishes documented for the Round Hickorynut.

Common Name	Scientific Name	Source (Basin)
Banded Sculpin	*Cottus carolinae*	Ehlo and Layzer 2014 (Tennessee)
Eastern Sand Darter*	*Ammocrypta pellucida*	Shepard 2017, pers. comm.; Clark 1976 (Ohio)
Emerald Darter	*Etheostoma baileyi*	Shepard 2006 (Cumberland)
Greenside Darter	*Etheostoma blennioides*	Ehlo and Layzer 2014; McNichols 2007 (Tennessee, Great Lakes)
Iowa Darter*	*Etheostoma exile*	McNichols 2007 (Great Lakes)
Fantail Darter	*Etheostoma flabellare*	Ehlo and Layzer 2014; McNichols 2007 (Tennessee, Great Lakes)
Cumberland Darter	*Etheostoma gore*	Shepard 2006 (Cumberland)
Spangled Darter*	*Etheostoma obama*	Ehlo and Layzer 2014 (Tennessee)
Variegate Darter*	*Etheostoma variatum*	Shepard 2006 (Cumberland)
Blackside Darter	*Percina maculata*	McNichols 2007 (Great Lakes)
Frecklebelly Darter	*Percina stictogaster*	Shepard 2006 (Cumberland)

*indicates optimal host in the study basin

4.3 Uncertainties

Life history uncertainties for the Round Hickorynut include patterns of age structure within populations (i.e., number within each age class or cohort in any population), survival of each age class, ranges of water temperatures at which transformation occurs, and information related to species-specific diet studies. There may be some secondary hosts capable of transforming juvenile Round Hickorynut at a low rate, potentially other darters such as additional members of the genus *Percina* in large river benthic habitats.

Due to limitations associated with space and capacity at many mussel propagation facilities, and priorities surrounding recovery of federally-protected mussel species, information regarding Round Hickorynut restoration potential through production is currently limited. This is a concern for the Cumberland and Great Lakes basins, due to lack of detectable individuals since 2000. As a result, these basins have restricted propagation feasilbility under captive culture techniques to bolster populations. There is recovery potential of the Round Hickorynut through propagation, as the White Sulphur Springs National Fish Hatchery and Kentucky Center for Mollusk Conservation have had transformation success in captivity; however, few juveniles survived to stockable sizes in those preliminary trials.

In many situations, abundance and precise locality information for most populations considered extirpated is lacking, and therefore it is difficult to specifically attribute localized extirpation to a specific stressor or species need. Many populations considered extant are represented by less than 10 observed live or fresh dead individuals since 2000. The species relies on a consistent level of reproductive success to maintain populations, but the actual environmental events that cue variations (increases or decreases) in reproductive success, which are estimated by recruitment in successive sampling events, is not documented.

Additionally, numeric water quality criteria specific for Round Hickorynut threshold tolerances are unknown. The species' capability to move and disperse is acknowledged as glochidia attach to fish, but the distance that adults are capable of dispersing within appropriate habitats or response to varying water levels, is unknown, but apparently very limited. Population estimates are lacking for the majority of populations, and estimates available are not comparable due to lack of survey efforts and inconsistent methodologies.

4.4 Summary of Resource Needs

As discussed in Chapter 1, we define viability as the ability of the Round Hickorynut to sustain populations in the wild over time (i.e., 20 to 30 years for the purpose of this assessment). The availability and quality of these resources, as well as the level of negative and beneficial influences acting upon these resources, will determine whether populations are resilient over time. Based upon the best available scientific and commercial information (summarized in sections 4.1 and 4.2, above), and acknowledging existing ecological uncertainties (section 4.3, above), the Round Hickorynut's resource and demographic needs (see Figure 4-1, below) are characterized as:

- Clean flowing water with appropriate water quality and temperate conditions, such as (but not limited to) dissolved oxygen above 2–3 ppm, ammonia generally below 0.5 ppm total ammonia-nitrogen, temperatures generally below 86 °F (30 °C), and (ideally) an absence of excessive total suspended solids, and other pollutants.

- Natural flow regimes that vary with respect to the timing, magnitude, duration, and frequency of river discharge events.

- Predominantly silt-free, stable sand, gravel, and cobble substrates.

- Suspended food and nutrients in the water column including, but not limited to phytoplankton, zooplankton, protozoans, detritus, and dissolved organic matter.

- Availability of sufficient host fish numbers to provide for glochidia infestation and dispersal. Host fish species include, but may not be limited to, darters of the family Percidae and genera *Ammocrypta*, *Etheostoma*, and *Percina*, as well as sculpins of the genus *Cottus*.

- Connectivity among populations. Although the species' capability to disperse is evident through historical occurrence within a wide range of rivers and streams, the fragmentation of populations by small and large impoundments has resulted in isolation and only patches of what once was occupied contiguous river and stream habitat. Genetic exchange occurs between and among mussel beds via sperm drift, host fish movement, and movement of mussels during high flow events. For genetic exchange to occur, connectivity must be maintained.

- Most freshwater mussels, including the Round Hickorynut, are found in mussel beds that vary in size and are often separated by stream reaches in which mussels are absent or rare (Vaughn 2012, p. 983). The species is often a component of a large healthy mussel assemblage within optimal mussel habitats; therefore, the beds in which they occur are necessary for the species to be resilient over time.

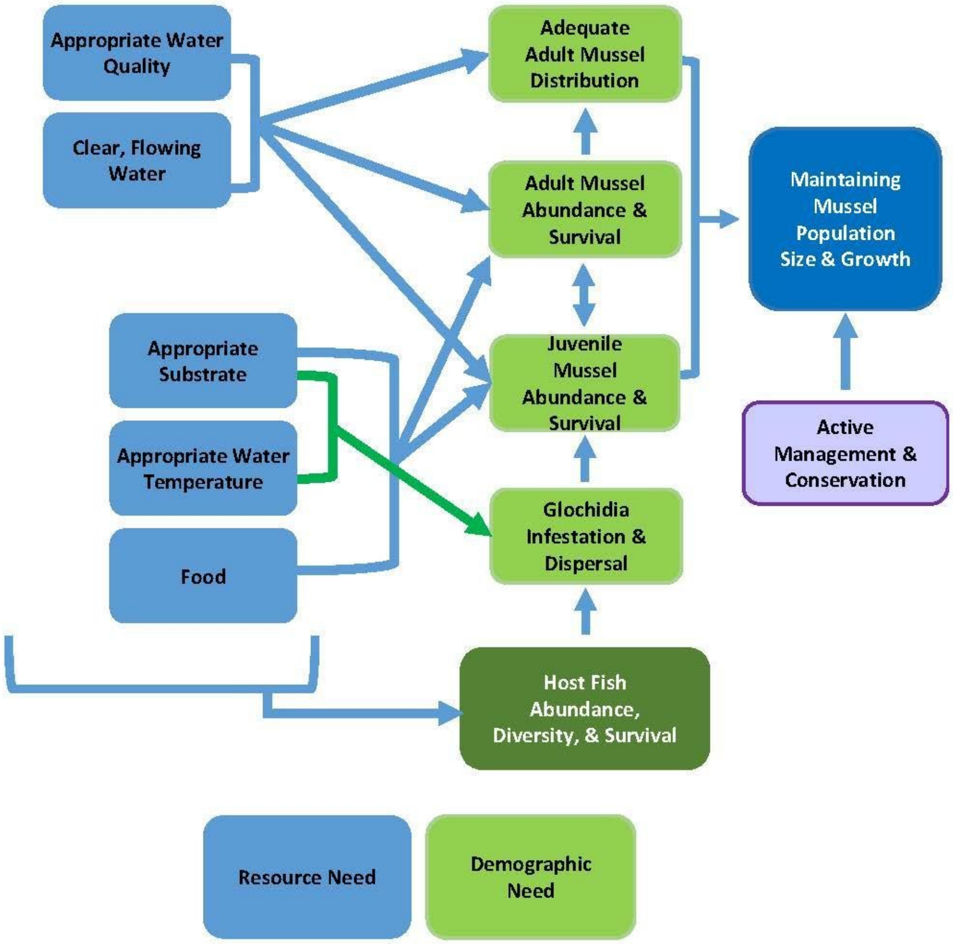

Figure 4-1. Resource and demographic needs of the Round Hickorynut.

CHAPTER 5 - CURRENT CONDITIONS, ABUNDANCE AND DISTRIBUTION

Fundamental to our analysis of the Round Hickorynut was the determination of scientifically sound analytical units at a scale useful for assessing the species (see section 2.1.2, above). In this report, we defined Round Hickorynut MUs and populations based primarily on known occurrence locations and stream connectivity. We acknowledge that specific Round Hickorynut demographic and genetic data to support this construct are sparse. However, this approach for assessing the species' condition has been used for other aquatic species in the eastern United States, therefore, it was considered an acceptable construct for this SSA report.

After identifying the factors (i.e., stressors) likely to affect the Round Hickorynut, we estimated the condition of each Round Hickorynut population. The population size and extent metrics used were selected because the supporting data were relatively consistent across the range of the species and at a resolution suitable for assessing the species at the population level. The output was a condition score for each Round Hickorynut population that was then used to assess the

Round Hickorynut across its range under the concepts of resiliency, representation, and redundancy. We acknowledge there is uncertainty regarding some of the scientific data and assumptions used to assess the biological condition of the Round Hickorynut (see section 5.4, below).

The Round Hickorynut is wide-ranging, and historically known from the Lower Mississippi, Tennessee, Cumberland, Ohio River, and Great Lakes basins. It is currently known from Alabama, Indiana, Kentucky, Michigan, Mississippi, Ohio, Pennsylvania, Tennessee, and West Virginia, and is extirpated from Georgia, Illinois, and New York. The results of surveys conducted since 2000 indicate the currently occupied range of the Round Hickorynut in the U.S. includes 65 rivers and streams. A summary of all known extant populations and their generalized estimated size is found in Appendix A.

5.1 Historical Conditions For Context

To summarize the overall current conditions, Round Hickorynut populations and MUs were considered extant if a live individual or fresh dead specimen was collected since 2000, or collections of the species were made since 1990 with no available negative mussel survey data of the population or MU to dispute that the species still occurs within the water body. Populations were considered extirpated based on documentation in literature, reports, or from communications with state malacologists and aquatic biologists. General reference texts on state and regional freshwater mussel fauna, such as Gordon and Layzer (1989), Cummings and Mayer (1992), Strayer and Jirka (1997), Parmalee and Bogan (1998), Jones *et al.* (2005), Williams *et al.* (2008), Watters *et al.* (2009), and Haag and Cicerello (2016) provided substantial information on species distribution, both past and present.

The Round Hickorynut is known historically from 297 populations and 138 MUs in 12 states. It occurrs in the Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi basins. The Round Hickorynut is considered extirpated from Georgia, Illinois, and New York. In total, 232 populations and 104 MUs are extirpated (Appendix B). The numbers of populations and MUs by basin are as follows: 25 populations and 16 MUs in the Great Lakes basin, 146 populations and 58 MUs in the Ohio River basin, 23 populations and 10 MUs in the Cumberland River basin, 29 populations and 13 MUs in the Tennessee River basin, and 9 populations and 7 MUs in the Lower Mississippi River basin (Figure 5-1). A table of all populations and MUs considered extirpated, along with the authority and year of each record, is found in Appendix B.

Populations of the Round Hickorynut have been lost from entire river drainages in which the species once occupied multiple tributaries, particularly in the Ohio basin, such as the Allegheny, Coal, Twelvepole, Little Scioto, Miami, and Vermilion River MUs (Appendix B). This systemic loss of populations is an alarming trend for the species. Published literature and museum records indicate that the Round Hickorynut was common and abundant in multiple MUs within these river systems (Call 1900, p. 494; Ortmann 1913, p. 298; Goodrich and van der Schalie 1944, p. 261; Carnegie Museum of Natural History [CMNH] records; Illinois Natural History Survey Museum [INHS] records). The state of Ohio alone has lost approximately 53 populations of Round Hickorynut, more than any other state (Watters *et al.* 2009, p. 210). The state of Indiana has lost approximately 22 MUs, more than any other state (Fig. 5-1). These states are particularly important for Round Hickorynut persistence because there are portions of both the Great Lakes and Ohio basins within state boundaries.

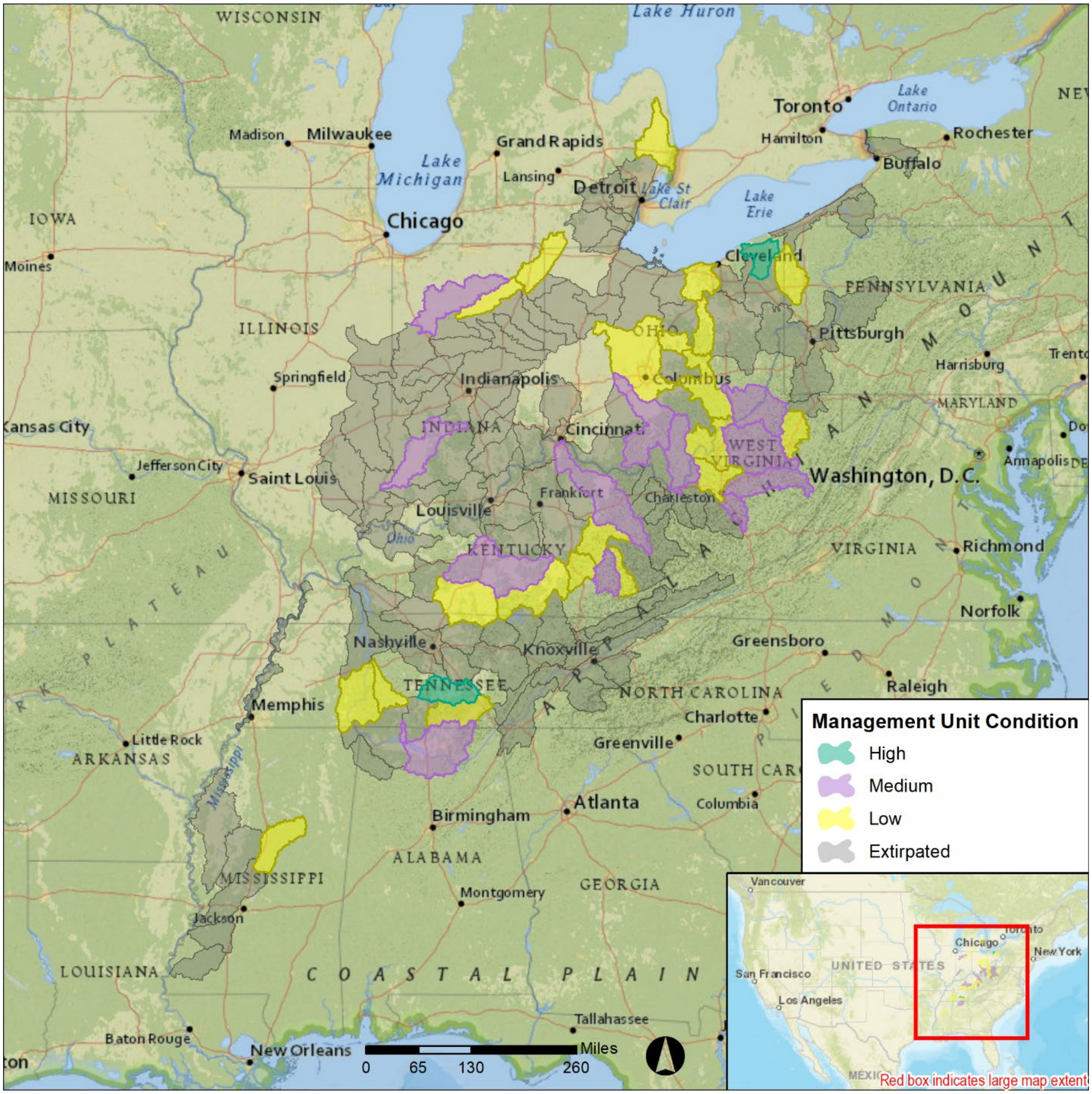

Figure 5-1. Distribution of the current and historically occupied Management Units (MUs; a.k.a. HUC 8s) of Round Hickorynut mussel in the United States. Currently occupied MUs are represented with low, medium, and high condition categories as described in Chapters 2 and 5 (Service 2019, unpublished data).

The decline and loss of meta-populations, and the resultant remaining small, isolated populations, is a pattern observed in other mussels in the Ohio, Cumberland, and Tennessee River basins specifically, and has led to species extinction (Haag 2012, p. 127). Population losses of the Round Hickorynut follow a pattern of direct loss of habitat due to impoundment and channelization, and indirect effects of fragmentation due to habitat destruction, as well as overall habitat degradation (Haag 2012, p. 127). Precipitous declines and extirpations of Round Hickorynut populations have been observed in the Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi basins, but especially in the Ohio and Cumberland basins (Appendix B).

Examples of water bodies where populations of the Round Hickorynut were formerly abundant and widespread, but now extirpated, include:

- Lake Erie, Ohio (OSUM, University of Michigan Museum of Zoology [UMMZ], and CMNH records)
- Crooked Creek, Pennsylvania (Ortmann 1913, p. 298)
- West Branch Mahoning River, Ohio (Swart 1940, p. 42)
- Coal River, West Virginia (CMNH and UMMZ records)
- Olentangy River, Ohio (Stein 1963, p. 109)
- Alum Creek, Ohio (OSUM records)
- Blaine Creek, Kentucky (Bay and Winford 1984, p. 19)
- Embarras River, Illinois (Parmalee 1967, p. 80)
- Big Vermilion River, Illinois (Parmalee 1967, p. 80)
- Cumberland River, Kentucky (Neel and Allen 1964, p. 442)
- Obey River, Tennessee (Shoup *et al*. 1941, pp. 67–68; UMMZ records)
- Stones River, Tennessee (Schmidt *et al.* 1989, p. 58; OSUM records)
- Red River, Tennessee/Kentucky (OSUM records)

In many instances, the specific cause for extirpation is unknown, and is likely attributable to a variety of compounded threats. Suggested causes include habitat loss, fragmentation, and degradation due to impoundment and navigational impacts; impaired water quality due to pollution and land use changes; and the introduction of nonnative species (Watters and Flaute 2010, p. 6; Watters 2000, p. 269). A more recent documented threat is the introduction around 1985 of the Zebra Mussel and its subsequent spread, which has decimated the Great Lakes mussel fauna, and as a result, non-native species are likely the greatest stressor to the remaining Round Hickorynut populations in the Great Lakes basin (Strayer 1999b, p. 75).

As early as 1909, pollution caused by coal mining and oil refineries, and habitat loss due to impoundment were identified as contributors to the decline of the freshwater mussel fauna in Pennsylvania (Ortmann 1909b, p. 97). Many of these threats to mussels continue today. In particular, mining and resource extraction impacts associated with the Marcellus Shale have been identified as contributing to declines of freshwater mussel diversity and abundance in MUs that harbor some of the most dense Round Hickorynut populations: the Elk, Little Kanwaha, and Kanawha in West Virginia (Ecological Specialists, Inc. (ESI) 2009, p. 22). There are currently two high condition populations in West Virginia (Middle Island Creek and Little Kanawha River).

However, the MUs in which these occur are under imminent threats associated with resource extraction, six tributary populations to these streams are considered extirpated, and as a result, these are not considered stronghold populations or MUs. Mining has been implicated specifically in mussel declines in the Cumberland River basin as well, where as many as 18

Round Hickorynut populations have been lost; resource extraction remains a threat to the last 2 remaining populations in the Cumberland River basin (Appendices A, D).

All extant populations of Round Hickorynut are affected to some extent by impoundments, which isolate populations and prevent upstream dispersal (see section 6.1.5). However, tributaries that maintain connectivity to river reaches without large flood control, water supply, or hydropower dam interruption are comparatively less affected. Examples include Mill Creek (tributary to the Grand River) and the Red Bird River (tributary to the South Fork Kentucky River). Although smaller impoundments (mill dams) still occur in these watersheds, there is probable gene flow between these tributaries and mainstem rivers.

5.2 Current Population Distribution, Abundance, and Trends

To assess the distribution, abundance, and (if data are available) trends of Round Hickorynut populations, we first assigned a status category of extant or extirpated to each population. Second, for extant populations, we estimated the occupied extent of each river or stream and size of each population so each could be evaluated relative to one another (Table 5-1). Due to lack of consistency of survey efforts, population size (Table 5-2) was based on count numbers of the species summarized from inventory data. Next, we developed threat condition categories (Table 5-3) based on our qualitative assessment of the magnitude and immediacy of a potential threat within each population. Finally, we assigned a low/medium/high overall condition category to each population and MU based on the combined consideration of the aforementioned population extent, size, and threat information (Table 5-4). Ten MUs are represented by more than one population. In this case, population rankings were averaged to get an overall management unit current and future condition for each scenario. When averaging population rankings, consideration was given to the population density, extent, and threats throughout the management unit.

The Round Hickorynut occurs in rivers and streams of differing widths and lengths in the Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi basins (Ortmann 1920, p. 275). Early naturalists observed mussel shape and form in the Ohio River drainage in particular, and recognized shell shape and size as highly variable and somewhat dependent on the location and the river or stream where individuals were located. The Round Hickorynut is a species that has a more compressed headwater form, and a more inflated, or swollen, large river form, with intergrades of these two in medium-sized rivers, where it is most commonly found (Ortmann 1925, p. 328).

Regarding the range of stream sizes occupied by the Round Hickorynut, the species' current condition includes populations within small streams such as Mill Creek in the Great Lakes basin, and Meathouse Fork and Richland Creek in the Ohio River basin. In these smaller streams, the species frequently exists near the mouths, thereby giving them ready access to a larger parent stream. Populations of Round Hickorynut in small streams are considered extirpated from the Cumberland and Tennessee basins (Irwin and Alford 2018, p. 28). However, it appears in surveys of small to large rivers. The Round Hickorynut attains a larger size in big rivers, such as in the Tennessee and Ohio River mainstems (Williams *et al*. 2008, p. 321). Additionally, although it is now considered extirpated from the mainstem Cumberland River and Mississippi

River, it formerly occurred in both these large rivers prior to impoundment, and was considered common in the upper and lower Cumberland River (Wilson and Clark 1914, p. 52; Casey 1986, p. 112; Wesler 2001, p. 115).

Population extent for each river or stream was based on available inventory data. Estimates of occupied river kilometers were derived from polygons generated by NHPs, natural resource datasets, and through mapping of point occurrence data. We evaluated this information by examining available appropriate habitat and its connectivity relative to natural or constructed barriers, such as waterfalls or dams. Additionally, if available, negative survey information on the species' extent within a river or stream reach informed the linear estimate of current occupation. Population extent was ranked as small, medium, or large, as described in Table 5-1, below.

Table 5-1. Population extent categories to help describe Round Hickorynut's distribution within rivers and streams throughout its current range.

Category	Description
Small	Species is estimated to continuously occur in less than 6.2 miles (mi) (10 km) of river/stream based on available survey information and negative data.
Medium	Species is estimated to continuously occur in more than 6.2 mi (10 km) but less than 30 mi (50 km) of river/stream based on available survey information and negative data.
Large	Species is estimated to continuously occur in more than 30 mi (50 km) of river/stream based on available survey information and negative data.

Our estimates of the extent of each population are displayed as maps in Appendix C. Population extent is mapped in ArcGIS v. 10.5. Data sources for population extent include NatureServe species' occurrence information sourced from states, primary literature, and gray literature; and reports and personal communications with state malacologists and aquatic biologists familiar with the extent of suitable mussel habitat within the drainage. We also used aerial imagery and topographic maps to delineate the maximum extent of the species potential occurrence.

Natural barriers, such as Kanawha Falls, and artificial barriers (dams) influence the Round Hickorynut and host fishes' capability to disperse. Additionally, when available, negative data (surveys that did not detect Round Hickorynut) from mussel inventories conducted within the known basins of Round Hickorynut occurrence were used to inform extent for each population. References on regional and state mussel fauna such as Williams *et al.* (2008), Watters *et al.* (2009), and Haag and Cicerello (2016), as well as published and unpublished survey efforts, provided substantial information on current species distribution.

Additionally, Schuster (1988), ESI (2000), and Watters and Flaute (2010) were valuable references for informing the Round Hickorynut current and former distribution in the mainstem Ohio River. There are only two remaining populations in the Ohio River mainstem, in the Belleville and Willow Island pools (reservoirs), which are comprised of large, older males

(Clayton 2019, pers. comm.). The Round Hickorynut potentially formerly occurred throughout the Ohio River mainstem, based on museum records from as many as nine reservoir pools (Watters and Flaute 2010, p. 11). Also, although there are no museum records for the Cannelton and Hannibal pools, and they therefore lacked necessary documentation to be included in our analyses, the Round Hickorynut formerly occurred both upstream and downstream of these reservoirs and likely occupied these reaches of the Ohio River prior to impoundment.

Population size for each river or stream was based on inventory data collected for freshwater mussels since 1900 (Appendix A). Various state and Federal agencies, academic institutions, and non-governmental organizations conducted inventories. Population size was ranked as small (very rare to uncommon in collections or surveys), medium (occasional to common in collections or surveys), or large (abundant in collections or surveys) (see Table 5-2).

Table 5-2. Population size categories to help describe the Round Hickorynut's abundance within rivers and streams throughout its current range.

Category	Description*
Small (very rare to uncommon in collections or surveys)	Less than 10 individuals (live or fresh dead, or weathered dead/subfossil) reported from the river/stream in any sampling event since 2000; qualitative collections of varying effort; surveys within known occupied reaches did not detect species, not enough information available to generate population estimate; or population potentially represented by larger older individuals not reproducing.
Medium (occasional to common in collections or surveys)	10–50 individuals (live, fresh dead) reported from the river/stream since 2000; and/or some quantitative information available for a population estimate at sampling locations within occupied river or stream reach (with large confidence intervals); potentially multiple size classes represented; or species is frequently observed or detected when preferred habitat is targeted in sampling efforts.
Large (abundant in collections or surveys)	More than 50 individuals (live) reported from the river/stream since 2000; or a population estimate for the river or a site within the river may already be available or possible due to the availability of quantitative data at sampling locations within occupied river or stream reach; or potentially some evidence of recent recruitment.

* (A population may meet one or more criteria but does not have to meet all)

Our estimates of the size of each population are detailed in Appendix A. Of important note regarding these estimates: some populations are ranked as small population sizes, but data on the species occurrences in these rivers and streams are scarce. For example, 22 populations represented by collections of five or fewer individuals of Round Hickorynut since 1990 are categorized as small population size. In many of these small population size examples, only fresh dead shells have been collected and no live Round Hickorynut have been observed.

For populations in the Shade River and Middle Fork Salt Creek drainages in Ohio, the most recent data available are from 1987 (Watters 1992b, p. 66; Grabarkiewicz 2014, p. 8). These streams should receive high survey priority to determine the current abundance and extent of the Round Hickorynut population and an updated census of the mussel fauna within the MUs. The

Middle Fork Salt Creek population size was considered large at the time of survey, so it is considered as such in this SSA. Additionally, these populations were considered extant by Watters *et al.* (2009, p. 211), so are included as extant populations in this status assessment.

Populations represented by collections of five or less Round Hickorynut live or fresh dead individuals since 1990:

Pine River (Michigan)
Spring Creek (West Virginia)
Scioto River (Ohio)
Middle Fork Kentucky River (Kentucky)
Red Bird River (Kentucky)
Red River (Kentucky/Tennessee)
Eel River (Indiana)
Stonecoal Creek (West Virginia)
Muskingum River (Ohio)
Killbuck Creek (Ohio)
Hughes River (West Virginia)
Reedy Creek (West Virginia)
Belle River (Michigan)
Black River (Ohio)
Fish Creek (Ohio/Indiana)
Right Fork West Fork River (West Virginia)
Kentucky River (Kentucky)
Rockcastle River (Kentucky)
Wakatomika Creek (Ohio)
Buffalo River (Tennessee)
Tennessee River (Tennessee)
Elk River (Tennessee)

We included these populations to be as thorough and inclusive as possible to evaluate the current status of the Round Hickorynut. However, it is difficult to make inferences about the current and future overall condition of these small, and potentially non-viable populations, especially with limited data and trend information. Some populations are represented by only one detection. Based on the numbers and patterns of already extirpated populations across the range of the species, it is possible that many of these populations represented by collections of five or less Round Hickorynut live or fresh dead individuals since 1990 are already in decline and are likely to be extirpated within 20 to 30 years (see Chapter 7).

Despite the current uncertainties regarding the density and extent of these populations, the basins in which the species occurs have been sampled well enough since 1900 to accurately establish the range of the Round Hickorynut and discern population trends in some situations. Available negative mussel data (mussel surveys in the river or stream that failed to detect Round Hickorynut) and information on threats to the aquatic fauna in these watersheds, such as EPA Clean Water Act (CWA) 303d (impaired waters and total maximum daily load) listing, were also used to inform this analysis.

Potential threats to the Round Hickorynut or its habitat were categorized in terms of magnitude and immediacy based on the best available information in literature or other sources, such as State Wildlife Action Plans (SWAP), watershed planning documents, or CWA 303(d) lists of impaired waters. We ranked threat levels based on their apparent or likely magnitude of presence in the drainage (Table 5-3). Round Hickorynut population characteristics (extent and size) were considered relative to current threats. Our estimates of the magnitude and immediacy of potential threats to each population are detailed in Appendix D.

Mussel declines in the Ohio, Cumberland, Tennessee, and Lower Mississippi basins are primarily the result of habitat and water quality loss and degradation (Neves 1993, p. 4). The invasion of nonnative species such as the Zebra Mussel (*Dreissena polymorpha*) has resulted in substantial decline in Great Lakes basin mussel populations and shifts in ecosystem function (Conroy and Culver 2005, p. 20; Schloesser *et al.* 2006, p. 315). The chief causes of lost or declining populations of mussels within these basins occupied by the Round Hickorynut are a combination of impairments resulting from impoundments, channelization, nonnative species, chemical contaminants, mining, agriculture, and sedimentation (Neves 1993, p. 4; Williams *et al.* 1993, p. 5; Watters 2000, p. 261).

Table 5-3. Categories to describe the magnitude and immediacy of potential threats influencing the Round Hickorynut.

Category	Description
Low	Threats to freshwater mussels or aquatic fauna have been identified in this HUC and are in literature or available in SWAPs - threats are minimal (potential threats identified but direct tie to loss of mussels possibly lacking) compared to other occupied rivers and streams or MUs that harbor the species. Public land holdings within the river or stream where the Round Hickorynut occurs were incorporated into this threat level.
Moderate	Threats to freshwater mussels or aquatic fauna have been identified or evaluated in this HUC and are in literature or available in SWAPs - threats are moderate (multiple threats identified but may not be imminent, or the status of the threat is unknown) compared to other occupied rivers and streams or MUs that harbor the species.
High	Threats to freshwater mussels or aquatic fauna have been identified and evaluated in this HUC and are in literature or available in SWAPs - threats are substantial (multiple threats identified and imminent) and cumulative, compared to other occupied rivers and streams or MUs that harbor the species.

Expanding human populations within the range of the species (e.g., Lawler *et al.* 2014, p. 55; Terando *et al.* 2014, p. 3) will invariably increase the likelihood that many, if not all, of the factors may negatively influence the viability of Round Hickorynut populations into the future. The level of threat that climate change exerts on the species rangewide is unknown, but the state of Pennsylvania considers the Round Hickorynut extremely vulnerable to climate change (Furedi 2013, p. 4), and has only one remaining population in the state (Shenango River). Regardless, the highly fragmented remaining populations rangewide, affected by the threats listed above, are affected by secondary impacts through climate change such as drought or prolonged flooding.

5.3 Estimated Viability of Round Hickorynut Mussel Based on Current Conditions

We define Round Hickorynut viability as the ability of the species to sustain healthy populations in natural river systems within a biologically meaningful timeframe. Using the SSA framework, we describe the species' current viability in terms of resiliency, representation, and redundancy.

5.3.1 Resiliency

Resiliency describes the ability of populations to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health, for example, birth versus death rates and population size. Highly resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities. For the purpose of this SSA, with a lack of broad, demographic data, each population's estimated size and extent helps provide a measure of resiliency given that larger mussel populations distributed over a larger area, in a non-linear orientation, would be better able to rebound from stochastic events than smaller populations with limited, linear distribution.

Populations and MUs were ranked according to the following overall condition categories: high, medium, and low (Table 5-4). As discussed above under section 5.2, these categories were informed by each population's extent, size, and probable threat level, with population size weighted more heavily than extent and threat level because of more limited information on current population extent and threats to the Round Hickorynut. Overall condition categories for each of the extant Round Hickorynut populations are presented in Table 5-5, below.

Table 5-4. Categories for estimating the overall current condition of Round Hickorynut mussel populations.

High (Stronghold) Populations	Medium Populations	Low Populations
Significant populations generally distributed over a sizeable and more or less contiguous length of stream (≥ 30 river miles (RM) (80 km)), with evidence of recent recruitment, and currently considered resilient.	Small, generally restricted populations with limited levels of recent recruitment and resiliency, and susceptible to extirpation within 20–30 years.	Very small and highly restricted populations with no evidence of recent recruitment and questionable resiliency, and that may be on the verge of extirpation in the immediate future.

Table 5-5. Extant populations of Round Hickorynut by major river basin, management unit (8 digit HUC), and their generalized population condition.

Major River Basin	Management Unit	Record State	Contiguous Population (occupied river/stream)	Current Condition
Great Lakes	St. Clair	MI	Pine River	Low
			Belle River	Low
			Black River	Low
Great Lakes	Grand	OH	Grand River	High
			Mill Creek (Grand)	Med
Great Lakes	Black-Rocky	OH	Black River	Low

Major River Basin	Management Unit	Record State	Contiguous Population (occupied river/stream)	Current Condition
Great Lakes	St. Joseph (Maumee)	OH	Fish Creek	Low
Ohio	Shenango	PA	Shenango River	Low
Ohio	West Fork	WV	West Fork River	Low
			Right Fork West Fork River	Low
			Kincheloe Creek	Low
			Hackers Creek	Low
			Stonecoal Creek	Low
			Jesse Run	Low
Ohio	Little Muskingum - Middle Island	WV	Middle Island Creek	High
			Meathouse Fork	Low
			McElroy Creek	Med
		WV/OH	Ohio River (Willow Island Pool)	Low
		WV	Buckeye Creek	Low
Ohio	Walhonding	OH	Killbuck Creek	Low
			Walhonding River	Low
			Mill Creek (Walhonding)	Med
Ohio	Muskingum	OH	Muskingum River	Low
			Wakatomika Creek	Low
Ohio	Raccoon - Symmes	OH	Symmes Creek	Med
Ohio	Little Kanawha	WV	West Fork Little Kanawaha River	Low

Major River Basin	Management Unit	Record State	Contiguous Population (occupied river/stream)	Current Condition
			Little Kanawha River	High
			Hughes River	Low
			North Fork Hughes River	Med
			Fink Creek	Low
			Leading Creek	Low
			Reedy Creek	Low
			Spring Creek	Low
			Middle Fork South Fork Hughes River	Low
			South Fork Hughes River	Med
Ohio	Upper Ohio - Shade	OH	Middle Branch Shade River	Low
			East Branch Shade River	Low
		WV/OH	Ohio River (Belleville Pool)	Low
Ohio	Upper Kanawha	WV	Kanawha River	Med
Ohio	Lower Kanawha	WV	Kanawha River	Med
Ohio	Elk River	WV	Elk River (West Virginia)	Med
Ohio	Upper Scioto	OH	Big Darby Creek	Low
			Big Walnut Creek	Low
Ohio	Lower Scioto	OH	Middle Fork Salt Creek	Med
			Scioto River	Low
Ohio	Licking	KY	Licking River	Med
Ohio	Middle Fork Kentucky	KY	Middle Fork Kentucky River	Low
Ohio	South Fork Kentucky	KY	South Fork Kentucky River	Med
			Red Bird River	Low

Major River Basin	Management Unit	Record State	Contiguous Population (occupied river/stream)	Current Condition
Ohio	Upper Kentucky	KY	Red River	Low
			Kentucky River	Low
Ohio	Tippecanoe	IN	Tippecanoe River	Med
Ohio	Eel (Wabash)	IN	Eel River	Low
Ohio	Lower White	IN	Richland Creek	Med
Ohio	Upper Green	KY	Green River	Med
Ohio	Barren	KY	Barren River	Low
Cumberland	Upper Cumberland - Lake Cumberland	KY	Buck Creek	Low
Cumberland	Rockcastle	KY	Rockcastle River	Low
Tennessee	Wheeler Lake	AL	Paint Rock River	Med
Tennessee	Lower Tennessee – Beech	TN	Tennessee River (Kentucky Reservoir)	Low
Tennessee	Upper Elk	TN	Elk River (Tennessee)	Low
Tennessee	Upper Duck	TN	Duck River	High
Tennessee	Buffalo	TN	Buffalo River	Low
Lower Mississippi	Upper Big Black	MS	Big Black River	Low

Condition category tables are a structured way to assess the current and future state of populations based on specific variables related to the ability of populations to adapt to changing environmental conditions and withstand stochastic or catastrophic events. Condition category tables are a transparent way to illustrate to the public which variables we are assessing and how these variables contribute to the overall status of populations. The tables allow us to weigh the variables differently depending on the importance of a variable to the species ecology. Using condition category tables is a common Service practice in SSAs when further quantitative methods to assess population risk on a continuous scale may be inappropriate due to insufficient data. Assigning condition or health based on multiple criteria, which is what the condition table does, is common in a variety of applications, such as: NatureServe's element occurrence rank, International Union for Conservation of Nature's (IUCN) red list criteria, risk level in IUCN Red List criteria, and indices of biological integrity (IBI)[7].

The Great Lakes basin has seven extant populations. Of these, the Grand River is in high condition, and a stronghold population. Mill Creek, a tributary to the Grand River, and contained within the same MU, is in medium condition, and the remaining five populations are in low condition. One MU, containing only low condition populations (Pine, Belle, and Black rivers) remains in Michigan. Only one population, Fish Creek, remains in the St. Joseph MU, which formerly harbored as many as seven populations, and the Round Hickorynut was considered common in locations (Clark and Wilson 1912, p. 21).

Of the 50 extant populations in the Ohio River basin, where the species has the largest number of populations and MUs both historically and presently, 35 (70 percent) currently have a low population condition. The majority of these low condition populations are small in extent and have a high magnitude of threats associated with impoundments, nonnative species, agriculture, and resource extraction. The Ohio River basin has 13 populations (26 percent) that are medium condition, including Symmes Creek, and the Licking, Tippecanoe, and Elk rivers, within the states of Ohio, Kentucky, Indiana, and West Virginia.

The Ohio basin has two high condition populations: Middle Island Creek and the Little Kanawha River in West Virginia, which are currently under a high level of threats predominantly due to resource extraction issues, which are degrading habitat and water quality (Downing *et al*. 2013, p. 12; WVDNR 2016, p. 35). Despite the abundance and distribution of Round Hickorynut in the Elk River, West Virginia, recruitment has not been documented in any mussel species since 2004 in the vicinity of Sutton, implicating water quality degradation as a factor (ESI 2009, p. 21).

Mussel monitoring in Middle Island Creek and the Little Kanawha River has indicated evidence of reproduction but a high level of threats associated with oil and gas resource extraction (WVDNR 2016, p. 38). Additionally, the Round Hickorynut is extirpated from streams in the MUs where these populations occur, and are bordered by low condition populations, therefore; despite containing high condition populations, the overall MUs (Little Muskingum-Middle Island and Little Kanawha) are not considered a stronghold for the species. However, the future viability of the Round Hickorynut, specifically in the Ohio Basin, is strongly reliant on this state, because it harbors 25 populations, more than any other state, and 7 MUs are within or intersect the state.

There are currently two populations and MUs in the Cumberland River basin: Buck Creek and Rockcastle River in Kentucky, both of which are in low condition. These populations are isolated from one another by Wolf Creek Reservoir and are threatened by siltation and sedimentation issues resulting from agriculture, forestry, and resource extraction, including coal mining and instream gravel mining (Blankenship and Crockett 1972, p. 37; Schuster *et al*. 1989,

---

[7] These examples are detailed at the following three internet sites:
http://help.natureserve.org/biotics/Content/Record_Management/Element_Occurrence/EO_Rank_a_species_EO.htm
http://www.iucnredlist.org/static/categories_criteria_3_1
https://www.pugetsoundstreambenthos.org/BIBI-Scoring-Types.aspx

p. 84; Cicerello 1993, p. 8; Hagman 2000, p. 35). Wolf Creek Dam, completed in 1951 by the US Army Corps of Engineers (Corps), and continued operation of the impoundment, has completely transformed the middle Cumberland River drainage. This transformation has resulted in a loss of approximately 50 percent of the mainstem riverine mussel fauna and recruitment failure of any species that are able to remain (Miller *et al*. 1984, p. 109; Haag and Cicerello 2016, pp. 14, 52). There are no populations remaining within the Tennessee portion of the Cumberland basin, and there are no high or medium condition populations of Round Hickorynut in the Cumberland basin.

The Tennessee River basin has five extant populations, including in the Tennessee, Buffalo, and Elk rivers, which are in low condition, the Paint Rock River, which is in medium condition, and the Duck River that is in high condition. The low condition populations have a moderate level of threats, primarily related to impoundment, agriculture, and resource extraction issues associated with sand and gravel dredging (Ahlstedt *et al.* 2005, p. 2; Reed 2014, p. 6). Commercial sand and gravel dredging, conducted on the Lower Tennessee River since at least the 1920's, and currently permitted on approximately 48 of the 95 river miles (RM), has degraded a significant portion of the available aquatic habitat. Significantly lower mussel abundance and diversity values have been observed at dredge sites, indicating bottom substrates altered by dredging and resource extraction operations do not provide suitable habitat to support mussel populations similar to those found inhabiting non-dredged reaches (Hubbs *et al.* 2006, p. 169).

The Duck River in Tennessee harbors incredible aquatic diversity, and although it has a stronghold population of Round Hickorynut, is under substantial threats associated with rapid urban development, land use changes, incompatible agricultural practices, wastewater management, water supply practices, and resource extraction activities (Corps, 2018, p. 2). Further, many developed communities in the watershed are experiencing periodic flooding which is only expected to worsen as development continues, and water quality and water supply are significant long-term resource management issues. The watershed's aquatic and terrestrial life is experiencing stress from increased development, hydraulic regime changes, and declining suitable habitats. Forty-six of the 64 watersheds were experiencing major to severe ecological disturbance compared to 15 watersheds experiencing minimal to minor ecological disturbance (Corps 2018, p. 2).

Although improvements in discharge and dissolved oxygen at Normandy Dam on the Duck River have improved water quality, aquatic habitats are fragmented by several low head mill dams and flows are altered through agricultural activities such as irrigation (Ahlstedt *et al.* 2017, p. 4). None of the formerly inhabited upper tributaries are currently occupied by the Round Hickorynut (Irwin and Alford 2018, p. 66). Water quality problems in the Duck River stem from agriculture; including riparian buffer alteration, bank erosion, sedimentation, nutrient loading, low dissolved oxygen, and land management. Water supply problems are controversial because a high quality and quantity water flow is essential for both supporting rare aquatic species and meeting the basin's growing municipal water demands (Corps 2018, p. 2). Agricultural activities, impoundment, and human development are the greatest threats to this population and the Upper Duck MU.

The Lower Mississippi River basin is home to a lone extant population, which is highly vulnerable to stochastic events due to its linear orientation, limited extent, and severe isolation from populations in other basins. The Big Black River population is considered to be in low condition with a high level of threats predominantly focused on river channel and habitat stability as well as extensive erosion and sedimentation resulting from intensive agriculture in the 1900s (Hartfield and Rummel 1985, p. 119; Hartfield 1993, p. 133; Jones *et al*. 2005, p. 80).

The overall current condition of the Round Hickorynut indicates the species has limited resiliency: 45 of the 65 populations (69 percent) are in low condition compared to 4 populations (6 percent) in high condition. Due to the imminent threats of mining and natural gas exploration in West Virginia, there are only two stronghold MUs (Grand and Upper Duck). Threats that are acting upon the high condition populations (Grand River in Ohio, Middle Island Creek and Little Kanawha River in West Virginia, the upper Duck River in Tennessee) include habitat and water quality degradation. The introduction of contaminants resulting from agriculture, fragmentation due to impoundment, human development pressures such as wastewater treatment discharges, irrigation, and mining, and oil and gas exploration are contributors to these threats (Tennessee Wildlife Resources Agency [TWRA] 2016, p. 18; Buchannan *et al*. 2017, p. 37).

In terms of abundance, the densest population is the Duck River in Tennessee (TWRA 2016, p. 33). However, the extent of this population is restricted to the upper Duck River, limited to a reach downstream of Lillard's Mill Dam. Despite high estimated abundances within this reach, the species is generally uncommon in the upper Duck River (Ahlstedt *et al*. 2017, p. 59). The population is linear in orientation in the upper portion of the river, and isolated from the Buffalo River population, fragmented by multiple mill dams. This current linear orientation is a reduction from its former dendritic occupation in tributaries such as Big Rock Creek, and the species has decreased in its overall population extent since the 1980s (Ahlstedt *et al*. 2017, pp. 144–147).

In terms of extent, the largest distributed Round Hickorynut population is within the Grand River in Ohio. This population does not attain the high densities of the Duck River population, and a large impoundment in the lower reaches (Harpersville Dam) affects available habitat by altering flows and thermal regimes and reducing connectivity, limiting dispersal of the species. Surveys have documented a decline in abundance in the lower reaches, and the majority of occurrences are within Ashtabula County, Ohio (Huehner 1996, p. 6; Huehner 1997, p. 16; Huehner 1999, p. 10; Huehner *et al.* 2005, pp. 59, 61). A medium condition population occurs in Mill Creek, and at the mouth of Rock Creek, which are tributaries to the Grand River, but confined to the lower reaches in Ashtabula County (Grabarkiewicz 2014, p. 10). Impoundment, human development pressures, agriculture, and nonnative species are the greatest threats to this population and the Grand MU.

Resource extraction reduces the condition of the MUs where there are high condition populations in the Ohio Basin. Stressors exerted on the species affect the stronghold populations and MUs in the Great Lakes and Tennessee basins. Pervasive stressors include impoundments, which separate these high condition populations from others within the Cumberland and Lower Mississippi basins. The resulting isolation and lack of connectivity decreases dispersal capability and increases vulnerability, and the potential for genetic isolation. Nonnative species, such as the Zebra Mussel, are an imminent threat to portions of the Great Lakes and Ohio River basin populations in particular, and water quality and habitat degradation resulting from agriculture, resource extraction, and human development (urbanization) act cumulatively as stressors on Round Hickorynut populations throughout its range.

5.3.2 Representation

Representation refers to the breadth of genetic or environmental diversity within a species and reflects the ability of a species to adapt to changing environmental conditions. The greater the diversity, the more successfully a species can respond to changing environmental conditions. In the absence of genetic data for the Round Hickorynut, we considered environmental diversity across the species range. The best available data indicate five representative units (i.e., five major river basins) where Round Hickorynut is currently found: the Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi basins.

Since there is very little genetic information available for the Round Hickorynut, we considered geographic range as a surrogate for geographic variation and proxy for potential local adaptation and adaptive capacity. We used hydrographic (management) units (at the basin level; see additional discussion in Chapter 2) to define representation because watershed boundaries and natural and artificial barriers constrain ecological processes, such as genetic exchange, and ultimately adaptive capacity, for aquatic species (Funk *et al*. 2018, p. 14).

The Round Hickorynut has one remaining population and MU in the Lower Mississippi basin, in the Big Black River, Mississippi, but museum records indicate that there were at least 9 populations and seven MUs in the basin historically (Appendix D). The population has moderate density, but is small in extent, linear, and severely fragmented from other basin populations such as the Tennessee and Ohio, limiting genetic exchange. Therefore, the Round Hickorynut is on the verge of already being reduced from five to four major river basins (a 20 percent reduction) compared to historical information. A high priority should be given to a range-wide genomics study of the Round Hickorynut to better understand this issue. Genomics could be used to promulgate recovery strategies for the species as well as other imperiled mussels that share a similar distributional pattern, such as the Rabbitsfoot, Snuffbox, Sheepnose, and Pyramid Pigtoe.

The Round Hickorynut has two remaining populations and MUs in the Cumberland River basin, both in low condition. The Cumberland basin once had 25 populations in 12 MUs across Kentucky and Tennessee. There are no Cumberland basin populations remaining in the state of Tennessee. The best available information suggests the Round Hickorynut has experienced significant declines within the basin (Schuster 1988, p. 668; Haag and Cicerello 2016, p. 178). It no longer occurs in the Cumberland River mainstem where it was abundant below Cumberland Falls (Neel and Allen 1964, p. 442; Casey 1985, p. 129). The remaining populations are isolated from one another by Wolf Creek Reservoir and experience a high level of threats. These threats are primarily associated with resource extraction and agriculture, as well as loss of habitat due to reservoir influence in lower Buck Creek and Rockcastle River. Mussels are incapable of migrating to more desirable environments (see Chapter 3, above). Therefore, when evaluating the current condition of the Lower Mississippi and Cumberland River basin populations combined, the species is at immediate risk of losing 40 percent of major river basin representation.

As evaluated by major river basin, the current distribution of the Round Hickorynut across its range currently reflects no decrease from historical representation, as the speices is still found in five major basins. However, the Lower Mississippi River basin is represented by only one population, and the Cumberland River basin is at immediate risk of extirpation due to two small, isolated populations under a high level of threats. Both of these basins have lost large numbers of populations since the turn of the 20th century, many since the 1960s (Appendix D). The variety of trend information available across its range (i.e., loss of populations in tributaries or major river systems, declines in population extent and size in portions of the species range) indicate that the Round Hickorynut's overall ability to adapt to changing environmental conditions is minimal. This is largely due to pervasive human alteration of habitats, such as the construction and operation of impoundments.

5.3.3 Redundancy

Redundancy refers to the number of populations of a species and their distribution across the landscape, reflecting the ability of a species to survive catastrophic events. The greater the size or number of populations, and the more widely they are distributed, the lower the likelihood a single catastrophic event will cause a species to become extinct. For a wide-ranging species such as the Round Hickorynut, a single catastrophic event that affects the species throughout its range is unlikely, and therefore the redundancy metric is potentially less informative than resiliency and representation metrics.

Round Hickorynut populations are widely distributed over nine states, and the redundancy metric used in this SSA is number of populations (Table 5-5, Appendix A). The Great Lakes basin contains 7 populations and 4 MUs; the Ohio River basin contains 50 populations and 22 MUs; the Cumberland River basin contains 2 populations and 2 MUs; the Tennessee River basin contains 5 populations and 5 MUs; while the Lower Mississippi River basin contains 1 population and MU. The numbers of extirpated populations and MUs by river basin are: 25 populations (16 MUs) in the Great Lakes basin, 146 populations (58 MUs) in the Ohio River basin, 23 populations (10 MUs) in the Cumberland River basin, 29 populations (13 MUs) in the Tennessee River basin; and 9 populations (7 MUs) in the Lower Mississippi River basin.

Given the current status encompasses 65 populations and 34 MUs throughout its range in the U.S., the species currently retains adequate redundancy for withstanding and surviving potential catastrophic events. However, it is important to note that a high percentage (69 percent; 45 of the 65 populations) are currently in low condition (*i.e.*, very small and restricted in linear extent with no evidence of recruitment). The Round Hickorynut has lost 232 of its 297 populations in the US, and 104 of its 138 MUs compared to historical conditions. Overall, the species has decreased redundancy across its range compared to its historical levels due to extirpation of an estimated 78 percent of populations and 75 percent of MUs.

5.4 Uncertainties of Current Condition

For a wide-ranging species with variable data availability across populations, there are many uncertainties including:

- Some gene flow potentially occurs among rivers, streams, and MUs without barriers to connectivity, although the timing and frequency of gene flow among these watersheds is not known, and may be inadequate to maintain genetic diversity among populations, due to distances separating populations or suitable habitat patches.

- Population genetic structure and its variation at differing spatial scales is completely unknown. We assume that the Round Hickorynut populations in large- and medium-sized rivers exhibit relatively larger amounts of within-population genetic variation and less differentiation over large spatial scales than populations in small streams (Berg *et al*. 2007, p. 1,437).

- We acknowledge that specific Round Hickorynut demographic and genetic data to support the approached construct are sparse. However, this approach for assessing the species' condition has been used for other aquatic species in the eastern U.S. and is based on the best available science; therefore, it was considered an acceptable construct for this SSA.

- Many of the populations ranked as low condition have little information available; some have had only one documented collection of the species, with no additional survey data to confirm recent presence or absence.

- Information on threats for such a large distributional range came from a wide variety of sources such as published literature and mussel survey reports. There is a paucity of information available on threats specific to the Round Hickorynut. In most instances, threats were reported as affecting the entire mussel fauna or aquatic fauna in general, but still apply for Round Hickorynut given similar resource needs.

- The level at which climate change is currently affecting populations is poorly understood. Population discontinuity and isolation is possible due to the dynamics in range shifts of the Round Hickorynut and its host fishes (primarily darters) as a result of warming climates, based on life history traits (Archambault *et al*. 2018, p. 880). However, the mechanisms behind these shifts and how they alter population connectivity and gene flow are uncertain, and less likely to be a greater threat than better-studied impacts on water quality and the habitat needs of the species (such as dams).

CHAPTER 6 - FACTORS INFLUENCING VIABILITY

In this chapter, we evaluate past, current, and future factors affecting what the Round Hickorynut needs for long-term viability. Aquatic systems face myriad natural and anthropogenic factors that influence species viability (Neves *et al.* 1997, p. 44; Strayer 2006, p. 272). Generally, these factors can be categorized as either environmental stressors (e.g., development, agriculture practices, forest management, dam operation, regulatory frameworks) or systematic changes (e.g., climate change, invasive species, barriers, and conservation management practices). Current and potential future effects, along with current distribution and abundance, help inform viability, and therefore vulnerability to extinction.

Negative factors influencing the viability of Round Hickorynut are presented below. In addition to describing the potential impacts and sources of each influence (Figure 6-1, below), we present examples from within the species range in an attempt to illustrate the scope and magnitude of the impacts based on the best available scientific and commercial information. Additionally, we present a summary of the beneficial conservation measures (regulatory and voluntary) occurring to reduce the impacts, and if those conservation measures are considered effective.

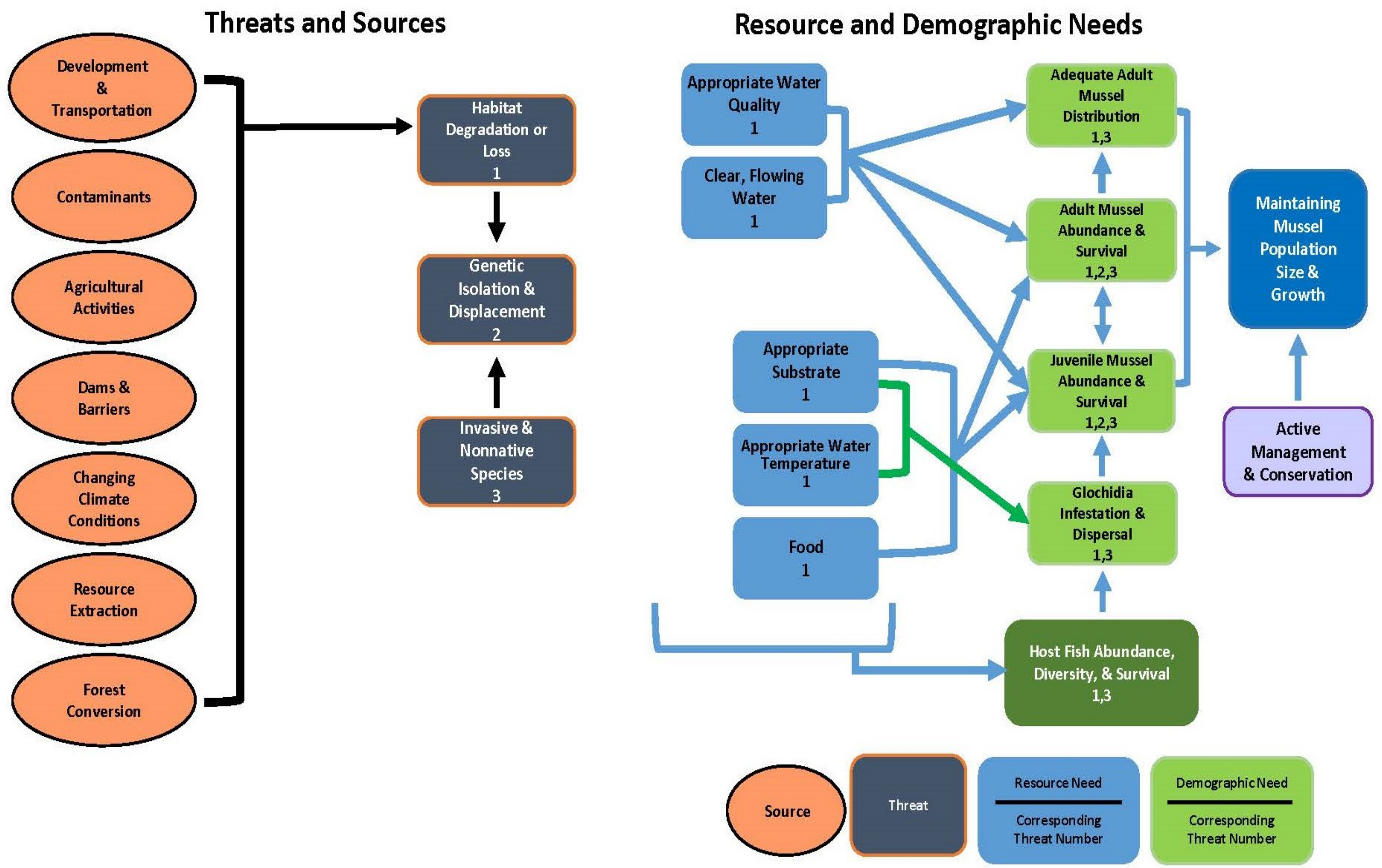

Figure 6-1. Influence diagram for Round Hickorynut, depicting threats, sources of threats, resources needs, and demographic needs.

6.1 Habitat Degradation or Loss

6.1.1 Development/Urbanization

The term "development" refers to urbanization of the landscape, including (but not limited to) land conversion for residential, commercial, and industrial uses and the accompanying infrastructure. The effects of urbanization may include alterations to water quality, water quantity, and habitat (both in-stream and streamside) (Ren *et al.* 2003, p. 649; Wilson 2015, p. 424).

Urban development can lead to increased variability in streamflow, typically increasing the extent and volume of water entering a stream after a storm and decreasing the time it takes for the water to travel over the land before entering the stream (Giddings *et al.* 2009, p. 1). An "impervious surface" refers to all hard surfaces like paved roads, parking lots, roofs, and even highly compacted soils like sports fields. Impervious surfaces prevent the natural soaking of rainwater into the ground and ultimately and gradually seeping into streams (Brabec *et al.* 2002, p. 499). Instead, rainwater accumulates and often flows into storm drains, which rapidly drain to local streams. This results in deleterious effects on streams in three important ways (USGS 2014, pp. 2–5):

(1) *Water Quantity*: Storm drains deliver large volumes of water to streams much faster than would naturally occur, often resulting in flooding and bank erosion that reshapes the channel and causes substrate instability. Increased high velocity discharges can cause species living in streams (including mussels) to be stressed, displaced, or killed by fast moving water and the debris and sediment carried in it. Displaced individuals may be left stranded out of the water once floodwaters recede.
(2) *Water Quality*: Pollutants (e.g., gasoline, oil drips, fertilizers) that accumulate on impervious surfaces may be washed directly into streams during storm events.
(3) *Water Temperature*: During warm weather, rain that falls on impervious surfaces becomes superheated and can stress or kill freshwater species when it enters streams.

Urbanization increases the amount of impervious surfaces (Center for Watershed Protection 2003, p. 1). The resulting storm water runoff affects water quality parameters such as temperature, pH, dissolved oxygen, and salinity, which in turn alters the water chemistry potentially making it inhospitable for aquatic biota. The rapid runoff also reduces the amount of infiltration into the soil to recharge aquifers, resulting in lower sustained streamflow, especially during droughts and dry periods (Giddings *et al.* 2009, p. 1).

Anthropogenic activities may act insidiously to lower water tables, making Round Hickorynut and other mussel populations susceptible to depressed flow levels. Water withdrawals for irrigation, municipal, and industrial water supplies are an increasing concern due to expanding human populations. Water infrastructure development, including water supply, reclamation, and wastewater treatment, results in pollution point discharges to streams. Concentrations of contaminants (including nitrogen, phosphorus, chloride, insecticides, polycyclic aromatic hydrocarbons, and personal care products) increase with urban development (Giddings *et al.* 2009, p. 2; Bringolf *et al.* 2010, p. 1,311).

Utility crossings and right-of-way maintenance are additional aspects of development that affect stream habitats. Direct impacts from utility crossings include direct exposure or crushing of individuals, sedimentation, and flow disturbance. Cleared rights-of-way result in direct runoff and increased stream temperature at the crossing location, and potentially promote maintenance utility and all-terrain vehicle access (which destabilize banks and instream habitat, leading to increased erosion). Maintenance of utility crossings are additional aspects of development that can influence stream habitats. Herbicides and their surfactants used to clear rights-of-way can also have deleterious effects to aquatic organisms (see Contaminants, section 6.1.3, below).

The Duck River population of Round Hickorynut is threatened by development encroaching from the city of Nashville and nearby smaller urban areas (TWRA 2016, p. 15). Regional land development and commerce are cited as threats to the integrity of the aquatic community of the Black River, Ohio (Lyons *et al.* 2007, p. 9). The Tuscarawas River in Ohio, where the Round Hickorynut is extirpated, has been severely degraded by industrial development (Hoggarth 1994, p. 3). The West Branch Mahoning, Olentangy, and Tuscarawas rivers in Ohio, where the species was historically considered common, but now extirpated, have been severely degraded by industrial development (Stein 1963, p. 106; Hoggarth 1994, p. 3). This development continues to affect other freshwater mussels as well as water quality in these MUs, limiting restoration potential for the Round Hickorynut (Welte 2012, p. 8; Haefner and Simonson 2018, p. 1).

The aquatic fauna of the lower Elk and Kanawha Rivers in West Virginia was directly affected by major chemical industries and commercial activity in Charleston, West Virginia, and to some extent legacy effects of these industries remain (Morris and Taylor 1978, p. 153; Taylor 1983, p. 13; WVDNR 2012, p. 12). However, the Kanawha River downstream of the Elk River has improved in water quality from past conditions, and an abundant and diverse mussel population is rebounding, indicating the Kanawha River has potential for recovery (Clayton 2018, pers. comm.).

Domestic and industrial pollution and fertilizer and pesticide runoff were implicated as causes of the mussel decline in the Shenango River, which harbors the sole remaining population of the Round Hickorynut in Pennsylvania (Bursey 1987, p. 43). Excessive sedimentation, wastewater effluents, and sediment toxicity, resulting from human perturbations, are considered current threats to the mussel fauna in the Shenango (Butler 2007, p. 42). Population centers along the Ohio, Cumberland, and Tennessee River main stems, as well as along rivers draining into the Great Lakes, have a long history of human settlement and associated construction within their floodplains, and are experiencing continued development within the Round Hickorynut's range in riparian areas along these rivers (Ohio River Valley Water Sanitation Commission 2016, p. 10). The Ohio River alone provides drinking water to over 5 million people (Ohio River Valley Water Sanitation Commission 2016, p. 15).

While other non-governmental organizations have similar missions, the Nature Conservancy in particular has targeted areas for conservation within some river and stream systems harboring extant populations of the Round Hickorynut. These include the lower Licking River, upper

Green River, and Buck Creek in Kentucky; the Tippecanoe River in Indiana; Big Darby Creek in Ohio; the upper Duck River in Tennessee, and the Paint Rock River in Alabama. Although the Nature Conservancy has few actual riparian inholdings in these watersheds, they have carried out community-based and partner-oriented projects that are intended to address aquatic species and instream habitat conservation. The Nature Conservancy has worked with state and Federal agencies and riparian landowners to help them restore and protect streambanks and riparian zones, and they collaborate with various other stakeholders in conserving aquatic resources.

Various small, isolated parcels of public land (e.g., state parks, state forests, wildlife management areas) lie along rivers and streams where Round Hickorynut occurs. However, vast tracts of riparian lands where Round Hickorynut occurs are privately owned, and the prevalence of privately-owned lands in streams with extant populations is comparatively much larger than the species' occurrence on public land. This will necessitate substantial additional voluntary conservation or maintenance of riparian vegetation for overall protection of stream health. It also somewhat diminishes the level of importance afforded by public lands that may experience various land use restrictions. In other words, activities within riparian vegetation on lands outside or upstream of public-owned lands may be pervasive and have a profound impact on the downstream mussel populations. Habitat protection benefits on public lands may therefore easily be negated by detrimental activities upstream or immediately downstream in a watershed.

The most important public land holding in the Ohio River is the Ohio River Islands National Wildlife Refuge (Refuge). The refuge includes all or parts of 21 islands and 3 mainland tracts totaling 3,220 acres (ac) (1,303 hectares (ha)) in the Ohio River from RM 35 (Shippingport, Pennsylvania) downstream to RM 397 (Manchester, Ohio, and adjacent Kentucky); islands are managed in six Ohio River pools (i.e., New Cumberland, Hannibal, Willow Island, Belleville, Racine, Meldahl). The location of Mammoth Cave National Park also provides a level of localized watershed protection against development pressures for the Round Hickorynut population in the upper Green River, Kentucky.

Portions of several watersheds with Round Hickorynut occur within U.S. Forest Service, lands, some with established riparian buffers (e.g., Middle Fork Kentucky, Red Bird, and Red Rivers, Daniel Boone National Forest, Kentucky). Additionally, the Red River, Buffalo River, and Big Darby Creek have extant Round Hickorynut populations and have been designated National Wild and Scenic Rivers or have similar state status (e.g., Grand River). However, these rivers have experienced water quality impairments despite some level of physical habitat protection. National or State designation typically insures that streams are maintained as free-flowing and limits riparian zone development to compatible activities (e.g., restrictions on zoning and land alterations from development, mining, silviculture).

Increased industrial, commercial, and residential development is more frequently cited as a threat to Round Hickorynut populations in the Great Lakes, and Ohio basins, and may be most likely to negatively affect the species in low condition populations, such as the Shenango River, Black River (Ohio), Black River (Michigan), Big Darby Creek, Scioto River, and Middle Fork Kentucky River. However, these are also a threat to the high condition Duck River population within the Tennessee basin. Increased human population growth projections indicate urban sprawl will affect Round Hickorynut populations in the Great Lakes, Tennessee, Cumberland,

and Ohio basins (Terando *et al.* 2014, p. 7; Tayyebi *et al.* 2015, p. 110). A frequently cited threat to mussels as a result of human development is poor wastewater discharge and point source treatments (ESI 1998, p. 91; ESI 2009, p. 14; see section 6.1.3, Contaminants, below).

The effects of commercial and residential urbanization and development on aquatic communities at large spatial scales are poorly studied (Wheeler *et al.* 2005, p. 162). Extant populations of Round Hickorynut are not concentrated in urban areas with large human occupation on the landscape; therefore, it is the potential rapid expansion of urban and suburban growth into rural and undeveloped areas that is most likely to affect Round Hickorynut populations. It is unknown whether the anthropogenic effects of development and urbanization are likely to impact the species at the individual or rangewide level. However, secondary impacts such as the increased likelihood of potential contaminant introduction, stream disturbance caused by impervious surfaces, barrier construction, and forest conversion are likely to act cumulatively on Round Hickorynut populations.

6.1.2 Transportation

A major aspect of urbanization is the resultant road development. Road development requires land clearing and increases impervious surfaces as well as habitat fragmentation. Roads are generally associated with negative effects on the biotic integrity of aquatic ecosystems, including changes in surface water temperatures and patterns of runoff, changes in sedimentation levels, and increased heavy metals (especially lead), salts, organics, and nutrients to stream systems (Trombulak and Frissell 2000, p. 18). Maintenance of road corridors includes the use of herbicides and the application of chemicals to increase the longevity of the road surfaces. The adding of salts through road de-icing results in high salinity runoff, which is toxic to freshwater mussels. In addition, a major impact of road development is improperly constructed culverts at stream crossings. These culverts act as barriers if flow through the culvert varies significantly from the rest of the stream, or if the culvert ends up being perched, and aquatic organisms, specifically mussel host fishes, cannot pass through them. Improperly installed culverts alter in-stream habitat, and can cause changes in stream depth, resulting in pools upstream and a destabilized channel downstream of the culvert.

Transportation also includes river commerce and river navigation impacts. Dredging and channelization as means of maintaining waterways have profoundly altered riverine habitats nationwide (Ebert 1993, p. 157). Channelization affects many physical characteristics of streams through accelerated erosion, increased bedload, reduced depth, decreased habitat diversity, geomorphic instability, and riparian canopy loss (Hartfield 1993, p. 139). All of these impacts contribute to loss of habitat for the Round Hickorynut, and alter habitats for host fish. Changes in both the water velocity and deposition of sediments not only alters physical habitat, but the associated increases in turbulence, suspended sediments, and turbidity affect mussel feeding and respiration (Aldridge *et al.* 1987, p. 25). High levels of suspended solids also result in low fertilization rates, which lead to reduced reproductive success, and can be an important factor in mussel declines (Gascho-Landis and Stoeckel 2015, p. 229).

Channel construction for navigation is known to increase flood heights, and is attributed to a decrease in stream length and increase in gradient (Hubbard *et al.* 1993, p. 135). As a result, flood events may be exacerbated, conveying into downstream reaches large quantities of sediment, potentially with adsorbed contaminants (see section 6.1.3, below), which covers suitable mussel habitat and adversely affects water quality. Channel maintenance, such as hydraulic (suction) dredging, may result in profound impacts downstream, including increased turbidity that may impede sight-feeding host fishes and sedimentation that smothers juvenile mussels (Ellis 1936, p. 39; Berkman and Rabeni 1987, p. 292). Round Hickorynut populations in the Vermilion and Embarras rivers are extirpated, and populations in the Eel and Killbuck Creek MUs are in low condition. These streams have been extensively dredged and channelized (Gammon and Gammon 1993, p. 78; Butler 2007, p. 63).

Taylor (1983, p. 3) stated that the Kanawha River in West Virginia below RM 79 lacked habitat suitable for freshwater mussels with dredging as a primary cause. The Round Hickorynut persists throughout most of the Kanawha River, but the highest densities are in a reach immediately below Kanawha Falls, which is above the head of navigation (Douglas 2000, p. 5). The Corps has not conducted open channel hydraulic dredging on the Kanawha River recently, but periodically use it, and continue to use clamshell dredges in the upper and lower approaches to lock chambers. Generally, dredging and disposal of dredged material are better managed today to avoid mussel impacts (Clayton 2019, pers. comm.).

Destructive flood control measures such as extensive stream channelization and snag removal have resulted in severe impacts to the freshwater mussel fauna and habitat in the Paint Rock River system, including the lower reaches of Estill Fork and Hurricane Creek, where the Round Hickorynut is considered extirpated (Ahlstedt 1995–96, p. 65). Approximately 20 RMs of Conewango Creek, as well as other portions of the Allegheny River drainage in New York, were channelized and straightened in the first half of the last century (Strayer *et al*. 1991, p. 68). Residual impacts continue based on mussel surveys, which indicate that the resulting dredged areas continue to have no riffle or run habitat (i.e., sufficient flow and habitat as described in section 4.1.1) (Crabtree 2009, p. 19).

Channelization activities, which include channel enlargement, channel realignment, clearing and snagging, and manipulation of banks, were widespread in lowland areas and in the lower reaches of rivers and streams occupied by the Round Hickorynut in the 1900s in the Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi basins (Haag and Cicerello 2016, p. 60). Studies indicate that even if active channelization is not currently ongoing, impacts of these actions can have permanent effects, such as mussel habitat destabilization (Hubbard *et al.* 1993, p. 142). Destabilization may result in altered habitat that may be more suitable for nonnative species, or in some situations elimination of the mussel fauna (Watters 2000, p. 274).

The Rivers and Harbors Act of 1946 authorized the Corps to maintain a navigable channel in rivers such as the Allegheny, Kanawha, Big Sandy, Ohio, Muskingum, Cumberland, and Tennessee to promote and facilitate river commerce. Open channel maintenance may require hydraulic or clamshell (scoop) dredging of the navigation channel and placement of the dredged material (spoil). Dredging and spoil disposal continue to impact habitat for the Round Hickorynut in the Kanawha and Muskingum rivers. These impacts include the reduction of suitable substrates for mussel settlement and growth, and increased suspended sediments and siltation, which adversely affects mussel feeding and respiration (Ebert 1993, p. 157). In addition to dredging and channel maintenance, impacts associated with barge traffic, which includes construction of fleeting areas, mooring cells, docking facilities, and propeller wash, disrupt mussel habitat (Taylor 1983, p. 5; Waters 2000, p. 268). Currently, these navigational activities affect at least five (8 percent) Round Hickorynut populations in the Ohio basin, which has seen a greater loss and decline of populations and MUs than any other basin.

Although most prevalent on the mainstem Ohio and Tennessee Rivers, commerce and commercial navigation currently affect Round Hickorynut populations in the Black and Muskingum rivers. These navigational impacts also previously affected the species to a greater extent in the lower Allegheny, lower Kanawaha, Big Sandy, and lower Green and Barren Rivers, where commercial navigation is now closed or reduced to localized areas, or the Round Hickorynut is considered extirpated. While direct impacts of navigation such as barge traffic are more likely to affect individual mussels, the scope of channel maintenance activities over extensive areas alters physical habitat and degrades water quality, which affects the species at the population level.

Currently, the remaining Ohio River mainstem Round Hickorynut populations in Belleville and Willow Island Pools, which are considered in low condition, are negatively affected by channel maintenance and navigation operations by direct alteration of the substrate and increasing total suspended solids. The exact density of this Ohio River population is uncertain due to challenges associated with surveying large river habitats, but areas around Neal Island within the Ohio River Islands refuge appear to support the best habitat remaining for the species (Clayton and Morrison 2014, p. 12).

The Ohio River Islands Refuge affords some protection from river commerce and navigation activities, but museum data indicate the Round Hickorynut probably occurred throughout the Ohio River (Watters and Flaute 2000, p. 11; Haag and Cicerello 2016, p. 179). Given its isolation by impoundments upstream and downstream, small extent and density, and exposure to significant threats, Round Hickorynut is considered a high priority species for restoration, but the opportunities for population expansion are limited (Service 2013, p. 45).

6.1.3 Contaminants

Contaminants contained in point and non-point discharges can degrade water and substrate quality and adversely impact mussel populations. Although chemical spills and other point sources of contaminants may directly result in mussel mortality, widespread decreases in density and diversity may result in part from the subtle, pervasive effects of chronic, low-level contamination (Naimo 1995, p. 354). The effects of heavy metals, ammonia, and other contaminants on freshwater mussels were reviewed by Mellinger (1972), Fuller (1974), Havlik and Marking (1987), Naimo (1995), Keller and Lydy (1997), and Newton *et al.* (2003).

The effects of contaminants from metals, chlorine, and ammonia are profound on juvenile mussels (Augspurger *et al.* 2003, p. 2,571; Bartsch *et al.* 2003, p. 2,566). Juvenile mussels may readily ingest contaminants adsorbed to sediment particles while pedal feeding (Newton and Cope 2007, p. 276). These contaminants also affect mussel glochidia, which are sensitive to some toxicants; this has been displayed on the Clinch River, where the Round Hickorynut is currently considered extirpated, but it formerly occurred in the Tennessee section of the river (Goudreau *et al.* 1993, p. 221; Jacobson *et al.* 1997, p. 2,386; Valenti *et al.* 2005, p. 1,243). The effects of ammonia on mussels may be aggravated in the future due to the expected effects of climate change, in part due to human population growth and increased concentrations associated with point source discharges.

Mussels are noticeably intolerant of heavy metals (Havlik and Marking 1987, p. 4). Even at low levels, certain heavy metals may inhibit glochidial attachment to fish hosts. Cadmium appears to be the heavy metal most toxic to mussels (Havlik and Marking 1987, pp. 4–9), although chromium, copper, mercury, and zinc also negatively affect biological processes (Naimo 1995, p. 355; Jacobson *et al.* 1997, p. 2,389; Valenti *et al.* 2005, p. 1,243). Long-term declines and extirpation of mussels from the Clinch River in Virginia have been attributed to copper and zinc contamination originating from wastewater discharges at electric power plants (Zipper *et al.* 2014, p. 9). This highlights that despite localized improvements, these metals can stay bound in sediments, affecting recruitment and densities of the mussel fauna for decades (Price *et al.* 2014, p. 12; Zipper *et al.* 2014, p. 9).

To the best of our knowledge, heavy metals and their toxicity to mussels have been documented in the Great Lakes, Clinton, Muskingum, Ohio, Fox, Clinch, and Tennessee Rivers where the Round Hickorynut either currently occurs or formerly occurred (Havlik and Marking 1987, pp. 4–9; van Hees *et al.* 2010, p. 606). Shell concentrations of manganese, a contaminant from coal mine wastes that is negatively correlated with freshwater mussel survival and biomass (Archambault *et al.* 2017, p. 402), and potentially assimilated by mussels as a replacement of calcium during growth, was documented at high levels in the Muskingum River, Ohio (Havlik and Marking 1987, p. 8). Coal plants are also located on the Kanawha, Green, and Cumberland Rivers, and the effects of these facilities on water quality and the freshwater mussel fauna, including the Round Hickorynut, are likely similar.

Among pollutants, ammonia warrants priority attention for its effects on mussels. It has been shown to be lethal to juveniles at concentrations as low as 0.7 ppm total ammonia nitrogen, normalized to pH 8 (range = 0.7–19.7 ppm) and lethal to glochidia at concentrations as low as 2.4 ppm total ammonia nitrogen, normalized to pH 8 (range = 2.4–10.4 ppm) (Augspurger *et al.* 2003, p. 2,574). The un-ionized form of ammonia is the most toxic to aquatic organisms, although the ammonium ion form may contribute to toxicity under certain conditions (Newton 2003, p. 1). Documented toxic effects of ammonia on freshwater bivalves include reduced survival, reduced growth, and reduced reproduction (Augspurger *et al.* 2003, p. 2,575; Mummert *et al.* 2003, p. 2,522). Ammonia has also been shown to cause a shift in glucose metabolism and to alter mussel's metabolic use of total lipids, phospholipids, and cholesterol (Chetty and Indira 1994, p. 693).

Sources of ammonia are agricultural (e.g., animal feedlots and nitrogenous fertilizers), municipal (e.g., outdated water treatment plants and industrial waste products), and from natural processes (e.g., precipitation and decomposition of organic nitrogen) (Goudreau *et al.* 1993, p. 222; Augspurger *et al.* 2003, p. 2,575; Newton 2003, p. 2,543). Toxic effects of ammonia are more pronounced at higher pH and water temperature because the level of the un-ionized form increases as a percentage of total ammonia (Mummert *et al.* 2003, p. 2,545; Newton 2003,

p. 2,544). Therefore, this contaminant may become more problematic for juvenile mussels during low flow, high temperature periods (Cherry *et al.* 2005, p. 378).

In stream systems, ammonia frequently is at its highest concentrations in interstitial spaces where juvenile mussels live and feed, and may occur at levels that exceed water quality standards (Frazier *et al.* 1996, p. 97; Cooper *et al.* 2005, p. 392). The U.S. Environmental Protection Agency (EPA) established ammonia water quality criteria (EPA 1985, entire) that may not be protective of mussels (Augspurger *et al.* 2003, p. 2,571). Ammonia is considered a limiting factor for survival and recovery of some mussel populations due to its high level of toxicity and because the highest concentrations occur in their microhabitats (Augspurger *et al.* 2003, p. 2,569).

Other common contaminants associated with households and urban areas, particularly those from industrial and municipal effluents, may include heavy metals, chlorine, phosphorus, and numerous other toxic compounds. Pharmaceuticals, hormones, and other organic wastewater contaminants were detected downstream from urban areas and livestock production (Kolpin *et al.* 2002, p. 1,208). These wastewater contaminants (82 of the 95 tested for) originated from a wide range of residential, industrial, and agricultural sources, and some are known to have deleterious effects on aquatic organisms (Kolpin *et al.* 2002, p. 1,210). Wastewater is discharged through National Pollutant Discharge Elimination System (NPDES)-permitted (and some non-permitted) sites throughout the country. In the Tennessee River basin, high counts of coliform bacteria originating from wastewater treatment plants have been documented, and degradation of water quality is a primary threat to aquatic fauna in (Neves and Angermeier 1990, p. 50).

The toxic effects of high salinity wastewater from oil and natural gas drilling on juvenile and adult freshwater mussels were observed in the Ohio River basin (Patnode *et al.* 2015, p. 55). Extraction of petroleum produces water with high chlorine concentrations, to which all stages of freshwater mussels are highly sensitive (Patnode *et al.* 2015, p. 56). The degradation of water quality as a result of land-based oil and gas drilling activities is a significant adverse effect on freshwater mussels, including the Round Hickorynut in the Ohio River basin. Populations in West Virginia, specifically in Middle Island Creek, and the West Fork, Kanawha, Little Kanawha, and Elk River systems, are under imminent threat of these actions (Clayton 2018, pers. comm.).

Chemical spills occur often and are devastating for isolated populations of rare, relatively immobile species with limited potential for recolonization, such as mussels (Wheeler *et al.* 2005, p. 155). Numerous streams throughout the range of the Round Hickorynut have experienced mussel and fish kills from toxic chemical spills, including Fish Creek, Indiana (Sparks *et al.* 1999, p. 12). The species no longer occurs in the Indiana portion of Fish Creek where the spill occurred and remains in low condition in the Ohio portion of Fish Creek. Contaminants from failing septic systems have been a problem in the headwaters of Richland Creek in Indiana, affecting one of three remaining populations of Round Hickorynut in the state (Grossman *et al*. 2013, p. 29).

Belleville Pool, which harbors one of the last two remaining populations of Round Hickorynut in the mainstem Ohio River, had a devastating mussel kill in 1999 as a result of contaminant spills from a ferro-alloy manufacturing facility, which negatively affected over 30 RM (Service 2007, p. 2). At the source of the spill there was 100 percent mortality of mussels in the right half (right downstream bank) of the Ohio River (Service 2007, p. 4). At the bend downstream of the spill in the Ohio River, more mixing occurred and eventually affected the entire width of river. An estimated 990,000 were mussels killed, including the Round Hickorynut (ESI 2015, p. 6; Service 2007, p. 5). However, only a few known mussel beds were assessed following this event, and many more mussels were likely adversely affected if not killed.

Catastrophic pollution events, coupled with pervasive sources of contaminants from municipal and industrial pollution and coal-processing wastes, have contributed to the decline of the Round Hickorynut and other mussel species (Havlik and Marking 1987, p. 6). Sediment from the Clinch River was found to be toxic to juvenile mussels, which has contributed to the decline and lack of recruitment of mussels in the Virginia portion of the river, implicating these spills in their lasting effects on not only aquatic species but also riverine habitat (Ahlstedt and Tuberville 1997, p. 74; Price *et al.* 2014, p. 855). Chemical spills will invariably continue to occur and have the potential to reduce or eliminate Round Hickorynut populations.

Spills of hazardous or toxic materials are an ongoing problem associated with commercial navigation and river-oriented industry, and a threat to freshwater mussels. Activities and areas of particular concern include vessel fueling operations (including midstream), barge loading/off-loading operations, queuing areas, and river reaches with heavy debris (Miller *et al.* 1989, p. 15). Spills also may damage or contaminate nearshore and depth-transitional areas where mussel beds are common (Miller and Payne 1998, p. 184).

Section 401 of the Federal CWA requires that an applicant for a Federal license or permit provide a certification that any discharges from the facility will not degrade water quality or violate water-quality standards, including those established by states. Section 404 of the CWA establishes a program to regulate the discharge of dredged and fill material into waters of the United States.

Permits to fill wetlands and fill, culvert, bridge, or re-align streams or water features are issued by the Corps under Nationwide Permits, Regional General Permits, or Individual Permits.

- *Nationwide Permits* are for "minor" impacts to streams and wetlands, and do not require an intense review process. These include stream impacts under 150 ft (45.7 m), and wetland fill projects up to 0.50 ac (0.2 ha). Mitigation is usually provided for the same type of wetland or stream affected, and is usually at a 2:1 ratio to offset losses and make the "no net loss" closer to reality.
- *Regional General Permits* are for various specific types of impacts that are common to a particular region; these permits will vary based on location in a certain region/state.
- *Individual Permit*s are for the larger, higher impact and more complex projects. These require a complex permit process with multi-agency input and involvement. Impacts in these types of permits are reviewed individually and the compensatory mitigation chosen may vary depending on project and types of impacts.

State and Federal Water Quality Programs

Current state regulations regarding pollutants are designed to be protective of aquatic organisms; however, unionids may be more susceptible to some pollutants than the test organisms commonly used in bioassays. Additionally, water quality criteria may not incorporate data available for freshwater mussels (March *et al.* 2007, pp. 2,066–2,067). A multitude of bioassays conducted on 16 mussel species (summarized by Augspurger *et al.* 2007, pp. 2,025–2,028) show that freshwater mollusks are more sensitive than previously known to some chemical pollutants, including chlorine, ammonia, copper, fungicides, and herbicide surfactants. Another study found that nickel and chlorine were toxic to a federally threatened mussel species at levels below the current criteria (Gibson 2015, p. 90). The study also found mussels are sensitive to sodium dodecyl sulfate, a surfactant commonly used in household detergents, for which water quality criteria do not currently exist.

Several studies have demonstrated that the criteria for ammonia developed by the EPA in 1999 were not protective of freshwater mussels (Augspurger *et al.* 2003, p. 2,571; Mummert *et al.* 2003, pp. 2,548–2,552; Newton *et al.* 2003, pp. 2,559–2,560). However, the EPA revised its recommended criteria for ammonia in 2013 after having considered newer toxicity data on sensitive freshwater mollusks. Adoption of the new ammonia criteria varies by state in the range of the Round Hickorynut (August 22, 2013; 78 FR 52192). NPDES permits are valid for 5 years; thus, even after the new criteria are adopted, it could take several years before facilities must comply with the new limits.

Despite regulations by existing authorities such as the CWA, pollutants continue to impair the water quality in portions of the Round Hickorynut's range. State and Federal regulatory mechanisms have helped reduce the negative effects of point source discharges since the 1970s, yet these regulations are difficult to monitor and implement. Although new water quality criteria are under development that will take into account more sensitive aquatic species, most current criteria do not. It is expected that several years will be needed to implement new water quality criteria throughout the Round Hickorynut's range.

6.1.4 Agricultural Activities

6.1.4.1 Nutrient Pollution

Farming operations, including concentrated animal feeding operations, can contribute to nutrient pollution when not properly managed (EPA 2016, entire). Fertilizers and animal manure, which are both rich in nitrogen and phosphorus, are the primary sources of nutrient pollution from agricultural sources. If fertilizers are not applied properly, at the right time of the year and with the right application method, water quality in the stream systems can be affected. Excess nutrients affect water quality when it rains or when water and soil containing nitrogen and phosphorus wash into nearby waters or leach into groundwater.

Excess nitrogen and phosphorus may cause algal blooms in surface waters (Carpenter *et al.* 1998, entire). Fertilized soils and livestock can be significant sources of nitrogen-based compounds like ammonia and nitrogen oxides (Carpenter *et al.* 1998, entire). Ammonia can be harmful to aquatic life if large amounts are deposited to surface waters (see section 6.1.3, Contaminants, above). The lack of stable stream bank slopes from agricultural clearing or the lack of stable cover crops between rotations on farmed lands can increase the amount of nutrients that enter nearby streams by way of increased soil erosion (cover crops and other vegetation will use excess nutrients and increase soil stability) (Barling and Moore 1994, p. 543). Livestock often use streams or artificial in-line ponds as a water source, which degrades water quality and stream bank stability and reduces water quantity available for aquatic fauna, like the Round Hickorynut, that may occur downstream from these agricultural activities.

6.1.4.2 Pumping for Irrigation

Irrigation is the controlled application of water for agricultural purposes through manmade systems to supply water requirements not satisfied by rainfall. It is common practice to pump water for irrigation from adjacent streams or rivers into a reservoir pond, or spray it directly onto crops. If the water withdrawal is excessive, this may cause impacts to the amount of water available to downstream sensitive areas during low flow months, resulting in dewatering of channels and stranding of mussels.

Some water withdrawal is done illegally (without permit if needed, or during dry time of year, or in areas where sensitive aquatic species occur without consultation). Currently, water withdrawals for irrigation are an imminent threat to Round Hickorynut populations in all basins in which it occurs, and are particularly detrimental to the high condition Duck River population (Corps 2012, p. 34). Water withdrawals for irrigation for agricultural uses have increased recently in the Tippecanoe River (Fisher 2019, pers. comm.), and when combined with drought, have combined impacts to surface waters which affect resource needs for the Round Hickorynut such as clean, flowing water (see Chapter 4).

6.1.4.3 Agriculture Exemptions from Permit Requirements

Normal farming (practices consistent with proper, acceptable customs and standards), silviculture, and ranching activities are exempt from the Section 404 permitting process under the CWA. This includes activities such as construction and maintenance of farm ponds, irrigation ditches, and farm roads. If the activity might affect rare aquatic species, the Corps requires farmers to ensure that any "discharge shall not take, or jeopardize the continued existence of a threatened or endangered species, or adversely modify or destroy the critical habitat of such species," and to ensure that "adverse impacts to the aquatic environment are minimized." However, the Corps does not require farmers to consult with appropriate State or Federal Agencies regarding these sensitive species, and agricultural Best Management Practices (BMPs) generally are not required unless applicants receive Federal grant funds; therefore, compliance is sporadic.

Agricultural impacts have been documented in streams where Round Hickorynut occurs. In the Ohio River basin, sedimentation and other point and non-point source pollution, primarily of agricultural origin, are identified as a primary threat to aquatic fauna of Big Darby Creek and Killbuck Creek, Ohio (Ohio EPA 2004, p. 1; Ohio EPA 2011, p. 31). Water quality problems in the North Fork Hughes River associated with agricultural runoff and livestock in and near stream were suggested as potential reasons for lack of unionids at survey sites, and indicate the long-term survival of the Round Hickorynut may be in jeopardy (ESI 1993, p. 19). Approximately 25 percent of the land use area in the West Fork River MU in West Virginia is in agriculture, and has increased by as much as 9 percent in recent years (US Department of Agriculture [USDA] 2010, p. 8). In the Richland Creek watershed in Indiana, agricultural impacts in riparian areas, such as bank erosion, which can result in increased suspended solids and turbidity, have led to water quality impairment (Indiana Department of Environmental Managment [IDEM] 2012, p. 9). Agricultural impacts have been noted to take a toll on mussel fauna in the Goose Creek watershed on the South Fork Kentucky River, where the Round Hickorynut is extirpated (Evans 2010, p. 15).

Deep alluvial soils, temperate climates, and production potential have facilitated the dramatic modification of the Mississippi Delta through intensive agricultural practices, where Round Hickorynut is considered extirpated (Mitchell and Peacock 2014, p. 629; Peacock *et al.* 2016, p. 121). Large-scale mechanized agricultural practices threaten the last remaining population in the Lower Mississippi River basin, in the Big Black River, where the species has already undergone range reduction (Peacock and James 2002, p. 123). The Duck, Buffalo, and Elk Rivers in Tennessee are watersheds with significant agricultural activity in their headwaters and tributaries and are a suspected cause for mussel community declines throughout those rivers (Reed 2014, p. 4). Conversion of agricultural land for suburban development is increasing at rapid rates in these watersheds (Woodside *et al.* 2004, p. 10; TWRA 2011, p. 13; Irwin and Alford 2018, p. 40).

Channelization associated with the draining of agricultural fields is a concern for the species, including, for example, significant permanent negative impacts on stream habitats in Indiana, including streams in the Mississinewa River drainage, where the Round Hickorynut is extirpated (Lau *et al.* 2006, p. 324). Specifically, the loss of riffle and pool habitats as a result of modification causes a lack of variable stream width, depth, flow, substrates and vegetative cover, and creates homogeneous habitats that do not support diverse fish assemblages (Lau *et al.* 2006, p. 327). The loss of stream habitats as a result of channelization affects the Round Hickorynut directly and indirectly, as it also relies on mixed substrates, habitat heterogeneity, and microhabitats supporting benthic fish species (Gordon and Layzer 1989, p. 28).

The decline of mussels has been tied to increases of density and scale of maize agriculture and prehistoric land use patterns (Peacock *et al.* 2005, p. 549). Conversion of forest to row crop and pasture agricultural practices have been identified as a primary factor in freshwater mussel declines. The specific impacts identified include loss of riparian vegetation, reduced water quality and erosion problems, siltation, introduction of pathogens related to poor agricultural and silvicultural practices, and presence of potentially high levels of nitrogenous wastes (Hanlon *et al.* 2009, p. 12).

6.1.4.4 Agricultural Activities Summary

The advent of intensive row crop agricultural practices has been cited as a potential factor in freshwater mussel decline and species extirpation in the eastern U.S. (Peacock *et al.* 2005, p. 550). Nutrient enrichment and water withdrawals, which are threats commonly associated with agricultural activities, have the potential to affect individual Round Hickorynut mussels although in some instances may be localized and limited in scope. However, chemical control using pesticides, including herbicides, fungicides, insecticides, and their surfactants and adjuvants, are highly toxic to juvenile and adult freshwater mussels (Bringolf *et al.* 2007, p. 2,092). Waste from confined animal feeding and commercial livestock operations is another potential source of contaminants that come from agricultural runoff. The concentrations of these contaminants that emanate from fields or pastures may be at levels that can affect entire Round Hickorynut populations, especially given the highly fragmented distribution of the species (also see section 6.1.3).

Agencies, such as the Natural Resources Conservation Service (NRCS) and the Soil and Water Conservation Districts, provide technical and financial assistance to farmers and private landowners. Additionally, county resource development councils and university agricultural extension services disseminate information on the importance of minimizing land use impacts, specifically agriculture, on aquatic resources. These programs help identify opportunities for conservation through projects, such as exclusion fencing and alternate water supply sources, which help decrease nutrient inputs and water withdrawals, and help keep livestock off of stream banks and shorelines, thus reducing erosion. However, the overall effectiveness of these programs over a large scale is unknown given Round Hickorynut's wide distribution across nine states with varying agricultural intensities.

Impacts from agricultural runoff and cultivation activities are a threat to the Round Hickorynut populations in the Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi basins. Specifically, agricultural impacts have affected and continue to affect high, medium, and low condition Round Hickorynut populations within the following river systems:

- Pine River (Michigan)
- Belle River (Michigan)
- Black River (Michigan)
- Shenango River (Pennsylvania)
- Elk River (West Virginia)
- Little Kanawha River (West Virginia)
- South Fork Hughes River (West Virginia)
- North Fork Hughes River (West Virginia)
- Fish Creek (Ohio)
- Killbuck Creek (Ohio)
- Big Darby Creek (Ohio)
- Tippecanoe River (Indiana)
- Richland Creek (Indiana)
- Licking River (Kentucky)
- Kentucky River (Kentucky)
- Duck River (Tennessee)
- Elk River (Tennessee)
- Paint Rock River (Alabama)
- Buffalo River (Tennessee)
- Big Black River (Mississippi)

Given the large extent of private land and agricultural activities within the range of the Round Hickorynut, the effects of agricultural activities that degrade water quality and result in habitat deterioration are not frequently detected until after the event(s) occur. In summary, agricultural activities are pervasive across the range of the Round Hickorynut. Populations are located in areas across nine states that have varying levels of agricultural activity. The effects of agricultural activities on the Round Hickorynut have been attributed as a factor in its historical decline and are considered a primary threat to the species (Peacock *et al*. 2005, p. 547; Lau *et al*. 2006, p. 319; Fisheries and Oceans Canada 2013, p. 19).

6.1.5 Dams and Barriers

The effects of impoundments and barriers on aquatic habitats and freshwater mussels are relatively well-documented (Watters 2000, p. 261). This section is intended to be a summary of the effects (as opposed to a comprehensive overview) that dams and other barriers have on the Round Hickorynut. Extinction/extirpation of North American freshwater mussels can be traced to impoundment and inundation of riffle habitats in all major river basins of the central and eastern U.S. (Haag 2009, p. 107). Humans have constructed dams for a variety of reasons: flood control, water storage, electricity generation, irrigation, recreation, and navigation (Eissa and Zaki 2011, p. 253). Dams, either natural (by beavers or by aggregations of woody debris) or man-made, have many impacts on stream ecosystems. Reductions in the diversity and abundance of mussels are primarily attributed to habitat shifts caused by impoundments (Neves *et al.* 1997, p. 63). The survival of mussels and their overall reproductive success are influenced:

- *Upstream of dams* – the change from flowing to impounded waters, increased depths, increased buildup of sediments, decreased dissolved oxygen, and the drastic alteration in resident fish populations.
- *Downstream of dams* – fluctuations in flow regimes, minimal releases and scouring flows, seasonal depletion of dissolved oxygen, reduced or increased water temperatures, and changes in fish assemblages.

Some studies have shown that some mussel populations may be more temporally persistent immediately downstream of small, low-head dams (Gangloff 2013, p. 476). This is due in part to the fact that many of these dams were constructed over 100 years ago and represent some of the only stable habitat patches remaining in streams that have been largely destabilized. Most of these dams function as fish barriers, and some have relatively consistent nutrient inputs below the dam, so host fish concentrations may be greater below an impoundment, leading to higher mussel abundances and faster growth rate. These small dams and their impoundments may perform some ecological functions that benefit mussel and fish species, including filtration and retention of elevated nutrient loads, and attenuation of floods from urban or highly agrarian watersheds (Gangloff 2013, p. 479). However, negative influences of most impoundments on freshwater mussels outweigh positives, and site-specific considerations regarding dam removal should be taken into account given these potential beneficial effects.

As mentioned above in section 6.1.2, Transportation, improperly constructed culverts at stream crossings may act as significant barriers, and have some similar negative effects as dams on stream systems. Fluctuating flows through the culvert can vary significantly from the rest of the stream, preventing fish passage and scouring downstream habitats. For example, if a culvert sits above the streambed, aquatic organisms cannot pass through them. These barriers fragment habitats along a stream course and contribute to genetic isolation of the aquatic species inhabiting the streams.

All rivers and streams currently occupied by the Round Hickorynut in the Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi basins are directly or indirectly affected by dams, thus directly influencing the species' distribution rangewide, perhaps more so than any other factors affecting the species. Impacts of these dams to the Round Hickorynut include population isolation, hydrological instability, high shear stress, scour, and cold water releases, which suppress mussel recruitment (Hardison and Layzer 2001, p. 79; Smith and Meyer 2010, p. 543; Hubbs 2012, p. 8).

Hypolimnetic discharges from hydropower dams, associated with peaking hydropower production, especially during peak spawning season, are a continual threat to the Round Hickorynut in the Ohio and Tennessee basins, and undoubtedly contributed to species decline in the Cumberland basin (Layzer *et al*. 1993, p. 69). This is particularly true of the medium condition populations in the Licking and Green rivers in Kentucky and the low condition population in the Elk River in Tennessee, because of the correlation of these cold water discharge "spikes" and the abortion of embryos and glochidia, resulting in mussel recruitment failure (McMurray *et al.* 1999, p. 61). A list of some of the dams currently directly influencing populations and the distribution of the Round Hickorynut include:

- Harpersfield Dam - Grand River (Ohio)
- Pymatuning and Shenango Dams - Shenango River (Pennsylvania)
- North Bend Dam - North Fork Hughes River (West Virginia)
- Burnsville Dam & Wells Lock and Dam - Little Kanawha River (West Virginia)
- Sutton Dam - Elk River (West Virginia)
- Dover Dam - Tuscarawas River (Ohio)
- Six Mile Dam - Walhonding River (Ohio)
- Alum, Hoover, Deer Creek Dams - Scioto River (Ohio)
- Cave Run Dam - Licking River (Kentucky)
- Kentucky River Dams - 14 Locks and Dams on the Kentucky River (Kentucky)
- Buckhorn Dam - Middle Fork Kentucky River (Kentucky)
- Green River Dam and 4 Locks and Dams - Green River (Kentucky)
- Barren River Dam and Lock and Dam 1 - Barren River (Kentucky)
- Wolf Creek Dam - Cumberland River (Tennessee/Kentucky)
- Normandy and Shelbyville, Lillards Mill, and Columbia Dams - Duck River (Tennessee)
- Tims Ford and Harms Mill Dams - Elk River (Tennessee)
- Pickwick, Wheeler, Wilson and Guntersville Dams - Tennessee River (Alabama and Tennessee)

Additionally, 11 Locks and Dams have been constructed on the Muskingum River in Ohio from Zanesville downstream to the Ohio River. Operational changes to incorporate hydropower in addition to flood control and navigation at six of these dams are underway. These changes increase the potential for negative impacts to the Round Hickorynut and other rare mussels in the Muskingum River through changes in shear velocity potentially affecting the substrate and unionid communities through alteration of habitat (ESI 2012, p. 26). Potential hydropower development is a threat to the last remaining population of the Round Hickorynut in Pennsylvania (Furedi 2013, p. 43).

The construction and continued operation of dams have historically resulted in extirpation of the Round Hickorynut in portions of its range. Construction of Wolf Creek Dam in Kentucky completely transformed the middle Cumberland River drainage, resulting in a loss of approximately 50 percent of the riverine mussel fauna (Haag and Cicerello 2016, pp. 14, 52). In the Caney Fork River, Tennessee, many adverse effects of impoundments are contributing to habitat loss for mussels, including altered temperature regimes, silt deposition, unstable substrates, sedimentation, oxygen depletion, altered river morphology, dewatering, and reservoir fluctuation (Layzer *et al.* 1993, p. 68).

In the South Fork Holston River, impoundment was identified as the biggest contributor to extirpation of a diverse and abundant native mussel fauna (Parmalee and Polhemus 2004, p. 231); this river harbored a population of Round Hickorynut prior to construction of the Tennessee Valley Authority's (TVA) Fort Patrick Henry, Boone, and South Holston Dam (Parmalee and Polhemus 2004, p. 239). Construction of Cherokee Dam in 1941 in the lower main stem Holston River, Tennessee, has resulted in extirpation of approximately 75 percent of the native mussel fauna downstream of the dam (Parmalee and Faust 2006, pp. 74–77), and large fluctuation in flow rates, water temperatures, and water depth hinder restoration potential (Parmalee and Faust 2006, p. 73).

Another dramatic example of dam impacts within Round Hickorynut's range is within the Ohio River, where there are 19 Locks and Dams on the mainstem between Pennsylvania and Illinois (Watters and Flaute 2010, p. 2). A net loss of 18.6 linear mi (30 km) of mussel beds has occurred between RM 317 and RM 981 since 1967 (Williams and Schuster 1989, p. 3; whose studies geographically overlap ESI 2000, p. 9). The most pronounced change is the complete absence of mussel beds in 51.8 mi (83 km) of the Ohio River above McAlpine Lock and Dam (Williams and Schuster 1989, p. 10). In the interval between 1967 and 1982, within the same study area above the McAlpine Lock and Dam, four high-lift dams (Cannelton, Newburgh, John T. Myers, and Smithland) replaced wicket dams (non-modern dams that helped regulate the river for boat passage); subsequently, between 1982 and 1994, eight mussel beds were lost entirely in tailwaters between RM 438 and RM 981 (Clarke 1995, p. 13).

Six Mile Dam on the Walhonding River in Ohio is slated for removal within the next few years (Boyer 2018, pers. comm.). The only remaining population of Round Hickorynut known from the Walhonding River is below this dam. Six Mile Dam has a strong influence on the numbers and distribution of freshwater fish and mussel species in the Walhonding River (Enviroscience 2010, p. 5). Habitat below the dam is currently considered unsuitable for mussels due to inappropriate substrates and areas of localized scour, but dam removal will presumably allow for the reestablishment of undivided fish and mussel communities, improved habitat connectivity, and natural sediment transport (Enviroscience 2010, p. 6).

Green River Lock and Dam 6 in the Ohio River basin in central Kentucky was removed in 2017 through a collaborative effort between state agencies, Federal agencies, and non-governmental partners. This dam removal expanded free flowing hydrological conditions of the Green River approximately 9.9 RM (16 km) downstream, as well as provided river habitat connectivity with the Nolin River. The Round Hickorynut was collected in post dam removal surveys in free-flowing reaches of the Green River (Compton *et al.* 2017, p. 28). The anticipated future removal of Lock and Dam 5 downstream will likely continue to open up riverine habitats for freshwater mussels in the middle and lower Green River, which harbors a Round Hickorynut population in and around Mammoth Cave National Park.

The Reservoir Release Improvement program, initiated by TVA in 1988, focuses on improvements in dissolved oxygen concentrations below dams, including initiating minimum flows at dams in the Tennessee basin (Higgins and Brock 1999, p. 4). This program has resulted in improved oxygen, decreased bank erosion, and stabilization of habitat in several MUs in the Tennessee basin (Scott *et al.* 1996, p. 5). Additionally, TVA has altered operations at Tims Ford Dam on the Elk River in Tennessee, specifically during summer months, which appears to have resulted in improved mussel recruitment (Howard 2017, pers. comm.). However, impacts to mussels continue to limit distribution, specifically affecting the remaining riverine habitat for the Round Hickorynut at other Tennessee dams, including lack of seasonal variability in flow releases at Normandy Dam, and persistent hypolimnetic discharges at other dams. The last remaining Round Hickorynut population in the Tennessee River, below Pickwick Dam, is threatened by the combined impacts of dams and navigation (Hughes and Parmalee 1999, p. 38).

Whether constructed for purposes such as flood control, navigation, hydropower, water supply, or multi-purpose uses, the construction and continued operation of dams is a pervasive negative influence on the Round Hickorynut and its habitat throughout its range. Although there are recent efforts to remove older, failing dams such as Lock and Dam 6 on the Green River, and current plans to remove others, such as Six Mile Dam on the Walhonding River, dams and their effects on Round Hickorynut population distribution have had perhaps the greatest documented negative influence on the species (Layzer *et al.* 1993, p. 68; Hardison and Layzer 2001, p. 79; Parmalee and Polhemus 2004, p. 239; Watters and Flaute 2010, p. 2).

Dams destroy habitat, alter and disrupt connectivity, and alter water quality and water quantity, all of which affect species needs for the Round Hickorynut at the individual and population levels. Populations in two of the three high MUs of Round Hickorynut are located below major impoundments used for hydropower, flood control and/or water supply (e.g., Burnsville Lake Dam, Little Kanawha River, West Virginia; and Normandy Dam, Duck River, Tennessee), and one is located above (Harpersfield Dam, Grand River, Ohio). There are numerous other smaller dams (mill dams) within these watersheds (i.e., Shelbyville, Lillards Mill, and Columbia dams on the Duck River). Efforts to entirely remove these mill dams are often cost prohibitive and can be detrimental to mussel populations remaining downstream or upstream (for reasons indicated above).

North Bend Dam on the North Fork Hughes River in West Virginia has only a one cubic foot/second (cfs) minimum flow release, which is not protective of aquatic life and extends drought conditions. While few new dams are likely to be constructed in the 21st century, Federal mandates issued to the Corps and TVA for the maintenance and continued operation of dams (such as Harpersville, Sutton, Cave Run, Normandy, and Green River Dam) make this a persistent population, basin, and rangewide threat to the Round Hickorynut.

6.1.6 Changing Climate Conditions

Changing conditions that can influence freshwater mussels include increasing or decreasing water temperatures and precipitation patterns that increase flooding, prolong droughts, or reduce stream flows, as well as changes in salinity levels (Nobles and Zhang 2011, pp. 147–148). An increase in the number of days with heavy precipitation over the next 25 to 35 years is expected across the Round Hickorynut's range (US Global Climate Change Research Program 2017, p. 207). Although the effects of climate change have potentially affected the Round Hickorynut, the timing, frequency, and extent of these effects is currently unknown.

It is important to consider possible climate change impacts to Round Hickorynut and its habitat. As mentioned in the Poff *et al.* (2002, pp. ii–v) report on Aquatic Ecosystems and Global Climate Change, impacts of climate change on aquatic systems can potentially include:

- Increases in water temperatures that may alter fundamental ecological processes, thermal suitability of aquatic habitats for resident species, and their geographic distribution, thus increasing the likelihood of species extinction and loss of biodiversity.
- Changes and shifts in seasonal patterns of precipitation and runoff, which can alter the hydrology of stream systems, affecting species composition and ecosystem productivity. Aquatic organisms are sensitive to changes in frequency, duration, and timing of extreme precipitation events such as floods or droughts, potentially resulting in interference of reproduction. Further, increased water temperatures and seasonally reduced streamflow can alter many ecosystem processes, including increases in nuisance algal blooms.
- Cumulative or synergistic impacts that can occur when considering how climate change may be an additional stressor to sensitive freshwater systems, which are already adversely affected by a variety of other human impacts, such as altered flow regimes and deterioration of water quality.
- Adapting to climate change may be limited for some aquatic species depending on their life history characteristics and resource needs. Reducing the likelihood of significant impacts would largely depend on human activities that reduce other sources of ecosystem stress to ultimately enhance adaptive capacity, which could include, but not be limited to: maintaining riparian forests, reducing nutrient loading, restoring damaged ecosystems, minimizing groundwater and surface water withdrawal, and strategically locating any new reservoirs to minimize adverse effects.
- Changes in presence or combinations of native and nonnative, invasive species could result in specific ecological responses to changing climate conditions that cannot be easily predicted at this time. These types of changes (e.g., increased temperatures that are more favorable to a nonnative, invasive species compared to a native species) can result in novel interactions or situations that may necessitate adaptive management strategies.
- Shifts in mussel community structure, which can stem from climate-induced changes in water temperatures since sedentary freshwater mussels have limited refugia from disturbances such as droughts and floods, and since they are thermo-conformers whose physiological processes are constrained by water temperature within species-specific thermal preferences (Galbraith *et al.* 2010, p. 1,176).

Our review of the best available information indicates that the State of Pennsylvania is the only state within the Round Hickorynut's range to specifically identify climate change as a potential impact to the species. Within Pennsylvania, Furedi (2013, p. 14) concluded the Round Hickorynut to be extremely vulnerable to climate change. The state assessed the abundance or geographic extent of the Round Hickorynut and determined the species to be extremely likely to substantially decrease or disappear by 2050 (Furedi 2013, p. 14).

Regardless of this assessment, the small, isolated, and threatened population in the Shenango River in Pennsylvania is already at an increased risk for extinction given the biological restrictions associated with small populations and reduced distribution (Furedi 2013, p. 3). The location of this population, positioned on the extremity of the range, make it more isolated, compounding gene flow and recolonization issues. While it is likely that climate change may further magnify the factors contributing to the decline of the species (e.g., barriers and associated fragmentation), the precise locations and extent of these magnifications that may be influenced specifically by changing climate conditions are difficult to predict.

Within the range of the species, shifts in the Round Hickorynut's species-specific physiological thresholds in response to altered precipitation patterns and resulting thermal regimes are possible. Additionally, nonnative, invasive species expansion because of climatic changes have the potential for long-term detriment to the Round Hickorynut and its habitat. The influences of these changes on the Round Hickorynut are possible in the future (see Scenario 3, section 7.5, below). However, the effects of landscape-level changes on rare or uncommon sedentary species such as freshwater mussels may be difficult to observe and quantify, requiring systematic collection of data over an extended time period (Ahlstedt *et al.* 2016a, p. 4).

Available life history data on the Round Hickorynut and its host fishes suggest that negative responses to alterations in thermal regimes could result in longitudinal shifts in distribution, underlying the importance of river and stream connectivity (Archambault *et al*. 2018, p. 889). At the basin and population scales, increases in greenhouse gas concentrations have the potential to decrease genetic diversity through reductions in stream connectivity for wide-ranging mussel species in the eastern U.S. (Inoue and Berg 2016, p. 10). However, the best available information does not indicate that changing climate conditions within the range of the Round Hickorynut are likely to have significant adverse effects at the rangewide scale, as compared to other mussel species that reside in the southwestern U.S., where increasing temperatures and decreasing precipitation levels are currently predicted to be more severe.

Linkages between climate and stream connectivity highlight not only the importance of maintaining current suitable habitats but also the linkages between these habitats and populations, especially for a species like the Round Hickorynut that is (currently) most commonly found in tributary systems and has exhibited severe loss in the Ohio and Tennessee basins primarily due to other anthropogenic activities (see also Appendices A and D). Therefore, climate change is considered a secondary factor currently influencing the viability of the Round Hickorynut and is not currently thought to be a primary factor in its occurrence and distribution throughout its range. Climate change could have a greater influence in the distribution of the species beyond the 20- to 30-year timeframe analyzed in this report due to potential loss of populations specifically in the Ohio basin, and could limit restoration and recovery potential in the Tennessee basin.

In summary, changing climate conditions are an increasing concern across the United States. The most significant concerns to consider for the Round Hickorynut and its aquatic habitat include the potential for alteration of the natural flow regime and thermal changes, which can contribute to reduced connectivity between populations, and increased risk of stress to individuals. Pollutants, specifically ammonia compounds, may be exacerbated by higher temperatures, which are predicted to increase. Other potential impacts are associated with changes in food web dynamics and the genetic bottleneck that can occur with low effective population sizes (Nobles and Zhang 2011, p. 148; Inoue and Berg 2016, p. 12).

At some point in the future beyond the 20- to 30-year timeframe analyzed in this report, if dramatic alterations of the natural flow regime occur with changes in habitat connectivity and other water quality impacts, the Round Hickorynut may be affected by climate change. Multi-scale climate models that can be interpreted at both the rangewide and population levels, and are tailored to benthic invertebrates, which incorporate genetic and life history information, are needed before Round Hickorynut declines can be correlated with climate change. At this time, the best available information does not indicate that changing climate conditions are playing a significant role in influencing the viability of the Round Hickorynut across its range.

6.1.7 Resource Extraction

6.1.7.1 Coal Mining

Across the Round Hickorynut's range, the most significant resource extraction impacts are from coal mining and oil and gas exploration. Activities associated with coal mining and oil and gas drilling can contribute chemical pollutants to streams. Acid mine drainage (AMD) is created from the oxidation of iron-sulfide minerals such as pyrite, forming sulfuric acid (Sams and Beer 2000, p. 3). This AMD may be associated high concentrations of aluminum, manganese, zinc, and other constituents (Tennessee Department of Environment and Conservation (TDEC) 2014, p. 72). These metals, and the high acidity saline drainage typically associated with AMD, can be acutely and chronically toxic to aquatic life (Jones 1962, p. 196). Implementation of the Surface Mining Control and Reclamation Act of 1977 has significantly reduced AMD from new coal mines; however, un-reclaimed areas mined prior to this regulation continue to generate AMD in portions of the Round Hickorynut's range.

Abandoned mines are the source of pollution in more than 5,600 mi (9,102 km) of impaired streams in Pennsylvania (Pennsylvania Department of Environmental Protection 2016, p. 51). The Shade River watershed in Ohio was once mined for coal and has a history of AMD. Sediment analyses indicated that iron, aluminum, and manganese, which are primary AMD metals, were the primary pollutants in sediments in the Shade River watershed (Globo and Lopez 2014, p. 1). Pollution indices indicated that the sediments were moderately to extremely polluted, with iron dominating. Low trace element concentrations in the Middle Shade River, resulting from the intense remediation or treatment of mine drainage, indicates regulatory intervention is necessary to remediate mining impacts. Mine drainage affects as much as 17 percent of stream miles in West Virginia (West Virginia Department of Environmental Protection (WVDEP) 2014, p. 20), and surface mining has been identified as a source of impairment for approximately 775 mi (1,247 km) of streams in Kentucky (Kentucky Department of Environmental Protection (KDEP) 2014, p. 66).

More specifically, in the upper Kentucky River MU where the Round Hickorynut population exhibits a lack of recruitment and is in low condition in the Red River and upper Kentucky River, historical un-reclaimed mines and active coal mines are prevalent (KDEP 2014, p. 66). The Round Hickorynut is extirpated from the Caney Fork, Little South Fork, Big South Fork, and Cumberland rivers in the upper Cumberland River basin (see Appendix B). These rivers have experienced water quality degradation resulting from acid mine drainage and intensive surface mining activity (Anderson *et al.* 1991, p. 6; Layzer and Anderson 1992, p. 97; Warren and Haag 2005, p. 1,383).

Although populations persist in the Rockcastle River and Buck Creek in the Cumberland basin, coal and gravel mining continues to occur in these watersheds. Both remaining populations are both in low condition, in low density, and are linear in orientation as opposed to occupying multiple tributaries such as Beaver Creek and the mainstem Cumberland River, from which the species is considered extirpated (Cicerello 1993 p. 21; Hagman 2000, p. 14). Mining continues to reduce water quality in streams in the Cumberland Plateau and Central Appalachian regions of Tennessee and Kentucky (upper Cumberland and Tennessee River basins) (TDEC 2014, p. 62), and is the primary source of low pH impairment of 376 mi (605 km) of stream in Tennessee (TDEC 2014, p. 53).

Coal mining has been implicated in sediment and water chemistry impacts in the Kanawha River in West Virginia, potentially limiting the Elk River Round Hickorynut population (Morris and Taylor 1978, p. 153). Haag and Cicerello (2016, p. 20) note that water quality throughout the Big Sandy River watershed is seriously and profoundly degraded by coal mining, which limits restoration potential. A formerly large population of Round Hickorynut, but now extirpated, occurred in Blaine Creek, in addition to Levisa Fork and several streams in the Little Sandy River drainage (Bay and Winford 1984, p. 19; Haag and Cicerello 2016, p. 179). Coal mining and AMD decimated mussel poulations throughout the entire Monongahela drainage, including populations of the Round Hickorynut in the upper and lower Monongahela River and Buffalo Creek (Appendix D). Additionally, water quality impairments from coal mining have introduced contaminants to the mussel fauna in the Goose Creek watershed of the South Fork Kentucky River, including coal fines, which smother habitats for the Round Hickorynut in the South Fork Kentucky River itself (Evans 2010, p. 15).

According to Ahlstedt *et al.* (2016b, p. 8), coal mining has resulted in discharges of industrial and mine waste fluids, black water release events, and fly-ash spills in the upper Tennessee River basin, and the Round Hickorynut is now extirpated from this portion of the drainage. The negative influence of mined land on mussels in the Tennessee River basin has also been demonstrated through elevated levels of zinc concentrations and dissolved manganese in mussel tissues, indicating chronic mussel exposure to contaminated runoff (Van Hassel 2007, p. 323). The concentrations of toxic metals as a result of coal processing and mining activities, in addition to water quality degradation from abandoned mines, is a population-level threat to the

Round Hickorynut in the Cumberland, Tennessee, and Ohio basins. Areas of intensive mining activity where the Round Hickorynut occurs, such as in the Ohio River basin (particularly in West Virginia, Ohio, and Kentucky) and Cumberland River basin (particularly Kentucky) are most vulnerable to this threat.

6.1.7.2 Natural Gas Extraction

Natural gas extraction in the Marcellus Shale region (the largest natural gas field in the United States that runs through northern Appalachia) has negatively affected water quality through accidental spills and discharges, as well as increased sedimentation due to increases in impervious surface and tree removal for drill pads and pipelines (Vidic *et al.* 2013, p. 6). Round Hickorynut populations in the Shenango, Elk, Little Kanawha, and Kanawha MUs are affected by these activities. Disposal of insufficiently treated brine wastewater is known to adversely affect freshwater mussels (Patnode *et al.* 2015, p. 62). Contaminant spills are also a concern.

Sediment appears to be the largest impact to mussel streams from gas extraction activities (Clayton 2018, pers. comm.). Excessive suspended sediments can impair feeding processes, leading to acute short-term or chronic long-term stress. Both excessive sedimentation and excessive suspended sediments can lead to reduced mussel populations (Ellis 1936, p. 29; Anderson and Kreeger 2010, p. 2). This sediment is generated by construction of the well pads, access roads, and pipelines (for both gas and water). The impact of pipelines crossing mussel streams through open-trenching, the preferred industry method, increases sediment load and contributes to a loss of mussel habitat through sedimentation, and the covering of appropriate substrates.

Since 2010, nearly 250 proposed pipeline crossings have had mussel surveys conducted in West Virginia, and with the rise in the gas industry, old pipelines are also being replaced on a large scale (Clayton 2018, pers. comm.). The release of drilling mud through fracturing is an additional potential impact to rivers and streams, as well as spill of frack fluids used in the well drilling process, which are high in chlorides and other chemicals (Patnode *et al.* 2015, p. 63).

These impacts have a high potential to occur in West Virginia and Pennsylvania where Round Hickorynut populations overlap with oil and gas exploration. Tank trucks hauling such fluids can overturn into mussel streams, which recently occurred in Meathouse Fork of Middle Island Creek (Clayton 2018, pers. comm.). It is presumed that many spills go unreported. Compressor and processing plants have also been constructed. One frack fluid processing plant and associated salt landfill has been constructed recently in the headwaters of the North Fork Hughes River, above a Round Hickorynut population (Clayton 2018, pers. comm.). Other significant sediment impact results from bank slippage and mudslides resulting from pipeline construction, access road construction, and well pad construction in mountainous terrain (Clayton 2018, pers. comm.).

6.1.7.3 Gravel Mining/Dredging

Instream sand and alluvial gravel mining has been implicated in the loss of mussel populations, including the Round Hickorynut, in the Tennessee, Cumberland, Ohio, and Lower Mississippi basins (Schmidt *et al.* 1989, p. 55; Hartfield 1993, p. 138; Watters 1994, p. 104). Negative impacts associated with gravel mining include stream channel modifications such as altered habitat, disrupted flow patterns, and sediment transport (Hagman 2000, p. 14). Additionally, water quality modifications result from gravel mining, including increased turbidity, reduced light penetration, increased temperature, and increased sedimentation. These habitat and water quality degradations reduce macroinvertebrate and fish populations, which suffer impacts to spawning and nursery habitat, and food web disruptions (Kondolf 1997, p. 541; Brown *et al.* 1998, p. 988).

The Corps and state water quality agencies retain regulatory oversight for sand and gravel mining, but some sand, gravel, and rock mining in rivers is unmonitored. Detection of destructive instream and riparian gravel mining is sometimes only observed through organismal inventory and river monitoring efforts. The extensive mining of gravel in riparian zones reduces vegetative buffers and causes channel instability, and has been implicated in mussel declines in the Walhonding River, Ohio, which harbors a low condition population of Round Hickorynut (Hoggarth 1995–1996, p. 150). Gravel mining continues to be a serious and imminent threat to the Round Hickorynut in Buck Creek, Kentucky, one of only two remaining low condition populations in the Cumberland River basin (Schuster *et al*. 1989, p. 84; Hagman 2000, p. 40).

6.1.7.4 Resource Extraction Summary

The concentrations of toxic metals as a result of coal processing and mining, in addition to water quality degradation from abandoned mines, is a population-level threat to the Round Hickorynut in the Cumberland, Tennessee, and Ohio basins. Areas of intensive mining activity where the Round Hickorynut occurs such as in the Ohio River basin (particularly West Virginia, Ohio, and Kentucky) and Cumberland River basin (particularly Kentucky) are most vulnerable to this threat.

Coal mining, AMD, and the legacy effects of abandoned mine runoff currently affect Round Hickorynut populations in the Ohio, Cumberland, and Tennessee basins. Additionally, the recent rapid expansion of oil and gas exploration in the Marcellus Shale region of WV and PA, and the anticipated future development of the Ithaca region in NY and PA, presents a current threat and future concern for the Round Hickorynut. The impacts of pipeline construction, well pad installation, and access road clearing are an imminent threat to Round Hickorynut populations especially in these states (Clayton 2018, pers. comm.; Welte 2018, pers. comm.).

The presence of a large number of mine waste ponds in the Ohio and Tennessee basins increase the risk of dam and levee failure and blowouts, resulting in mining waste covering the substrate, which could be catastrophic to Round Hickorynut populations. Although not considered a threat to the last remaining populations in the Cumberland basin, resource extraction and acid mine drainage have been cited as a contributor to the loss of mussel species in the Cumberland River basin (Haag and Cicerello 2016, p. 15). This is specifically true in the Big South Fork Cumberland River and Cumberland River, where the Round Hickorynut no longer occurs, and which may limit recovery opportunities in those watersheds (Layzer and Anderson 1992, p. 97; Ahlstedt *et al.* 2003–2004, p. 39).

Oil and gas exploration activities in the Little Kanawaha River and Middle Island Creek, including secondary impacts of water withdrawal, access road construction, and pipeline construction, are an imminent threat to the high condition Round Hickorynut populations within these rivers (Clayton 2018, pers. comm.). Additionally, direct and indirect effects of water quality degradation, pollution, and chemical toxicity as a result of active or past mining activities affect freshwater mussel populations throughout much of the historical and current range of the Round Hickorynut (Haag and Cicerello 2016, pp. 9–16).

Resource extraction, including oil and gas exploration, is also affecting medium condition populations in the Ohio River basin in particular, including the Elk River, McElroy Creek, South Fork Hughes River, North Fork Hughes River, Kanawha River, Green River, and South Fork Kentucky River. When combined with the legacy effects of coal mining and its associated infrastructure, this is a substantive imminent threat to the species.

A large number of low condition populations in the Ohio and Cumberland basins are affected by resource extraction activities, including; the Right Fork West Fork River, Kincheloe Creek, Hackers Creek, Stonecoal Creek, Jesse Run, Meathouse Fork, Buckeye Creek, Killbuck Creek, West Fork Little Kanawaha River, Hughes River, Fink Creek, Leading Creek, Reedy Creek, Spring Creek, Middle Fork South Fork Hughes River, Kanawha River (lower),Middle Branch Shade River, East Branch Shade River, Red River, Middle Fork Kentucky River, Red Bird River, and Rockcastle River (see Appendix D). These impacts include water quality degradation of past or present mining and current oil and gas exploration.

Commercial sand and gravel mining and dredging are affecting populations of the Round Hickorynut in the Great Lakes, Cumberland, Tennessee, and Ohio basins, including the Black River, Big Walnut Creek, Buck Creek, Walhonding River, and Tennessee River (Hoggarth 1995–96, p. 150; Hagman 2000, p. 40; Lyons *et al.* 2007, p. 9; Hoggarth and Grumney 2016, p. 57). Round Hickorynut populations in the Kanawha River, West Virginia, are concentrated in tailwater reaches below locks and dams that have periodic dredging to the lock approaches and to maintain the navigation channel.

Dredging activities have permanently altered substrates and hydraulic patterns in some riverine habitats where the Round Hickorynut formerly occurred, including the mainstem Ohio, Tennessee, and Cumberland rivers (Sickel 1982, p. 4), contributing to habitat loss for freshwater mussels. Additionally, although aggregate extraction activities no longer occur in the Allegheny River, the long-lasting impacts of these activities remain, which limits restoration potential particularly in the lower reaches, where the Round Hickorynut is extirpated (Ortmann 1919, p. 223; Smith and Meyer 2010, p. 542).

6.1.8 Forest Conversion

A forested landscape provides many ideal conditions for aquatic ecosystems. Depending on the structure and function of the forest, and particularly if native, natural mixed hardwood-conifer forests comprise the active river area, rain is allowed to slowly infiltrate and percolate (as opposed to rapid surface runoff). A variety of food resources enter the stream and river via leaf litter and woody debris; banks are stabilized by tree roots; habitat is created by occasional wind throw; and riparian trees shade the stream or river and maintain thermal climate.

Silvicultural activities, when performed according to strict forest practices guidelines or BMPs, can retain adequate conditions for aquatic ecosystems; however, when forest practice guidelines or BMPs are not followed, these activities can also cause measurable impacts and contribute to myriad stressors facing aquatic systems throughout the eastern U.S. (Warrington *et al.* 2017, p. 8). Both small- and large-scale forestry activities have significant impacts depending on the physical, chemical, and biological characteristics of adjacent streams (Allan 1995, p. 107).

Today, forests are harvested and converted for many reasons including, but not limited to: financial gain to the property owner by timber harvest, residential and commercial development, conversion for various agricultural practices, wood and paper products, manufacturing, and fuel for electricity generation (Alig *et al.* 2010, p. 2; Maestas 2013, p. 1). In many cases, natural mixed hardwood-conifer forests are clear-cut and either left to naturally regenerate or planted in rows of monoculture species such as pine, which is grown for timber building supplies and pulp products (Allen *et al.* 1996, p. 4; Wear and Greis 2012, p. 13).

Clearing large areas of forested wetlands and riparian systems eliminates shade once provided by the tree canopies, exposing streams to more sunlight and increasing the in-stream water temperature (Wenger 1999, p. 35). The increase in stream temperature and light after deforestation alters macroinvertebrate and other aquatic species richness and abundance composition in streams to various degrees depending a species tolerance to temperature change and increased light in the aquatic system (Kishi *et al.* 2004, p. 283; Couceiro *et al.* 2007, p. 272; Caldwell *et al.* 2014, p. 2,196).

Sediment runoff from cleared forested areas is a known stressor to aquatic systems (e.g., Webster *et al.* 1992, p. 232; Jones III *et al.* 1999, p. 1,455; Broadmeadow and Nisbet 2004, p. 286; Aust *et al.* 2011, p. 123). The physical characteristics of stream channels are affected when large quantities of sediment are added or removed (Watters 2000, p. 263). Mussels and fish are potentially affected by changes in suspended and bed material load, bed composition associated with increased sediment production and runoff in the watershed, channel changes in form, stream crossings, and inadequately buffered clear-cut areas, all of which can be significant sources of sediment entering streams (Taylor *et al.* 1999, p. 13).

Many forestry activities are not required to obtain a CWA 404 permit, as silviculture activities such as harvesting for the production of fiber and forest products are exempted (EPA 2017, p. 1). The construction of logging roads through the riparian zone can directly degrade nearby stream environments (Aust *et al.* 2011, p. 123). Logging roads constructed in wetlands adjacent to headwater drains and streams fall into this exemption category, but may affect the aquatic system for years, as these roads do not always have to be removed immediately.

Roads remain as long as the silviculture operation is ongoing, thus wetlands, streams, or ditches draining into the more sensitive areas may be heavily affected by adjacent fill and runoff if BMPs or FMPs fail or are not maintained, causing sedimentation to travel downstream into more sensitive in-stream habitats. Stream crossings tend to have among the lowest BMP implementation rates (Warrington *et al.* 2017, p. 9). Requirements maintain that flows are not to be restricted by logging roads, but culverts are only required per BMP and FMP and are not always adequately sized or spaced, or properly installed.

Forestry practices that do not follow BMPs and FMPs can influence a river or stream's natural flow regime, resulting in altered habitat connectivity. Logging staging areas, logging ruts, and not replanting are all associated impacts that are a threat to downstream aquatic species. BMPs and FMPs typically require foresters to ensure that discharge shall not adversely modify or destroy the habitat of federally protected species, and to ensure that adverse impacts to the aquatic environment are minimized. However, foresters are not required to consult with appropriate state or Federal agencies regarding unlisted sensitive species, though consultation typically results in beneficial measures that best reduce potential impacts prior to moving forward with management activities.

Around the turn of the 21st century, biologists, foresters, and managers recognized the need for wholesale implementation of BMPs and FMPs to address many of the aforementioned issues related to forest conversion and silvicultural practices. Currently, forestry BMP and FMP manuals suggest planning road systems and harvest operations to minimize the number of stream crossings. Proper construction and maintenance of crossings reduces soil erosion and sedimentation with the added benefit of increasing harvest operation efficiency (National Council for Air and Stream Improvement 2015, p. 2).

Monoculture stands can influence overall water cycle dynamics (e.g., increased evapotranspiration and overall reduced stream flows) (Swank and Miner 1968, entire; Swank and Douglass 1974, entire), as well as result in a reduced biodiversity in the canopy, middle and understory vegetation, and fauna that use the area. Furthermore, the aquatic habitats of streams in these monoculture-forested areas lose heterogeneity in food resources due to reduced variety in allochthonous inputs (i.e., energy inputs derived from outside the stream system, or leaf matter that falls into streams), and this effect is mirrored among invertebrate and fish populations, including filter-feeding mussels and benthic insectivorous fish and amphibians (Webster *et al.* 1992, p. 235; Allan 1995, p. 129; Jones III *et al.* 1999, p. 1,454).

6.2 Invasive and Nonnative Species

Approximately 42 percent of federally endangered or threatened species are estimated to be significantly affected by nonnative, nuisance species across the nation, and nuisance species are significantly impeding recovery efforts for them in some way (National Invasive Species Council Management Plan 2016, p. 2). When a nonnative species is introduced into an ecosystem, it may have many advantages over native species, such as easy adaptation to varying environments and a high tolerance of living conditions that allow it to thrive in its new habitat.

There may not be natural predators to keep the nonnative species in check; therefore, it can potentially be more successful and reproduce more often, further reducing the biodiversity in the system. The native species may become an easy food source for invasive species, or the invasive species may carry diseases that extirpate populations of native species. Examples of nonnative species that affect freshwater mussels like the Round Hickorynut are the Asian Clam (*Corbicula* *fluminea*), Zebra Mussel (*Dreissena polymorpha*), Quagga Mussel (*Dreissena bugenis*), Black Carp (*Mylopharyngodon piceus*), Round Goby (*Neogobius melanostomus*), Didymo (a.k.a. rock snot; *Didymosphenia geminata*), and Hydrilla (a.k.a. water-thyme; *Hydrilla verticillata*).

The Asian Clam alters benthic substrates, may filter mussel sperm or glochidia, competes with native species for limited resources, and causes ammonia spikes in surrounding water when they die off en masse (Scheller 1997, p. 2). The Asian Clam is hermaphroditic, enabling fast colonization and is believed to practice self-fertilization, enabling rapid colony regeneration when populations are low (Cherry *et al.* 2005, p. 378). Reproduction and larval release occur biannually in the spring and in the late summer. A typical settlement of the Asian Clam occurs with a population density ranging from 100 to 200 clams per square meter, which may not be detrimental to native unionids; however, populations can grow as large as 3,000 clams per square meter, which at this density influence both food resources and competition for space for the Round Hickorynut.

Asian Clam are prone to have die-offs that reduce available dissolved oxygen and increase ammonia, which can cause stress and mortality to the Round Hickorynut (Cherry *et al.* 2005, p. 377). Asian Clam are a ubiquitous presence in rivers and streams of eastern North America. Asian Clam are present throughout the range of the Round Hickorynut, and the competitive interactions and effects of their massive die-offs have been documented, but the complete impacts of these nonnative bivalves on native unionids is not completely understood. Regardless, the abundance and extent of Asian Clam throughout the range of the Round Hickorynut are considered a threat to all populations and MUs across all basins.

Zebra mussels are listed by Congress (by statute) as Injurious Wildlife under the Lacey Act (50 CFR §16). The arrival and proliferation of the Zebra Mussel in the Ohio River in the early 1990s corresponded with a significant decline in native freshwater mussel populations (Watters and Flaute 2010, p. 1). Dreissenid mollusks, such as the Zebra Mussel and Quagga Mussel, are a threat to native freshwater mussels. These nonnative mollusks are known to occur in the Great Lakes, Ohio, Tennessee, and the St. Lawrence basins. Mussels, such as the Round Hickorynut, are adversely affected by dreissenids through direct colonization, reduction of available habitat, changes in the biotic environment, or a reduction in food sources (MacIsaac 1996, p. 292). Zebra mussels are also known to alter the nutrient cycle in aquatic habitats, affecting other mollusks and fish species (Strayer *et al.* 1999, p. 22).

Since its introduction in the Great Lakes in 1986, Zebra Mussel colonization has resulted in the decline and regional extirpation of freshwater mussel populations in lakes and river systems across North America (Schloesser *et al.* 1996, p. 303; Schloesser *et al.* 1998, p. 300). One of the direct consequences of the invasion of Zebra and Quagga mussels is the local extirpation of native freshwater mussel populations. This results from: (1) attaching to shells of native mussels, which can kill them, due to heavy infestations that can prevent valve closure (dreissenid mussels are sessile, and cling to hard surfaces); (2) affecting vertical and lateral movements of mussels; and (3) outcompeting native mussels and other filter feeding invertebrates for food. The decline and extirpation of native freshwater mussels in the Great Lakes and its tributaries has been attributed to Zebra Mussel invasion (Schloesser *et al.* 2006, p. 307). Zebra and Quagga Mussel densities are highly variable annually, and may depend on discharge rates, water temperatures, settlement location, and predator presence (Cope *et al.* 2006, p. 185).

This problem has been particularly acute in some areas of the U.S. that have a very rich diversity of native freshwater mussel species, such as the Great Lakes, Ohio, and Tennessee River systems. Zebra Mussel population levels in the Belleville Pool on the Ohio River in 2000 contributed to the mortality of approximately 25 percent of native mussels, including the Round Hickorynut (Clayton 2019, pers. comm.). Although Zebra mussels persist in this reach of the Ohio River, they no longer occur at densities as high as previously reported. Lake Erie, Lake St. Clair, and the Detroit River in the Great Lakes basin have sizable populations of Zebra mussels, which are considered the primary factor for the decline and extirpation of the Round Hickorynut in these water bodies, all of which formerly harbored large populations (McNichols 2007, p. 43).

The Round Goby (*Neogobius melanostomus*) first invaded North America in 1990 when it was discovered in the St. Clair River, and has been collected in numerous Great Lakes tributaries, where it is considered abundant (Poos *et al.* 2009 p. 1,269). The Round Goby can out-compete native benthic fishes (such as darters and sculpin) for food and other resources, and may also prey especially heavily on juvenile native mussels such as Round Hickorynut (Bradshaw-Wilson *et al*. 2019, p. 268) (Figure 6-2).

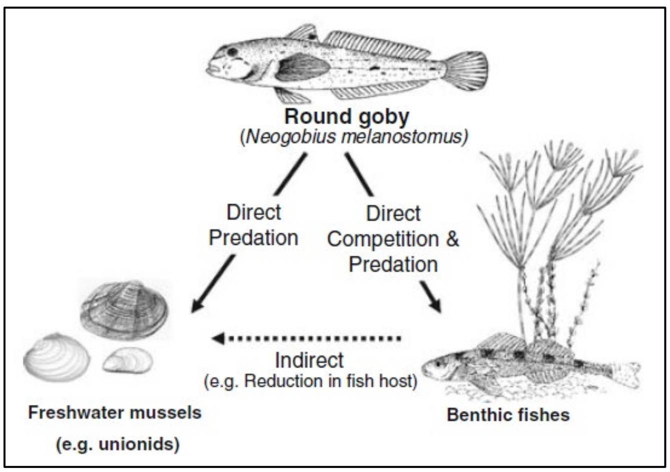

Figure 6-2. Conceptual illustration of the direct and indirect effects of Round Goby on native freshwater mussels (From Poos *et al*. 2009, p. 1,271).

The two nonnative plant species that are most problematic for the Round Hickorynut are Hydrilla and Didymo, although an additional species known as Golden Alga (*Prymnesium parvum*), a marine algae, has spread into the upper Ohio River basin. This Golden Alga is a potential threat to mussel populations, particularly during low-flow years when coupled with brine discharges, and is believed to be the trigger for a mussel kill in Dunkard Creek, West Virginia (Anderson and Kreeger 2010, p. 9). Hydrilla is an aquatic plant that alters stream habitat, decreases flows, and contributes to sediment buildup in streams (Balciunas *et al*. 2002, p. 2). High sedimentation can cause suffocation, reduce stream flow, and make it difficult for mussels' interactions with host fish necessary for development.

Hydrilla can quickly dominate native vegetation, forming dense mats at the surface of the water and dramatically altering the balance of the aquatic ecosystem. Hydrilla covers spawning areas for native fish and can cause significant reductions in stream oxygen levels when in bloom, but also when dead and decomposing (Colle *et al.* 1987, p. 410). Hydrilla is widespread in the Ohio, Cumberland, and Tennessee River systems. Didymo or "rock snot" is a nonnative alga (diatom) that can alter the habitat and change the flow dynamics of a site (Jackson 2016, p. 970). Invasive plants often grow uncontrolled and can smother habitat, affect flow dynamics, alter water chemistry, increase water temperatures, and can even contribute to streams drying out completely, especially in drought conditions (Colle *et al.* 1987, p. 416).

Black Carp, a molluscivore, has been reported in Arkansas, Illinois, Mississippi, and Missouri (Nico *et al.* 2005, p. 155). It is established in Louisiana (since the early 1990s), and observed most recently in 2018 in Tennessee and Kentucky (Nico and Neilson 2019, USGS Nonindigenous Aquatic Species Database). Black Carp are also listed as Injurious Wildlife under the Lacey Act. The species is present in the lower Ohio, Cumberland, and Tennessee River basins. There is high potential that Black Carp will negatively impact native aquatic communities by direct predation, thus reducing populations of native mussels and snails, many of which are considered endangered or threatened (Nico *et al.* 2005, p. 193).

Given their size and diet preferences, Black Carp have the potential to restructure benthic communities by direct predation and removal of algae-grazing snails. Mussel beds consisting of smaller individuals and juvenile recruits are probably most vulnerable to being consumed by Black Carp (Nico *et al.* 2005, p. 192). Furthermore, because Black Carp attain a large size (well over 3.28 ft (1 m) long), and their life span is reportedly over 15 years, and therefore have the potential to cause significant harm to native molluscs by way of predation to multiple age classes (Nico *et al.* 2005, p. 77).

The Aquatic Nuisance Species (ANS) Task Force, co-chaired by the Service and the National Oceanic and Atmospheric Administration, encourages state and interstate planning entities to develop management plans describing detection and monitoring efforts of aquatic nuisance and nonnative species, prevent efforts to stop their introduction and spread, and control efforts to reduce their impacts. Management plan approval by the ANS Task Force is required to obtain funding under Section 1204 of the ANS Prevention and Control Act. Plans are a valuable and effective tool for identifying and addressing ANS problems and concerns across many jurisdictions. Each state within the range of the Round Hickorynut has either a plan approved by or submitted to the ANS Task Force, or a plan under development. These plans have been effective in terms of raising awareness at the state level of the severity of ecological damage that nonnative and nuisance species are capable of, but most are in early stages of implementation.

Although there are nonnative species present throughout the range of the Round Hickorynut in the Great Lakes, Ohio, Cumberland, and Tennessee basins, the greatest concentration of nonnative species that has the potential to affect mussels is in the Great Lakes and Ohio basins. These nonnative species discussed above affect Round Hickorynut individuals through competitive interactions, water quality degradation, predation, and habitat alteration.

The only Round Hickorynut populations remaining in the Ohio River mainstem are currently affected by the nonnative vegetation and mollusks listed above. The low condition Round

Hickorynut populations in the Cumberland and Tennessee basins (Buck Creek, Rockcastle River, Buffalo River, Elk River) are also directly affected by established populations of Asian Clam, and are perhaps most vulnerable to its competitive interactions. However, all populations of Round Hickorynut in all basins are affected to some degree by the Asian Clam. In summary, the presence of nonnative species is a substantial threat to the Round Hickorynut throughout its range, but the concentration of nonnative species in the Great Lakes basin is most problematic, given the documented decline of native mussel populations in association with invasion of nonnative species.

6.3 Genetic Isolation and Displacement

The Round Hickorynut exhibits several inherent traits that influence population viability, including relatively small population size and limited recruitment at many locations compared to other mussels (see Appendix A). The Round Hickorynut prefers sites with clean, flowing water and stable substrates (see Sections 4.1.1–4.1.3), and even in stronghold populations (Grand and Duck rivers) they comprise only a small component of the larger mussel fauna (Haag and Cicerello 2016, p. 179).

Small population size puts the species at greater risk of extirpation from stochastic events (e.g., drought) or anthropomorphic changes and management activities that affect habitat. In addition, small, isolated Round Hickorynut populations, as in the Big Black River in Lower Mississippi, may have reduced genetic diversity, be less genetically fit, and more susceptible to disease during extreme environmental conditions (Frankham 1996, p. 1,505) compared to large populations (currently the Grand River, Little Kanawha River, and Duck River).

Genetic drift occurs in all species, but may be minimized or negated in some isolated populations, which could be especially deleterious with a small population size. Lack of drift is more likely to negatively affect populations that have a smaller effective population size (number of breeding individuals) and populations that are geographically spread out and isolated from one another. Factors such as low effective population size, genetic isolation, relatively low levels of fecundity and recruitment, and limited juvenile survival could all affect the ability of this species to maintain current population levels or rebound. Additionally, the small size and limited movement of Round Hickorynut fish hosts (darters and sculpins) limits natural expansion of populations (Vaughn 2012, p. 6).

Fragmentation (i.e., the breaking apart of habitat segments, independent of habitat loss (Fahrin 2003; p. 299)) and isolation contribute to the extinction risk that mussel populations face from stochastic events (Haag 2012, pp. 336–338). Streams are naturally dynamic, creating or shifting areas of quality habitat over a particular period. A number of factors, most of which interact to create stable patches of suitable and unsuitable mussel habitat, bring about habitat fragmentation (natural and human-induced) in stream systems. Some causes, like barriers, directly fragment habitat. Other causes, such as drought, water quality, host fish movement, substrate stability, and adjacent land use, lead to increasing stream fragmentation in subtle and interdependent ways.

Dendritic streams and rivers are highly susceptible to fragmentation and may result in multiple habitat fragments and isolated populations of variable size (Fagan 2002, p. 3,247). In contrast to landscapes where multiple routes of movement among patches are possible, pollution or other habitat degradation at specific points in dendritic landscapes can completely isolate portions of the system (Fagan 2002, p. 3,246). Connectivity between patches (mussel beds or occupied habitat) is important in landscapes where these patches of suitable habitat are created or destroyed. Where populations are small, extirpation caused by demographic stochasticity (e.g., changes in the proportion of males and females, the reproductive potential of females, survival of individuals) happens often, and populations must be re-established by colonization from other patches. Given that these conditions may apply to many lotic mussel populations, connectivity of mussel populations and their required resources is an important factor to consider for Round Hickorynut persistence (Newton *et al.* 2008, p. 428).

Impoundments result in the genetic isolation of mussel populations and fishes that act as their hosts (Vaughn 2012, p. 6; also see section 6.1.5, above). Perched or improperly maintained culverts at stream crossings can also act as significant barriers (see section 6.1.2 and 6.1.5, above), and have similar effects as dams on stream systems. Fluctuating flows through a culvert can differ significantly from the rest of the stream, preventing fish passage and scouring downstream habitats. The likelihood is high that some Round Hickorynut populations are below the effective population size required to maintain long-term genetic and population viability (see Chapter 5, above and Appendix A). Recruitment reduction or failure is a potential problem for many small Round Hickorynut populations rangewide, a potential condition exacerbated by its reduced range and increasingly isolated populations.

A once extensive Round Hickorynut population occurred through much of the Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi basins. On a geological scale, there were limited barriers preventing genetic interchange among its tributary sub-populations. With the completion of hundreds of dams in the 1900s, many main stem Round Hickorynut populations were lost, resulting in isolation of tributary populations. Without the level of genetic interchange that the species experienced historically (i.e., without barriers such as reservoirs), small isolated populations that may now be comprised predominantly of adult individuals could be slowly dying out. Even given the very improbable absence of other anthropogenic threats, these disjunct populations could be lost simply due to the consequences of below-threshold effective population sizes.

The best available information suggests that general degradation of many isolated stream reaches is continuing to result in ever decreasing patches of suitable habitat. This is particularly a concern for the last remaining population in the Lower Mississippi basin, which is small and linear in extent. Extensive reaches of unsuitable habitat in the lower Mississippi River prevent mussel dispersal and, in turn, limit genetic exchange (Inoue and Berg 2016, p. 8). Thus, these threats appear to be acting insidiously to contribute to the decline of Round Hickorynut populations over time (Butler 2005, p. 114).

Only 62 primarily disjunct streams of 298 historically occupied areas continue to harbor populations of the Round Hickorynut, likely partial testimony to the principle of effective population size and its role in population loss. The rarity displayed by most Round Hickorynut populations creates challenges for resource managers to incorporate conservation measures that address many of the genetic issues associated with maintaining a high level of genetic diversity, while balancing the population needs of other sympatric mussel species with various life-history strategies.

6.4 Factors Currently Believed To Have Limited Effects on Round Hickorynut Populations

At this time, our analysis of the best available scientific and commercial information suggests that harvest and overutilization, host fish, disease, parasites, and predation are not likely resulting in population- or rangewide-level negative impacts to the Round Hickorynut. Some of these impacts may be influencing Round Hickorynut individuals in specific locations and examples are given below.

6.4.1 Harvest and Overutilization

Commercial harvest associated with the button and pearl industries of the 19th and 20th centuries, as well as the search for native pearls, likely contributed to the decline of freshwater mussels in the Great Lakes, Ohio, Cumberland, and Tennessee basins (Anthony and Downing 2001, p. 2,072). The Round Hickorynut was considered to be heavily exploited during the first half of the 20th century for the production of mother of pearl buttons (Anthony and Downing 2001, p. 2,078).

Native Americans harvested mussels for food (Parmalee and Klippel 1974, p. 421). There is limited documentation regarding harvest of the Round Hickorynut, but it was likely included among their catch, because it has been documented from numerous archaeological sites (Bogan 1990, p. 136; Peacock *et al.* 2016, p. 127). Although the Round Hickorynut shell does not attain a comparatively large size, the species was valued during the first half of the 20th century for the production of buttons due to its thick shell, durability, and luster (Wilson and Clark 1914, p. 52). Wilson and Clark (1914) also documented large piles comprised of tons of mussel shells, along the Cumberland River. Single beds were harvested a decade or more for pearls. Böpple and Coker (1912, p. 10) reported a particularly habitat disruptive method of harvest where “a plow drawn by a strong team” was sometimes used in shallow Clinch River shoals, enabling pearlers to pick up mussels that were buried in the substrate.

Despite the alarm generated over exploitation events in historical times, the collective impact from human harvest of mussels’ pales in the shadow of the impacts realized from habitat alteration. It is unlikely that exploitation activities have completely eliminated Round Hickorynut populations, but rather, they have potentially contributed to the species’ historical decline. The Round Hickorynut is not currently a commercially-valuable species, but it may be inadvertently harvested as “by catch” or by inexperienced mussel collectors unfamiliar with commercial species identification.

Mussel harvest is illegal in Indiana, Ohio, West Virginia, and regulated Pennsylvania. Most states with active commercial harvest allow mussel harvesters to dive for mussels. In Kentucky, mussels may legally be harvested only by brail (i.e., dragging poles with hooks drug along the bottom of a river). Most states that allow commercial harvest, such as Alabama, Kentucky, and Tennessee, have established mussel sanctuaries where harvest is prohibited in the few places where commercial harvest occurs within the range of the Round Hickorynut. Sanctuaries are generally associated with beds that have state- or federally-listed mussels present.

Watters and Dunn (1993–94, p. 253) specifically mention the Round Hickorynut's significant decline from previous surveys, and potential over-harvest of the mussel beds in the Muskingum River. A recent survey of the lower Muskingum River by ESI (2012, p. 103) reported collection of only one weathered dead Round Hickorynut at 1 of 10 sites. A potential explanation of the increasing rarity of the Round Hickorynut and other riverine mussels in the Muskingum River may be a result of years of intensive commercial activity. Although illegal harvest of protected off-limits mussel beds occurs rangewide, commercial harvest is not thought to currently have a significant impact on the Round Hickorynut. The Muskingum River may at least in part serve as an example of the impacts of threats such as habitat fragmentation and loss combined with previous intensive collection activities on freshwater mussels.

Most river and stream reaches inhabited by this species are restricted, and its populations are relatively small in density (see Appendix A). Overall, the future potential direct threat of harvest and overutilization is minimal, and considered a small fraction of what it was 20 years ago. The best available information suggest commercial harvest is not likely to be an issue in the future for the long-term viability of the Round Hickorynut.

6.4.2 Host Fishes

The overall distribution of mussels is, in part, a function of the dispersal of their host fish. There is limited potential for immigration between populations other than through the attached glochidia being transported to a new area or to another population (see section 3.4, above). The Round Hickorynut depends on darters and sculpins for dispersal, which are small, generally sedentary benthic fishes, therefore, barriers such as dams limit recolonization potential (see section 6.1.5, above). Small populations are more affected by this limited immigration potential, contributing to random loss of genetic diversity, and potentially increasing the risk of inbreeding depression (Geist 2010, p. 78). Populations that are eliminated due to stochastic events cannot be recolonized naturally, leading to reduced overall redundancy and representation.

The documented primary host fish species for the Round Hickorynut are a combination of riverine darters and sculpins species. Families of host fishes known for the genus *Obovaria* require clean flowing water over mixed substrates and are intolerant of impoundment, and since they are benthic, are generally unable to take advantage of fish passage opportunities such as fish ladders (Haag 2012, p. 347). Factors that contribute to habitat loss and water quality degradation of Round Hickorynut such as dams, fragmentation, resource extraction, contaminants, and nonnative species are considered to act simultaneously on its host fish.

Prior to initiation of modified pulsing discharge regimes at hydropower dams in the Tennessee River basin, such as in the Holston and French Broad rivers, Tennessee, where the Round Hickorynut is extirpated, operation of Cherokee and Douglas dams was limited to peaking hydroelectric power. Hydropeaking reduced habitat available for mussel colonization through aerial exposure of shoals when not generating, destabilized substrates, and increased water temperatures (Layzer and Scott 2006, p. 475; Parmalee and Faust 2006, p. 73). While restoration potential of other mussel species that use darters and sculpin has improved, the prognosis for restoring the Round Hickorynut below Douglas Dam is unknown (Layzer and Scott 2006, p. 481). Restoration potential below Cherokee Dam is poor, presumably due to a lack of nearby populations from which to translocate individuals and the lack of effectiveness in re-establishing suitable natural riverine conditions (Parmalee and Faust 2006, p. 77). Similar conditions likely limited host fish abundance and distribution in the Elk River downstream of Tims Ford Dam prior to flow release modifications (TVA 2008, p. 5).

The greatest concentration of hydropower dam operation and its effects on host fishes for the Round Hickorynut is in the Ohio, Cumberland, and Tennessee River systems. Wolf Creek Dam on the Cumberland River impounds riverine habitat and isolates the two remaining populations of Round Hickorynut in the Rockcastle River and Buck Creek. Impoundments are managed and stocked to promote recreational opportunities for larger, predatory fishes and are unlikely to support populations of darters and sculpins, which are the predominant host fishes for the Round Hickorynut. Conditions that reduce available fish hosts above and below dams also likely affect Round Hickorynut occurrence in all impounded rivers.

The threat of limited host fish availability under these conditions is influenced by impoundment and dam operations, in addition to host fish distributional limitations. The impacts of Round Goby on the Round Hickorynut and its host fishes is through competition and predation, and this represents an additional nonnative species stressor to the populations in the Great Lakes basin (Poos *et al.* 2010, p. 1,282). Also, the decline in abundance and distribution of the Eastern Sand Darter, a host fish for the Round Hickorynut, represents a concern. The best available scientific and commercial information suggests that the availability and distribution of host fish is not a limiting factor in Round Hickorynut distribution throughout its entire range, but rather in specific locations in the Great Lakes and Ohio basins. Populations of mussels and their host fish have become isolated over time following the construction of major dams and reservoirs throughout the range of the Round Hickorynut.

6.4.3 Enigmatic Population Declines

Mussel populations occasionally experience declines in the absence of obvious severe point or non-point source pollution or severe habitat loss and destruction. These declines are termed enigmatic population declines due to their mysterious and currently puzzling nature (Haag 2012, p. 341). The cause of these die-offs is unknown, but researchers suspect disease may be a factor (Grizzle and Brunner 2009, p. 454). Contaminants that are not easily observable, such as metals bound in sediments, a result of past land use, could also be a contributor (Price *et al.* 2014, p. 855; see also section 6.1.3, above). Such declines have occurred within rivers and streams occupied by the Round Hickorynut (Neves 1987, p. 9). Fish and aquatic insect communities in locations where these mussel die-offs have been documented sometimes remain relatively intact; however, juvenile mussels are sensitive to the unknown factors causing the declines, and the Round Hickorynut is likely affected (Haag 2012, p. 342).

Mussel die-offs of unknown origin have been observed since at least the 1980s and continue to occur, particularly in the eastern U.S. (Neves 1987, p. 9; Freshwater Mollusk Conservation Society 2018). They have been documented the Ohio and Tennessee basins in past decades

(Ahlstedt *et al.* 2016a, p. 9), and as recently as 2016–2017 in the Clinch River (Tennessee) and Big Darby Creek (Ohio) (Richard 2018, p. 2). These die-offs were observed along at least a 50-mi (80-km) stretch, and both sick and dead mussels have been reported from both rivers. A long-term monitoring site on the Elk River in West Virginia indicates the Round Hickorynut has not been exhibiting recruitment paired with unexplained mortality since 2004 (ESI 2009, p. 19; Clayton 2018, pers. comm.). A recent die-off of mussels in Big Darby Creek, including Round Hickorynut, remains unexplained (Sasson 2017, p. 5). Mussel die-offs are thought to be a combination of many environmental factors and are an imminent threat to the Round Hickorynut, specifically low condition populations like Big Darby Creek that are linear in orientation and do not appear to exhibit recruitment.

6.4.4 Parasites

Mussel parasites include water mites, trematodes, leeches, bacteria, and some protozoa (Grizzle and Brunner 2009, p. 433). Although these organisms are generally not suspected to be a major limiting factor for mussel populations in general, reproductive output can be negatively correlated with mite abundance, and physiological condition is negatively correlated with trematode abundance (Gangloff *et al.* 2008, p. 28). Trematodes live directly in mussel gonads and may negatively affect gametogenesis (i.e., the process in which cells undergo meiosis to form gametes). Trematodes can completely fill mussel gonads, to the exclusion of gonadal tissue (Garner 2019, pers. comm.). It is possible mussels are more susceptible to parasites after anthropogenic factors reduce their fitness (Henley 2018, pers. comm.).

6.4.5 Predation

Native Americans extensively harvested freshwater mussels for food and ornamental uses (Morrison 1942, p. 348; Bogan 1990, p. 112). According to Zimmerman *et al.* (2003, p. 28), flatworms are voracious predators on newly metamorphosed juvenile mussels in culture facilities. Young juveniles may also fall prey to various other invertebrates, such as *Hydra*, non-biting midge larvae (Chironomidae), dragonfly larvae (Odonata), and crayfish (*Cambarus* spp.). Although mammals such as raccoon, mink, otter, hogs and rats, and turtles and birds occasionally feed on mussels, the threat from these species is not considered significant to Round Hickorynut, perhaps due to lowered natural availability and abundances (Edelman *et al*. 2015, p. 474).

Among mussel predators, the Muskrat (*Ondatra zibethicus*) is probably cited most often (Tyrrell and Hornbach 1998, p. 301), but the North American River Otter (*Lontra canadensis*) is also a lesser-studied substantial predator. Based on a study of Muskrat predation on imperiled mussels in the upper North Fork Holston River in Virginia, this predation could limit the recovery potential of endangered mussel species or contribute to the local extirpation of already depleted mussel populations (Neves and Odom 1989, p. 939). Five Round Hickorynut specimens were recovered from multiple collections from the Holston River, Tennessee, where the species is now considered extirpated; the shells had Muskrat incisor scrape marks resulting from extraction from the substrate and/or feeding activity (Parmalee and Faust 2006, p. 74).

In collections from Muskrat middens at two mussel beds on the Muskingum River, Ohio, 60 Round Hickorynut specimens were collected (0.53 percent relative abundance; Watters 1994, p. 66). This indicates that the species may be vulnerable to seasonally variable mammal predation. The Round Hickorynut was formerly considered common in the Muskingum River, but there is no evidence of reproduction or recruitment (Watters and Dunn 1993–94, p. 253), and no live individuals were detected during a recent survey (ESI 2012, p. 108). Therefore, this population is currently in low condition (Appendix A). Predation by Muskrats may represent a seasonal and localized threat to the Round Hickorynut, but unless populations are at a critically low number of individuals is not likely a substantial threat at the MU or basin level. Since Muskrat predation is generally size-selective (Tyrrell and Hornbach 1998, p. 301), this threat is considered to be more likely to affect large individuals rather than at a population level.

Some species of native fish, such as Freshwater Drum (*Aplodinotus grunniens*) and Redear Sunfish (*Lepomis microlophus*) feed on mussels and potentially upon young; however, predation by Black Carp is considered a more significant threat since they attain a greater size, live comparatively longer, and have not co-evolved with Round Hickorynut populations (see section 6.2, above). Recent evidence indicates that 77 percent of Round Goby diet can be comprised of native unionids, which is an increasing threat in the Great Lakes and Ohio basins where that species is established (Bradshaw-Wilson *et al*. 2019, p. 266). Based on the best available information, the overall threat posed by vertebrate and invertebrate predators on the Round Hickorynut in most instances is considered less significant than other threats that are currently influencing population status rangewide, but Black Carp and Round Goby are an increasing threat in the Great Lakes and Ohio basins.

6.5 Overall Summary of Factors Affecting the Species

Factors discussed in this chapter that are currently affecting the Round Hickorynut include those that are systemic and contribute to the greatest threats impacting the species and its resource needs across its range, including: habitat loss and alteration, water quality impairment, and more site-specific threats, such as invasive species. The topics discussed in this chapter are reflective of the best available scientific and commercial information as it pertains to the Round Hickorynut.

Impacts to freshwater mussels and benthic riverine aquatic organisms, in general, often involve multiple interrelated actions, involve compounded stressors, and rarely lack a single causative agent; therefore, they are not easy to observe and may be difficult to quantify after they occur. While factors such as climate change, host fish availability, disease, or predation may affect the species, the best available information does not suggest they are currently acting as significant contributors to Round Hickorynut decline. Commercial harvest was likely a significant threat that previously/historically contributed to species decline, but it is not currently affecting the Round Hickorynut, and is unlikely to be a future threat.

The current resiliency, redundancy, and representation of the Round Hickorynut is directly tied to population and habitat fragmentation by the construction of impoundments throughout the species range. Habitat loss and alteration from dam operations continue to impact populations specifically in the Ohio, Tennessee, and Cumberland basins. Impoundments fragment and isolate populations from one another, prevent dispersal that reduces gene flow, and compounds stressors such as the introduction of contaminants and pollution.

Across all basins in which the Round Hickorynut currently occurs, there are one or more threats to the species, which results in effects to individuals and populations at a more rapid rate. The combined impacts of dams and barriers, resource extraction, agricultural activities, and nonnative species have led to localized extirpations of the Round Hickorynut, and a cumulative loss of 80 percent of its populations compared to its historical distribution. Overall, the greatest threats currently to the Round Hickorynut are habitat alteration and loss, water quality degradation, nonnative species, and genetic isolation, which affect resource and demographic needs for the species.

A variety of stressors contribute to these threats, which may vary in intensity and duration based on temporal and spatial considerations, but similar prevalent impacts have been observed on the Round Hickorynut resiliency, redundancy, and representation of the species throughout its range. In the Great Lakes basin, the primary stressors are nonnative species, impoundments, and genetic isolation. In the Ohio River basin, the primary stressors are impoundments, resource extraction, and agricultural activities. In the Cumberland River basin, the primary stressors are impoundments, resource extraction, and agricultural activities. In the Tennessee River basin, the primary stressors are impoundments, agricultural activities, and urbanization. In the Lower Mississippi River basin, the primary stressors are genetic isolation, agricultural activities, and impoundments.

Throughout the species range, impacts of contaminants and mussel die-offs are difficult to measure and almost impossible to predict, but have been documented in the Fish Creek in the Great Lakes basin and Big Darby Creek in the Ohio basin, and other secondary factors such as predation and climate change are increasingly concerning as small populations become more isolated.

CHAPTER 7 - FUTURE CONDITIONS

This chapter summarizes our evaluation of what the species' likely future conditions will be under different scenarios, and applies these forecasts to the concepts of resiliency, representation, and redundancy to describe future Round Hickorynut viability.

Overall, the Round Hickorynut has greater numbers of populations in medium-sized rivers, such as the South Fork Kentucky River, as compared to large or small rivers (see below). The Round Hickorynut was categorized as a component of a medium river-mussel assemblage by Evans (2010, p. 13), who generally characterized the species as being found at locations where the drainage area was greater than 463 square miles (mi^2) (1,200 square kilometers (km^2)). Wide variation in river and stream occupation by Round Hickorynut is difficult to characterize succinctly. For the purposes of future condition scenarios *only*, populations of the species are generalized in three categories according to drainage size and area: streams and small rivers (less than 463 mi^2 (1,200 km^2)), medium rivers (463–4,633 mi^2 (1,200–12,000 km^2)), and large rivers (greater than 4,633 mi^2 (12,000 km^2)).

Using these categories, the Round Hickorynut is extant in comparatively fewer large rivers than smaller streams and medium rivers. The species formerly occurred in numerous large river mainstems such as the Wabash, Mississippi, and Cumberland rivers (Appendix D). It persists in large rivers such as the Ohio, Tennessee, Tippecanoe, Kentucky, and Kanawha rivers. The Round Hickorynut no longer occurs in any small streams in the Lower Mississippi River basin, or large rivers in the Cumberland and Lower Mississippi basins.

7.1 Future Scenario Considerations

The factors influencing the viability of Round Hickorynut include: (1) physical habitat degradation or loss, (2) water quality degradation, (3) invasive and nonnative species, and (4) genetic isolation and displacement (see Figure 6-1, above). Each of these factors are projected to continue into the future at varying degrees, depending on the populations and locations across the landscape (e.g., some sources of habitat degradation or loss are likely to be more significant in some populations than others). We attempted to discern this variance by using the best available information on proposed projects and modeling efforts (e.g., climate change/Resource Concentration Pathway [RCP][8] models). To the best of our knowledge, commercial harvest of freshwater mussels, although a likely contributor to the decline of the Round Hickorynut to date, is unlikely to occur in the future due to strict regulation of harvest and the depressed global demand for shells; thus, this factor is not carried forward in our analysis of potential future conditions.

7.2 Future Scenarios

We forecast the Round Hickorynut's future conditions, in terms of resiliency, representation, and redundancy, under three plausible future scenarios. These three scenarios forecast the Round Hickorynut's viability over approximately 20 to 30 years, which is a range representing at least two generations. We concentrated on this duration because: (1) the species lives 10 to 15 years, and (2) long-term trend information on Round Hickorynut abundance and threats is not available across the species range to contribute to meaningful alternative timeframes. Also, the year 2050, approximately 30 years from the completion of this SSA, is a typical cut-off date for predictions by the International Panel on Climate Change Climate (IPCC) (Furedi 2013, p. 2).

Given there are 65 populations and 34 MUs under consideration, we describe the threats that may occur at the basin scale as opposed to each of the populations or MUs, i.e., within the Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi basins, the five major basins the species inhabits. However, we also point out specific populations and MUs to illustrate examples for each of the scenarios. The factors that influence the species either remain constant from current conditions (scenario 1), improve (scenario 2), or become worse (scenario 3).

---

[8] RCP refers to a greenhouse gas concentration (not emissions) trajectory adopted by the Intergovernmental Panel on Climate Change (IPCC) in its 5th Assessment Report (IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.). Four pathways were selected by the IPCC for climate modeling and research, all describing potential future climate outcomes, and all considered possible depending on the amount of greenhouse gases that are emitted in the future.

Resiliency of Round Hickorynut populations depends on future water quality, habitat quality, availability of flowing water, substrate suitability, abundance and distribution of host fish species, and habitat connectivity. We expect Round Hickorynut populations to experience changes to these resource needs in different ways under the different scenarios. We project the future resiliency of each population based on events likely to occur under each scenario. We did not include an assessment of reproduction for the future scenarios; rather, the abundance of the populations in the future reflects whether reproduction, and more importantly, recruitment, are occurring. We also project an overall condition for each population as either High, Medium, Low, or Very Low (the latter condition equating to extirpation or functionally extirpated; see Table 7-1 for definitions).

Table 7-1. Condition categories used to determine the overall projected future conditions of Round Hickorynut populations.

Future Condition Category	Description
High	Populations are expected to have high resiliency. Sizable populations generally distributed over a significant and more or less contiguous length of stream (greater than or equal to 30 river miles), with evidence of recent recruitment, and multiple age classes are represented. Water quality parameters predominantly meet designated uses and habitat conditions remain optimal for species detection. Connectivity among populations is maintained within MUs such that populations are not linearly distributed (i.e., occur in tributary streams within a management unit), or habitat is available for expansion. These populations are expected to persist in 20 to 30 years and withstand stochastic events.
Medium	Small generally restricted populations with limited levels of recent recruitment and characteristics of viability, and susceptible to extirpation within 20 to 30 years. Appropriate substrates are generally maintained with flow that mimics natural conditions. Water quality and habitat degradation may occur but not at a level that negatively affects both the density and extent of a population. Individuals possibly still occur in tributary streams, such that within a MU, populations are not linearly distributed. Resiliency is less than under high conditions, but the majority (approximately 75 percent) is expected to persist beyond 20 to 30 years; however, loss of smaller tributary populations is possible. Populations are smaller and less dense than the high condition category.
Low	Very small and highly restricted populations, with little to no evidence of recent recruitment, and of questionable viability and detectability. These populations may be still observable in very low numbers compared to historical conditions but may be on the verge of extirpation in the short-term future (if not already extirpated). Population sizes may be below detectable levels despite consistent survey efforts within formerly occupied range, or may only be represented by highly isolated, or older, non-recruiting individuals. Loss of mussel habitat or water quality degradation within the formerly occupied river/stream reach has been measured or observed. Populations are linearly distributed within a management unit and are not likely to withstand stochastic events. These populations have low resiliency and are the least likely to persist in 20 to 30 years.
Very Low	Populations are expected to no longer occur in a river/stream or management unit in the future (20 to 30 years). Contiguous mussel habitat has been lost and water quantity or quality limits colonization potential. Previous evidence of population limited to relic or weathered dead shells only. Populations are considered extirpated or functionally extirpated within 20 to 30 years.

For each scenario, we used the best available scientific and commercial information to determine the likelihood that a particular condition would apply in 20 to 30 years. For example, we used state, city, and county development planning documents, peer-reviewed literature projections, mussel expert advice and input, and our experience and best professional judgement. We used the scale in Table 7-2, below, to estimate these likelihoods.

Table 7-2. Explanation of confidence terminologies used to estimate the likelihood of a particular future condition category.

Confidence Terminology	Explanation
Highly likely	We are more than approximately 90 percent certain this condition category will occur.
Moderately likely	We are approximately 50 to 90 percent certain this condition category will occur.
Somewhat likely	We are less than approximately 50 percent certain this condition category will occur.

7.3 Scenario 1

Under this scenario, factors influencing current Round Hickorynut populations are assumed to remain constant into the future.

Factors influencing Round Hickorynut populations are assumed to remain constant into the future for the next 20 to 30 years, including existing habitat degradation and beneficial conservation actions, and climate and hydrological conditions. This scenario assumes the current levels monitoring capacity are consistent (i.e., population augmentation is not currently taking place).

Scenario 1 assumes that existing patterns and rates of land use change continues across the species range (Lawler *et al.* 2014, p. 56), including urban growth and changes in agricultural practices (Newton *et al.* 2008, p. 434; Terando *et al.* 2014, p. 4; Lasier *et al.* 2016, p. 672). This scenario also assumes that existing regulatory mechanisms and voluntary conservation measures indirectly benefiting the species remain in place and no new/additional conservation measures are added. See Figure 7-1 below.

Great Lakes basin

Nonnative species, such as Asian Clam, Zebra Mussel, and Quagga Mussel, which are likely the greatest threat to the populations in this basin, continue to negatively influence populations basin-wide. Zebra mussels are established in the Pine and Belle River, Michigan, and Black River in Ohio, and are predominant in Lake Erie, to which all of these rivers drain. Asian Clam abundance and distribution is widespread within the range of the species and competes for food and nutrients needed for mussel growth and development. Competition for space and resources from Zebra and Quagga mussels result in reduced fitness of Round Hickorynut in the low condition/medium river populations (Belle River, Pine River, Black River [Ohio]). The Black River in Michigan is not infested with Zebra mussels, and potentially offers refugia from this stressor to mussels in the Great Lakes (Haas 2009, p. 42). Nonnative species such as dressneids (Zebra and Quagga mussels) are the greatest imminent threat to Round Hickorynut populations in the Great Lakes basin, as they have contributed to the decimation of the mussel fauna in this basin.

There is a small to moderate reduction in water discharge due to drought conditions, and negative changes in physical habitat features due to agricultural practices, human population growth, and resource extraction activities in stream tributaries and medium rivers that affect individuals (e.g., Fish Creek, Pine River, Belle River, Black River [Michigan]). Water quality declines are evident in river populations currently identified as low condition due to untreated or poorly treated wastewater discharges, development, resource extraction, and high risk of contaminant spills (e.g., Black River, Ohio).

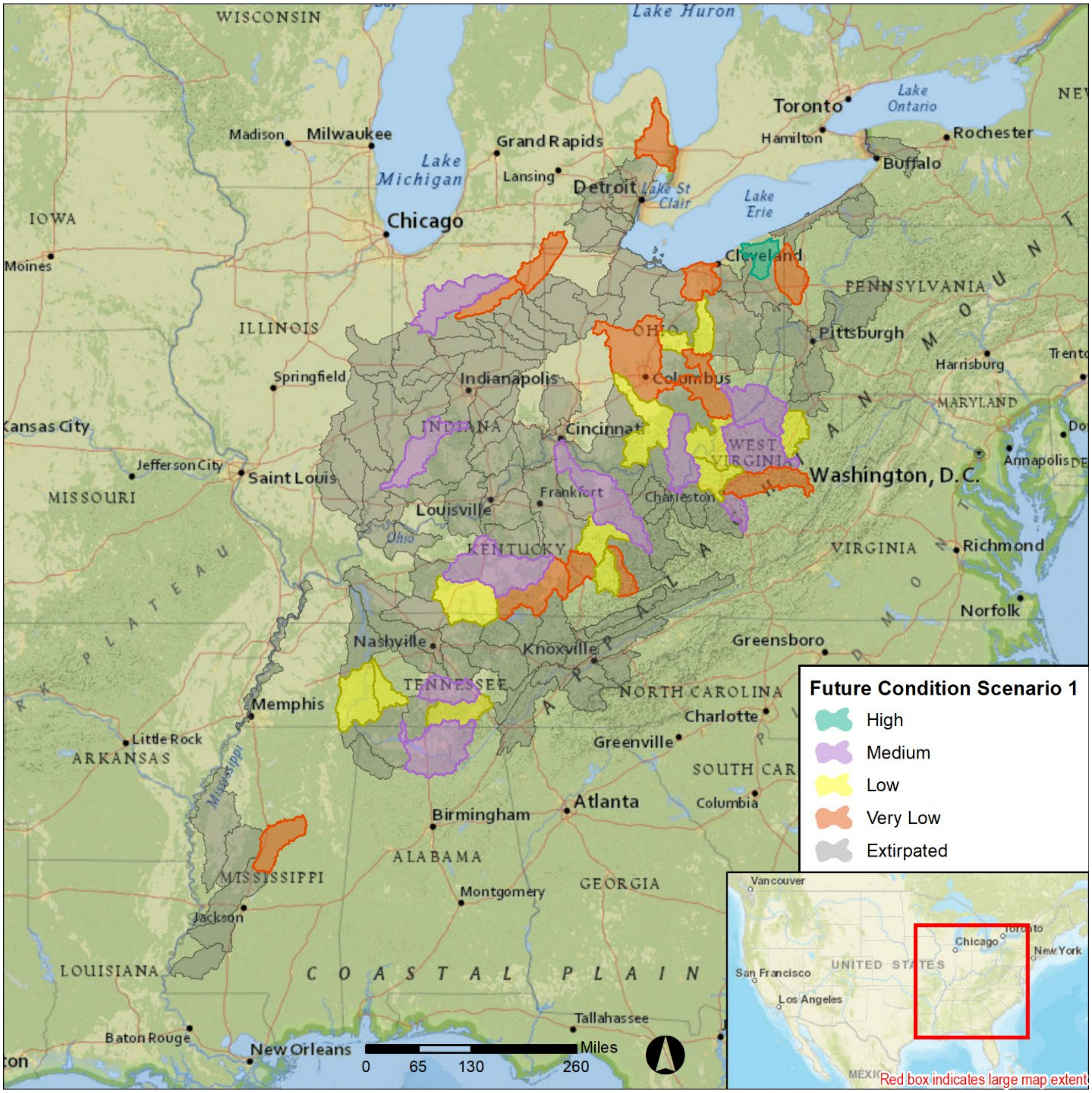

Figure 7-1. Distribution of the current and historically occupied Management Units (MUs; a.k.a. HUC8s) of Round Hickorynut under Future Condition Scenario 1. Currently occupied MUs are represented with very low (i.e., no survival or survival uncertain; no longer observable), low, medium, and high condition categories (as described in Chapter 7; Service 2019, unpublished data).

For example, diminishment of flow conditions through agricultural practices that increase pressure on groundwater aquifers makes individual mussels more susceptible to drought (which can expose aquatic habitat, isolate mussels during sperm and juvenile mussel dispersal, increase predation, and concentrate contaminants), more susceptible to temperature increases, and, in extreme situations, can impede the delivery of sufficient dissolved oxygen. Lower flows also foster the concentration of contaminants, and Fish Creek, an isolated population in low condition in Ohio, has a history of contaminant spills (Sparks *et al.* 1999, p. 12). The pervasive impacts of water quality degradation can affect this population which is linear, small in extent, isolated by dams, and low density.

Habitat fragmentation is an issue for the stronghold Great Lakes basin population (i.e., Grand River). A large impoundment (Harpersfield Dam) on the lower Grand River, operated by the Corps, limits downstream dispersal and genetic exchange with other Great Lakes populations, and limits access to suitable habitat. There are also impoundments on Mill Creek and the Black River, Ohio (Lyons *et al.* 2007, p. 10). While connectivity is currently maintained between Mill Creek and the Grand River, another tributary, Rock Creek, is impounded, and mussel habitat in the upper reaches of Mill Creek and in the lower reaches of the Grand River is limited for the Round Hickorynut. The populations in Mill Creek and Grand River likely function as a meta-population, with the potential for source-sink dynamics (Huener *et al.* 2005 p. 61; Grabarkiewicz 2014, p. 27). Under this scenario, the currently small, isolated, linear Lake St. Clair populations/MU (Belle, Pine, and Black Rivers in Michigan) are lost, resulting in extirpation of the species from Michigan.

<u>*Ohio River basin*</u>

There is a small to moderate reduction in water discharge due to drought conditions, and negative changes in physical habitat features due to agricultural practices, human population growth, and resource extraction activities in stream tributaries that affect individuals in low and medium condition populations (e.g., tributary populations in West Fork, Walhonding, Upper Ohio-Shade, Little Kanawha, and Upper Scioto MUs). Diminishment of low flows makes Round Hickorynut individuals more susceptible to drought (which can expose aquatic habitat, isolate mussels during sperm and juvenile mussel dispersal, increase predation, and concentrate contaminants), more susceptible to temperature increases, and, in extreme situations, can impede the delivery of sufficient dissolved oxygen. Lower flows also foster the concentration of contaminants.

Water quality declines are evident in river populations currently identified as medium condition due to untreated or poorly-treated wastewater discharges, human development, resource extraction, and high risk of contaminant spills (e.g., populations in Little Muskingum-Middle Island, Symmes Creek, South Fork Hughes River, Lower Scioto, Walhonding River, Elk River, Licking River, South Fork Kentucky, Tippecanoe, Lower White, Upper Green MUs). The pervasive impacts of water quality degradation can affect these entire populations.

Habitat degradation continues in large-river populations due to development, navigational impacts such as increases in river commerce traffic between coal landing facilities, and extensive agriculture in riparian areas. For example, suction dredging below locks and dams in the Ohio and lower Kanawha River to maintain the navigation channel can be a source of direct mussel mortality. In the Kentucky River, streamside development and agriculture causes sedimentation that fills in the interstitial spaces needed by juvenile mussels and host fish eggs. This habitat degradation has the potential to affect individuals initially, but over time, results in impacts to populations.

Nonnative species, such as Asian Clam, Zebra Mussel, and Quagga Mussel, continue to negatively influence populations basin-wide. Asian Clam abundance and distribution is widespread within the range of the species and competes for food and nutrients needed for mussel growth and development. Competition for space and resources from Zebra and Quagga mussels result in reduced fitness of Round Hickorynut in the Ohio, Kanawha, and Kentucky rivers.

Habitat fragmentation is a common issue for many of the Ohio River basin populations. Impoundments on the Shenango, Walhonding, and Green Rivers, where there are dams both upstream and downstream of Round Hickorynut populations, limit access to suitable habitat and isolate populations, which in turn limits the amount of genetic exchange between populations.

Cumberland River basin

Water quality degradation continues to affect the Cumberland River basin populations (Rockcastle River and Buck Creek). Due to their already low condition and linear orientation, this detrimental activity can result in direct mortality of Round Hickorynut. The small population size and increased distance between sexually mature individuals, along with increases in total suspended solids, makes it subsequently harder for females to intake sperm, negatively affecting reproduction and recruitment. The low densities of these populations, increased threats of siltation and sedimentation from erosion from agricultural activity (Hagman 2000, p. 43), coupled with water quality degradation due to current and past mining activities (Houp and Smathers 1995, p. 116), and isolation due to Wolf Creek Reservoir, results in the loss of these populations. This is a loss of 20 percent of the species representation due to extirpation from the Cumberland River basin.

Tennessee River basin

Small to moderate reductions in water discharge occur due to drought and agricultural activities in the Duck River, a high condition population, the Paint Rock River, a medium condition population, and the Buffalo and Elk rivers, low condition populations. These water discharge reductions result in habitat loss through increased sedimentation and siltation, which covers substrates used for mussel settlement. Wastewater and runoff from land use activities have increased concentrations of contaminants, such as ammonia and chlorine. Discharge reductions and water extraction activities also result in periodic loss of connectivity between mussel populations. Impacts from periodic loss of connectivity between suitable habitat patches can be exacerbated if they occur during reproductively active periods of sperm distribution (limiting the ability of sperm to fertilize eggs) or juvenile mussel dispersal (limiting the distribution of the mussel in the stream).

Water quality declines are evident in rivers with low condition populations (Elk and Buffalo Rivers) due to untreated or poorly treated wastewater discharges, and high risk of contaminant spills, affecting entire populations due to predominantly linear distributions. Habitat degradation continues in the Duck River due to increasing human development pressures and extensive agriculture in riparian areas. This degradation results in direct habitat loss, increased sediment that fills substrate spaces required for juvenile mussel development and host fish eggs, and excessive storm water flows that erode substrate habitat. Habitat degradation continues in the Tennessee River due to development, navigational impacts such as dredging and increases in river commerce traffic, and extensive agriculture in riparian areas. This degradation results in direct habitat loss, increased sediment that fills substrate spaces required for juvenile mussel development and host fish eggs, and excessive storm water flows that erode substrate habitat.

Nonnative species such as Asian Clam continue to impact populations basin-wide through competitive interactions for food and nutrients. Habitat fragmentation is a common and problematic issue for the Tennessee River basin populations. A large water supply impoundment, Normandy Dam on the Duck River, and hydropower dams, Tims Ford Dam on the Elk River, and Pickwick Dam on the Tennessee River, fragment and isolate populations. Smaller dams such as Lillards Mill and Harms Mill dams limit the mussel's access to suitable habitat and dispersal potential. As a result, these changes limit the amount of genetic exchange between populations.

Lower Mississippi River basin

Habitat alteration occurs in this basin through channelization, bank erosion, widened channels, uniform flows, unstable sediments, and meander cutoffs; this threat continues as the most significant threat to the species and remaining population in this basin. Intensive agricultural activities contribute substantial runoff within the Big Black River, which covers substrates used for settlement (Jones *et al.* 2005, p. 84). Water quality degradation through high levels of suspended solids continues in this low condition population, which can affect respiration and smother invertebrates, resulting in direct mortality of mussels. The small extent, increased threats of siltation and sedimentation from erosion from agricultural activity, and severe isolation from other basin populations result in the loss of this population, which, in turn, eliminates 20 percent of the species representation across its range.

7.3.1 Resiliency

Under Scenario 1, factors currently influencing Round Hickorynut populations remain constant into the future. In total, 23 of 65 Round Hickorynut populations (35 percent) and 13 of 34 MUs (9 percent) deteriorate in resiliency, and are predicted to be extirpated. The loss of these populations and MUs result in extirpation of the species from Pennsylvania and Mississippi. Twenty-eight of the remaining 42 populations (65 percent), and 11 of the remaining 21 MUs (52 percent) are in low condition. The two populations and MUs in the Cumberland basin (Rockcastle River and Buck Creek), and the sole population and MU in the Lower Mississippi Basin (Big Black River) are predicted extirpated under this scenario, due to genetic isolation caused by habitat fragmentation and distance between populations.

As many as 42 (65 percent) of the current 65 populations maintain some resiliency over time as existing regulatory and voluntary conservation measures continue to be implemented to counteract existing threats. Notably, the Grand River population in the Great Lakes Basin is able to maintain its high resiliency under this scenario, largely due to the large extent of the population and maintenance of riparian buffers along most of the river corridor. However, the effect of current levels of river and population fragmentation, sedimentation, oil and gas exploration, and increases in numbers and individuals of nonnative species continue to result in habitat loss, water quality degradation, and competition for food resources and suitable substrates, which leads to reduced recruitment and low mussel abundance and survival.

Improvements in dissolved oxygen and reduction of hypolimnetic flow releases from hydropower dams continue to aid populations in some rivers such as the Elk and Duck River in Tennessee, but these populations are linear and confined to upper reaches and still vulnerable to stochastic events. Hypolimnetic discharges continue to be a problem for other populations such as the medium condition populations in the Green and Licking rivers in Kentucky. We estimate that only 1 out of 65 populations (1.5 percent) would be in high condition (i.e., the Grand River in the Great Lakes basin), 13 populations (20 percent) in medium condition, and 28 populations (43 percent) in low condition. As many as 23 populations (35 percent) are may no longer be detectable or are potentially extirpated (i.e., very low condition as represented in Figure 7-1, above).

Under this scenario:

- In the Great Lakes basin, 4 of 7 populations and 2 of 4 MUs are predicted to be extirpated (very low condition).
- In the Ohio River basin, 16 of 49 populations and 6 of 22 management units are predicted to be extirpated (very low condition).
- In the Cumberland River basin, all populations/MUs (2 of 2 populations and 2 of 2 MUs) are predicted to be extirpated (very low condition).
- In the Lower Mississippi River basin, the single remaining [current] population/MU is predicted to be extirpated (very low condition).

The St. Clair, Black-Rocky, St. Joseph, Shenango, Muskingum, Little Kanawha, Elk (West Virginia), Upper Scioto, Middle Fork Kentucky, Eel, Upper Cumberland - Lake Cumberland, Rockcastle, and Upper Big Black MUs are considered extirpated. Of the 42 current populations projected to persist (high, medium, or low condition), 28 (67 percent) will be in low condition, and 21 MUs will be represented across the species range (Figure 7-1)

7.3.2 Representation

With 28 populations (67 percent) expected to be in low condition under Scenario 1, the species is at an increased risk of extirpation, or falling into very low condition, in all but the high and medium condition populations (14 total). The watersheds with high and medium condition populations under this scenario (*e.g.*, Grand River, Symmes Creek, Tippecanoe River, and Paint Rock River) would maintain representation in the Great Lakes, Ohio, and Tennessee basins. However, populations deteriorating to very low condition predict the extirpation of the species from the Cumberland and Lower Mississippi basins, extirpation from the states of Pennsylvania and Mississippi, and a 40 percent loss of basin representation.

7.3.3 Redundancy

Under Scenario 1, redundancy for the Round Hickorynut is reduced from current conditions. The predicted loss of the Buck Creek and Rockcastle River populations from the Cumberland basin would result in extirpation from the Cumberland River drainage. Additionally, the loss of Round Hickorynut from the Big Black River would mean the species' extirpation from the Lower Mississippi River basin. In the Great Lakes, Ohio, and Tennessee basins where populations are more numerous and redundant, the best available information suggests that an additional 20 populations (68 percent) would likely be extirpated. Of the 28 low condition populations that persist, almost all are linear in extent, and increase the species vulnerability to additional river and stream extirpation in the Great Lakes, Ohio, and Tennessee basins.

7.4 Scenario 2

Under this scenario, factors that negatively influence most of the extant populations are reduced by additional conservation, beyond the continued implementation of existing regulatory or voluntary conservation actions.

Conservation measures may include: implementation of additional BMPs, increased environmental regulations or enforcement of existing regulation improvements in aquatic connectivity, and active species management, such as captive propagation or translocation efforts using brood stock from all three basins. Under Scenario 2, there is an optimistic species response to the factors influencing mussel viability, and conservation measures are implemented for targeted translocation, propagation, or augmentation. Additionally, restoration efforts using existing resources and capacity are successful, and monitoring costs decrease. See Figure 7-2, below, for MU condition under Scenario 2.

Scenario 2 assumes some actions of positive intervention are thoughtfully designed and executed as feasible and appropriate conservation plans. Such plans may be implemented by a combination of Federal, state, and local governments, including river authorities, municipalities, and other "water regulators" along with non-governmental organization conservation groups, private landowners, and other stakeholders informed by biologists with expertise in the conservation of freshwater mussels and their habitats. Also, increased enforcement of environmental regulations helps address contamination issues, and mitigation of resources lost due to impacts provides opportunities for conservation funds, such as translocation or propagation activities.

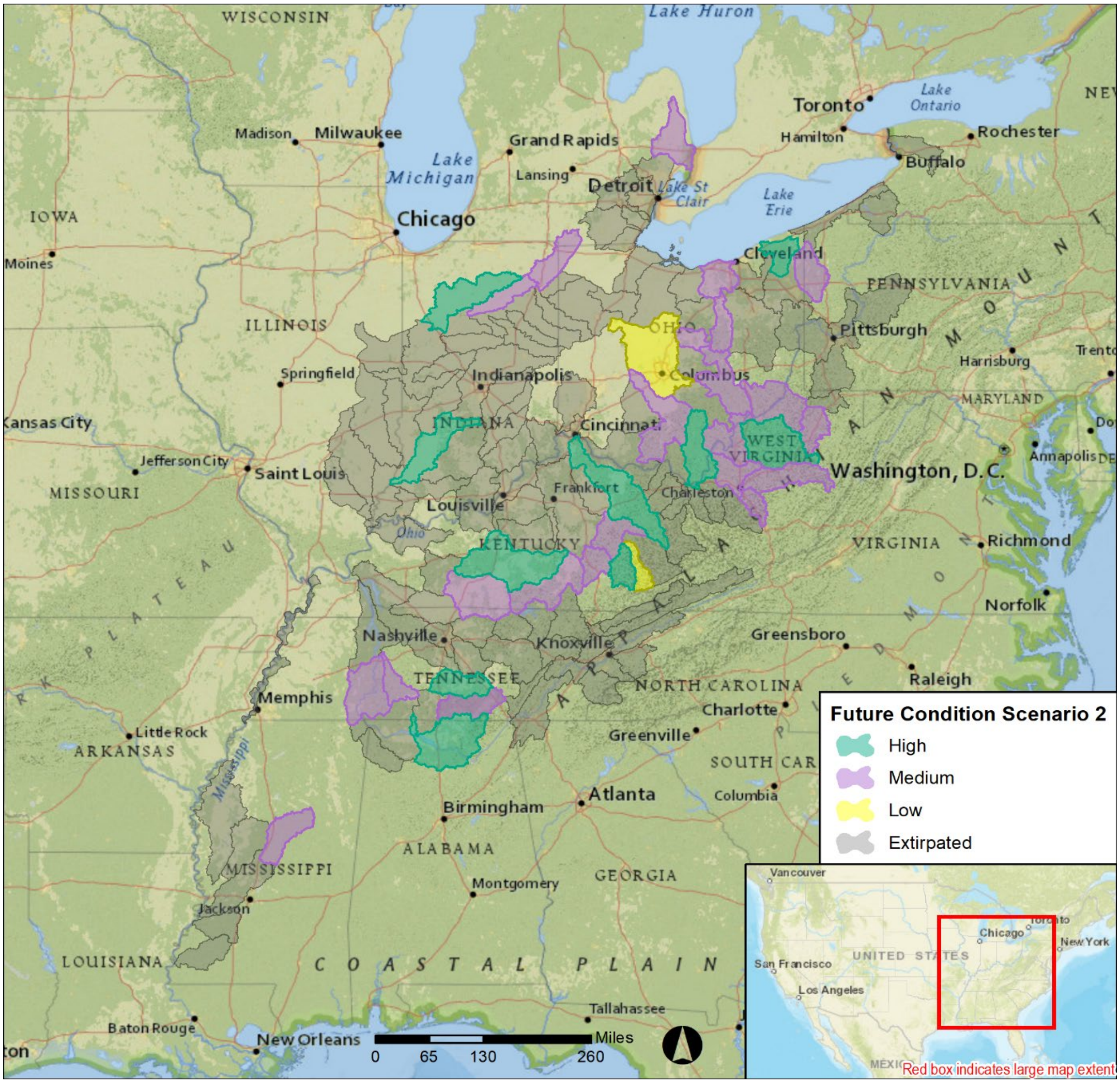

Figure 7-2. Distribution of the current and historically occupied Management Units (MUs; a.k.a. HUC8s) of Round Hickorynut under Future Condition Scenario 2. Currently occupied MUs are represented with low, medium, and high condition categories (as described in Chapter 7; Service 2019, unpublished data). There are no very low condition (extirpated) populations projected under this scenario.

Great Lakes basin

Studies are conducted on nonnative species (Round Goby, Zebra Mussel, Asian Clam, Quagga Mussel) that leads to better understanding of how to reduce the impacts of their spread basin-wide, thereby potentially reducing risk of predation and decreasing competition for food and nutrients in mussel beds. Host fish (darter) abundances increase due to increased effectiveness of Round Goby exclusion and control. The Black River in Michigan is not infested with Zebra Mussels and potentially offers refugia from this stressor to mussels in the Great Lakes basin. The Harpersfield Dam, a barrier on the lower Grand River, limits movement of nonnatives upstream out of Lake Erie, and potentially offers refugia within the Grand River (a potential stronghold population under this scenario). This refugia would enable this population to be a source from which to use broodstock for propagation or translocation efforts.

The natural flow regime is maintained in tributary populations (Mill Creek and Fish Creek) to the maximum extent possible, and improvements in physical habitat are achieved due to environmental outreach and awareness, which reduces water quality degradation. The Round Hickorynut is able to withstand minor impacts from climate change, such as prolonged drought or flooding, due to increases in the abundance of individuals. Opportunities for improvements in habitat connectivity are achieved, which allow for within-basin expansion, potentially connecting Fish Creek, which is currently isolated, or facilitating dispersal downstream into the St. Joseph River.

Water quality improves in river populations that are in low condition due to better treatment of wastewater discharges, especially in rural areas (Pine, Belle and Black Rivers in Michigan; and Black River in Ohio). Targeted programs are developed and implemented to improve water quality through BMPs concerning agricultural practices and development, and measurable success is achieved. Impacts from agricultural activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are monitored and enforcement of violations is conducted in a timely manner, potentially reducing long-term issues. Additional protective measures are undertaken and riparian corridors are re-established. Risks of population loss due to contaminant spills is lessened through the presence of non-linear populations within MUs (e.g., St. Clair, Black-Rocky).

Ohio River basin

The natural flow regime is maintained in tributary populations to the maximum extent possible, and improvements in physical habitat are achieved due to environmental outreach and awareness, which reduces water quality degradation. The Round Hickorynut is able to withstand minor impacts of prolonged drought or flooding, due to increases in the abundance of individuals in small streams. Opportunities for improvements in habitat connectivity are achieved, which allow for within-basin expansion, potentially connecting isolated stream or small river populations to other populations. Population restoration or augmentation is possible (e.g., Shenango, West Fork, Walhonding, Upper Scioto, Lower Scioto, Middle Fork Kentucky, Eel, Barren MUs).

Water quality improves in river populations that are currently in medium condition due to better treatment of wastewater discharges, especially in rural areas. Targeted programs are developed and implemented to improve water quality through BMPs concerning agricultural practices and development, and measurable success is achieved. Impacts from resource extraction activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are monitored and enforcement of violations is conducted in a timely manner, potentially reducing long-term issues. Additional protective measures are undertaken and regulations developed for oil and gas exploration in concentrated areas. Risks of population loss due to contaminant spills is lessened through the presence of non-linear populations within MUs (e.g., Symmes Creek, Upper

Kanawha River, Elk River [WV], Licking River, Tippecanoe River, Licking River, Richland Creek, Upper Green River).

Habitat degradation in large river populations due to development, navigational impacts such as dredging and increases in river commerce traffic, and extensive agriculture in riparian areas is mitigated through use of existing funds or establishment of conservation funds for Round Hickorynut species restoration initiatives. The costs of monitoring large river mussel populations decrease due to advances in technology, leading to better annual estimates of mussel bed distribution (for instance, environmental deoxyribonucleic acid (DNA), or sonar exploration of river beds and mussel habitat), and areas that can be targeted for survey efforts. Existing public lands such as the Ohio River Island Refuge (Neal Island) are capable of providing refugia for brood stock to further translocation/captive propagation efforts (e.g., Muskingum, Elk, Kanawha, Kentucky, and Ohio Rivers).

Studies are conducted on nonnative species (Asian Clam, Zebra Mussel, Black Carp) that leads to better understanding of how to reduce the impacts of their spread basin-wide, thereby reducing risk of predation, and decreasing competition for food and nutrients in mussel beds.

Cumberland River basin

Water quality improves in the small Rockcastle River and Buck Creek populations due to better treatment of wastewater discharges, especially in rural areas. Targeted programs are developed and implemented to improve water quality through BMPs concerning agricultural practices and development, and measurable success is achieved. Impacts from resource extraction activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are monitored and enforcement of violations is conducted in a timely manner, potentially reducing long-term issues. Habitat degradation in the Rockcastle River and Buck Creek due to agriculture and mining impacts in riparian areas is mitigated through restoration efforts, which could address sediment and erosion problems, in order to increase the amount of available mussel habitat.

With existing public lands such as the Daniel Boone National Forest in Kentucky capable of providing refugia for brood stock to further translocation/captive propagation efforts, the Round Hickorynut can be reintroduced into former portions of its range in the Cumberland River drainage through successful captive propagation efforts and partnerships (e.g., Big South Fork Cumberland National River and Recreation Area).

Tennessee River basin

Similar to the Ohio River basin, the natural flow regime is maintained for populations in the Paint Rock, Duck, Buffalo, and Elk Rivers to the maximum extent possible, and improvements in physical habitat are achieved due to environmental outreach and awareness. Human population growth is planned and managed through sustainable development initiatives. The Round Hickorynut is able to withstand impacts from prolonged drought or flooding, and opportunities for improvements in habitat connectivity or translocation potential are achieved, allowing for increases in abundance and Round Hickorynut expansion into upstream and downstream reaches of the Duck and Elk Rivers and their tributaries, which may have been formerly occupied.

Water quality improves due to better treatment of wastewater discharges, especially in rural areas. Targeted programs are developed to improve water quality through agricultural and development BMPs. Impacts from agricultural activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are regulated, monitored, and enforcement of violations are conducted in a timely manner, potentially reducing long-term contamination issues. Risks of population loss from contaminant spills (resulting in suboptimal water quality conditions) are lessened through the presence of non-linear populations.

Similar to the Ohio River basin, habitat degradation in the Tennessee River due to human population growth, navigational impacts such as dredging and increases in river commerce traffic, and extensive agriculture in riparian areas is mitigated. This is potentially through use of existing funds or establishment of conservation funds for Round Hickorynut species' restoration initiatives. The cost of monitoring large river mussel populations decreases due to advances in technology, leading to better annual estimates of mussel bed distribution (for example, eDNA, or sonar exploration of river beds and mussel habitat), and areas that can be targeted for survey efforts. Improved management of nonnative species such as Asian Clam is implemented and studies are conducted that lead to a better understanding of how to reduce the effects of their spread basin-wide, thereby reducing the risk of predation and decreasing competition for food and nutrients in mussel beds.

Lower Mississippi River basin

Water quality improves due to better treatment of wastewater discharges, especially in rural areas. Targeted programs are developed to improve water quality through agricultural and development BMPs. Impacts from agricultural activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are regulated, monitored, and enforcement of violations are conducted in a timely manner, potentially reducing long-term contamination issues. Risks of population loss from contaminant spills (resulting in suboptimal water quality conditions) are lessened through the presence of non-linear populations, and potential population expansion into formerly occupied tributaries or adjacent river drainages to the Big Black River. Improved management of nonnative species such as Asian Clam is implemented and studies are conducted that lead to better understanding of how to reduce the effects of their spread basin-wide, thereby reducing the risk of predation, and decreasing competition for food and nutrients in mussel beds (similar to the Ohio and Tennessee basins).

7.4.1 Resiliency

Under Scenario 2, factors that negatively influence most of the extant populations are reduced by additional conservation. There is an improvement in resiliency from current condition (positive change in condition category) for 32 of 64 (50 percent) of the Round Hickorynut populations, and for 18 of 34 MUs (53 percent). Resiliency is maintained, and potentially improves as regulatory and voluntary conservation measures continue to be implemented. The effects of current levels of sedimentation and wastewater discharges are reduced rangewide, resulting in:

protection of suitable substrates, and improved non-point source water treatment for maintenance of water quality standards. Under this scenario, there is potential for reduced river and habitat fragementation due to habitat improvement, resulting in increased suitable habitat conditions and population connectivity within MUs. These overall improved conditions are predicted to lead to improved recruitment and increased mussel abundance and survival.

Programs targeted to improve water quality through agricultural and development BMPs and riparian buffer initiatives are developed and implemented. Impacts from agricultural and human development activities are monitored and violations are enforced in a timely manner, potentially reducing long-term contamination issues, and leading to better water resource planning at regional and local scales. Improvements in dissolved oxygen and reduction of hypolimnetic flow releases from hydropower and water supply dams continue to aid populations in the Elk and Duck River in Tennesseee, and alternative flow-release strategies are explored and implemented by the Corps and TVA. Recent and potential future dam removals or fish and habitat improvement initiatives stand to aid populations in some rivers (West Fork, Walhonding, Eel, Green, and Elk).

Under this scenario, which is considered highly optimistic based on the current level of threats, none of the 65 extant populations are in very low condition and extirpation of populations is unlikely. However, it is important to keep in mind that some of the [current] low condition populations may already not be viable, especially those that are restricted by impoundments both upstream and downstream, such as in the Upper Scioto, Muskingum, and Middle Fork Kentucky rivers. Improvements to populations within MUs likely result in non-linear population distributions, which improves resilience to stochastic events within and across basins. Under Scenario 2, we estimate that 15 out of 65 populations (23 percent) and 9 of 34 MUs (27 percent) would be in high condition. Thirty-seven (57 percent) populations and 22 (65) MUs would be in medium condition. Nine and 9 (14 percent) of populations and 3 MUs (9 percent) would be in low condition (Figure 7-2).

7.4.2 Representation

The Round Hickorynut retains representation over time, with 52 high and medium populations maintained among all five currently occupied basins (Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi). The Ohio and Cumberland basins could also potentially increase representation further through reintroduction efforts into the Allegheny River, the Big South Fork Cumberland River, or other suitable locations. Populations within MUs are not linearly distributed, and natural or human-assisted improvements in population and habitat connectivity reduce the risk of genetic isolation.

However, with 12 populations (18 percent) estimated to be in low condition regardless of additional conservation measures being implemented, it is possible the species could decline in certain portions of its range. Many impoundments that influence species distribution are operated by Federal agencies such as the Corps and TVA, under congressionally-authorized mandates for hydropower, navigation, flood control, and water supply. Therefore, changes in operations are only revisted during their water control manual update process (generally every 10-30 years), and requires substantial stakeholder involvement.

The presence of low condition populations and MUs under this scenario is also due, in part, to amount of time it would take for habitat improvements, such as dam removals or stream restoration initiatives, to actually benefit the Round Hickorynut. The concentration of increased predation, competition, and factors that can lead to the spread of nonnative species could continue to be a problem for the Round Hickorynut in the Great Lakes and Ohio basins. These factors indicate that regardless of no overall projected loss in resiliency at the population and MU levels, reductions in numbers of individuals or extent of populations are possible.

7.4.3 Redundancy

The Round Hickorynut maintains redundancy under this scenario. There is no loss of populations or MUs, and therefore, all basins in which the species currently occurs continue to support the species. The best available information suggests that it is possible no currently extant populations become extirpated under Scenario 2. Natural or human-assisted population expansion into portions of its formerly occupied range occurs in all three basins. If reintroductions are feasible and advised, conditions under which the species persists also results in possibly improved redundancy.

If Round Hickorynut densities within currently occupied basins are suitable, expanded distribution can be achieved due to within-basin augmentation through translocation around barriers. In addition, if captive propagation using within-basin brood stock proves successful, populations in the Allegheny, Ohio, and Big South Fork Cumberland rivers could be re-established within the species range, due to the presence of public lands and agency partnerships. Reintroductions and improved conservation in the Cumberland and Mississippi River basins, which currently have low redundancy, are possible under this scenario.

7.5 Scenario 3

Under this scenario, factors that influence the current extant populations of Round Hickorynut are likely to become worse from the implementation of known existing and projected development, resource extraction, hydroelectric or water supply projects, etc. Additional risks to the species and its habitat (e.g., climate change) are more challenging to predict with accuracy at this time.

In general, this scenario assumes that all existing threats and associated sources of threats are worse in the future, leading to reductions in water quality in those areas that are already poor and increased habitat degradation of areas that are not fully supporting resource needs (i.e., appropriate food, nutrients, and water quality condition) for aquatic life. The abundance and distribution of host fishes decline. Climate change (e.g., drought, increased changes in precipitation levels/events) begins to affect the Round Hickorynut at the species and population levels. Climate condition and variations from the natural flow regime, with periodic drought and flooding, may result in desiccation, scour, and increased sedimentation and deposition in high quality mussel habitats. This scenario assumes that existing regulatory mechanisms and voluntary conservation measures that are benefiting the species would remain in place, although funding and staffing constraints likely prohibit significant additional protections (see Figure 7-3).

Under Scenario 3, the Round Hickorynut's response to multiple impacts results in significant declines coupled with limited propagation capacity or limited capacity for reintroductions or augmentations. Monitoring capabilities also decrease due to cost and time. In general, this scenario considers a future where conditions are worse for the species across its entire range compared to current conditions (Chapter 5). In this scenario, there is quantifiable reduction or negative effects to all of the species' resource and demographic needs (flow reduction, decline in water quality, reduced connectivity between populations, etc.), which are observable at the population and MU level across the species range.

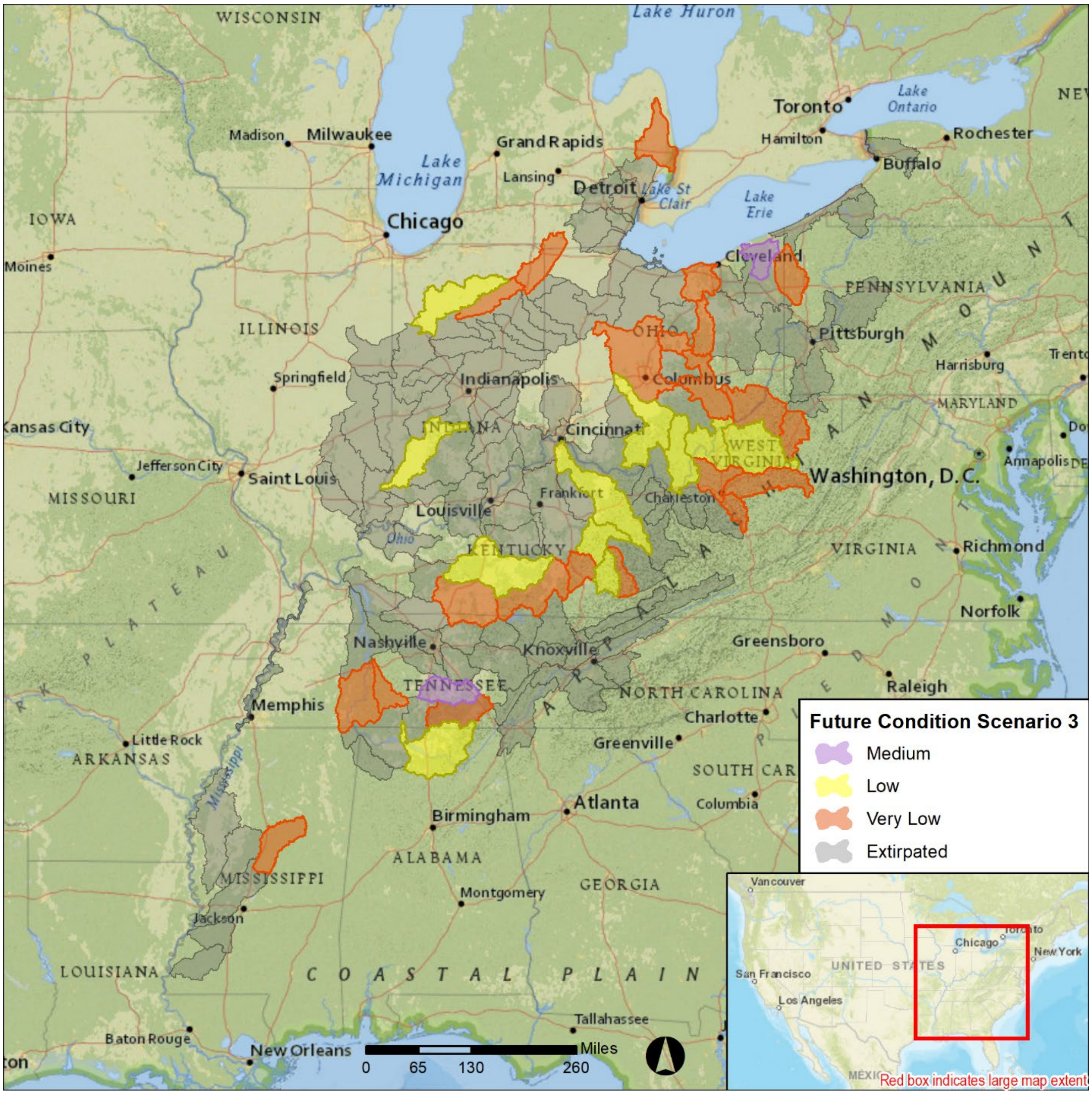

Figure 7-3. Distribution of the current and historically occupied Management Units (MUs; a.k.a. HUC8s) of Round Hickorynut under Future Condition Scenario 3. Currently occupied MUs are represented with very low (i.e., no survival or survival uncertain; no longer observable),

low, medium, and high condition categories (as described in Chapter 7; Service 2019, unpublished data).

Great Lakes basin

The proliferation and spread of nonnative species (Round Goby, Zebra Mussel, Asian Clam, Quagga Mussel) results in invasion of new streams and rivers within the Round Hickorynut's range, and increasing competition for Round Hickorynut resource needs and predation on the species. Host fish (darter) abundances decrease due to Round Goby competitive interactions. The Black River in Michigan becomes infested with Zebra mussels, decreasing potential refugia from this stressor to mussels in the Great Lakes. Only the Grand River population maintains resiliency due to tributary occupancy (Mill Creek), but is reduced from its current representation as a stronghold population because it is reduced in density and no longer supports a large enough population to use as a possible source for propagation or translocation efforts.

There are discharge reductions in Fish Creek [Ohio] and Mill Creek [Michigan] that lead to alterations in the natural flow regime and changes to the physical habitat requirements of the species (i.e., reduced frequency of flow events that help keep clean-swept substrates), which lead to reduced connectivity and Round Hickorynut recruitment, affecting the entire populations in small streams. Although Fish Creek is spring-fed, increasing agricultural withdrawals and development pressure leads to a reduced groundwater table and more frequent drying of riffle habitats and substrates, limiting host fish and mussel colonization potential.

Water quality deteriorates for the Pine, Belle, and Black River populations in Michigan and the Black River in Ohio due to lack of treatment of wastewater discharges, especially in rural areas; however, the degree of water quality decline is substantially worse than that experienced under Scenario 1. There is little to no water quality improvement through BMPs concerning agricultural practices and development. Impacts from agricultural activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are exacerbated by increased conversion of pasture to row-crop or urban land uses, increasing the potential for stochastic events that have significant influence on the survival of the Round Hickorynut. Risks of population losses due to contaminant spills are increased compared to Scenario 1 through the presence of linear populations within MUs. Under this scenario, the currently small, isolated, linear Lake St. Clair MU and populations (Belle, Pine, and Black Rivers) are lost, resulting in extirpation of the species from Michigan.

Ohio River basin

There are discharge reductions in tributaries that lead to alterations in the natural flow regime and changes to the physical habitat requirements of the species (i.e., reduced frequency of flow events that help keep clean-swept substrates), which lead to reduced connectivity and Round Hickorynut recruitment affecting the entire populations in small streams. The species is unable to withstand impacts from some changing climate conditions, such as prolonged drought or periodic flooding, which results in desiccation, scour, and increased sedimentation and deposition in shoal habitats occupied by the Round Hickorynut. Habitat fragmentation increases, reducing connectivity more than what would occur under Scenario 1, further reducing opportunities for Round Hickorynut expansion.

The Round Hickorynut is unable to withstand impacts from some changing climate conditions, such as prolonged drought or periodic flooding, which results in desiccation, scour, and increased sedimentation and deposition in shoal habitats occupied by the Round Hickorynut. Habitat fragmentation increases, reducing connectivity more than what would occur under Scenario 1, further reducing opportunities for Round Hickorynut expansion. If all populations in small streams and rivers persist, they become more constricted and genetically isolated from medium and large river populations (e.g., tributary populations in West Fork, Walhonding, Upper Ohio-Shade, Little Kanawha, and Upper Scioto MUs).

Water quality deteriorates for the populations currently classified as medium condition due to lack of treatment of wastewater discharges, especially in rural areas; however, the degree of water quality decline is substantially worse than that experienced under Scenario 1. There is little to no water quality improvement through BMPs concerning agricultural practices and development. Impacts from resource extraction activities (water withdrawal, stream contamination, deposition of fine sediment, etc.) are exacerbated by increased localized concentrations of abandoned mines and oil and gas exploration, increasing long-term water contamination issues that have significant influence on the survival of the Round Hickorynut. Risks of population losses due to contaminant spills are increased compared to Scenario 1 through the presence of linear populations within MUs (e.g., populations in Little Muskingum-Middle Island, Symmes Creek, South Fork Hughes, Lower Scioto, Walhonding, Little Kanawaha, Elk [WV], Licking, South Fork Kentucky, Tippecanoe, Lower White, Upper Green MUs).

Habitat degradation in large-river populations due to development, navigational impacts such as increases in river commerce traffic between coal landing facilities, and extensive agriculture in riparian areas becomes significantly worse. In the Kentucky River, streamside development and agriculture causes sedimentation that fills in the interstitial spaces needed by juvenile mussels and host fish eggs. Systemic habitat degradation from multiple stressors has the potential to affect individuals initially, but over time, results in impacts to populations, and when widespread within large river systems such as the Kentucky and Kanawha, impacts the entire MUs.

Nonnative species, such as Asian Clam, Zebra Mussel, and Quagga Mussel, continue to negatively influence populations basin-wide. Asian Clam abundance and distribution is widespread within the range of the species and competes for food and nutrients needed for mussel growth and development. Black Carp are currently not found in the upper Ohio basin, but represent a significant predator, and are capable of invading new large river habitats due to extremes in flow conditions brought on by changing climate conditions, such as prolonged flooding. Competition for space and resources from Zebra and Quagga mussels result in reduced fitness of Round Hickorynut in the Ohio, Kanawha, and Kentucky Rivers.

Habitat fragmentation is a common issue for many of the Ohio River basin populations. Impoundments on the Shenango, Walhonding, and Green Rivers, where there are dams both upstream and downstream of Round Hickorynut populations, limit access to suitable habitat and isolate populations, which in turn limits the amount of genetic exchange between populations. Under this scenario, the currently small, isolated, linear Shenango River population is lost, resulting in extirpation of the species from Pennsylvania.

Cumberland River basin

Habitat and water quality degradation continues at a much more rapid rate in the two [currently] low condition Cumberland River basin populations (Rockcastle River and Buck Creek) than under Scenario 1. Increases in total suspended solids are not addressed through community outreach and education about erosion control. Partnership opportunities with the US Forest Service and NRCS working with private landowners are limited in scope, thus not effective, or are not implemented due to lack of funding and personnel. The previously low densities of these populations, increased threats of siltation and sedimentation from erosion from agricultural activity, coupled with water quality degradation due to current and past mining activities present physical and chemical obstacles to Round Hickorynut survival.

Wolf Creek reservoir already contributes to habitat loss and alteration, low population sizes and genetic isolation due to lack of proximity to other basin populations. Nutrients are also limiting in Cumberland River basin, which can lead to mussel starvation under prolonged droughts or floods. Under this scenario, the Buck Creek and Rockcastle River populations are lost due to reductions in abundance below effective population sizes and lack of proximity of individuals contributing to fertilization and reproduction failure. The extirpation of these populations results in loss 20 percent of the species representation due to complete elimination from the Cumberland River basin.

Tennessee River basin

Significant water discharge reductions occur in the Duck River, a currently high condition population, due to Normandy Dam operations to address water supply demands associated with human development pressures. Drought and agricultural activities, along with added development pressures, result in habitat loss through increased sedimentation and siltation, which covers substrates used for settlement in the Paint Rock River, currently a medium condition population and the Buffalo and Elk Rivers, currently low condition populations. Water extraction activities associated with row-crop agriculture also result in periodic loss of connectivity between populations. Impacts from periodic loss of connectivity between suitable habitat patches can be exacerbated if they occur during reproductively active periods of sperm distribution (limiting the ability of sperm to fertilize eggs) or juvenile mussel dispersal (limiting the distribution of the mussel in the stream). This degradation results in direct habitat loss, and increased sediment that fills substrate spaces required for juvenile mussel development and host fish eggs, and excessive storm water flows that erode suitable habitat.

Water quality declines are obvious in rivers with low condition populations. The Elk, Tennessee, and Buffalo rivers in Tennessee are affected by untreated or poorly treated wastewater discharges. There is a high risk of contaminant spills affecting these entire populations, due to linear distributions. Wastewater and runoff from land use activities have increased concentrations of contaminants such as ammonia and chlorine, which affects respiration and reproduction in the Round Hickorynut in these rivers.

Habitat degradation continues and worsens in the Tennessee River populations due to human population growth, sedimentation, and navigational impacts, such as dredging and increases in river commerce traffic. Activities that formerly only affected individuals, such as barge traffic and fleeting, are now negatively influencing entire populations, due to increasing rarity of the species. There is an increase in the magnitude of agricultural activities in riparian areas to accommodate population growth. This results in loss of appropriate habitat patches and habitat heterogeneity, which increases the likelihood of Round Hickorynut isolation and extirpation from the Tennessee River. The cost of monitoring large river mussel populations increases due to reductions in staffing of agency partners and reliance on private industry for data and survey information, reducing the capabilities of gathering annual estimates of species abundance and distribution.

Nonnative species such as Asian Clam continue to impact populations basin-wide through competitive interactions for food and nutrients. A large water supply impoundment (Normandy Dam on the Duck River), a hydropower dam (Tims Ford Dam on the Elk River), and smaller dams (such as Lillards Mill and Harms Mill) limit the mussel's access to suitable habitat and isolate populations, which in turn limits the amount of genetic exchange between populations. Habitat fragmentation from impoundment results in increasing genetic isolation and becomes a more pervasive issue for the Tennessee River basin populations. Only the Duck River and Paint Rock River populations maintain resiliency, but both are reduced in extent.

Lower Mississippi River basin

Habitat alteration through channelization, bank erosion, widened channels, uniform flows, unstable sediments, and meander cutoffs has occurred in the lower portion of the Lower Mississippi River basin, remaining the greatest threat to this population. Past intensive agricultural activities combine with current channel instability to contribute substantial runoff within the Big Black River, which covers substrates used for settlement (Jones *et al.* 2005, p. 84). These impacts are exacerbated and occur at a much more rapid rate than under Scenario 1, with minimal opportunity for education, outreach, or restoration initiatives. Water quality degradation through high levels of suspended solids continues in this [currently] low condition population, which can affect respiration and smother invertebrates, resulting in direct mortality of mussels in the Big Black River population. Coupled with reductions in abundance due to its linear and limited extent, this population becomes vulnerable to a single stochastic event. Imminent threats and severe isolation from other basin populations result in the loss of this population, which eliminates 20 percent of the species representation across its range. Under this scenario, the species is extirpated from the state of Mississippi and the Lower Mississippi River basin.

7.5.1 Resiliency

Under Scenario 3, where conditions become worse, 46 of 65 (70 percent) of the Round Hickorynut populations, and 20 of 34 (59 percent) of MUs become extirpated. Under this scenario, all populations and MUs deteriorate in resiliency (negative change in condition category from current condition). Current threats continue along with elevated (compared to Scenario 1) impacts to populations and MUs from changing climate conditions. Significant changes may not be observed at first due to continued implementation of existing regulatory and voluntary conservation measures that help reduce (but not eliminate) habitat and water quality degradation.

Increased levels of river and population fragmentation through isolation and sedimentation result in decreased habitat and population connectivity within MUs, and deposition of fine sediments into suitable substrates. The magnitude and scale of wastewater discharges and oil and gas exploration result in lack of non-point source water treatment, which leads to recruitment failure and decreased mussel abundance and survival throughout a significant proportion of Round Hickorynut's range.

Targeted programs to improve water quality through BMPs concerning agricultural practices and anthropogenic land uses are limited in scope, and thus are less effective, or not developed at all, due to funding shortfalls. There is an increase of impacts from resource extraction activities, such as oil and gas drilling in the Ohio and Cumberland basins, which contributes to long-term water contamination issues. Decreases in dissolved oxygen and changes to thermal regimes such as the increased potential of hypolimnetic flow releases from hydropower dams suppress populations in some rivers already negatively affected. Additional hydropower development at dams currently used for flood control results in localized scouring in existing downstream Round Hickorynut habitat (e.g., Elk (Tennessee), Muskingum River, North Fork Hughes River, Little Kanawha River, Elk River).

Regardless of ongoing regulatory and voluntary conservation measures, 46 of 64 populations (70 percent) that deteriorate in resiliency have the potential to drop below detectable levels or become extirpated (very low condition). Genetic isolation occurs due to fragmentation, and all populations remaining within MUs become linearly distributed, decreasing resilience to stochastic events. We estimate that none of the current 65 populations would be in high condition, only 2 (10 percent) of the remaining 19 populations would be in medium condition, and 17 (90 percent) would be in low condition. The number of populations (19) and MUs (24) that persist across the species range under this scenario are dependent on public lands or watersheds with aquatic species conservation incorporated into long-term planning strategies. Rivers such as the Grand, Green, Paint Rock and Duck, which have resource protection measures such as BMPs, offer the only refugia from threats; but given the loss of resiliency, there would be limited conservation opportunities.

7.5.2 Representation

The Round Hickorynut loses representation over time, with no high condition populations in the five currently occupied basins (Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi). Additionally, populations in the Cumberland and Lower Mississippi basins are lost, and extirpation from these basins occurs, leading to a 40 percent reduction in representation across the species range. There is only one population remaining in the Great Lakes basin, the Grand River in Ohio, which is reduced from a stronghold population due to increasing development and nonnative species invasion pressures. Remaining populations within MUs in the Great Lakes, Ohio, and Tennessee basins are linearly distributed due to reductions in population and habitat connectivity, thus resulting in substantial fragmentation and a high likelihood of genetic isolation.

With 17 of the remaining 19 populations (90 percent) in low condition and the potential extirpation (very low condition) of 46 of the current 65 populations (71 percent) under Scenario 3, the species would be in significant decline in the majority of its range. All but two populations, the Grand and Duck, would be in low or very low condition. These populations and MUs are currently strongholds for the species, but are reduced to medium condition under this scenario due to a loss of tributary populations, isolation, and risk of loss due to a stochastic event. Additionally, the loss of stream and small river populations and the resulting lack of metapopulations significantly increases the species' extinction risk.

7.5.3 Redundancy

The Round Hickorynut loses redundancy compared to current conditions. The best available information suggests that 46 of the currently extant 65 populations (61 percent), and 20 of the currently extant MUs (59 percent), are predicted to become extirpated. Loss of populations and MUs in all portions of its currently occupied range occurs in all five basins, and there are no longer any high condition populations to use for brood stock for translocation or captive propagation efforts. Under this scenario, the species is lost from the states of Pennsylvania, Michigan, and Mississippi.

CHAPTER 8 - OVERALL SYNTHESIS

The goal of this assessment is to describe the current and potential future conditions of the Round Hickorynut in terms of resiliency, representation, and redundancy by using the best available commercial and scientific information. To capture the uncertainty associated with the degree and extent of potential future risks and their impacts on the species' needs, we assessed potential future conditions using three plausible scenarios. These scenarios were based on a variety of negative and positive influences on the species across its current nine-state range, allowing us to predict potential changes in habitat used by the Round Hickorynut. The results of our analysis describe a range of possible conditions in terms of the number and distribution of Round Hickorynut populations (Table ES-1).

Historical Range and Abundance - The historical range of the Round Hickorynut included streams and rivers across 12 states, including New York, Pennsylvania, West Virginia, Indiana, Illinois, Ohio, Kentucky, Virginia, Tennessee, Georgia, North Carolina, and Alabama. This range encompassed five major basins: the Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi. The best available information suggests that at least 296 populations and 139 MUs occurred over this range in the U.S.; however, it is also likely that more populations were present and undetected, prior to the use of more intensive contemporary survey methods.

Current Viability Summary - The current range extends over nine states; the species is considered extirpated in Georgia, Illinois, and New York. This range encompasses five major river basins. Round Hickorynut representation in the Cumberland River basin is restricted to two linear populations within two MUs, while it exists in the Lower Mississippi River basin in a single population. Therefore, while the species currently maintains representation from historical conditions, it is at immediate risk of losing 40 percent (2 of 5 basins) representation due to these small, isolated populations under a high degree of threats that have resulted in habitat loss and water quality degradation.

Overall, the Round Hickorynut has lost an approximate 232 of 297 known populations (78 percent), and 104 of 138 MUs (75 percent). This includes 25 populations in the Great Lakes basin, 150 populations in the Ohio River basin, 23 populations in the Cumberland River basin, 29 populations in the Tennessee River basin, and 9 populations in the Lower Mississippi River basin (Appendix B). Of the current populations, 4 (6 percent) are estimated to be highly resilient, 16 (23 percent) are moderately resilient, and 45 (69 percent) have low resiliency.

A cautionary emphasis should be placed on the fact that the Round Hickorynut was once a much more common, occasionally abundant, component of the mussel assemblage in rivers and streams across much of the eastern U.S. Population extirpations have been extensive and widespread within every major river basin where the Round Hickorynut is found. Surveys throughout eastern North America have not targeted the Round Hickorynut specifically, and as a result, there could have been additional population losses or declines that have gone undocumented. Conversely, it is possible that there are populations that have gone undetected. However, the majority of the species range has been relatively well surveyed for freshwater mussel communities, and the likelihood is small that there are substantial or stronghold populations that are undetected. Patterns of population extirpation and declines are pronounced particularly in the Ohio River basin, which appears to be the basin most important for redundancy and representation for the species, due to its documented historical distribution and remaining concentration of populations within the basin.

Populations of the Round Hickorynut have been apparently lost from entire watersheds and MUs in which the species once occupied multiple tributaries, such as the Allegheny, Coal, Little Scioto, Miami, and Vermilion River MUs in the Ohio River basin. The state of Ohio, for example, has lost 53 populations of Round Hickorynut, along with 19 MUs (Watters *et al.* 2009, p. 210). A table of all populations and MUs considered extirpated along with the authority of each record, and the year of the record, can be found in Appendix B. The species is also critically imperiled in Canada, and as a result, the future of the species in Canada may be reliant on hatchery supported activities or augmentation activities coordinated with the U.S.

Precipitous declines and extirpations of Round Hickorynut populations have been documented in the Great Lakes, Ohio, Cumberland, Tennessee, and Lower Mississippi basins. These declines and extirpations are exhibited in museum collections and reported in published literature accounts of the species (Appendix D). While this documentation could be a result of more intensive survey effort in the core of the species distribution, regardless, the extirpation of formerly abundant and extensive populations is a cautionary note for current and future condition projections, and has been most pronounced in the Ohio and Cumberland basins.

Examples of rivers where it is extirpated within these basins include: Crooked Creek, Pennsylvania (Ortmann 1913, p. 298); West Branch Mahoning River, Ohio (Swart 1940, p. 42); Coal River, West Virginia (Carnegie Museum and University of Michigan Museum of Zoology records); Olentangy River, Ohio (Stein 1963, p. 109), Alum Creek (OSUM records); Blaine Creek, Kentucky (Bay and Winford 1984, p. 19); Embarras River, Illinois (Parmalee 1967, p. 80); Big Vermilion River, Illinois (Parmalee 1967, p. 80); Cumberland River, Kentucky (Neel and Allen 1964, p. 442); Stones River, Tennessee (OSUM records); and Red River Tennessee/Kentucky (OSUM records).

Future Condition Scenarios - An important assumption of the predictive analysis presented herein is that future population resiliency is largely dependent on water quality, water flow, instream habitat conditions, and riparian conditions (see Resource Needs, Chapter 4). Our assessment predicts that if conditions remain the same, 40 of 65 populations (62 percent) would experience negative changes to these important habitat requisites, including the potential loss of 23 populations. This includes the predicted extirpation of the two populations in the Cumberland River basin and the population in the Lower Mississippi River basin.

Under Scenario 3, no highly resilient populations are able to persist, and 90 percent of remaining populations are in low condition. Alternatively, the scenario that suggests additive conservation measures beyond those currently implemented (Scenario 2) could result in the continued persistence of all 65 populations in the future. However, of important note is that approximately 40 of 65 (62 percent) of these are currently low condition populations. Many of the known populations of the Round Hickorynut have been collected as 10 or fewer individuals, with limited extent information available, due to the lack of survey effort targeting the species (Appendix A). The risks facing the Round Hickorynut populations varied among scenarios and is summarized below (see Table 8-1 and Table ES-1).

Middle Fork Salt Creek and Shade River population projections in Ohio are based on surveys that pre-date 2000, because there are no recent surveys of those drainages, and there is no trend information preceding the 1990s. Thus, the status of these populations are unknown and making future condition projections is difficult. However, agricultural activities, urbanization, and coal mining affect water chemistry in the Shade River drainage (Gbolo and Lopez 2013, p. 2). As a result, elevated phosphate concentrations associated with anthropogenic sources such as fertilizers and agricultural inputs have been documented, and mining impacts have resulted in total phosphorus, manganese, and iron ion concentrations that exceed water quality standards (Gbolo and Lopez 2013, p. 9). In the Salt Creek drainage, sources of impairments include excessive nutrients and physical habitat degradation as a result of stream channelization, livestock access to streams, and loss of floodplains and streamside vegetation (Ohio Environmental Protection Agency 2009, p. 2). Habitat and water quality problems have led to both the Shade River and Salt Creek watershed listings on Ohio’s list of impaired waters (Ohio Environmental Protection Agency 2009, p. 2). These impacts are consistent with stressors to Round Hickorynut populations throughout the Ohio River basin and rangewide.

Given Scenario 1, lowered resiliency, representation, and redundancy is expected. We predict that only one of the current four high condition populations would remain in high condition. Under this scenario, only the Great Lakes basin (one of the five basins currently occupied by the species), would retain a highly resilient population, the Grand River. Of the 65 extant populations, 13 (20 percent) would be in medium condition, and 28 populations (43 percent) in low condition. We estimate extirpation of 23 out of 65 (35 percent) populations. Redundancy would decline due to these population and MU losses, resulting in a loss of the species from Pennsylvania and Mississippi. Representation would be reduced through extirpation of populations and MUs in the Cumberland and Great Lakes basins, a 40 percent loss of redundancy compared to current conditions. Under this scenario, only three of the five currently occupied river basins (Great Lakes, Ohio, and Tennessee) continue to harbor Round Hickorynut populations.

Given Scenario 2, we predict higher levels of resiliency in some portions of the Round Hickorynut's range than was estimated for Scenario 1; representation and redundancy would remain the same level as current conditions with the species continuing to occur within all currently occupied MUs and states across the species 9-state range. Up to 15 populations (23 percent) are predicted to be high condition, compared to the current 4 populations in high condition currently. Scenario 2 also predicts 37 populations (57 percent) in medium condition and 13 populations (20 percent) in low condition. All currently occupied major river basins would remain occupied, and the existing levels of redundancy and representation would improve. There are sufficient population sizes within each basin to facilitate augmentation and restoration efforts, whether it be within-basin translocations or captive propagation techniques. It is possible that this scenario is the least likely to occur in the future as compared to Scenario 1 or 3. This is because it will take many years (potentially beyond the 20- to 30-year time frame analyzed in this report) for all of the beneficial effects of management actions that are necessary to be implemented on the landscape.

Given Scenario 3, we predict a significant decrease in resiliency, representation, and redundancy across the species range. Redundancy would be reduced from five major river basins to three basins, with extirpations expected to occur in the Cumberland and Lower Mississippi basins. No high condition populations would remain, and 46 (71 percent) of the 65 extant populations are likely to become extirpated. The resiliency of the remaining 19 populations is expected to be reduced to 2 populations (10 percent) in medium condition and 17 (90 percent) in low condition. In addition to the potential loss of 46 populations, 20 (59 percent) of the extant 34 MUs are predicted to no longer harbor the species. Representation could be reduced to 14 MUs across 3 major river basins. Extirpations are expected from the states of Pennsylvania, Michigan, and Mississippi, leaving six states (as compared to the current 9, and historically 12) occupied by the species.

Overall Summary - Estimates of current and future resiliency for the Round Hickorynut (Table 8-1, below) are low given that 4 of 65 populations and 2 of 34 MUs are estimated to be highly resilient (6 percent). Only 16 populations (25 percent) and 11 MUs (32 percent) are estimated to be moderately resilient. The remaining 45 populations (69 percent) and 21 MUs (62 percent) are in low condition and have limited resiliency. Seventy-eight pecent (232) of the known populations of the species (297) are considered extirpated. The Round Hickorynut faces a variety of factors negatively influencing the species, including habitat alteration, degradation, or loss (i.e., declines in water quality, loss of stream flow, riparian and instream fragmentation, and genetic isolation/displacement from development, urbanization, contaminants, agricultural activities, impoundments, changing climate conditions, resource extraction, and forest conversion). These factors have contributed to population and MU loss and decline, as well as impacts associated with invasive and nonnative species, and effects from past commercial harvest and overutilization.

These negative influences, which are expected to be exacerbated by continued growing human populations that demand associated development, energy, infrastructure, and water needs, as well as (but to a lesser degree than the former) climate change, were important factors in our assessment of the future viability of the Round Hickorynut. Given current and potential future decreases in resiliency, populations become more vulnerable to extirpation from stochastic events (particularly the small populations that are linearly distributed), in turn, resulting in concurrent losses in representation and redundancy. Predictions of the Round Hickorynut's habitat conditions and population factors in the future suggest possible extirpation of between 23 (35 percent) and 46 (71 percent) of the current 65 extant populations, and 13 (38 percent) and 20 (59 percent) of the current 34 MUs, unless additional conservation or beneficial management actions are implemented and effective.

Table 8-1. Summary of Round Hickorynut mussel population size, extent, threat level, current conditions, and potential future conditions. Names of Management Units (MU) follow USGS HUC 8 level nomenclature.

Management Unit	Contiguous Population (occupied river/stream)	Population Extent (small, med, large)	Population size (small, med, large)	Threat Level (low, moderate, high)	Current Condition	Future condition - Scenario 1	Future condition - Scenario 2	Future condition - Scenario 3
GREAT LAKES BASIN								
St. Clair	Pine River	Small	Small	Moderate	Low	Very Low	Medium	Very Low
	Belle River	Medium	Small	Moderate	Low	Very Low	Medium	Very Low
	Black River	Medium	Small	Low	Low	Low	Medium	Very Low
Grand	Grand River	Large	Large	Moderate	High	High	High	Medium
	Mill Creek (Grand)	Small	Medium	Moderate	Medium	Medium	High	Low
Black-Rocky	Black River	Small	Small	High	Low	Very Low	Medium	Very Low

Management Unit	Contiguous Population (occupied river/stream)	Population Extent (small, med, large)	Population size (small, med, large)	Threat Level (low, moderate, high)	Current Condition	Future condition - Scenario 1	Future condition - Scenario 2	Future condition - Scenario 3
St. Joseph (Maumee)	Fish Creek	Small	Small	Moderate	Low	Very Low	Medium	Very Low
OHIO RIVER BASIN								
Shenango	Shenango River	Medium	Small	High	Low	Very Low	Medium	Very Low
West Fork	West Fork River	Small	Small	High	Low	Low	Medium	Very Low
	Right Fork West Fork River	Small	Small	High	Low	Very Low	Low	Very Low
	Kincheloe Creek	Small	Small	High	Low	Low	Medium	Very Low
	Hackers Creek	Med	Small	High	Low	Very Low	Low	Very Low
	Stonecoal Creek	Small	Small	High	Low	Very Low	Low	Very Low
	Jesse Run	Small	Small	Moderate	Low	Low	Medium	Very Low
Little Muskingum - Middle Island	Middle Island Creek	Large	Large	High	High	Medium	High	Low
	Meathouse Fork	Med	Medium	High	Low	Very Low	Low	Very Low
	McElroy Creek	Med	Medium	High	Medium	High Low	Low	Very Low
	Ohio River (Willow Island Pool)	Small	Small	High	Low	Very Low	Low	Very Low
	Buckeye Creek	Small	Small	High	Low	Very Low	Low	Very Low

Management Unit	Contiguous Population (occupied river/stream)	Population Extent (small, med, large)	Population size (small, med, large)	Threat Level (low, moderate, high)	Current Condition	Future condition - Scenario 1	Future condition - Scenario 2	Future condition - Scenario 3
Walhonding	Killbuck Creek	Small	Small	High	Low	very low	Low	Very low
	Walhonding River	Medium	Medium	High	Low	Low	Medium	Very Low
	Mill Creek (Walhonding)	Small	Medium	Moderate	Medium	Medium	Medium	Low
Muskingum	Muskingum River	Medium	Small	High	Low	Very Low	Medium	Very Low
	Wakatomika Creek	Small	Small	High	Low	Very Low	Low	Very Low
Raccoon - Symmes	Symmes Creek	Small	Small	Moderate	Medium	Medium	High	Low
Little Kanawha	West Fork Little Kanawaha River	Medium	Small	High	Low	Low	Medium	Very Low
	Little Kanawha River	Large	Large	High	High	Medium	High	Low
	Hughes River	Small	Small	High	Low	Low	Medium	Very Low
	North Fork Hughes River	Medium	Medium	High	Medium	Low	High	Very Low
	Fink Creek	Small	Small	High	Low	Low	Medium	Very Low
	Leading Creek	Med.	Small	High	Low	Low	Medium	Very Low
	Reedy Creek	Small	Small	High	Low	Low	Medium	Very Low

Management Unit	Contiguous Population (occupied river/stream)	Population Extent (small, med, large)	Population size (small, med, large)	Threat Level (low, moderate, high)	Current Condition	Future condition - Scenario 1	Future condition - Scenario 2	Future condition - Scenario 3
	Spring Creek	Small	Small	High	Low	Low	Medium	Very Low
	South Fork Hughes River	Large	Large	High	Medium	Low	High	Low
	Middle Fork South Fork Hughes River	Small	Small	High	Low	Low	Medium	Very Low
Upper Ohio - Shade	Middle Branch Shade River	Small	Small	Moderate	Low	Low	Medium	Low
	East Branch Shade River	Small	Small	Moderate	Low	Low	Medium	Low
	Ohio River (Belleville Pool)	Small	Small	High	Low	Low	Medium	Very Low
Upper Kanawha	Kanawha River	Large	Large	High	Medium	Medium	Medium	Very Low
Lower Kanawha	Kanawha River	Medium	Low	High	Low	Low	Medium	Very Low
Elk River	Elk River (WV)	Large	Large	High	Medium	Very Low	Medium	Very Low
Upper Scioto	Big Darby Creek	Large	Small	High	Low	Very Low	Low	Very Low
	Walnut Creek	Small	Medium	Moderate	Low	Low	Medium	Very Low
	Big Walnut Creek	Large	Small	High	Low	Very Low	Low	Very Low
Lower Scioto	Middle Fork Salt Creek	Small	Large	Low	Medium	Medium	High	Low

Management Unit	Contiguous Population (occupied river/stream)	Population Extent (small, med, large)	Population size (small, med, large)	Threat Level (low, moderate, high)	Current Condition	Future condition - Scenario 1	Future condition - Scenario 2	Future condition - Scenario 3
	Scioto River	Medium	Small	High	Low	Very Low	Low	Very Low
Licking	Licking River	Large	Small	Moderate	Medium	Medium	High	Low
Middle Fork Kentucky	Middle Fork Kentucky River	Small	Small	High	Low	Very Low	Low	Very Low
South Fork Kentucky	South Fork Kentucky River	Med.	Small	High	Medium	Low	High	Low
	Red Bird River	Small	Small	Moderate	Low	Low	Medium	Low
Upper Kentucky	Red River	Small	Small	High	Low	Low	Medium	Low
	Kentucky River	Med.	Small	High	Low	Low	Medium	Very Low
Tippecanoe	Tippecanoe River	Large	Medium	Moderate	Medium	Medium	High	Low
Eel (Wabash)	Eel River	Small	Small	Moderate	Low	Very Low	Med.	Very Low
Lower White	Richland Creek	Medium	Medium	Low	Medium	Medium	High	Low
Upper Green	Green River	Large	Medium	Moderate	Medium	Medium	High	Low
Barren	Barren River	Small	Small	Moderate	Low	Low	Medium	Very Low
CUMBERLAND								
Upper Cumberland - Lake Cumberland	Buck Creek	Small	Small	Moderate	Low	Very Low	Medium	Very Low

Management Unit	Contiguous Population (occupied river/stream)	Population Extent (small, med, large)	Population size (small, med, large)	Threat Level (low, moderate, high)	Current Condition	Future condition - Scenario 1	Future condition - Scenario 2	Future condition - Scenario 3
Rockcastle	Rockcastle River	Med.	Small	High	Low	Very Low	Medium	Very Low
TENNESSEE								
Wheeler Lake	Paint Rock River	Large	Medium	Low	Medium	Medium	High	Low
Lower Tennessee - Beech	Tennessee River (Kentucky Reservoir)	Small	Small	High	Low	Low	Medium	Very Low
Upper Elk	Elk River (TN)	Small	Small	Moderate	Low	Low	Medium	Very Low
Upper Duck	Duck River	Large	Large	Med.	High	Medium	High	Medium
Buffalo	Buffalo River	Small	Small	Moderate	Low	Low	Medium	Very Low
Lower Mississippi								
Upper Big Black	Big Black River	Small	Medium	Moderate	Low	Very Low	Medium	Very Low

LITERATURE CITED

NOTE: SOME OF THE WORKS CITED ARE NOT WITHIN THE MAIN BODY OF THE DOCUMENT BUT IN THE APPENDICES.

Ahlstedt, S.A. 1983. The molluscan fauna of the Elk River in Tennessee and Alabama. American Malacological Bulletin 1:43–50.

Ahlstedt, S.A. 1989. Update of the Watts Bar Nuclear Plant preoperational monitoring of the mussel fauna in upper Chickamauga Reservoir. Tennessee Valley Authority Water Resources Report. 32 pp.

Ahlstedt, S.A. 1991a. Twentieth century changes in the freshwater mussel fauna of the Clinch River (Tennessee and Virginia). Walkerana 5(13):73–122.

Ahlstedt, S.A. 1991b. Cumberlandian Mollusk Conservation Program: mussel surveys in six Tennessee Valley streams. Walkerana 5(13):123–160.

Ahlstedt, S.A. 1995–96. Status survey for federally listed endangered freshwater mussel species in the Paint Rock River system, northeastern Alabama, U.S.A. Walkerana 8(19):63–80.

Ahlstedt, S.A. 2009. Federal fish and wildlife annual permit report submitted to Ohio USFWS Field Office, Columbus, Ohio. 6 pp.

Ahlstedt, S.A. 2012. Federal fish and wildlife annual permit report submitted to the Ohio U.S. Fish and Wildlife Field Office, Columbus, Ohio. 6 pp.

Ahlstedt, S.A. 2019. Phone call with Steve Ahlstedt, USGS (retired), on August 5, 2019.

Ahlstedt, S.A., and C.F. Saylor. 1995-96. Status survey of the little-wing pearlymussel, *Pegias fabula* (Lea, 1838). Walkerana 8(19):81-105.

Ahlstedt, S.A., and J.D. Tuberville. 1997. Quantitative reassessment of the freshwater mussel fauna in the Clinch and Powell Rivers, Tennessee and Virginia. Pp. 72–97 in: K.S. Cummings, A.C. Buchanan, C.A. Mayer, and T.J. Naimo, eds. Conservation and management of freshwater mussels II: initiatives for the future. Proceedings of a UMRCC symposium, October 1995, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Ahlstedt, S.A., and T.A. McDonough. 1995–96. Summary of pre-operational monitoring of the mussel fauna in the upper Chickamauga Reservoir (Tennessee River) in the vicinity of TVA's Watts Bar Nuclear Plant, 1983–1993. Walkerana 8(19):107–126.

Ahlstedt, S.A., J.R. Powell, R.S. Butler, M.T. Fagg, D.W. Hubbs, S.F. Novak, S.R. Palmer, and P.D. Johnson. 2004. Historical and current examination of freshwater mussels (Bivalvia: Margaritiferidae, Unionidae) in the Duck River basin Tennessee. Final Report: Tennessee Wildlife Resource Agency contract FA-02-14725-00.

Ahlstedt, S.A., S. Chance, and C. Saylor. 2005a. Baseline information of freshwater mussel populations at five fixed-station monitoring sites in the Elk River, Tennessee. Unpublished report to Tennessee Valley Authority. 16 pp.

Ahlstedt, S.A., M.T. Fagg, R.S. Butler, and J.F. Connell. 2005b. Long-term trend information for freshwater mussel populations at twelve fixed-station monitoring sites in the Clinch and Powell Rivers of eastern Tennessee and southwestern Virginia. Report prepared for U.S. Fish and Wildlife Service, Cookeville, Tennessee. 38 pp.

Ahlstedt, S., R. Butler, Z. Couch, S. Brunderman, M. Compton, and E. Brett. 2014. Current status of freshwater mussel populations in the Little South Fork Cumberland River drainage, McCreary and Wayne counties, Kentucky (2013): Continuing collapse of a once fabulous fauna. Final report to the US Fish & Wildlife Service Kentucky Field Office and Kentucky Waterways Alliance. 16 pp.

Ahlstedt, S.A., M.T. Fagg, R.S. Butler, J.F. Connell, and J.W. Jones. 2016. Quantitative Monitoring of Freshwater Mussel Populations from 1979–2004 in the Clinch and Powell Rivers of Tennessee and Virginia, with Miscellaneous Notes on the Fauna. Freshwater Mollusk Biology and Conservation 19:1–18.

Ahlstedt, S.A., J.W. Jones, and C. Walker. 2017a. Current status of freshwater mussel populations in the Clinch River at the Appalachia Power Company's Clinch River Steam Plant, Russell County, Virginia. Malacological Review 45/46:213–225.

Ahlstedt, S.A., J.R. Powell, R.S. Butler, M.T. Fagg, D.W. Hubbs, S.F. Novak, S.R. Palmer, and P.D. Johnson. 2017b. Historical and current examination of freshwater mussels (Bivalvia: Margaritiferidae: Unionidae) in the Duck River basin, Tennessee, U.S.A. Malacological Review 45:1–163.

Akers, P.E. 2000. The freshwater mussels (Bivalvia: Unionidae) of the Rolling Fork River drainage of Kentucky. M.S. thesis, Eastern Kentucky University. 36 pp.

Alig, R. S. Stewart, D. Wear, S. Stein, and D. Nowak. 2010. Conversions of Forest Land: Trends, Determinants, Projections, and Policy Considerations. Chapter in Advances in Threat Assessment and Their Application to Forest and Rangeland Management. U.S. Forest Service General Technical Report PNW-GTR-802.

Aldridge, D. W., Payne, B. S., & Miller, A. C. 1987. The effects of intermittent exposure to suspended solids and turbulence on three species of freshwater mussels. Environmental Pollution 45(1):17–28.

Allan, J.D. 1995. Stream Ecology: Structure and Function of Running Waters. Chapman and Hall. New York.

Allen, A.W., Y.K. Bernal, and R.J. Moulton. 1996. Pine Plantations and Wildlife in the Southeastern United States: An Assessment of Impacts and Opportunities. Information and Technology Report 3, U.S. Department of Interior, Washington, D.C. 40 pp.

Allan, J.D., D.L. Erikson, and J. Fay. 1997. The influence of catchment land use on stream integrity across multiple spatial scales. Freshwater Biology 37:149–161.

Anderson, R.M., and D.A. Kreeger. 2010. Potential for impairment of freshwater mussel populations in Delaware River Basin Commission special protection waters as a consequence of natural gas exploratory well development. 14 pp.

Anderson, R.M., J.B. Layzer, and M.E. Gordon. 1991. Recent catastrophic decline of mussels (Bivalvia: Unionidae) in the Little South Fork Cumberland River, Kentucky. Brimleyana 17:1–8.

Anthony, J.L., and J.A. Downing. 2001. Exploitation trajectory of a declining fauna: a century of freshwater mussel fisheries in North America. Canadian Journal of Fisheries and Aquatic Sciences 58:2,071–2,090.

Archambault, J.M., W.G. Cope, and T.J. Kwak. 2018. Chasing a changing climate: Reproductive and dispersal traits predict how sessile species respond to global warming. Diversity and Distributions 24:880–891.

Augspurger, T., A.E. Keller, M.C. Black, W.G. Cope, and F.J. Dwyer. 2003. Water quality guidance for protection of freshwater mussels (Unionidae) from ammonia exposure. Environmental Toxicology and Chemistry 22(11):2,569–2,575.

Augspurger, T., F. J. Dwyer, C. G. Ingersoll, and C. M. Kane. 2007. Advances and opportunities in assessing contaminant sensitivity of freshwater mussel (Unionidae) early life stages. Environmental Toxicology and Chemistry 26:2,025–2,028.

Aust, W.M., Carroll, M.B., Bolding, M.C., and C.A. Dolloff. 2011. Operational forest stream crossings effects on water quality in the Virginia Piedmont. Southern Journal of Applied Forestry 35:123–130.

Badra, P.J. 2009. Status of native freshwater mussels, including the Northern Riffleshell (Epioblasma torulosa rangiana) and Rayed Bean (Villosa fabalis), in Detroit River, Michigan. Report prepared by the Michigan Natural Features Inventory for the Michigan U.S. Fish and Wildlife Service Coastal Program. 20 pp.

Badra, P.J., and R.R. Goforth. 2003. Freshwater mussel surveys of Great Lakes tributary rivers in Michigan. Report prepared by the Michigan Natural Features Inventory for the Michigan Department of Environmental Quality. 44 pp.

Baker, F.C. 1922. The molluscan fauna of the Big Vermilion River, Illinois, with special reference to its modification as the result of pollution by sewage and manufacturing wastes. Illinois Biological Monographs Vol. VII, 2. 164 pp.

Balciunas, J.K, M.J. Grodowitz, A.F. Cofranesco, and J.F. Shearer. Hydrilla. *in*: Van Driesche, R., 2002, Biological Control of Invasive Plants in the Eastern United States, USDA Forest Service Publication Forest Health Technology Enterprise Team, 2002–04, 413 pp.

Barling, R.D., and I.D. Moore. 1994. Role of buffer strips in management of waterway pollution: A review. Environmental Management 18(4):543–558.

Barnhart, M.C., W.R. Haag, and W.N. Roston. 2008. Adaptations to host infection and larval parasitism in Unionoida. Journal of the North American Benthological Society 27(2):370–394.

Barr, W.C., S.A. Ahlstedt, G.D. Hickman, and D.M. Hill. 1993–94. Cumberlandian Mollusk Conservation Program. Activity 8: analysis of macrofauna factors. Walkerana 7(17-18):159–224.

Bartsch, M.R., T.J. Newton, J.W. Allran, J.A. O'Donnell, and W.B. Richardson. 2003. Effects of pore-water ammonia on situ survival and growth of juvenile mussels (*Lampsilis cardium*) in the St. Croix riverway, Wisconsin, USA. Environmental Toxicology and Chemistry 22(11):2,561–2,568.

Bates, J.M. 1969. Pennsylvania mussel studies: June 1, 1968-October 1, 1969. Final Report to the U.S. Bureau of Commercial Fisheries, Contract No. 14-17-003-434.

Bates, J.M., and S.D. Dennis. 1985. Mussel resource survey State of Tennessee. Unpublished report to the Tennessee Wildlife Resources Agency, Technical Report 85-3, Nashville. 149 pp.

Bay, R.T., and D.B. Winford. 1984. The mussel fauna of the proposed Yatesville Reservoir project area, Johnson and Lawrence Counties, KY. U.S. Army Corps of Engineers, Huntington District, Huntington, WV. 53 pp.

Berg, D.J., A.D. Christian, and S.I. Guttman. 2007. Population genetic structure of three freshwater mussel (Unionidae) species within a small stream system: significant variation at local spatial scales. Freshwater Biology 52:1,427–1,439.

Berg, D.J., T.D. Levine, J.A. Stoeckel, and B.K. Lang. 2008. A conceptual model linking demography and population genetics of freshwater mussels. Journal of the North American Benthological Society 27(2):395–408.

Berkman, H.E, and C.F. Rabeni. 1987. Effect of siltation on stream fish communities. Environmental Biology of Fishes. 18(4):285–294.

Blalock, H.N., and J.B. Sickel. 1996. Changes in mussel (Bivalvia: Unionidae) fauna within the Kentucky portion of Lake Barkley since impoundment of the lower Cumberland River. American Malacological Bulletin. 13(1/2):111-116.

Blankenship, S. and D.R. Crockett. 1972. Changes in the freshwater mussel fauna of the Rockcastle River at Livingston, Kentucky. Transactions of the Kentucky Academy of Science. 33:37–39.

Bogan, A.E. 1990. Stability of recent unionid (Mollusca: Bivalvia) communities over the past 6000 years. Pp. 112–136 in: W. Miller, III, ed. Paleocommunity temporal dynamics: the long-term development of multispecies assemblies. The Paleontological Society Special Publication No. 5.

Bogan, A.E., and G.W. Davis. 1990a. Report #3. The Unionidae of Pennsylvania: rare, endangered, extinct. Allegheny River survey: river miles 31.5–45.5, navigation pools 5 and 6, September 18–20, 1990. Academy of Natural Sciences of Philadelphia, Pennsylvania. 8 pp.

Bogan, A.E., and G.W. Davis. 1990b. Report #2. The Unionidae of Pennsylvania: rare, endangered, extinct. Allegheny River survey: river miles 98.4–120.2, August 20–23, 1990. Academy of Natural Sciences of Philadelphia, Pennsylvania. 8 pp.

Böpple, J.F., and R.E. Coker. 1912. Mussel resources of the Holston and Clinch River, Tennessee and Virginia. U.S. Bureau of Fisheries, Document No. 765:3–13.

Bonner, T.H., E.L. Oborny, B.M. Littrell, J.A. Stoeckel, B.S. Helms, K.G. Ostrand, P.L. Duncan, and J. Conway. 2018. Multiple freshwater mussel species of the Brazos River, Colorado River, and Guadalupe River basins. CMD 1 - 6233CS. Final Report to Texas Comptroller of Public Accounts. February 28, 2018. 306 pp.

Boyer, A. 2018. Personal communication on April, 10, 2018, between U.S. Fish and Wildlife Service personnel. Angela Boyer (Ohio Field Office, Columbus, Ohio) and Andrew Henderson, regarding the Six Mile Dam on the Walhonding River in Coshocton County, Ohio.

Brabec, E., S. Schulte, and P.L. Richards. 2002. Impervious surfaces and water quality: a review of current literature and its implications for watershed planning. Journal of Planning Literature 16(4):499–514.

Bradshaw-Wilson, C., J. Stauffer, J. Wisor, K. Clark, and S. Mueller. 2019. Documentation of freshwater mussels (Unionidae) in the diet of Round Gobies (*Neogobius melanostomus*) within the French Creek watershed, Pennsylvania. American Midland Naturalist 181:259–270.

Bringolf, R.B., W.G. Cope, C.B. Eads, P.R. Lazaro, M.C. Barnhart, and D. Shea. 2007. Acute and chronic toxicity of technical-grade pesticides to glochidia and juveniles of freshwater mussels (Unionidae). Environmental Toxicology and Chemistry 26(10):2,086–2,093.

Bringolf, R.B., R.M. Heltsley, T.J. Newton, C.B. Eads, S.J. Fraley, D. Shea, and W.G. Cope. 2010. Environmental occurrence and reproductive effect of the pharmaceutical fluoxetine in native freshwater mussels. Environmental Toxicology and Chemistry 29(6):1,311–1,318.

Broadmeadow, S. and T.R. Nisbet. 2004. The effects of riparian forest management on the freshwater environment: a literature review of best management practices. Hydrology and Earth System Sciences 8(3):286–305.

Brown, A.V., M.M. Lyttle, and K.B. Brown. 1998. Impacts of gravel mining on gravel bed streams. Transactions of the American Fisheries Society. 127:979–994.

Brown, C.J.D., C. Clark, and B. Gleissner. 1938. The size of certain naiades from western Lake Erie in relation to shoal exposure. American Midland Naturalist 19(3):682-701.

Brown, J.K., 2010. Spatial distribution of freshwater mussels (Unionidae) in Ohio Brush Creek watershed, southern Ohio. Doctoral dissertation, Ohio University. 77 pp.

Brown, M.E., M. Kowalewski, R.J. Neves, D.S. Cherry, and M.E. Schreiber. 2005. Freshwater mussel shells as environmental chronicles: Geochemical and taphonomic signatures of mercury-related extirpations in the North Fork Holston River, Virginia. Environmental Science and Technology. 39(2005):1,455–1,462.

Buchanan, B.P., D.A. Auerbach, R.A. McManamay, J.M. Taylor, A.S. Flecker, J.A. Archibald, D.R. Fuka, and M.T. Walter. 2017. Environmental flows in the context of unconventional natural gas development in the Marcellus Shale. Ecological Applications 27(1):37–55.

Bursey, C.R. 1987. The unionid (Mollusca: Bivalvia) of the Shenango River in Mercer County, Pennsylvania. Proceedings of the Pennsylvania Academy of Sciences 61(1):41–43.

Butler, R.S. 2002. Status Assessment Report for the Rayed bean, *Villosa fabalis*, occurring in the Mississippi River and Great Lakes systems (U.S. Fish and Wildlife Service Regions 3, 4, and 5, and Canada). Report Prepared by the Ohio River Valley Ecosystem Team Mollusk Subgroup. 68 pp.

Butler, R.S. 2005. Status Assessment Report for the Rabbitsfoot, *Quadrula cylindrica*, a freshwater mussel occurring in the Mississippi River and Great Lakes Basins. Report Prepared by the Ohio River Valley Ecosystem Team Mollusk Subgroup. 208 pp.

Butler, R.S. 2007. Status Assessment Report for the Snuffbox, *Epioblasma triquetra*, a freshwater mussel occurring in the Mississippi River and Great Lakes Basins. Report Prepared by the Ohio River Valley Ecosystem Team Mollusk Subgroup. 212 pp.

Cairns, J., Jr., J.S. Crossman, K.L. Dickman, and E.E. Herrick. 1971. Chemical plants leave unexpected legacy in two Virginia rivers. Science 198:1,015–1,020.

Caldwell, P. C. Segura, S.G. Laird, G. Sun, S.G. McNulty, M. Sandercock, J. Boggs, and

J.M. Vose. 2014. Short-term stream water temperature observations permit rapid assessment of potential climate change impacts. Hydrological Processes 29(9):2,196–2,211.

Call, R.E. 1900. A descriptive catalogue of the mollusca of Indiana. Annual report of the Indiana Department of Geology and Natural Resources, 1899. 201 pp.

Call, R.E. 1894. A contribution to a knowledge of Indiana Mollusca. Proceedings of the Indiana Academy of Science (1893):140–156.

Call, R.E. 1896. Second contribution to a knowledge of Indiana Mollusca. Proceedings of the Indiana Academy of Science (1895):135–146.

Call, R.E. 1897. The hydrographic basins of Indiana and their molluscan fauna. Proceedings of the Indiana Academy of Science (1896):247–257.

Call, R.E. 1900. A descriptive illustrated catalogue of the Mollusca of Indiana. 24th Annual Report of the Indiana Department of Geology and Natural Resources for 1899:335–535, 1013-1017.

Call, S.M., and K. Robinson. 1983. Mollusks from an archaeological site in Woodford County, Kentucky. American Malacological Bulletin 1: 31–34.

Campbell, D.C., and C. Lydeard. 2012b. The genera of Pleurobemini (Bivalvia: Unionidae: Ambleminae). American Malacological Bulletin 30(1):19–38.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Shartley, V.H. Smith. 1998. Non point Pollution of Surface Waters with Phosphorus and Nitrogen. Ecological Applications 8(3):559–568.

Casey, J.L., 1986. The prehistoric exploitation of unionacean bivalve molluscs in the Lower Tennessee-Cumberland-Ohio River valleys in western Kentucky. Simon Fraser University, unpublished Master's Thesis. 196 pp.

[CBD] Center for Biological Diversity. 2010. Petition to List 404 Aquatic, Riparian and Wetland Species from the Southeastern United States as Threatened or Endangered Under the Endangered Species Act. Submitted on behalf of CBD, Alabama Rivers Alliance, Clinch Coalition, Dogwood Alliance, Gulf Restoration Network, Tennessee Forests council, West Virginia Highlands Conservancy, Tierra Curry, and Noah Greenwald. Dated April 20, 2010. Pp. 538–540.

Chen, L.Y., A.G. Heath, and R.J. Neves. 2001. Comparison of oxygen consumption of freshwater mussels (Unionidae) from different habitats during declining dissolved oxygen concentration. Hydrobiologia 450:209–215.

Cherry, D.S., J.L. Scheller, N.L. Cooper, and J.R. Bidwell. 2005. Potential effects of Asian clam (*Corbicula fluminea*) die-offs on native freshwater mussels (Unionidae) I: water-column ammonia levels and ammonia toxicity. Journal of the North American Benthological Society 24(2):369–380.

Chetty, A.N., and K. Indira. 1994. Alterations in the tissue lipid profiles of *Lamellidens marginalis* under ambient ammonia stress. Bulletin of Environmental Contamination and Toxicology 53:693–698.

Cicerello, R.R. 1993. A survey of the Unionids (Bivalvia: Unionidae) of the Rockcastle River, Middle Fork to Billows, Kentucky. Kentucky State Nature Preserves Commission, Frankfort. 30 pp.

Cicerello, R.R. 1999. A survey of the freshwater mussels (Mollusca: Unionoidea) of the Green River, Green River Lake Dam to Mammoth Cave National Park, Kentucky. Kentucky State Nature Preserves Commission, Frankfort. 42 pp.

Cicerello, R.R., M.L. Warren, Jr., and G.A. Schuster. 1991. A distributional checklist of the freshwater unionids (Bivalvia: Unionoidea) of Kentucky. American Malacological Bulletin 8(2):113–129.

Clark, C.F. 1977. The freshwater naiads of Ohio, Part I: St. Joseph River of the Maumee. Sterkiana (65-66):14–36.

Clark, H.W., and C.B. Wilson 1912. The mussel fauna of the Maumee River. Bureau of Fisheries Document Number 757. 94 pp.

Clarke, A.H. 1995. Survey of mussel beds in the lower Ohio River (ORM 438.1 to 981.0). Unpublished report, ECOSEARCH, Inc., Port Arthur, Texas, for U.S. Army Corps of Engineers, Louisville, Kentucky. 123 pp + appendices.

Clayton, J.L. 1994. Freshwater bivalves in Elk River, West Virginia, with emphasis on federally endangered species. Proceedings of the West Virginia Academy of Science 66(2-4):7–15.

Clayton, J.L. 2018. Email communication with Janet Clayton, West Virginia Division of Natural Resources (WVDNR), on September 22, 2018 regarding threats to mussels in West Virginia.

Clayton, J.L. 2019. Email communication with Janet Clayton, West Virginia Division of Natural Resources (WVDNR), on August 18, 2019 regarding status of and threats to Round Hickorynut populations in West Virginia.

Clench, W.J., and Van Der Schalie. 1944. Notes on naiads from the Green, Salt, and Tradewater rivers in Kentucky. Michigan Academy of Science, Arts, and Letters. 29:223–228.

Cochran, T.G., Jr., and J.B. Layzer. 1993. Effects of commercial harvest on unionid habitat use in the Green and Barren Rivers, Kentucky. Pp. 61–65 *in:* K.S. Cummings, A.C. Buchanan, and L.M. Koch, eds. Conservation and management of freshwater mussels. Proceedings of a UMRCC symposium, October 1992, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Coker, R.E. 1919. Fresh-water mussels and mussel industries of the United States. U.S. Bureau of Fisheries Document 865. Washington, DC. 89 pp.

Colle, D.E., J.V. Shireman, W.T. Haller, J.C. Joyce, and D.E. Canfield. 1987. Influence of *Hydrilla* on harvestable sport-fish populations, angler use, and angler expenditures at Orange Lake, Florida. North American Journal of Fisheries Management 7:410–417.

[Corps] U.S. Army Corps of Engineers. 2006. Ohio River Mainstem System Study Integrated Main Report. System Investment Plan/Programmatic Environmental Impact Statement. 453 pp.

[Corps] U.S. Army Corps of Engineers. 2012. Duck River Watershed Tennessee. Initial Watershed Assessment. 57 pp.

[Corps] U.S. Army Corps of Engineers. 2018. Duck River Watershed Tennessee. Final Watershed Assessment. 318 pp.

[COSEWIC] Committee on the Status of Endangered Wildlife in Canada. 2003. COSEWIC assessment and update status on the Round Hickorynut *Obovaria subrotunda* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 31 pp.

Compton, M.C., B.D. Yahn, L.T. Phelps. 2017. Preliminary ecological assessment of the Green and Nolin Rivers in Mammoth Cave National Park, Kentucky, following the removal of lock and dam #6. Kentucky State Nature Preserves Commission Report to the U.S. Fish and Wildlife Service, Frankfort, Kentucky.

Conroy, J.D., and D.A. Culver. 2005. Do dreissenid mussels affect Lake Erie ecosystem stabiliy processes? American Midland Naturalist 153:20–32.

Cooper, N.L., J.R. Bidwell, and D.S. Cherry, D.S. 2005. Potential effects of Asian Clam (*Corbicula fluminea*) die-offs on native freshwater mussels (Unionidae) II: porewater ammonia. Journal of the North American Benthological Society 24(2):381–394.

Cope, W.G., M.R. Bartsch, and J.E. Hightower. 2006. Population dynamics of Zebra Mussels *Dreissena polymorpha* (Pallas, 1771) during the initial invasion of the upper Mississippi River, USA. Journal of Molluscan Studies 72:179–188.

[COSSARO] Committee on the Status of Species at Risk in Ontario. 2013. COSSARO Candidate Species at Risk Evaluation for Round Hickorynut, *Obovaria subrotunda*. 14 pp.

Couceiro, S., Hamada, N., Luz, S., Forsberg, B., and Pimentel, T. 2007. Deforestation and sewage effects on aquatic macroinvertebrates in urban streams in Manaus, Amazonas, Brazil. Hydrobiologia. 575:271–284.

Cudmore, B., C.A. MacKinnon, and S.E. Madzia. 2004. Aquatic species at risk in the Thames River watershed, Ontario. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2707. 132 pp.

Cummings, K.S., and J.M.K. Berlocher. 1990. The naiads or freshwater mussels (Bivalvia: Unionidae) of the Tippecanoe River, Indiana. Malacological Review 23:83–98.

Cummings, K.S., and C.A. Mayer. 1992. Field guide to freshwater mussels of the Midwest. Illinois Natural History Survey Manual 5. Champaign, Illinois.

Cummings, K.S., C.A. Mayer, L.M. Page, and J.M.K. Berlocher. 1987. Survey of the freshwater mussels (Mollusca: Unionidae) of the Wabash River drainage. Phase I: lower Wabash and Tippecanoe Rivers. Illinois Natural History Survey Technical Report No. 1987(5). 149 pp.

Cummings, K.S., C.A. Mayer, and L.M. Page. 1988. Survey of the freshwater mussels (Mollusca: Unionidae) of the Wabash River drainage. Phase II: upper and middle Wabash River. Illinois Natural History Survey Technical Report 1988(8). 47 pp.

Cummings, K.S., C.A. Mayer, and L.M. Page. 1992. Survey of the freshwater mussels (Mollusca: Unionidae) of the Wabash River drainage. Final Report. Illinois Natural History Survey Technical Report 1992. 201 pp.

Center for Watershed Protection. 2003. Impacts of Impervious Cover on Aquatic Systems. Watershed Protection Research Monograph No. 1. Ellicott City, Maryland. 158 pp.

Danglade, E. 1922. The Kentucky River and its mussel resources. Monograph. U.S. Department of Commerce, Bureau of Fisheries Document 934.

Davis, G.W., and A.E. Bogan. 1990a. The Unionidae of Pennsylvania: rare, endangered, extinct. Academy of Natural Sciences of Philadelphia, Pennsylvania. 86 pp.

Davis, G.W., and A.E. Bogan. 1990b. Report No. 2. The Unionidae of Pennsylvania: rare, endangered, extinct. Allegheny River survey: river miles 98.4-120.2, August 20–23, 1990. Academy of Natural Sciences of Philadelphia, Pennsylvania. 10 pp.

Dennis, S.D. 1981. Mussel fauna of the Powell River, Tennessee and Virginia. Sterkiana 71:1–7.

Dennis, S.D. 1985. Distributional analysis of the freshwater mussel fauna of the Tennessee River system, with special reference to possible limiting effects of siltation. Tennessee Wildlife Resources Agency Report No. 85-2, Nashville. 171 pp.

Diamond, J.M., D.W. Bressler, and V.B. Serveiss. 2002. Assessing relationships between human land uses and the decline of native mussels, fish, and macroinvertebrates in the Clinch and Powell River watershed, USA. Environmental Toxicology and Chemistry 21(6):1147–1155.

Dimmock, R.V. and A.H. Wright. 1993. Sensitivity of Juvenile Freshwater Mussels to hypoxic, thermal and acid stress. The Journal of the Elisha Mitchell Scientific Society 109(4):183–192.

Dinkins, G.R., and S.A. Ahlstedt. 2007. Survey for native mussels in the Elk River at the Camp Creek Truss Bridge, Clay County, West Virginia. Report Prepared for KCI Technologies, Inc. 64 pp.

Dinkins, G.R., B.J. Dinkins, and R.T. Eldridge. 2017. Survey for freshwater mussels in the Elk River in the vicinity of the anomaly in the Tennessee Natural Gas Pipeline, Kanawha County, West Virginia. Report prepared for Environment and Archaeology, LLC and Tennessee Gas Pipeline Company, LLC. 81 pp.

Douglas, B. 2000. A survey of the mussel fauna of the upper Kanawha River, West Virginia (RM 95.5–91.0) and a review of mussel species currently known to be present in the Kanawha River (RM 95.5-0.0). U.S. Fish and Wildlife Service, West Virginia Field Office report. 13 pp.

Downing, M., K. Fisher, D. Packett, and R. Thornton. 2013. West Virginia Watershed Assessment Pilot Project: Little Kanawha River Watershed Assessment. Report Prepared by The Nature Conservancy for the West Virginia Department of Environmental Protection and the United States Environmental Protection Agency. 190 pp.

Dunn, H.L., B.E. Sietman, and D.E. Kelner. 2000. Evaluation of recent unionid (Bivalvia) relocations and suggestions for future relocations and reintroductions. Pp. 169–183 *in*: P.D. Johnson and R.S. Butler, eds. Freshwater Mollusk Symposium Proceedings—Part II: musseling in on…biodiversity. Proceedings of the 1st symposium of the Freshwater Mollusk Conservation Society, March 1999, Chattanooga, Tennessee. Ohio Biological Survey, Columbus.

Ebert, D.J. 1993. Dredging. Pp. 157-164. in: C.F. Bryan, and D.A. Rutherford, eds. Impacts on warm water streams: Guidelines for evaluation. Southern Division, American Fisheries Society, Little Rock, Arkansas.

Edleman, A.J., J. Moran, T.J. Garrabrant, and K.C. Vorreiter. 2015. Muskrat predation of native freshwater mussels in Shoal Creek, Alabama. Southeastern Naturalist 14(3):473-483.

[ESI] Ecological Specialists, Inc. 1993a. Mussel habitat suitability and impact analysis of the Tippecanoe River. Indiana Department of Natural Resources, Indianapolis, and U.S. Fish and Wildlife Service, Bloomington, Indiana. 102 pp.

[ESI] Ecological Specialists, Inc. 1993b. Final Report: North Fork Hughes River unionid survey near proposed Dam 21C, Ritchie County, West Virginia. Prepared for the U.S. Soil Conservation Service, Morgantown, West Virginia. 42 pp.

[ESI] Ecological Specialists, Inc. 1995. A unionid status and distributional survey in the Salamonie and Mississinewa Rivers. Indiana Department of Natural Resources, Indianapolis. 40 pp.

[ESI] Ecological Specialists, Inc. 1996. Unionid survey of the lower Muskingum River: Miles 77.4–34.1. Report Prepared for the Ohio Department of Natural Resources. 77 pp.

[ESI] Ecological Specialists, Inc. 1998. Unionid survey upstream and downstream of 16 point sources in the Tippecanoe River. Final Report to the U.S. Fish and Wildlife Service, Bloomington, Indiana. 97 pp.

[ESI] Ecological Specialists, Inc. 2000. Freshwater mussels (Bivalvia: Unionidae) of the upper Ohio River. Report for the Mussel Mitigation Trust Fund Committee, Cincinnati, Ohio, and U.S. Fish and Wildlife Service, Cookeville, Tennessee. 99 pp.

[ESI] Ecological Specialists, Inc. 2003. Final Report: Characterization of Tippecanoe River unionid communities, Pulaski, White, and Carroll counties, Indiana. Report prepared for MWH. 40 pp.

[ESI] Ecological Specialists, Inc. 2009. Amended report: Analysis of threats to the distribution of unionid mussels in the Elk River, West Virginia, Clay, Braxton, and Kanawha counties. Unpublished report prepared for the U.S. Fish and Wildlife Service, Elkins, West Virginia Field Office. 110 pp.

[ESI] Ecological Specialists, Inc. 2012. Unionid mussel communities near proposed hydropower facilities in the Muskingum River, 2011. Unpublished report prepared for Free Flow Power. 136 pp.

[ESI] Ecological Specialists, Inc. 2015. 12th annual unionid mussel monitoring near a proposed coal mine, Elk River, West Virginia, 2014. Unpublished report prepared for Wolfpen Knob Development Company. 133 pp.

Ehlo, C.A., and J.B. Layzer. 2014. Population Demographics and Life History of the Round Hickorynut (Obovaria subrotunda) in the Duck River, Tennessee. American Midland Naturalist. 171:1–15.

Eissa, A.E. and M.M. Zaki. 2011. The impact of global climatic changes on the aquatic environment. Procedia Environmental Sciences 4:251–259.

Ellis, M.M. 1936. Erosion silt as a factor in aquatic environments. Ecology 17:29–42.

EnviroScience, Inc. 2007. Freshwater mussel survey for Dover Dam safety assurance program.

Unpublished survey report for Burgess and Niple, Ltd. and the U.S. Army Corps of Engineers, Huntington District. 29 pp.

EnviroScience, Inc. 2009. 2008 Freshwater mussel translocation and monitoring of the American Electric Power Dresden Plant on the Muskingum River (River Mile ~90). Unpublished survey report to American Electric Power. 62 pp.

EnviroScience, Inc. 2010. A survey of freshwater mussel on the Walhonding River at Six Mile Dam, Coshocton County, Ohio. Unpublished survey report to the Ohio Department of Natural Resources. 37 pp.

EnviroScience, Inc. 2012. Quantitative freshwater mussel surveys in four locations on Fish Creek and the St. Joseph River in Williams County, Ohio, September 2012. Unpublished survey report for The Nature Conservancy, Indiana Field Office, and the Indiana Department of Natural Resources. 31 pp.

[EPA] U.S. Environmental Protection Agency. 1985. Ambient water quality criteria for ammonia. Office of Water Regulations and Standards, Criteria and Standards Division, EPA 440/5-85-001, Washington, DC.

[EPA] U.S. Environmental Protection Agency. 2013. 78 FR 52192, Rec. Criteria for ammonia

[EPA] U.S. Environmental Protection Agency. 2016. Nutrient Pollution – The Sources and Solutions: Agriculture. *https://www.epa.gov/nutrientpollution/sources-and-solutions-agriculture* (Accessed: October 1, 2018).

[EPA] U.S. Environmental Protection Agency. 2018. Section 404 of the Clean Water Act. *https://www.epa.gov/cwa-404/exemptions-permit-requirements* (Accessed: October 1, 2018).

Etnier, D.A., and W.C. Starnes. 1993. The Fishes of Tennessee. University of Tennessee Press, Knoxville. 708 pp.

Evans, R. 2010. Freshwater mollusk monitoring in the South Fork Kentucky River system. Final report to the Kentucky Department of Fish and Wildlife Resources, State and Tribal Wildlife Grants Program. Kentucky State Nature Preserves Commission, Frankfort, Kentucky. 152 pp.

Evans, R., and T. Smith. 2006. Freshwater mussel surveys in Pools 4 and 6, Allegheny River. Unpublished report to the U.S. Fish and Wildlife Service, Pennsylvania Field Office, State College, Pennsylvania. 8 pp.

Fagan, W.F. 2002. Connectivity, fragmentation, and extinction risk in dendrictic metapopulations. Ecology 83(12):3,243–3,249.

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. Annual Reviews of Ecology, Evolution, and Systematics 34(2003):487–515.

Fetchner, F.R. 1963. Checklist of east central Illinois Unionidae. Nautilus 76(3):99–101.

Fisheries and Oceans Canada. 2013. Recovery strategy for the Round Hickorynut (*Obovaria subrotunda*) and Kidneyshell (*Ptychobranchus fasciolaris*) in Canada. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada. Ottawa. vi + 70 pp.

Fisher, B.E. 2006. Current status of freshwater mussels (Order Unionoida) in the Wabash River drainage of Indiana. Proceedings of the Indiana Academy of Science 115(2):103–109.

Fisher, B.E. 2019. Indiana Department of Natural Resources. Email communication on February 19, 2011, regarding water withdrawals for irrigation for agricultural use, and status of Round Hickorynut populations in Indiana.

Fleece, C. 2012. Ohio River freshwater mussel survey for the proposed Rolling Hills Generating, LLC conversion and pipeline project, Gallia, Meigs, and Vinton counties, Ohio. Unpublished report prepared by Stantec for Rolling Hills Generating, LLC. 88 pp.

Fobian, T.B., M.L. Buntin, J.T. Holifield, T.A. Tarpley, J.T. Garner, and P.D. Johnson. 2014. Freshwater mussels (Unionidae) in the Paint Rock River (Jackson, Madison, and Marshall counties), Alabama. Southeastern Naturalist 13(2):347-366.

Frankham, R. 1996. Relationship of genetic variation to population size in wildlife. Conservation Biology 10(6):1,500–1,508.

Frazier B.E., Naimo T.H., and M.B. Sandheinrich. 1996. Temporal and vertical distribution of total ammonia nitrogen and un-ionized ammonia nitrogen in sediment pore water from the upper Mississippi River. Environmental Toxicology Chemistry 15:92–99.

Freshwater Mollusk Conservation Society. 2018. Mollusk health & disease workshop program. 11th biennial workshop. LaCrosse, Wisconsin. 47 pp.

Frietag, T.M. 1984. Recent naiad molluscs of the Detroit River. American Malacological Union Abstracts 1984:105.

Fuller, S.L.H. 1974. Clams and mussels (Mollusca: Bivalvia). Pp. 215–273 in: C.W. Hart, Jr., and S.L.H. Fuller, eds. Pollution ecology of freshwater invertebrates. Academic Press, New York.

Funk, W.C., B.R. Forster, S.J. Converse, C. Dartst, S. Morey. 2019. Improving conservation policy with genomics: a guide to integrating adaptive potential into U.S. Endangered Species Act decisions for conservation practitioners and geneticists. Conservation Genetics. 20:115 (*https://doi.org/10.1007/s10592-018-1096-1*)

Furedi, M. 2013. An examination of the effects of climate change on species in Pennsylvania.

Pennsylvania Natural Heritage Program, Western Pennsylvania Conservancy, Pittsburgh, Pennsylvania. 83 pp.

Galbraith, H.S., D.E. Spooner, and C.C. Vaughn. 2010. Synergistic effects of regional climate patterns and local water management on freshwater mussel communities. Biological Conservation 143:1,175–1,183.

Gammon, J.R., and C.W. Gammon. 1993. Changes in the fish community of the Eel River resulting from agriculture. Proceedings of the Indiana Academy of Science 102:67–82.

Gangloff, M.M. 2013. Taxonomic and ecological tradeoffs associated with small dam removals. Aquatic Conservation: Marine and Freshwater Ecosystems, 23:475-480. DOI: 10.1002/aqc.2383.

Gangloff, M.M., K.K. Lenertz, and J.W. Feminella. 2008. Parasitic mite and trematode abundance are associated with reduced reproductive output and physiological condition of freshwater mussels. Hydrobiologia 610:25–31.

Garner, J. 2018. Email communication with Andrew Henderson on November 25, 2018, regarding threats to mussels.

Garner, J.T., and S.W. McGregor. 2001. Current status of freshwater mussels (Unionidae, Margaritiferidae) in the Muscle Shoals area of Tennessee River in Alabama (Muscle Shoals revisited again). American Malacological Bulletin 16(1/2):155–170.

Gascho-Landis, A.M., and J.A. Stoeckel. 2015. Multi-stage disruption of freshwater mussel reproduction by high suspended solids in short and long-term brooders. Freshwater Biology 61(2):229–238.

Gatenby, C.M., R.J. Neves, and B.C. Parker. 1996. Influence of sediment and algal food on cultured juvenile freshwater mussels. Journal of the North American Benthological Society 15(4):597–609.

Gbolo, P., and D.L. Lopez. 2013. Chemical and geological control on surface water within the Shade River watershed in southeastern Ohio. Journal of Environmental Protection 4(1):1–11.

Gibson, K.J. 2015. Acute Toxicity Testing on Freshwater Mussels (Bivalvia: Unionidae) and Freshwater Snails (Gastropoda: Caenogastropoda). Unpublished Master's Thesis, Troy University, Troy, Alabama. 129 pp.

Giddings, E.M.P., A.H. Bell, K.M. Beaulieu, T.F. Cuffney, J.F. Coles, L.R. Brown, F.A. Fitzpatrick, J. Falcone, L.A. Sprague, W.L. Bryant, M.C. Peppler, C. Stephens, and G. McMahon. 2009. Selected physical, chemical, and biological data used to study urbanizing streams in nine metropolitan areas of the United States, 1999–2004: U.S. Geological Survey Data Series 423. 11 pp. + data tables.

Geist, J. 2010. Strategies for the conservation of endangered freshwater pearl mussels (*Margaritifera margaritifera* L.): A synthesis of conservation genetics and ecology. Hydrobiologia 644:69–88.

Godwin, J.C. 2002. Monitoring of federally listed and rare mussels in the Paint Rock River. Report prepared by the Alabama Natural Heritage Program for the Alabama Department of Conservation and Natural Resources, Montgomery. 80 pp.

Gooch, C.H., W.J. Pardue, and D.C. Wade. 1979. Recent mollusk investigations on the Tennessee River: 1978. Tennessee Valley Authority, Muscle Shoals, Alabama, and Chattanooga, Tennessee. 126 pp.

Goodrich, C. 1932. The Mollusca of Michigan. Michigan Handbook Series No. 11, University of Michigan, Ann Arbor. 132 pp.

Goodrich, C., and H. van der Schalie. 1932. Part I. On an increase in the naiad fauna of Saginaw Bay, Michigan. Part II. The naiad species of the Great Lakes. Occasional Papers of the Museum of Zoology University of Michigan No. 238. 14 pp.

Goodrich, C., and H. van der Schalie. 1944. A revision of the Mollusca of Indiana. American Midland Naturalist 32(2):257–326.

Gordon, M.E. 1991. Survey of the aquatic Mollusca of the Sequatchie River and Battle Creek drainages, Tennessee. Tennessee Cooperative Fishery Research Unit, Cookeville. 21 pp.

Gordon, M.E., and J.B. Layzer. 1989. Mussels (Bivalvia: Unionidea) of the Cumberland River: Review of life histories and ecological relationships. U.S. Fish and Wildlife Service Biological Report 89(15). 99 pp.

Gordon, M.E., and G. Sherman. 1995. Survey of endangered mussels in the Barren and Green Rivers. Unpublished report, Tennessee Technological University, Cookeville, for the Kentucky Department of Fish and Wildlife Resources, Frankfort, Kentucky. 44 pp.

Goudreau, S., R.J. Neves, and R.J. Sheehan. 1993. Effects of wastewater treatment plant effluents on freshwater mollusks in the upper Clinch River, Virginia, U.S.A. Hydrobiologia 252(3):211–230.

Grabarkiewicz, J. 2014. A Unionid survey of the Grand River tributaries, Ashtabula County and Trumbull County, Ohio. Report to the Ohio Division of Wildlife. 32 pp.

Grabarkiewicz, J. and T. Crail. 2006. Freshwater mussels of the Maumee drainage, 2nd edition. 66 p.

Grandmaison, D., J. Mayasich, and D.A. Etnier. 2004. Eastern Sand Darter Status Assessment. Report prepared for the US Fish & Wildlife Service Region 3 office. 51 pp.

Grizzle, J.M., and C.J. Brunner. 2009. Infectious diseases of freshwater mussels and other freshwater bivalve mollusks. Reviews in Fisheries Science 17(4):425–467.

Grossman, A., M. Hanauer, and G. Korinek. 2013. Plummer Creek Watershed Management Plan. Green County Soil & Water Conservation District Watershed Coordinator Team Report. 163 pp.

Haag, W. 2009. Past and future patterns of freshwater mussel extinctions in North America during the Holocene. Holocene Extinctions (2009):107–128.

Haag, W. 2012. North American Freshwater Mussels: Natural History, Ecology, and Conservation. Cambridge University Press, Cambridge, New York.

Haag, W.R., and J.L. Staton. 2003. Variation in fecundity and other reproductive traits in freshwater mussels. Freshwater Biology 48:2,118–2,130.

Haag W.R. and A.L. Rypel. 2010. Growth and longevity in freshwater mussels: evolutionary and conservation implications. Biological Reviews 86(1):225–247.

Haag, W.R., and R.R. Cicerello. 2016. A distributional atlas of the freshwater mussels of Kentucky. Scientific and Technical Series Number 8. Kentucky State Nature Preserves Commission, Frankfort, Kentucky. 299 pp.

Haag, W.R., and M.L. Warren. 2003. Host fishes and infection strategies of freshwater mussels in large Mobile Basin streams, USA. Journal of the North American Benthological Society 22(1):78–91.

Haas, R.C. 2009. Black River Assessment. State of Michigan Department of Natural Resources Fisheries Division Special Report 51. 295 pp.

Haefner, R.J., and L.A. Simonson. 2018. Summary of hydrologic data for the Tuscarawas River basin, Ohio, with an annotated bibliography. U.S. Geological Survey Scientific Investigations Report 2010–5010. 115 pp.

Hagman, T.E. 2000. Stress analysis and Mussel (Bivalvia: Unionidae) bed mapping of Buck Creek in Pulaski County, Kentucky, utilizing Geographic Information Systems with special emphasis on the four endangered mussels living in the stream. Eastern Kentucky University. Unpublished Master's Thesis. 100 pp.

Hanlon, S.D., M.A. Petty, and R.J. Neves. 2009. Status of native freshwater mussels in Copper Creek, Virginia. Southeastern Naturalist 8(1):1–18.

Hartfield, P.D. 1993. Headcuts and their effect on freshwater mussels. Pp. 131–141 *in:*

K.S. Cummings, A.C. Buchanan, and L.M. Koch, eds. Conservation and management of freshwater mussels. Proceedings of a UMRCC symposium, October 1992, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Hartfield, P.D., and D. Ebert. 1986. The mussels of southwest Mississippi streams. American Malacological Bulletin 4(1) (1986):21-23.

Hartfield, P.D., and R.G. Rummel. 1985. Freshwater mussels (Unionidae) of the Big Black River, Mississippi. The Nautilus 99(4):116–119.

Hardison, B.S., and J.B. Layzer. 2001. Relations between complex hydraulics and the localized distribution of mussels in three regulated rivers. Regulated Rivers: Research and Management 17:77–84.

Harmon, J.L. 1989. Freshwater bivalve mollusks (Bivalvia: Unionidae) of Graham Creek, a small southeastern Indiana stream. Malacology Data Net 2(5-6):113-121.

Harmon, J.L. 1992. Naiades (Bivalvia: Unionidae) of Sugar Creek, East Fork White River drainage, in central Indiana. Malacology Data Net 3(1-4):31-42.

Havlik, M.E., and L.L. Marking. 1987. Effects of contaminants on naiad mollusks (Unionidae): a review. Unpublished report, U.S. Fish and Wildlife Service Resource Publication 164. 20 pp.

Henley, W.F. 2018. Email communications with Bill Henley, Virginia Polytechnic Institute and State University (VPI), June 12, 2018.

Hersey, K.A., J.D. Clark and J.B. Layzer. Consumption of freshwater bivalves by Muskrats in the Green River, Kentucky. American Midland Naturalist 170(2):248–259.

Higgins, J.M., and W.G. Brock. 1999. Overview of reservoir release improvements at 20 TVA dams. Journal of Energy Engineering 125(1):1–17.

Hoeh, W.R., and R.J. Trdan. 1985. Freshwater mussels (Pelecypoda: Unionidae) of the major tributaries of the St. Clair River, Michigan. Malacological Review 18:115–116.

Hoggarth, M.A. 1992. The Unionidae and Corbiculidae of the Little Miami River system in southwestern Ohio. Walkerana 6(16):247-293.

Hoggarth, M.A. 1994. The unionidae (Mollusca:Bivalvia) of the Walhonding River, Coshocton County, Ohio. Unpublished report to the Ohio Department of Natural Resources and the U.S. Fish and Wildlife Service, Region 3 office. 37 pp.

Hoggarth, M.A. 1995–96. The Unionidae (Mollusca: Bivalvia) of the Walhonding River, Coshocton County, Ohio, including the federally endangered catspaw (*Epioblasma obliquata obliquata*), fanshell (*Cyprogenia stegaria*), and clubshell (*Pleurobema clava*) mussels. Walkerana 8(20):149–176.

Hoggarth, M.A. 1999. Descriptions of some of the Glochidia of the Unionidae. Malacologia 1999. 41(1):1–118.

Hoggarth, M.A. 2002. A study of the mussels (Unionidae) of Fish Creek county RT 10-0.10, Williams County, Ohio. Report prepared for CH2M Hill. 13 pp.

Hoggarth, M.A. 2012. A report on a mussel survey of the Blanchard River at Interstate Route 75 bridge in Findlay, Hancock County, Ohio. Report prepared for Stantec Consulting Services, Inc. 19 pp.

Hoggarth, M.A. 2014. A report on the results of a mussel relocation on the Walhonding River at Lake Park, Coshocton County, Ohio. Report prepared for Lake Park, Coshocton County and County Park District. 30 pp.

Hoggarth, M.A., and M. Grumney. 2016. The distribution and abundance of mussels (Bivalvia: Unionidae) in lower Big Walnut Creek from Hoover Dam to its mouth, in Franklin and Pickaway counties, Ohio. Ohio Journal of Science 116(2):48–59.

Hoggarth, M.A., D.A. Kimberly, and B.G. Van Allen. 2007. A study of the mussels (Mollusca: Bivalvia: Unionidae) of Symmes Creek and tributaries in Jackson, Gallia and Lawrence counties, Ohio. Ohio Journal of Science 107(4):57–62.

Hoos, A.B., J.A. Robinson, R.A. Aycock, R.R. Knight, and M.D. Woodside. 2000. Sources, instream transport, and trends of nitrogen, phosphorus, and sediment in the lower Tennessee River basin, 1980–96: U.S. Geological Survey Water-Resources Investigations Report 99–4139. 96 pp.

Houp, R.E., 1993. Observations on long-term effects of sedimentation on freshwater mussels (Mollusca: Unionidae) in the North Fork of Red River, Kentucky. Transactions of the Kentucky Academy of Science. 54(3-4):93–97.

Houp, R.E., and K.L. Smathers. 1995. Extended monitoring of mussels (Bivalvia: Unionidae) in the Rockcastle River at Billows, Kentucky, an historical site. Transactions of the Kentucky Academy of Science 56(3-4):114–116.

Howard, C. 2017. Email communication with Chuck Howard, Tennessee Valley Authority (TVA), May 15, 2017 regarding mussel surveys in the Elk River, TN.

Howells, R.G, R.W. Neck, and H.D. Murray. 1996. Freshwater Mussels of Texas. Texas Parks and Wildlife Press. 224 pp.

Hubbard, W.D., D.C. Jackson, and D.J. Ebert. 1993. Channelization. Pp. 135-–55 *in:* E.F. Bryan and D.A. Rutherford, eds. Impacts on warm-water streams: guidelines for evaluation. Warm-water Stream Committee, Southern Division, American Fisheries

Society, Little Rock, Arkansas.

Hubbs, D.W. 2019. Personal communication on July 17, 2019 regarding status of the Round Hickorynut in Tennsessee.

Hubbs, D.W. 2012. Orangefoot Pimpleback and Catspaw survey, Tennessee and Cumberland Rivers, Tennessee. Report prepared for Kentucky Waterways by Tennessee Wildlife Resources Agency, Project 7367. 52 pp.

Hubbs, D.W. 2016. 2015 Duck River Quantitative Mussel Survey. Tennessee Wildlife Resources Agency Aquatic Habitat Protection Program. Fisheries Report 16–06. 60 pp.

Hubbs, D.W., S. Chance, L. Colley, and B. Butler. 2011. 2010 Duck River Quantitative Mussel Survey. Tennessee Wildlife Resources Agency Aquatic Habitat Protection Program. Fisheries Report 11–04. 60 pp.

Hubbs, D.W., D. McKinney, D. Sims, S. Lanier, and P. Black. 2006. Aggregate extraction impacts on unionid mussel species richness and density. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies (2006):169–173.

Huehner, M.K. 1996. A survey of Unionid mussels of the Grand River's Wild and Scenic section. Final Report to the Ohio Department of Natural Resources, Division of Natural Areas and Preserves, Columbus, Ohio. 19 pp.

Huehner, M.K. 1997. A survey of Unionid mussels of the Grand River's Scenic section. Final Report to the Ohio Department of Natural Resources, Division of Natural Areas and Preserves, Columbus, Ohio. 24 pp.

Huehner M.K. 1999. Mussel survey of Grand River headwaters and distribution of the Clubshell in Pymatuning Creek. Final Report to the Ohio Department of Natural Resources, Division of Natural Areas and Preserves, Columbus, Ohio. 30 pp.

Huehner, M.K., R.A. Krebs, G. Zimmerman, and M. Mejia. 2005. The Unionid mussel fauna of Northeastern Ohio's Grand River. Ohio Journal of Science 105(3):57–62.

Hughes, M.H., and P.W. Parmalee. 1999. Prehistoric and modern freshwater mussel (Mollusca: Bivalvia: Unionoidea) faunas of the Tennessee River: Alabama, Kentucky, and Tennessee. Regulated Rivers: Research & Management 15:25–42.

[IDEM] Indiana Department of Environmental Management. 2012. Total maximum daily load for *Escherichia coli* (*E. coli*) for the Richland Creek watershed, Greene, Monroe, and Owen counties. Office of Water Quality Report. 46 pp.

Inoue, K., and D.J. Berg. 2016. Predicting the effects of climate change on population connectivity and genetic diversity of an imperiled freshwater mussel, Cumberlandia monodonta (Bivalvia: Margaritiferidae), in riverine systems. Global Change Biology (2006):1–23.

Inoue, K., D.M. Hayes, J.L. Harris, and A.D. Christian. 2013. Phylogenetic and morphometric analyses reveal ecophenotypic plasticity in freshwater mussels *Obovaria jacksoniana* and *Villosa arkansasensis* (Bivalvia: Unionidae). Ecology and Evolution 3(8):2670–2683.

Integrated Taxonomic Information System. 2017. (*https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=80051#null*). Accessed October 1, 2018.

Illinois Natural History Survey. 2017. Mollusk collection Round Hickorynut record database query. Champaign, Illinois.

Irwin, K.L., and J.B. Alford. 2018. Survey of native mussels in the upper Duck and Harpeth River drainages, Tennessee. University of Tennessee Report submitted to the Tennessee Wildlife Resources Agency. 134 pp.

Isom, B.G. 1969. The mussel resource of the Tennessee River. Malacologia 7(2-3):397–425.

Isom, B.G. 1974. Mussels of the Green River, Kentucky. Transactions of the Kentucky Academy of Science 35(1-2):55-57.

Isom, B.G., and P. Yokley, Jr. 1968. The mussel fauna of Duck River in Tennessee, 1965. American Midland Naturalist 80(1):34–42.

Isom, B.G., and P. Yokley, Jr. 1973. The mussels of the Flint and Paint Rock River systems of the southwest slope of the Cumberland Plateau in north Alabama - 1965 and 1967. American Midland Naturalist 89(2):442–446.

Isom, B.G., Yokley, P., and C.H. Gooch. 1973. Mussels of the Elk River basin in Alabama and Tennessee 1965-1967. American Midland Naturalist 89(2):437-442.

Jackson, L.J., L. Corbett, and G. Scrimgeour. 2016. Environmental constraints on *Didymosphenia geminata* occurrence and bloom formation in Canadian Rocky Mountain lotic systems. Canadian Journal of Fisheries and Aquatic Sciences 73:964–972.

Jacobson, P.J., R.J. Neves, D.S. Cherry, and J.L. Farris. 1997. Sensitivity of glochidial stages of freshwater mussels (Bivalvia: Unionidae) to Copper. Environmental Toxicology and Chemistry 16:2,384–2,392.

Jansen, W., Bauer, G., & E. Zahner-Meike. 2001. Glochidial mortality in freshwater mussels. *In* Ecology and evolution of the freshwater mussels Unionoida (pp. 185-211). Springer, Berlin, Heidelberg.

Jenkinson, J. J. 1988. Resurvey of freshwater mussel stocks in the Duck River, Tennessee. Tennessee Valley Authority, River Basin Operations, Water Resources Report, Knoxville, Tennessee. 28 pp.

Johnson, R.I. 1980. Zoogeography of North American Unionacea (Mollusca: Bivalvia) north of the maximum Pleistocene glaciation. Bulletin of the Museum of Comparative Zoology 149(2):77–189.

Johnson, R.I., and H.B. Baker. 1973. The Types of Unionacea (Mollusca: Bivalvia) in the Academy of Natural Sciences of Philadelphia. Proceedings of the Academy of Natural Sciences of Philadelphia. 125(9):145–186.

Jones, J.R.E. 1962. Fish and river pollution. Elsevier. 212 pp.

Jones J.W., E.W. Hallerman, and R.J. Neves. 2006. Genetic management guidelines for captive propagation of freshwater mussels (Unionoidea). Journal of Shellfish Research 25(2):527–535.

Jones, R.L., W.T. Slack, and P.D. Hartfield. 2005. The freshwater mussels (Mollusca: Bivalvia: Unionidae) of Mississippi. Southeastern Naturalist 4(1):77–92.

Jones III, E.B.D., G.S. Helfman, J.O. Harper, and P.V. Bolstad. 1999. Effects of Riparian Forest Removal on Fish Assemblages in Southern Appalachian Streams. Conservation Biology 13(6):1,454–1,465.

[KDEP] Kentucky Department for Environmental Protection. 2014. Integrated Report to Congress on the condition of water resources in Kentucky, 2014, volume 1. Division of Water, Frankfort, Kentucky. 104 pp. + appendices.

Keller, A.E., and M. Lydy. 1997. Biomonitoring and the hazards of contaminants to freshwater mollusks. Unpublished report in: Freshwater mollusks as indicators of water quality: a workshop. U.S. Geological Survey Biological Resources Division and National Water Quality Assessment Program.

Kirsch, P.H. 1894. A report upon investigations in the Maumee River basin during the summer of 1893. Bulletin of the United States Fish Commission. pp. 314-337.

Kishi, D., M. Murakami, S. Nakano, and Y. Taniguchi. 2004. Effects of forestry on the thermal habitat of Dolly Varden (*Salvelinus malma*). Ecological Research 19:283–290.

Kitchel, H.E. 1985. Life history of the endangered shiny pigtoe pearly mussel, *Fusconia edgariana*, in the North Fork Holston River, Virginia. M.S. Thesis. Virginia Polytechnic Institute and State University. 129 pp.

Kolpin, D.W., E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D. Zaugg, L.B. Barber, and H.T. Buxton. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999–2000: a national reconnaissance. Environmental Science and Technology 36(6):1,202–1,211.

Kondolf, G.M. 1997. Hungry water: Effects of dams and gravel mining on river channels. Environmental Management 21(4):533–551.

Kovalak, W.P., S.D. Dennis, and J.M. Bates. 1986. Sampling effort required to find rare species of freshwater mussels. Rationale for sampling and interpretation of ecological data in the assessment of freshwater ecosystems. American Society for Testing and Materials STP 894:34-45.

Krebs, R.A., W.C. Borden, E.R. Steiner, M.S. Lyons, W. Zawiski, and B.M. Walton. 2010. Determinants of mussel diversity in Lake Erie tributaries. Journal of the North American Benthological Society 29(2):506-520.

Krumholz, L.A., R.L. Bingham, and E.R. Meyer. 1969. A survey of the commercially valuable mussels of the Wabash and White rivers of Indiana. Proceedings of the Indiana Academy of Science 79:205–226.

[KYSNPC] Kentucky State Nature Preserves Commission. 2017. Database record export for Round Hickorynut. Frankfort, Kentucky.

[KYCWCS] Kentucky Comprehensive Wildife Conservation Strategy. 2015. Kentucky Department of Fish and Wildlife Resources, #1 Sportsman's Lane, Frankfort, Kentucky 40601. http://fw.ky.gov/WAP/Pages/Default.aspx

[KYDOW] Kentucky Division of Water. 1998. Report to Congress on Water Quality. Kentucky Natural Resources and Environmental Protection Cabinet. 35 pp.

Lasier, P.J., M.L. Urich, S.M Hassan, W.N. Jacobs, R.B. Bringolf, K.M. Owens. 2016. Changing agricultural practices: Potential consequences to aquatic organisms. Environmental Monitoring and Assessment 2016 (12):188–672.

Lau, J.K., T.E. Lauer, and M.L. Weinman. 2006. Impacts of channelization on stream habitats and associated fish assemblages in east central Indiana. American Midland Naturalist. 156:319–330.

Laudermilk, E.L. 1993. A survey of the unionids (Bivalvia: Unionidae) of the mainstream Licking River and selected tributaries below Cave Run Reservoir, Kentucky. M.S. thesis, Eastern Kentucky University, Richmond. 75 pp.

Lawler, J.J., D.J. Lewis, E. Nelson, A.J. Plantinga, S. Polasky, J.C. Withey, D.P. Helmers, S. Martinuzzi, D. Pennington, and V.C. Radeloff. 2014. Projected land-use change impacts on ecosystem services in the United States. Proceedings of the National Academy of Sciences 2014:55–57.

Layzer, J.B., and R.M. Anderson. 1992. Impacts of the coal industry on rare and endangered aquatic organisms of the upper Cumberland River basin. Kentucky Department of Fish and Wildlife Resources, Frankfort, and Tennessee Wildlife Resources Agency, Nashville. 118 pp.

Layzer, J.B., M.E. Gordon, and R.M. Anderson. 1993. Mussels: the forgotten fauna of regulated rivers. A case study of the Caney Fork River. Regulated Rivers: Research and Management 8:63–71.

Layzer, J.B., and D. Crigger. 2001. The relationship between stream discharge and mussel recruitment. Unpublished report, Tennessee Cooperative Fishery Research Unit, Cookeville. 30 pp.

Layzer, J.B., and E.M. Scott, Jr. 2006. Restoration and colonization of freshwater mussels and fish in a southeastern United States tailwater. River Research and Applications 22:475–491.

Lea, I. 1831. Observations on the naiads, and descriptions of new species of that and other families. Transactions of the American Philosophical Society 4(1834):63–121.

Lefevre, G. and W.C. Curtis. 1912. Studies on the reproduction and artificial propagation of fresh-water mussels (Vol. 30). U.S. Government Printing Office.

Letson, E.J. 1905. Check list of the Mollusca of New York. Bulletin of the New York State Museum 88:1-112.

[LEC] Lewis Environmental Consulting. 2008. Mussel surveys at Barren River miles 7.7, 9.7, 12, and 14 in Warren County, Kentucky to assess pipeline crossing impacts to mussel beds. Report prepared for Gulfstar Energy, LLC. Morgantown, Kentucky. 85 pp.

[LEC] Lewis Environmental Consulting. 2011. 2010 Mussel survey of Green River pools 2, 3, and 4. Report prepared for U.S. Army Corps of Engineers, Louisville District. 202 pp.

[LEC] Lewis Environmental Consulting. 2014. Huntington District Corps of Engineers 2014 Mussel surveys in support of the navigation dredge program. Report prepared for U.S. Army Corps of Engineers, Huntington District. 323 pp.

Lopes-Lima, M., L.E. Burlakova, A.Y. Karateyev, K. Mehler, M. Seddon, and R. Sousa. 2018. Conservation of freshwater bivalves at the global scale: diversity, threats, and research needs. Hydrobiologia 810 (1):1–14.

Lyons, M.S., R.A. Krebs, J.P. Holt, L.J. Rundo, and W Zawiski. 2007. Assessing causes of change in the freshwater mussels (Bivalvia: Unionidae) in the Black River, Ohio. American Midland Naturalist 158:1–15.

MacIsaac, H.G. 1996. Potential abiotic and biotic impacts of Zebra Mussels on the inland waters of North America. American Zoologist 36:287–299.

Maestas, A. 2013. Study: Rising demand of southeast trees puts wildlife, biodiversity at risk; landmark study examines rapidly expanding forest biomass energy development in Southeastern U.S. National Wildlife Federation.

Mackie, G.L. 1996. Diversity and status of Unionidae (Bivalvia) in the Grand River, a tributary of Lake Erie, and its drainage basin. Report prepared for Ontario Ministry of Natural Resources. 45 pp.

Mackie, G.L., and J.M. Topping. 1988. Historical changes in the unionid fauna of the Syndenham River watershed and downstream changes in shell morphometrics of three common species. Canadian Field-Naturalist 102:617-626.

March, F.A., F.J. Dwyer, T. Augspurger, C.G. Ingersoll, N. Wang, and C.A. Mebane. 2007. An evaluation of freshwater mussel toxicity data in the derivation of water quality guidance and standards for copper. Environmental Toxicology Chemistry 10:2,066–2,074.

Martin, E. and C. Apse. 2014. Northeast Aquatic Connectivity: An Assessment of Dams on Northeastern Rivers. The Nature Conservancy and Northeast Association of Fish and Wildlife Agencies. Brunswick, Maine. 102 pp.

Maury, C.J. 1917. Freshwater shells from central and western New York. The Nautilus 29-33.

McCann, M.T., and R.J. Neves. 1992. Toxicity of coal-related contaminants to early life stages of freshwater mussels in the Powell River, Virginia. Unpublished report to U.S. Fish and Wildlife Service, Asheville, North Carolina. 92 pp.

McGregor, M.A., A.C. Shepard, J.J. Culp, F. Vorisek, J. Hinkle. 2009. Five-year quantitative monitoring at Thomas Bend on the Green River, Kentucky. Annual Research Highlights of the Kentucky Department of Fish and Wildlife Resources. 2 pp.

McGregor, S.W., and D.N. Shelton. 1995. A qualitative assessment of the unionid fauna of the headwaters of the Paint Rock and Flint Rivers of North Alabama and adjacent areas of Tennessee. Report by the Geological Survey of Alabama to the Alabama Department of Conservation and Natural Resources. 34 pp.

McMurray, S.E., G.A. Schuster, and B.A. Ramey. 1999. Recruitment in a freshwater unionid (Mollusca: Bivalvia) community downstream of Cave Run Lake in the Licking River, Kentucky. American Malacological Bulletin 15(1):57–63.

McNichols, K.A. 2007. Implementing recovery strategies for mussel species at risk in Ontario. University of Guelph. Unpubished Master's Thesis. 193 pp.

McLeod, J.M, H.L. Jelks, S. Pursifull, and N.A. Johnson. 2017. Characterizing the early life history of an imperiled freshwater mussel (*Ptychobranchus jonesi*) with host-fish determination and fecundity estimation. Freshwater Science 36(2):338–350.

Mellinger, P.J. 1972. The comparative metabolism of cadmium, mercury, and zinc as environmental contaminants in the freshwater mussel, *Margaritifera margaritifera*. Ph.D. dissertation, Oregon State University, Corvallis. 129 pp.

Metcalfe-Smith, J.L., J.D. Maio, S.K. Staton, and S.R. DeSolla. 2003. Status of the freshwater mussel communities of the Syndenham River, Ontario, Canada. American Midland Naturalist 150(1):37-50.

Miller, A.C., L. Rhodes, and R. Tippit. 1984. Changes in the naiad fauna of the Cumberland River below Lake Cumberland in Central Kentucky. The Nautilus 98(3):107–110.

Miller, A.C., B.S. Payne, and C.M. Way. 1989. Phase I studies: Impacts of commercial navigation traffic on freshwater mussels - A review. U.S. Army Corps of Engineers, Vicksburg Experiment Station Report prepared for the Mussel Mitigation Trust, Columbus, Ohio. 57 pp.

Miller, A.C., B.S. Payne, and L.T. Neill. 1994. A recent re-evaluation of the bivalve fauna of the lower Green River, Kentucky. Transactions of the Kentucky Academy of Science 55:46–54.

Miller, A.C., and B.S. Payne. 1995. An analysis of freshwater mussels (Unionidae) in the Upper Ohio River near Huntington, West Virginia: 1993 studies. U.S. Army Corps of Engineers Technical Report EL-95-2. Waterways Experiment Station, Vicksburg, Mississippi. 64 pp.

Miller, A.C., and B.S. Payne. 1998. Effects of disturbances on large-river mussel assemblages. Regulated Rivers: Research and Management 14:179–190.

Miller, A.C., and B.S. Payne. 2000. Potential impacts of the North Fork Hughes River project, Ritchie County, West Virginia, 1999, on freshwater mussels (Unionidae). U.S. Army Corps of Engineers, Vicksburg Experiment Station report prepared for the Natural Resources Conservation Service. 30 pp.

Mitchell, J., and E. Peacock. 2014. A prehistoric freshwater mussel assemblage from the Big Sunflower River, Sunflower County, Mississippi. Southeastern Naturalist 13(3):626–638.

Mohler, J.W., P. Morrison, and J. Haas. 2006. The mussels of Muddy Creek on Erie National Wildlife Refuge. Northeastern Naturalist 13(4):569–582.

Moles, K.R., and J.B. Layzer. 2008. Reproductive ecology of *Actinonaias ligamentina* (Bivalvia: Unionidae) in a regulated river. Journal of the North American Benthological Society 27(1):212–222.

Morey, D.F., and G.M. Crothers. 1998. Clearing Up Clouded Waters: Palaeoenvironmental analysis of freshwater mussel assemblages from the Green River shell middens, western Kentucky. Journal of Archaeological Science 25:907–926.

Morris, J.S., and R.W. Taylor. 1978. A survey of the freshwater mussels (Bivalvia: Unionidae) of the Kanawha River of West Virginia. The Nautilus 92(4):153–155.

Morris, Todd. 2018. Fisheries and Oceans Canada. Personal communication with Andrew Henderson April 11, 2018 regarding Round Hickorynut population in Canada.

Morrison, J.P.E. 1942. Preliminary report on mollusks found in the shell mounds of the Pickwick Landing basin in the Tennessee River Valley. Pp. 337–392 *In*: W.S. Webb and D.L. DeJarnette, eds. An archeological survey of Pickwick basin in the adjacent portions of the states of Alabama, Mississippi, and Tennessee. Bureau of American Ethnology, Bulletin No. 129.

Mulcrone, R.S. 2004. Incorporating habitat characteristics and fish hosts to predict freshwater mussel (Bivalvia: Unionidae) distributions in the Lake Erie drainage, southeastern Michigan. University of Michigan Dissertation. 151 p.

Mummert, A.K., R.J. Neves, T.J. Newcombe, and D.S. Cherry. 2003. Sensitivity of juvenile freshwater mussels (*Lampsilis fasciola*, *Villosa iris*) to total and un-ionized ammonia. Environmental Toxicology and Chemistry 22(11):2,545–2,553.

Murphy, J.L. 1971. Molluscan remains from four archeological sites in northeastern Ohio. Sterkiana 43:21-25.

Naimo, T.J. 1995. A review of the effects of heavy metals on freshwater mussels. Ecotoxicology 4:341–362.

National Invasive Species Council Management Plan. 2018. *https://www.doi.gov/sites/doi.gov/files/uploads/2016-2018-nisc-management-plan.pdf*

Neel, J.K., and W.R. Allen. 1964. The mussel fauna of the upper Cumberland basin before its impoundment. Malacologia 1(3):427–459.

Nelson, I.I., R.G. Villella, and R.F. Villella. 2010. Assessing the Presence and Potential Habitat for Reintroduction of Priority Freshwater Mussel Species in the Shenango River. U.S. Geological Survey Report to the Pennsylvania Department of Transportation. Kearneysville, West Virginia. 42 pp.

Newton, T.J., J.W. Allran, J.A. O'Donnell, M.R. Bartsch, and W.B. Richardson. 2003. Effects of ammonia on juvenile unionid mussels (*Lampsilis cardium*) in laboratory sediment toxicity tests. Environmental Toxicology and Chemistry 22(11):2,554–2,560.

Newton, T.J., D.A. Woolnough, and D.L. Strayer. 2008. Using landscape ecology to understand and manage freshwater mussel populations. Journal of the North American Benthological Society 27(2):424–439.

Neves, R.J. 1987. Recent die-offs of freshwater mussels in the United States: an overview. Pp. 7–18 *in:* R.J. Neves (ed.). Proceedings of the workshop on die-offs of freshwater mussels in the United States, June 1986, Davenport, Iowa. Virginia Polytechnic Institute and State University, Blacksburg.

Neves, R.J. 1991. Mollusks. Pp. 251–319 *in:* K. Terwilliger, coordinator. Virginia's endangered species. Proceedings of a symposium, April 1989, Blacksburg, Virginia. McDonald and Woodward Publishing Co., Blacksburg.

Neves, R.J. 1993. A state-of-the unionid address. Pp. 1–10 *in*: K.S. Cummings, A.C. Buchanan, and L.M. Koch, eds. Conservation and management of freshwater mussels. Proceedings of a UMRCC symposium, October 1992, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Neves, R.J., and M.C. Odom. 1989. Muskrat predation on endangered freshwater mussels in Virginia. Journal of Wildlife Management 53(4):934–941.

Neves, R. J., and P. L. Angermeier. 1990. Habitat alteration and its effects on native fishes in the upper Tennessee River system, east-central USA. Journal of Fish Biology 37:45–52.

Neves, R.J., A.E. Bogan, J.D. Williams, S.A. Ahlstedt, and P.W. Hartfield. 1997. Status of Aquatic Mollusks in the Southeastern United States: A Downward Spiral of Diversity; Chapter 3 (pp.44–86) in Aquatic Fauna in Peril: The Southeastern Perspective, edited by G.W. Benz and D.E. Collins (1997), Special Publication 1. Southeast Aquatic Research Institute. Lenz Design and Communications, Decatur, Georgia. 554 pp.

Newton, T.J. 2003. The effects of ammonia on freshwater unionid mussels. Environmental Toxicology and Chemistry 22:3,543–3,544.

Newton, T.J., J.W. Allran, J.A. O'Donnell, M.R. Bartsch, and W.B. Richardson. 2003. Effects of ammonia on juvenile unionid mussels (*Lampsilis cardium*) in laboratory sediment toxicity tests. Environmental Toxicology and Chemistry 22:2,554–2,560.

Newton, T.J. and W.G. Cope. 2007. Biomarker responses of unionid mussels to environmental contaminants. Pp. 257-284 *in*: J.L. Farris and J.H. Van Hassel, eds. Freshwater Bivalve Ecotoxicology. CRC Press, Boca Raton, Florida.

Nichols, S.J., and D. Garling. 2000. Food‐web dynamics and trophic‐level interactions in a multispecies community of freshwater unionids. Canadian Journal of Zoology 78:871–882.

Nico, L.G., J.D. Williams, and H.L. Jelks. 2005. Black Carp: biological synopsis and risk assessment of an introduced fish. American Fisheries Society Special Publication No. 32. 337 pp.

Nico, L.G., and M.E. Neilson. 2018. *Mylopharyngodon piceus* (Richardson, 1846): U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Florida, *https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=573*. Revision Date: August 6, 2018, Peer Review Date: April 1, 2016, Access Date: August 26, 2018.

Nobles, T. and Y. Zhang. 2011. Biodiversity Loss in Freshwater Mussels: Importance, Threats, and Solutions. Chapter 6 (pp. 137–162) in Biodiversity Loss in a Changing Planet, edited by O. Grillo and G. Venora (2011). InTech, Rijeka, Croatia. 328 pp.

[ODNR] Ohio Department of Natural Resources; Ohio Division of Wildlife. 2015. Ohio's State Wildlife Action Plan. Columbus, Ohio, USA.

Ohio Department of the Environmental Protection Agency. 2004. Darby at the crossroads: A summary of Ohio EPA's work and collaboration to protect and restore an important water resource. 16 pp.

Ohio Department of the Environmental Protection Agency. 2011. Biological and water quality study of the Killbuck Creek Watershed, 2009. 108 pp.

Ohio Mussel Survey Protocol. 2018. Ohio Department of Natural Resources (ODNR), Division of Wildlife and U.S. Fish and Wildlife Service, Ohio Ecological Services Field Office. *https://wildlife.ohiodnr.gov/portals/wildlife/pdfs/licenses%20&%20permits/OH%20Mussel%20Survey%20Protocol.pdf* (Accessed October 1, 2018).

Ohio River Valley Water Sanitation Commission. 2016. Assessment of Ohio River water quality conditions 2010–2014. Cincinnati, Ohio. 74 pp.

Ortmann, A.E. 1909a. A preliminary list of the Unionidae of western Pennsylvania, with new localities for species from eastern Pennsylvania. Annals of the Carnegie Museum 5(2-3):178–210.

Ortmann, A.E. 1909b. The destruction of the fresh-water fauna in western Pennsylvania. Proceedings of the American Philosophical Society 48(191):90–110.

Ortmann, A.E. 1913. The Alleghenian Divide, and its influence upon the freshwater fauna. Proceedings of the American Philosophical Society 52(210):287–390.

Ortmann, A.E. 1919. A monograph of the naiades of Pennsylvania. Part III: systematic account of the genera and species. Memoirs of the Carnegie Museum 8(1):1–384.

Ortmann, A.E. 1920. Correlation of shape and station in freshwater mussels. Proceedings of the American Philosophical Society 59(4):268–312.

Ortmann, A.E. 1921. The anatomy of certain mussels from the upper Tennessee. The Nautilus 34(3):81–91.

Ortmann, A.E. 1924. The naiad-fauna of Duck River in Tennessee. American Midland Naturalist 9(1):18–62.

Ortmann, A.E. 1924. Distributional features of naiades in tributaries of Lake Erie. American Midland Naturalist 9(3):101–117.

Ortmann, A.E. 1925. The naiad fauna of the Tennessee River system below Walden Gorge. American Midland Naturalist 9(8):321–372.

[OSUM] Ohio State University Museum Mollusk Collection. 2018. Museum Database Query by Andrew Henderson.

Pardue, W.J. 1981. A survey of the mussels (Unionidae) of the upper Tennessee River 1978. Sterkiana 71:41–51.

Parmalee, P.W. 1960. Mussels from the Angel site, Indiana. The Nautilus 74(2):70–75.

Parmalee, P.W. 1967. The freshwater mussels of Illinois. Illinois State Museum Popular Science Series Vol. VIII. 136 pp.

Parmalee, P.W. 1988. A comparative study- of late prehistoric and modern molluscan faunas of the Little Pigeon River system, Tennessee. American Malacological Bulletin 6(2):165–178.

Parmalee, P.W., and A.E. Bogan. 1986. Molluscan remains from aboriginal middens at the Clinch River Breeder Reactor Plant site, Roane County, Tennessee. American Malacological Bulletin 4(1):25–37.

Parmalee, P.W., and A.E. Bogan. 1998. The freshwater mussels of Tennessee. The University of Tennessee Press, Knoxville, Tennessee. 328 pp.

Parmalee, P.W., and H.D. Faust. 2006. Diversity and relative abundance of preimpoundment freshwater mussel (Bivalvia: Unionidae) populations in the lower Holston River, Tennessee. Journal of the Tennessee Academy of Science 81(3–4):73–78.

Parmalee, P.W., and R.R. Polhemus. 2004. Prehistoric and pre-impoundment populations of freshwater mussels (Bivalvia: Unionidae) in the South Fork Holston River, Tennessee. Southeastern Naturalist 3(2):231 –240.

Parmalee, P.W., and W.E. Klippel. 1974. Freshwater mussels as a prehistoric food resource. American Antiquity 39(3):421–434.

Parmalee, P.W., and W.E. Klippel. 1984. The Naiad Fauna of the Tellico River, Monroe County, Tennessee. American Malacological Bulletin 3(1):41–44.

Parmalee, P.W., W.E. Klippel, and A.E. Bogan. 1980. Notes on the prehistoric and present status of the naiad fauna on the middle Cumberland River, Smith County, Tennessee. The Nautilus 94(3):93–105.

Parmalee, P.W., W.E. Klippel, and A.E. Bogan. 1982. Aboriginal and modern freshwater mussel assemblages (Pelecypoda: Unionidae) from the Chickamauga Reservoir, Tennessee. Brimleyana 8:75–90.

Patnode, K.A., R.M. Anderson, L. Zimmermann, E. Hittle, and J.W. Fulton. 2015. Effects of high salinity wastewater discharges on unionid mussels in the Allegheny River, Pennsylvania. Journal of Fish and Wildlife Management 6(1):55–70.

Peacock, E., and T.R. James. 2002. A prehistoric Unionid assemblage from the Big Black River drainage in Hinds County, Mississippi. Journal of the Mississippi Academy of Sciences. 47(2):121–125.

Peacock, E., W.R. Haag, and M.L. Warren, Jr. 2005. Prehistoric decline in freshwater mussels coincident with the advent of maize agriculture. Conservation Biology 19(2):547–551.

Peacock, E., J. Mitchell, and C. Jenkins. 2016. Pre-columbian freshwater mussel assemblages from the Tallahatchie River in the Lower Mississippi River alluvial basin, U.S.A. American Malacological Bulletin 34(2):121–132.

Pennsylvania Department of Environmental Protection. 2016. Final Pennsylvania integrated water quality monitoring and assessment report. Clean Water Act Section 305(b) Report and 303(d) List. 87 pp.

Pilsbry, H.A., and S.N. Rhoads. 1896. Contributions to the zoology of Tennessee. No. 4, Mollusks. Proceedings of the Academy of Natural Sciences of Philadelphia 48:487–506.

Poff, N.L., M.M. Brinson, and J.W. Day, Jr. 2002. Aquatic ecosystems and global climate change: Potential Impacts on Inland Freshwater and Coastal Wetlands Ecosystems in the United States. Pew Center on Global Climate Change. 56 pp.

Poos, M., A.J. Dextrase, A.N. Schwalb, and J.D. Ackerman. Secondary invasion of the Round Goby into high diversity Great Lakes tributaries and species at risk hotspots: potential new concerns for endangered freshwater species. Biological Invasions 12:1,269–1,284.

Price, J.E., C.E. Zipper, J.W. Jones, and C.T. Franck. 2014. Water and sediment quality in the Clinch River, Virginia and Tennessee, USA, over nearly five decades. Journal of the American Water Resources Association 50(4):837–858.

Rahm, E.J. 2008. Spatial distribution and microhabitat of adult and juvenile mussels (Bivalvia: Unionidae) within a bed. Unpublished Master's Thesis, Tennessee Technological University. Cookeville, Tennessee. 52 pp.

Reed, M.P. 2014. Freshwater mussels (Bivavia: Margaritiferidae and Unionidae) of the Buffalo River drainage, Tennessee. University of Tennessee, unpublished Master's Thesis. 98 pp.

Ren, W., Y. Zhong, J. Meligrana, B. Anderson, W.E. Watt, J. Chen, H. Leung. 2003. Urbanization, land use, and water quality in Shanghai: 1947–1996. Environment International 29(5):649–659.

Rhoads, S.N. 1899. On a recent collection of Pennsylvanian mollusks from the Ohio River system below Pittsburg. The Nautilus 12:133–138.

Ricciardi, A., R.J. Neves, and J.R. Rasmussen. 1998. Impending extinctions of North American freshwater mussels (Unionoida) following the Zebra Mussel (*Dreissena polymorpha*) invasion. Journal of Animal Ecology 67:613–619.

Richard, J. 2018. Freshwater mussel die-offs: Insights from a Compilation of Known Cases. Presentation at the Freshwater Mollusk Conservation Society Mollusk Health and Disease Workshop, La Crosse, Wisconsin. 23 pp.

Sams, J.I., and K.M. Beer. 2000. Effects of coal-mine drainage on stream water quality in the Allegheny and Monongahela river basins – sulfate transport and trends. Water-Resources Investigations Report 99-4208. U.S. Geological Survey, National Water-Quality Assessment Program, Lemoyne, Pennsylvania. 17 pp.

Sasson, A. 2017. Summary of 2016 Big Darby Creek Mussel Die-off. Report prepared by the Nature Conservancy of Ohio. 28 pp.

Scheller, J.L. 1997. The effects of dieoffs of Asian Clams (*Corbidula fluminea*) on Native Freshwater Mussels (Unionidae). M.S. thesis. Virginia Polytechnic Institute and State University. 100 pp.

Schloesser, D.W., T.F. Nalepa, and G.L. Mackie. 1996. Zebra Mussel Infestation of Unionid Bivalves (Unionidae) in North America. American Zoologist 36:300–310.

Schloesser, D.W., W.P. Kovalak, G.D. Longdon, K.L. Ohnesorg, and R.D. Smithee. 1998. Impact of zebra and quagga mussels (*Dreissena* spp.) on freshwater unionids (Bivalvia: Unionidae) in the Detroit River of the Great Lakes. American Midland Naturalist 140(2):299–313.

Schmerfeld, J. 2006. Reversing a textbook tragedy. Endangered Species Bulletin 31(1):12–13.

Schmidt, J.E., and M.A. Zeto. 1986. Naiad distribution in the Mud River drainage, southwestern West Virginia. Malacology Data Net 1(4):69–78.

Schmidt, J.E., M.A. Zeto, and R.W. Taylor. 1983. A survey of the freshwater mussel fauna of the Little Kanawha River basin. Pp. 131–139 in: A.C. Miller, compiler. Report of freshwater mollusks workshop, October 1982. U.S. Army Corps of Engineers Waterways Experimental Station, Vicksburg, Mississippi.

Schmidt, J.E., R.D. Estes, and M.E. Gordon. 1989. Historical changes in the mussel fauna (Bivalvia: Unionoidea) of the Stones River, Tennessee. Malacological Review. 22:55–60.

Schuster, G.A. 1988. The distribution of unionids (Mollusca: Unionidae) in Kentucky.

Kentucky Department of Fish and Wildlife Resources, Frankfort. 1,099 pp.

Schuster, G.A., R.S. Butler, and D.H. Stansbery. 1989. A survey of the Unionids (Bivalvia: Unionidae) of Buck Creek, Pulaski County, Kentucky. Transactions of the Kentucky Academy of Sciences 50(1–2):79–85.

Scott, E.M., Jr., K.D. Gardner, D.S. Baxter, and B.L. Yeager. 1996. Biological and water quality responses in tributary tailwaters to dissolved oxygen and minimum flow improvements. Tennessee Valley Authority, Norris, Tennessee. 211 pp.

Seaber, P.R., F.P. Kapinos, G.L. Knapp. 1987. Hydrologic Unit Map, U.S. Geological Survey Water-Supply Paper 2294. 63 pp.

[Service] U.S. Fish and Wildlife Service. 2007a. Final restoration plan and environmental assessment for the Ohio River fish, mussel, and snail restoration. 36 pp.

[Service] U.S. Fish and Wildlife Service. 2007b. Purple Cat's Paw Pearlymussel (Epioblasma obliquata obliquata) 5-year review: summary and evaluation. USFWS Columbus Ohio Field Office.

[Service] U.S. Fish and Wildlife Service. 2011. Endangered and Threatened Wildlife and Plants; Partial 90-Day Finding on a Petition to List 404 Species in the Southeastern United States as Endangered or Threatened With Critical Habitat. 76 FR 59836–59862.

[Service] U.S. Fish and Wildlife Service. 2013. 2013 Accomplishment report, Ohio River restoration project. Natural Resources Damage Assessment and Restoration Project 0273. 50 pp.

[Service] U.S. Fish and Wildlife Service. 2016. U. S. Fish and Wildlife Service Species Status Assessment Framework: an integrated analytical framework for conservation. Version 3.4, dated August 2016.

[Service] U.S. Fish and Wildlife Service. 2017. Species status assessment report for the Atlantic Pigtoe (*Fusconaia masoni*). Version 1.2. March 2017. Atlanta, Georgia.

[Service] U.S. Fish and Wildlife Service. 2018b. Eastern Hellbender (*Cryptobranchus alleganiensis alleganiensis*) Species Status Assessment. Version 1 Draft Report, January 2018.

[Service] U.S. Fish and Wildlife Service. 2018c. Longsolid Mussel (*Fusconaia subrotunda*) Species Status Assessment. Version 1 Draft Report, November 2018.

[Service] U.S. Fish and Wildlife Service. 2019. Unpublished data prepared and analyzed for management units and Round Hickorynut populations, Asheville, North Carolina.

Shelford, V.E., and M.W. Boesel. 1942. Bottom animal communities of the island area of western Lake Erie in the summer of 1937. The Ohio Journal of Science 42:179–190.

Shepard, A.C. 2006. Identification of suitable host fishes for the Round Hickorynut mussel (*Obovaria subrotunda*) from Kentucky. Eastern Kentucky University Master's Thesis. 33 pp.

Shepard, A.C. 2017. KYFW. Email communications regarding host fish studies at the Cumberland Mollusk Center, with Andrew Henderson, U.S. Fish and Wildlife Service

Shoup, C.S., J.H. Peyton, and G. Gentry. 1941. A limited biological survey of the Obey River and adjacent streams in Tennessee. Journal of the Tennessee Academy of Science 16(1):48–76.

Sickel, J.B. 1982. A survey of the freshwater mussel of the lower Cumberland River from Barkley Dam tailwater downstream to the Ohio River. Report to the U.S. Army Corps of Engineers, Nashville District. 24 pp.

Sickel, J.B., and C.C. Chandler. 1996. Unionid fauna of the lower Cumberland River from Barkley Dam to the Ohio River, Kentucky (Mollusca: Bivalvia: Unionidae). Transactions of the Kentucky Academy of Science 57(1):33–46.

Sickel, J.B., and M.D. Burnett. 2005. Historical mussel and aquatic snail database for the Tennessee River between Kentucky lock and dam on the Ohio River. Report to the U.S. Army Corps of Engineers, Nashville District. 45 pp.

Sickel, J.B., M.D. Burnett, C.C. Chandler, C.E. Lewis, H.N. Blalock-Herod, and J.J. Herod. 2007. Changes in the freshwater mussel community in the Kentucky portion of Kentucky Lake, Tennessee River, since impoundment by Kentucky Dam. Journal of the Kentucky Academy of Science 68(1):68–80.

Simpson, C.T. 1914. A descriptive catalogue of the naiades or pearly fresh-water mussels. Parts I-III. Bryant Walker, Detroit, MI, xii + 1540 pp.

Smith, D.R., R.F. Villella, and D.P. Lemarie. 2001. Survey protocol for assessment of endangered freshwater mussels in the Allegheny River, Pennsylvania. Journal of the North American Benthological Society 20(1):118–132.

Spaeth, J., C. Swecker, and K. McGill. 2015. Freshwater mussel (Unionidae) surveys on the Ohio River (Markland pool) in Clermont and Hamilton counties, Ohio. Final Report prepared by Environmental Solutions and Innovations, Inc. for Duke Energy. 277 pp.

Sparks, B.L., and D.L. Strayer. 1998. Effects of low dissolved oxygen on juvenile *Elliptio complanata* (Bivalvia: Unionidae). Journal of the North American Benthological Society 17(1):129–134.

Sparks, D., C. Chaffee, and S. Sobiech. 1999. Fish Creek preservation and restoration.

Endangered Species Bulletin 24(1):13–14.

Spooner, D. and C.C. Vaughn. 2008. A trait-based approach to species' roles in stream ecosystems: climate change, community structure, and material cycling. Oecologia 158:307–317.

Spurlock, B.D. 1981. The naiads (Mollusca: Unionidae) from two prehistoric sites along the Ohio River, Mason County, West Virginia. Unpublished Master's Thesis, Marshall University, Huntington, West Virginia. 65 pp.

Stansbery, D.H. 1962. A century of change in the naiad population (of the upper Scioto River drainage of central Ohio). Bulletin of the American Malacological Union Annual Reports for 1961:20–22.

Stansbery, D.H. 1965. The naiad fauna of the Green River at Munfordville, Kentucky. Bulletin of the American Malacological Union Annual Reports for 1965:13–14.

Stansbery, D.H. 1972. A preliminary list of the naiad shells recovered from the Buffalo Site. In: Broyles, Bettye, J. (ed.): A late 17th century Indian village site in Putnam County, West Virginia. Report of Archaeological Investigations Number 6, West Virginia Geological and Economic Survey, Morgantown, West Virginia.

Stantec Consulting Services. 2014. Mussel surveys on the Scioto and Sandusky Rivers. Unpublished report to the Ohio Department of Natural Resources. 68 pp.

Starnes, L.B., and A.E. Bogan. 1982. Unionid mussels (Bivalvia) from Little South Fork Cumberland River, with ecological and nomenclatural notes. Brimleyana 8:101–119.

Stein, C.B. 1963. The Unionidae (Mollusca: Pelecypoda) of the Olentangy River in central Ohio. Ohio State University, unpublished Master's Thesis. 157 pp.

Sterki, V. 1892. A few observations concerning death of freshwater Mollusca. The Nautilus 5:135–136.

Sterki, V. 1894. The land and freshwater Mollusca in the vicinity of New Philadelphia, a contribution to the natural history of Tuscarawas Co., Ohio. 21 pp.

Strayer, D.L. 1980. The freshwater mussels (Bivalvia: Unionidae) of the Clinton River, Michigan, with comments on man's impact on the fauna, 1870-1978. The Nautilus 94(4):142–149.

Strayer, D.L. 1983. The effects of surface geology and stream size on freshwater mussel (Bivalvia, Unionidae) distribution in southeastern Michigan, U.S.A. Freshwater Biology 13:253–264.

Strayer, D.L. 1999a. Use of flow refuges by unionid mussels in rivers. Journal of the North

American Benthological Society 18(4):468–476.

Strayer, D.L. 1999b. Effects of alien species on freshwater mollusks in North America. Journal of the North American Benthological Society 18(1):74–98.

Strayer, D.L. 2006. Challenges for freshwater invertebrate conservation. Journal of the North American Benthological Society 25(2):271–287.

Strayer, D.L. 2008. Freshwater mussel ecology: a multifactor approach to distribution and abundance. Vol. 1. University of California Press. 216 pp.

Strayer, D.L., and K.J. Jirka. 1997. The pearlymussels of New York State. New York State Museum Memoir 26. University of the State of New York. Albany, New York.

Strayer, D.L., K.J. Jirka, and K.J. Schnieder. 1991. Recent collections of freshwater mussels (Bivalvia: Unionidae) from western New York. Walkerana 5(13):63–72.

Strayer, D.L., J.A. Downing, W.R. Haag, T.L. King, J.B. Layzer, T.J. Newton, and S.J. Nichols. 2004. Changing perspectives on pearly mussels, North America's most imperiled animals. BioScience 54(5):429–439.

Strayer, D.L., and H.M. Malcom. 2012. Causes of recruitment failure in freshwater mussel populations in southeastern New York. Ecological Applications 22:1,780–1,790.

Stodola, A.P., S.A. Douglass, and D.K. Shasteen. 2014. Historical and current distributions of freshwater mussels in Illinois. Illinois Natural History Survey Technical Report 2014 (37). 83 pp.

Swank, W.T. and J.E. Douglass. 1974. Streamflow Greatly Reduced by Converting Deciduous Hardwood Stands to Pine. Science 185(4154):857–859. DOI:10.1126/science.185.4154.857

Swank, W. T., and N. H. Miner. 1968. Conversion of Hardwood-Covered Watersheds to White Pine Reduces Water Yield. Water Resources Research 4(5):947–954.

Swart, L.H. 1940. An ecological survey of the mollusks of the west branch of the Mahoning River. Kent State University thesis. 71 pp.

Swecker, C., and J. Garofalo. 2013a. Freshwater mussel surveys at two locations on Walnut Creek along the proposed ATEX Express project in Fairfield and Pickaway counties, Ohio. Report prepared for Blanton & Associates, Ind. and Enterprise Liquids Pipeline LLC. 33 pp.

Swecker, C., and J. Garofalo. 2013b. Freshwater mussel surveys on the Little Miami River along the proposed ATEX Express project in Warren county, Ohio. Report prepared for Blanton & Associates, Ind. and Enterprise Liquids Pipeline LLC. 21 pp.

Surber, T. 1915. Identification of the Glochidia of Fresh-Water Mussels. Bureau of Fisheries Document No. 813.

Taylor, R.W. 1980a. A survey of the freshwater mussels of the Ohio River from Greenup Locks and Dam to Pittsburg, Pennsylvania. Report submitted to the U.S. Army Corps of Engineers, Huntington District. 79 pp.

Taylor, R.W. 1980b. Freshwater bivalves of Tygart Creek, Northeastern Kentucky. The Nautilus 94(2):89–91.

Taylor, R.W. 1983a. A survey of the freshwater mussels of the Kanawha River from river head (Gauley Bridge, West Virginia) to river mouth (Point Pleasant, West Virginia). U.S. Army Corps of Engineers, Huntington District. 62 pp.

Taylor, R.W. 1983b. The freshwater naiad (mussel) fauna of the Nolin River in the Green River drainage of central Kentucky (Mollusca: Bivalvia). The Nautilus 97(3):109–112.

Taylor, R.W., and R.C. Hughart. 1981. The freshwater naiads of Elk River, West Virginia, with comparison of earlier collections. The Nautilus 95(1):21–25.

Taylor, R.W., and B.D. Spurlock. 1981. A survey of the freshwater mussels (Mollusca: Unionidae) of Middle Island Creek, West Virginia. Brimleyana 7:155–158.

Taylor, R.W., and B.D. Spurlock. 1982. The changing Ohio River naiad fauna: A comparison of early Indian middens with today. The Nautilus 96(2):49–51.

Taylor, S.E., R. Rummer, K.H. Yoo, R.A. Welch, and J.D. Thompson. 1999. What we know and don't know about water quality at stream crossings. Journal of Forestry 97(8):12–17.

[TDEC] Tennessee Department of Environment and Conservation. 2014. 2014 305(b) report: the status of water quality in Tennessee. Division of Water Pollution Control, Nashville, Tennessee. 114 pp.

[TWRA] Tennessee Wildlife Resources Agency. 2011. 2010 Duck River Quantitative Mussel Survey. Aquatic Habitat Protection Program Report 11–04. 48 pp.

[TWRA] Tennessee Wildlife Resources Agency. 2016. 2015 Duck River Quantitative Mussel Survey 16–06. 60 pp.

Terando, A.J., J. Costanza, C. Belyea, R.R. Dunn, A. McKerrow, and J.A. Collazo. 2014. The southern megalopolis: Using the past to predict the future of urban sprawl in the southeast United States. PLOS ONE 9(7):1–8.

Tevesz, M.J.S., L. Rundo, R.A. Krebs, B.G. Redmond, and A.S. Dufresne. 2002. Changes in the freshwater mussel (Mollusca: Bivalvia) fauna of the Cuyahoga River, Ohio, since late prehistory. Kirtlandia 53:13–18.

Tiemann, J.S. 2005. Freshwater mussel (Bivalvia: Unionidae) survey of the Brouilletts Creek basin in Illinois and Indiana. Proceedings of the Indiana Academy of Science 114(1):33–42.

Tolin, W.A. 1987. A survey of freshwater mussel fauna, Unionidae, in the mainstem of the upper Ohio River, the lower Monongahela River, and the Allegheny River, Pennsylvania. U.S. Fish and Wildlife Service, State College, Pennsylvania, and U.S. Army Corps of Engineers, Pittsburgh, Pennsylvania. 13 pp.

Tolin, W.A., and P.A. Schettig. 1984. A survey of the freshwater mussels (Unionidae) of the lower Big Sandy River basin. U.S. Fish and Wildlife Service, Elkins, West Virginia. 70 pp.

Trombulak, S.C. and C.A. Frissell. 2000. Review of Ecological Effects of Roads on Terrestrial and Aquatic Communities. Conservation Biology 14(1):18–33.

Tyrrell, M., and D.J. Hornbach. 1998. Selective predation by Muskrats on freshwater mussels in two Minnesota rivers. Journal of the North American Benthological Society 17(3):301–310.

U.S. Department of Agriculture. 2010. Final Environmental Assessment for dam modifications on the West Fork River, Harrison County, West Virginia. Report prepared by USDA Natural Resources Conservation Service [NRCS] in cooperation with US Fish & Wildlife Service for the City of Clarksburg, West Virginia Water Board. 174 pp.

U.S. Global Climate Change Research Program. Fourth National Climate Assessment. *https://www.globalchange.gov/nca4*

[USGS] U.S. Geological Survey. 2018. Effects of Urbanization on Stream Ecosystems. *http://water.usgs.gov/nawqa/urban/* (Accessed: October 1, 2018).

[USGS] U.S. Geological Survey. 2018. *https://water.usgs.gov/GIS/huc.html*. (Accessed: October 1, 2018).

Valenti, T.W., D.S. Cherry, R.J. Neves, and J. Schmerfeld. 2005. Acute and chronic toxicity of mercury to early life stages of the rainbow mussel, *Villosa iris* (Bivalvia: Unionidae). Environmental Toxicology and Chemistry 24(5):1,242–1,246.

Vanatta, E.G. 1915. Rafinesque's Types of Unio. Proceedings of the Academy of Natural Sciences of Philadelphia 67(3):549–559.

Van Cleave, H.J. 1940. Ten years of observation on a fresh-water mussel population. Ecology 21(3):363–370.

van der Schalie, H. 1938. The naiad fauna of the Huron River, in southeastern Michigan. University of Michigan Miscellaneous Publication 40:1–114.

van der Schalie, H. 1939. Additional notes on the naiades (freshwater mussels) of the lower Tennessee River. American Midland Naturalist 22(2):452–457.

van der Schalie, H. 1973. The mollusks of the Duck River drainage in central Tennessee. Sterkiana 52:45-55.

Van Hassel, J.H. 2007. Case Study: Discrimination of Factors Affecting Unionid Mussel Distribution in the Clinch River, Virginia, USA. Pp. 311-333. *in:* J.L. Farris and J.H. Van Hassel, eds. Freshwater Bivalve Ecotoxicology. CRC Press, Boca Raton, Florida.

Vaughn, C.C. 2012. Life history traits and abundance can predict local colonization and extinction rates of freshwater mussels. Freshwater Biology 57(5):982–992.

Vaughn, C.C., and C.M. Taylor. 1999. Impoundments and the decline of freshwater mussels: a case study of an extinction gradient. Conservation Biology 13:912–920.

Vaughn, C.C. 2003. The mussel fauna of the Glover River, Oklahoma. Proceedings of the Oklahoma Academy of Science 83:1–6.

Vidic, R.D., S.L. Brantley, J.M. Vandenbossche, D. Yoxtheimer, and J.D. Abad. 2013. Impact of shale gas development on regional water quality. Science 340(1235009):1–9.

Wang, N., C.G. Ingersoll, I.E. Greer, D.K. Hardesty, C.D. Ivey, J.L. Kunz, W.G. Brumbaugh, F.J. Dwyer, A.D. Roberts, T. Augspurger, C.M. Kane, R.J. Neves, and M.C. Barnhart. 2007. Chronic toxicity of copper and ammonia to juvenile freshwater mussels (Unionidae). Environmental Toxicology and Chemistry 26(10):2,048–2,056.

Warren, M.L., Jr., and W.R. Haag. 2005. Spatio-temporal patterns of the decline of freshwater mussels in the Little South Fork Cumberland River, USA. Biodiversity and Conservation 14:1,383–1,400.

Warrington, B.M., W.M. Aust, S.M. Barrett, W.M. Ford, C.A. Dolloff, E.B. Schilling, T.B. Wigley, and M.C. Bolding. 2018. Forestry best management practices relationships with aquatic and riparian fauna: A review. Forests 8(331):1–16.

Watters, G.T. 1988. A survey of the freshwater mussels of the St. Joseph River system, with emphasis on the federally endangered white cat's paw pearly mussel. Indiana Department of Natural Resources, West Lafayette. 27 pp.

Watters, G.T. 1990. 1990 survey of the Unionids of the Big Darby Creek system. Final Report to The Nature Conservancy Ohio Chapter. 238 pp.

Watters, G.T. 1992a. Unionids, fishes, and the species-area curve. Journal of Biogeography 19:481–490.

Watters, G.T. 1992b. Distribution of the Unionidae in south central Ohio. Malacology Data Net

3(1–4):56–90.

Watters, G.T. 1993-1994. Sampling freshwater mussel populations: The bias of Muskrat middens. Walkerana 7(17/18):63–69.

Watters, G.T. 1994. Unionidae of the Big Darby Creek system in central Ohio, U.S.A. Malacological Review 27:99–107.

Watters, G.T. 1998a. Freshwater mussel surveys of the Big Darby Creek system in central Ohio. Ohio Biological Survey Notes 1:19–24.

Watters, G.T. 1998b. Freshwater mussel surveys of the Fish Creek system in Ohio and Indiana. Ohio Biological Survey Notes 1:25–29.

Watters, G.T. 2000. Freshwater mollusks and water quality: effects of hydrologic and instream habitat alterations. Pp. 261–274 *in*: P.D. Johnson and R.S. Butler, eds. Freshwater Mollusk Symposium Proceedings—Part II: musseling in on…biodiversity. Proceedings of the 1st symposium of the Freshwater Mollusk Conservation Society, March 1999, Chattanooga, Tennessee. Ohio Biological Survey, Columbus.

Watters, G.T., and H.L. Dunn. 1993–94. The Unionidae of the lower Muskingum River (RM 34.1-0), Ohio, U.S.A. Walkerana 7(17/18):225–263.

Watters, G.T., M.A. Hoggarth, and D.H. Stansbery. 2009. The Freshwater Mussels of Ohio. The Ohio State University Press, Columbus, Ohio. 421 pp.

Watters, G.T., and C.J.M. Flaute. 2010. Dams, zebras, and settlements: The historical loss of freshwater mussels in the Ohio River mainstem. American Malacological Bulletin 28:1–12.

Way, C.M., and D.N. Shelton. 1997. Quantitative ecological survey of a mussel bed at Ohio River mile 617.0 to 617.5. Pp. 63-67 *in*: K.S. Cummings, A.C. Buchanan, C.A. Mayer, and T.J. Naimo, eds. Conservation and management of freshwater mussels II: initiatives for the future. Proceedings of a UMRCC symposium, October 1995, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Wear, D.N. and J.G. Greis. 2012. The Southern Forest Futures Project: summary report. General Technical Report SRS-GTR-168. Asheville, North Carolina: U.S. -Forest Service, Southern Research Station. 54 pp.

Webster, J.R., S.W. Golladay, E.F. Benfield, J.L. Meyer, W.T. Swank, and J.B. Wallace. 1992. Catchment disturbance and stream response: An overview of stream research at Coweeta Hydrologic Laboratory. *In*: River conservation and management, P.J. Boon, P. Calow and G.E. Petts, eds. 231–253. Chichester, England: John Wiley and Sons Ltd.

Weilbaker, C., C.D. Baker, B.J. Forsyth, C.M. Christenson, and R.W. Taylor. 1985. The freshwater naiads, Bivalvia, Unionidae, of the Blue River, a southern Indiana tributary of the Ohio River. Proceedings of the Indiana Academy of Science 94:687–691.

Weiss, J.L. 1993. Factors influencing the distribution and abundance of freshwater mussels in the Barren River, Kentucky, with emphasis on the role of host fishes. Unpublished Master's Thesis, Tennessee Technological University. Cookeville, Tennessee. 71 pp.

Welte, N. 2012. Mussel species of concern - Round Hickorynut status change/documentation form. Pennsylvania Biological Survey Bivalve Technical Subcommittee. 36 pp.

Wenger, S. 1999. A Review of the Scientific Literature on Riparian Buffer Width, Extent, and Vegetation. University of Georgia, Institute of Ecology, Athens, Georgia. 59 pp.

Wesler, K.W. 2001. Excavations at Wickliffe Mounds. The University of Alabama Press, Tuscaloosa. 178 pp.

[WVDEP] West Virginia Department of Environmental Protection. 2014. West Virginia integrated water quality monitoring and assessment report 2014. Charleston, West Virginia. 291 pp.

[WVDNR] West Virginia Division of Natural Resources. 2012. Section 6 report to the U.S. Fish and Wildlife Service on the conservation and enhancement of populations of federally listed mussels in West Virginia and to assist with the range-wide recovery of the species. 76 pp.

[WVDNR] West Virginia Division of Natural Resources. 2014. Section 6 report to the U.S. Fish and Wildlife Service on the conservation and enhancement of populations of federally listed mussels in West Virginia and to assist with the range-wide recovery of the species. 78 pp.

[WVDNR] West Virginia Division of Natural Resources. 2015. Section 6 report to the U.S. Fish and Wildlife Service on the conservation and enhancement of populations of federally listed mussels in West Virginia and to assist with the range-wide recovery of the species. 68 pp.

[WVDNR] West Virginia Division of Natural Resources. 2016. Section 6 report to the U.S. Fish and Wildlife Service on the conservation and enhancement of populations of federally listed mussels in West Virginia and to assist with the range-wide recovery of the species. 62 pp.

Wheeler, A.P., P.L. Angermeier, and A.E. Rosenberger. 2005. Impacts of new highways and subsequent landscape urbanization on stream habitat and biota. Reviews in Fishery Science 13:141–164.

Wilson, C.B., and H.W. Clark. 1914. The mussels of the Cumberland River and its tributaries. Report to the U.S. Commission of Fisheries for 1912, Special Papers. 63 pp.

Wilson, C.O. 2015. Land use/land cover water quality nexus: quantifying anthropogenic influences on surface water quality. Environmental Monitoring and Assessment 187(7):424.

Williams, J.C., and G.A. Schuster. 1989. Freshwater mussel investigations of the Ohio River: mile 317.0 to mile 981.0. Report to the Kentucky Department of Fish and Wildlife Resources, Frankfort. 57 pp.

Williams, J.D., M.L. Warren, Jr., K.S. Cummings, J.L. Harris, and R.J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18(9):6–22.

Williams, J.D., A.E. Bogan, and J.T. Garner. 2008. Freshwater mussels of Alabama and the Mobile Basin of Georgia, Mississippi, and Tennessee. University of Alabama Press, Tuscaloosa.

Williams, J.D., A.E. Bogan, R.S. Butler, K.S. Cummings, J.T. Garner, J.L. Harris, N.A. Johnson, and G.T. Watters. 2017. A revised list of the freshwater mussels (Mollusca: Bivalvia: Unionida) of the United States and Canada. Freshwater Mollusk Biology and Conservation 20:33–58.

Winters, R. 1973. List of naiads, and localities, collected during 1969–1972. Pittsburg Shell Club Bulletin. 2 pp.

Wolf, S., B. Hartl, C. Carroll, M.C. Neel, and D.N. Greenwald. 2015. Beyond PVA: Why recovery under the Endangered Species Act is more than population viability. BioScience 65(2):200–207.

Woodside, M.D., Hoos, A.B., Kingsbury, J.A., Powell, J.R., Knight, R.R., Garrett, J.W., Mitchell, III, Reavis L., and Robinson, J.A. 2004. Water quality in the Lower Tennessee River basin, Tennessee, Alabama, Kentucky, Mississippi, and Georgia, 1999–2001: Reston, Virginia, U.S. Geological Survey Circular 1233. 38 pp.

Yeager, M.M., D.S. Cherry, and R.J. Neves. 1994. Feeding and burrowing behaviors of juvenile rainbow mussels, *Villosa iris* (Bivalvia: Unionidae). Journal of the North American Benthological Society 13(2):217–222.

Zanatta, D.T. 2019. Personal communication on April 16, 2019 regarding status of Round Hickorynut populations in Michigan and Canada.

Zanatta, D.T. 2000. Biotic and abiotic factors relating to distribution of Unionid mussel species in Lake St. Clair. University of Guelph. Unpublished Master's Thesis. 131 pp.

Zanatta, D.T., G.L. Mackie, J.L. Metcalfe-Smith, and D.A. Woolnough. 2002. A refuge for native freshwater mussels (Bivalvia: Unionidae) from impacts of the exotic Zebra Mussel (*Dreissena polymorpha*) in Lake St. Clair. Journal of Great Lakes Research 28(3):479–

489.

Zanatta, D.T., and R.W. Murphy. 2006. Evolution of active host-attraction strategies in the freshwater mussel tribe Lampsilini (Bivalvia: Unionidae). Molecular Phylogenetics and Evolution 41 (1):195–208.

Zeto, M.A. 1982. Notes on the freshwater mussels (Unionidae) of the upper Monongahela River basin, West Virginia. The Nautilus 96(4):127-129.

Zeto, M.A., W.A. Tolin, and J.E. Schimidt. 1987. The freshwater mussels (Unionidae) of the upper Ohio River, Greenup and Belleville Pools, West Virginia. The Nautilus 101(4):182-185.

Zimmerman, L.L., R.J. Neves, and D.G. Smith. 2003. Control of predaceous flatworms *Macrostomum* sp. in culturing juvenile freshwater mussels. North American Journal of Aquaculture 65:28–32.

Zipper, C.E., B. Beaty, G.C. Johnson, J.W. Jones, J.L. Krstolic, B.J.K. Ostby, W.J. Wolfe, and P. Donovan. 2014. Freshwater mussel population status and habitat quality in the Clinch River, Virginia and Tennessee, USA: A featured collection. Journal of the American Water Resources Association 50(4):807–819.

APPENDIX A—SUMMARY OF EXTANT POPULATIONS AND THEIR ESTIMATED SIZE

Within this appendix, the authority of each record is presented, the year of the record, and the shell condition (i.e., live/fresh dead, relic). This information has been gathered from a large body of published and unpublished survey work rangewide since the 1800s, but predominantly since 1950. More current, unpublished distribution and status information has been obtained from biologists with State Heritage Programs, Department of Natural Resources programs, other state and federal agencies, non-governmental organizations, academia, and museums.

When referring to shell condition, fresh dead shells still have flesh attached to the shell, or at least retain a luster to their nacre, and may have a hinge intact and pliable, indicating relatively recent death. Relic shells may have been reported as either weathered or subfossil. Weathered dead or relic shells often have a loss of or peeling periostracum and faded or dull nacre (Ohio Mussel Survey Protocol 2018, p. 47). Fresh dead shells probably indicate the continued presence of the species at a site, while weathered relic shells only probably indicate that the population in question is extirpated (Butler 2007, p. 17). For all appendices the following abbreviations are used: QLTOT = qualitative total of all mussels all species, encountered live; QNTOT = quantitative total of all mussels, all species encountered live; QN = quantitative total of Round Hickorynut encountered live; QL = qualitative total of Round Hickorynut encountered live; TL = total length; RA = relative abundance of Round Hickorynut in survey; HE = hours effort; FD = fresh dead; D = dead; R = relic; L = live; CR = county road; RM = river mile; US = upstream; DS = downstream.

GREAT LAKES BASIN (CANADA)

Management Unit: Lake St. Clair
Province: Ontario

(Canada 1) Contiguous population: Lake St. Clair

Year of last live or fresh dead observation: 2016, Fisheries & Oceans Canada
Estimated occupied area: COSEWIC estimates range in St. Clair delta area to be 8 km^2.
Notes: Mitchell's Bay/Walpole Island, Bassett Island, Squirrel Island, Chematogan Bay Live since 2000; Comprises 0.011% of the overall mussel community, at a density of 0.0006/m2 (COSSARO 2013, p. 6). OSUM 14706, 14936, UMMZ 198040; Canada Mussel Database from 2003-2005: 36 L/1 FD @ ~ 7 sites; Zanatta et al. (2002), from 1999-2001 collected 53 L @ 3 of 95 sites; Formerly the largest population in Canada. May be functionally extirpated in Canada, no evidence of reproduction in last decade (Morris 2018, pers. comm.)

Management Unit: Syndenham
Province: Ontario

(Canada 2) Contiguous population: East Syndenham River

Year of last live or fresh dead observation: 2014, Fisheries & Oceans Canada
Estimated occupied length: Approx 50 km based on Fisheries & Oceans Canada 2013
Notes: Comprises 0.0024% of the overall mussel community (COSSARO 2013, p. 6); Significant decline in the East Syndenham, from 29 specimens to 1 between 1991–1999. (Metcalfe-Smith et al. 2003, p. 41). Accounted for 10% of mussel community at Dresden in 1973 (Metcalfe-Smith et al. 2003,

p. 42). Significant proportion of sites where species was found alive reduced from 73% from 1929-1991 to 8% 1997-1999 (Metcalfe-Smith et al. 2003, p. 43).

GREAT LAKES BASIN (USA)

Management Unit: St. Clair

(1) Contiguous population: Pine River

State: Michigan
County: St. Clair
Year of last live or fresh dead observation: 2002, Michigan Natural Features Inventory; Service 2019, unpublished data
Estimated occupied length: 6.5 km
Notes: New occurrences documented by Badra & Goforth 2003; From large streams on the lake plain (Strayer 1983, p. 261). 1 L/2 FD @ 3 of 4 sites; Only 2 live occurrences for the Pine River ever documented Badra and Goforth 2003. p. 35. Hoeh and Trdan 1985, p. 116 listed the species as Rare in the Pine River, and did not detect *O. subrotunda* in the Black or Belle rivers.

Management Unit: St. Clair

(2) Contiguous population: Belle River

State: Michigan
County: St. Clair
Year of last live or fresh dead observation: 2002, Michigan Natural Features Inventory; Service 2019, unpublished data
Estimated occupied length: 11 km
Notes: New occurrences documented by Badra & Goforth 2003; From large streams on the lake plain (Strayer 1983, p. 261). 1 L/2 FD @ 3 of 11 sites; Only 2 live occurrences for the Belle River ever documented Badra and Goforth 2003. p. 35. Mulcrone 2004, p. 132, reported 4 individuals at 1 site sampled in 1995. OSUM 45678, OSUM 20928, OSUM 13913, MCZ 194362, OSUM 24350; 1 collection by H. Athearn 4 i. above Marine City 1951. Likely the best remaining population in Michigan (D. Zanatta 2018, Central Michigan University, pers. comm.).

Management Unit: St. Clair

(3) Contiguous population: Black River

State: Michigan
County: St. Clair
Year of last live or fresh dead observation: 2011, Michigan Natural Features Inventory; Service 2019, unpublished data
Estimated occupied length: 21.5 km
Notes: Recent survey by MNFI documented the species in East St. Clair Co. only; 1 historic record from Salinac Co. From large streams on the lake plain (Strayer 1983, p. 261). 4 valves collected in 1930 (2 in UMMZ 106292), 1 individual observed in 2010 (MNFI database; Service 2019, unpublished data).

Management Unit: Grand

(4) Contiguous population: Grand River

State: Ohio
County: Trumbull, Ashtabula, Lake
Year of last live or fresh dead observation: 2002
Estimated occupied length: Approx. 150 km based on Huehner data from the 1990s

Notes: Huhener et al 2005 p. 61 indicates shifts in abundance of *O. subrotunda* specifically in the middle and lower sections. Collectively, the 3 surveys by Huehner covered RM 11.2–91.8; Qual. = 160 L @ 33 of 68 sites, 86 D @ 23 sites; HE = 183; QLTOT = 10,225; RA = 1.6% (9th of 27 spp. L). Quant. = 10 L @ 2 sites in ~86 one MSQ; MD = ~0.11; QNTOT = 1670; RA = 0.6%; This contiguous population includes the mouths of Rock Creek and Center Creek (1 live at mouth of Rock Creek, 1 subfossil at mouth of Center Creek (Grabarkiewicz 2014, p. 20, 26). 387 total museum records as of 2002; total present collected in river as of 2002 = 171 (Huehner et al 2005, p. 60). OSUM 59889, OSUM 59790, OSUM 12357, CM 61.9388, OSUM 59297, OSUM 44353, OSUM 59774, OSUM 21527, 21571, 21600, 21630(19), 22586, OSUM 20815, 60107, OSUM 20293(229), 60007, OSUM 12437, OSUM 7313, OSUM 46438, CM 61.9386, 61.9387; UMMZ 62366, OSUM 57905, OSUM 40140, 41275, OSUM 40070, OSUM 7327, UMMZ 150206, CM 61.9984, OSUM 56225, USNM 162004

Management Unit: Grand

(5) Contiguous population: Mill Creek

State: Ohio
County: Ashtabula
Year of last live or fresh dead observation: 2014, Grabarkiewicz, Michigan Department of Transportation
Estimated occupied length: Approx. 4 km based on Grabarkiewicz 2014, p. 10.
Notes: OSUM 21638 (1969); 37 collected Live at 4 of 14 sites in lowermost reaches of Mill Creek, one recent recruit documented by Grabarkiewicz 2014, p. 13; Grabarkiewicz 2014, p. 27: reproducing population in lower reach of Mill Creek.

Management Unit: Black-Rocky

(6) Contiguous population: Black River

State: Ohio
County: Lorain
Year of last live or fresh dead observation: 2005-2006, Lyons *et al.* 2007 p. 3
Estimated occupied length: Approx. 25 KM based on Lyons *et al.* 2007 p. 3
Notes: Confined to mainstem Black River in Lorain Co., OH; Tevesz et al. (2002) reported 3 valves excavated from archaeological sites; Lyons et al 2007, p. 11: 1 D @ 1 of 6 sites on mainstem

Management Unit: St. Joseph (Maumee)

(7) Contiguous population: Fish Creek

State: Ohio
County: Williams
Year of last live or fresh dead observation: 1996; 7 Dead collected from 3 sites by EnviroScience 2012, p. 7; listed as extant in Watters *et al.* 2009, p. 211
Estimated occupied length: 6.5 KM based on OSUM records; confined to Williams Co., OH, formerly occurred in Dekalb Co., IN.
Notes: Listed as uncommon in Fish Creek by Watters et al. 2009, p. 211. Hoggarth 2002, p. 11, cites a Clark 1977 collection of 1 individual in the vicinity of the CR 10 Bridge (Williams Co.). Watters (1998): ≥3 L/FD @ 3 of 7 sites, R @ 2 others; OSUM 31313, 31385; Watters (1988): 2 L/1 FD @ 2 of 9 sites, R @ 4 others, OSUM 65387(3), 65419(R), 65494(R), 65518(1); OSUM 29586, 29620, OSUM 372, 1216; UMMZ 173725; Clark 1977, p. 29, 1 spec. @ 1 of 5 sites; OSUM 46436

OHIO RIVER BASIN

Management Unit: Shenango

(8) Contiguous population: Shenango River
State: Pennsylvania
County: Mercer
Year of last live or fresh dead observation: 2010, PABFC database records; Service 2019, unpublished data
Estimated occupied length: Approx. 37 km
Notes: Nelson et al. (2010), p. 25, documented this species from a 37.2 km (23.1 mile) stretch of the Shenango River between the Pymatuning Reservoir and Shenango River Lake. Bursey (1987), p. 43 documented live individuals of this species from the same 37.2 km stretch (at Jamestown) and downstream of the Shenango River Lake dam at Sharpsville, total encountered at 2 of 6 sites. Bursey described the occurrence of Round Hickorynut in the Shenango River as "occasional." Nelson et al. (2010), p. 25, found two live Round Hickorynut in one 8.4 km (5.2 mile) section and five live Round Hickorynut in another, 6.2 km (3.9 mile) section of the 37.2 km portion of the river. Ortmann 1909, Ortmann 1919, Bursey 1987, p. 43, CM 61.3558, 61.3559, 61.4765, 61.4769

Management Unit: West Fork
(9) Contiguous population: West Fork River
State: West Virginia
County: Harrison
Year of last live or fresh dead observation: 2001, Ralph Taylor, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Less than 5 km
Notes: All contemporary collections limited to Harrison Co. in the upper portion of the drainage, Station WF 2: Below Hackers Creek at Rt 35 bridge; Ortmann (1913, 1919); CM 61.5430, 61.5951; Ortmann 1919 had collections from Lewis Co. (2 sites)

Management Unit: West Fork
(10) Contiguous population: Right Fork West Fork River
State: West Virginia
County: Lewis
Year of last live or fresh dead observation: 2002, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Less than 1 km
Notes: Walkersville covered bridge CR 19/17 - bridge replacement survey, 1 collection of 1 individual at 1 site

Management Unit: West Fork
(11) Contiguous population: Kincheloe Creek
State: West Virginia
County: Harrison/Lewis
Year of last live or fresh dead observation: 2010, EnviroScience, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 7 km
Notes: All collections limited to Harrison Co., some sites border Lewis Co. line, 5 L, 1 FD collected since 1995 at 3 sites.

Management Unit: West Fork
(12) Contiguous population: Hackers Creek
State: West Virginia

County: Harrison, Lewis
Year of last live or fresh dead observation: 2018, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 10 km
Notes: All collections limited to Harrison and Lewis Co.; 74 L/1 FD/ 30 R collected since 1993 at multiple sites; INHS 28129, Dying population, only 10 live collected since 2000

Management Unit: West Fork
(13) Contiguous population: Stonecoal Creek
State: West Virginia
County: Lewis
Year of last live or fresh dead observation: 2012, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Less than 1 km
Notes: All collections in Lewis Co., in vicinity of Gaston Sunset Drive @ Old Arch Bridge. 2 Live, 1 Relic collected in 2 surveys in 2012

Management Unit: West Fork
(14) Contiguous population: Jesse Run
State: West Virginia
County: Lewis
Year of last live or fresh dead observation: 1994, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Less than 1 km
Notes: No surveys since to confirm presence/absence, Station 10: Jesse Run, CR 8 .1 mi from Jct with CR 7; 1 WVDNR collection, in 1994 of 8 live individuals.

Management Unit: Little Muskingum - Middle Island
(15) Contiguous population: Middle Island Creek
State: West Virginia
County: Doddridge, Tyler, Pleasants
Year of last live or fresh dead observation: 2018, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 75 km
Notes: Doddridge Co.: OSUM 22893 (1969) 17 specs., MCZ 40404, OSUM 14393, UMMZ 51523 (1930); Tyler Co.: MUMC 1912 (1980), OSUM 22850, 22885(40) (1969), ESI 2014, p. 21 (age 3); Pleasants Co.: OSUM 22863 (1969) OSUM 61776(R), 61819(1), 61880(3), 61886(1), 61985(R), 62019(1), 62031(11), 62085(4), 62099(3), 62229(R), OSUM 51774, OSUM 45737, OSUM 39709, OSUM 6676, OSUM 46546; Numerous contemporary (1990-present) collections from all 3 counties (WVDNR database, Service 2019, unpublished data). Various collection methods (snorkel, scuba, hand picking, bank searches). A long-term monitoring site was established by WVDNR below Falls Mills in 2012. This population has been used as source for broodstock associated with restoration (translocation) efforts to re-establish the species in the Ohio River. Multiple year classes found during excavations at long-term monitoring site. 2012 Density estimate at 1.4/m2 with population size estimated at 3500 individuals in 100m stream reach. 2017 density estimated at 1/m2 with population estimate of 2500 individuals in 100m stream reach.

Management Unit: Little Muskingum - Middle Island
(16) Contiguous population: Meathouse Fork
State: West Virginia

County: Doddridge
Year of last live or fresh dead observation: 2018, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 20 km
Notes: Stream is located entirely within Doddridge Co., 180 Live individuals collected from this stream since 2000; from 1997-1999 160 L @ 5 of 6 sites; 126 L @ RM 84.27. From Clayton (2018, pers. comm.) 49 surveys have been conducted on Meathouse Fork since 1995. At least 10 of these have been directly related to gas pipeline crossing. Various collection methods (snorkel, scuba, hand picking, bank searches)

Management Unit: Little Muskingum - Middle Island
(17) Contiguous population: McElroy Creek
State: West Virginia
County: Tyler, Doddridge
Year of last live or fresh dead observation: 2017, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 25 km
Notes: All collections from Center Point WV to Alma WV; 44 L/ 2 FD/ 4 R reported from stream since 2010; 5 of 7 surveys in this stream related to pipeline crossings indicating significant resource extraction in the watershed.

Management Unit: Little Muskingum - Middle Island
(18) Contiguous population: Buckeye Creek
State: West Virginia
County: Doddridge
Year of last live or fresh dead observation: 2017, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 5 km
Notes: All collections from the lower 5 KM of stream, in vicinity of Smithburg; stream is located entirely within Doddridge Co., runs adjacent to WV CR 50/32; 16 Live/3 FD/3 R observed since 1999 from 4 sites.

Management Unit: Little Muskingum - Middle Island
(19) Contiguous population: Ohio River (Willow Island Pool)
State: West Virginia/Ohio
County: Pleasants (WV)/Washington (OH)
Year of last live or fresh dead observation: 2008, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 1 km
Notes: 1 live individual reported at the mouth of Reas Run, ORM 151 right bank. 1969-1999 (Subfossil) ESI 2000; Taylor 1980, p. 40, lists Ortmann pre 1920 collections; MCZ 240041 (Sterki record); MCZ 240041, MCZ 240042, ESI (2000), OSUM 63928, OSUM 53427, OSUM 6463, CM 61.4766, 61.4767, 61.5434, CM 61.10788, 61.10790, OSUM 19249, CM 46988

Management Unit: Walhonding
(20) Contiguous population: Killbuck Creek
State: Ohio
County: Coshocton
Year of last live or fresh dead observation: 2012, Ahlstedt 2012, p. 4
Estimated occupied length: Approx. 8 km

Notes: Ahlstedt 2012 has only live collection in vicinity of SR 60 bridge crossing; relic collected downstream from Helmick Covered Bridge. Ahlstedt is only collector that has reported *O. subrotunda* from Killbuck Creek and his collections are limited to Coshocton Co., only 2 individuals ever reported; only one known live collection of *O. subrotunda* in Killbuck Creek, despite intensive collections associated with Purple Catspaw.

Management Unit: Walhonding

(21) Contiguous population: Walhonding River

State: Ohio
County: Coshocton
Year of last live or fresh dead observation: 2013, Hoggarth 2014
Estimated occupied length: Approx. 25 km
Notes: From Hoggarth 1995-1996, p. 159: found sporadically from river mile 22.2 to river mile 0.0. From Hoggarth 1995-1996, p. 159: It was never common, with one living specimen located at each of five sites, and two living specimens located at one site. This species comprised of 0.24% of the total unionid fauna collected from the river. From Hoggarth 2014, p. 16. 18 Live collected US and DS of Lake Park in 2013. Hoggarth (1995–96): 7 L @ 6 of 19 sites, 13 R @ 4 others; QLTOT = 7997; RA = 0.1% (tied for 23rd of 31 spp. L); 2 dead collected by Enviroscience in 2009 below Six Mile Dam Coshocton Co. OSUM 67019, 67393, 67402, OSUM 60633, 60829, 60837(1), 60936, OSUM 60706, OSUM 65005, OSUM 50564, OSUM 42094, OSUM 34488, OSUM 40713, OSUM 26186, 26431, OSUM 21512, OSUM 18801, OSUM 18053, 18080, 20012, 20066, 20309, OSUM 12886, 14515, OSUM 11065, 11302, 11436, OSUM 6140, 6212, OSUM 11017, OSUM 4117, 4131, 4172, OSUM 46191, OSUM 75400.

Management Unit: Walhonding

(22) Contiguous population: Mill Creek

State: Ohio
County: Coshocton
Year of last live or fresh dead observation: 2008, Ahlstedt 2009
Estimated occupied length: Approx. 5 km
Notes: 8 L/41 FD/25 R @ 2 sites; HE = 6; Length 33–60 mm; OSUM 84914. Only one known collection, Ahlstedt sampled this stream to look for potential Purple Catspaw habitat because Killbuck Creek nearby was too high to sample.

Management Unit: Muskingum

(23) Contiguous population: Muskingum River

State: Ohio
County: Muskingum, Morgan, Washington
Year of last live or fresh dead observation: 2013, Eco-Tech
Estimated occupied length: Approx. 8 km
Notes: 2 live collected by Eco-Tech at the AEP Dresden Plant (upstream Beverly Dam RM 90 2013. Only 1 WD shell collected below Malta Dam (Beverly Pool) 2007 (ESI 2010, p. 103). Large collections since 1990 in Muskingum appear to be limited to older non-reproducing individuals, all specimens in 1992 were old individuals, and there was no indication that this species is reproducing in the study area (Watters and Dunn 1993-94, p. 253). Listed as rare in the Muskingum River by Watters et al 2009, p. 211. ESI 1996, p. 8 report 65 live from 1970-1995. Largest live collection is from Watters and Dunn 1993-1994 who collected 48 L/FD @ 5 of 6 beds in 240 ¼ M^2; TOT = 11,145 (1875 L); RA = 0.43% (11th of 40 spp.). However, more recent surveys detected the species at only 1 site from Zanesville to the OH River, indicating a significant range reduction. OSUM 45063, OSUM 36677, OSUM 55983, OSUM 47474, 47623, 47643, 47759, 47875, 47926, 48259, 48700, 48753, 48923, 48944, 48966, 49245, 49254,

49341, OSUM 44118, 45107, 45282, 45589, OSUM 37582, OSUM 62888, OSUM 24128, OSUM 14735, OSUM 6361, 6391, OSUM 5602, OSUM 4011, INHS 27706, OSUM 48272(3), 49406(R), 49518(R), 49537(5), 49615(R), 49714(10), 49992(5), 50016(R), 50146(R), 50153(1), 50162(1), OSUM 40087, 40294, 41205, 47974, OSUM 42497, OSUM 23616, 23623, 23863(17), OSUM 17041, OSUM 8811, OSUM 46445, OSUM 44007, OSUM 43952, OSUM 10218, OSUM 67861, MUMC 4223, OSUM 1505, OSUM 52971, OSUM 50389, 50610, 51016, 51398, 51487, 51683, 51756, 51848, 51879, 51950, 51981, 51993, 52013, 52035, 52082, 52088, OSUM 47576, 49494, 49503, 50406, 50848, 50865, 50885, 51068, 51124, 51302, 51374, OSUM 44030, 44042, 44545, MCZ 293607, OSUM 40287, 40470, 40881, 41075, 41192, 43340, 45609, OSUM 34673, 35673, 35693, 36864, OSUM 26865, 26985, 41690, OSUM 25748, OSUM 22802(10), 23406, 23559(12), OSUM 20389, NCSMNS 33530; OSUM 17336, 18672, OSUM 16478, UMMZ 247876, MCZ 261089, 268040; OSUM 14878, 23097(14), OSUM 10620, 10771, 12286, 13025(13), OSUM 7206, 7188, 11036, 11086, OSUM 5915, 6273(15), 6320, 6332, 6375, 6451, 6456, 6643, 6733, OSUM 5198, 5220(18), OSUM 14373(27), 46583, OSUM 46428, OSUM 46884, OSUM 44249(13), 44287, 45898(20), 46946(18), OSUM 5165, OSUM 23844, 43933(10), 45919, UMMZ 255278, OSUM 47241, 47242, 47243(11)

Management Unit: Muskingum

(24) Contiguous population: Wakatomika Creek

State: Ohio
County: Muskingum
Year of last live or fresh dead observation: 2009, Ahlstedt 2009, p. 6
Estimated occupied length: Approx. 8 km based on Ahlstedt 2009 and OSUM collection records
Notes: Only 4 individuals reported from creek off Narrows Road just upstream from Rt. 60 bridge crossing, Cass Township, Muskingum Co., OH; only one known contemporary collection of 1 female 33 mm TL. OSUM 40415 (1 specimen), OSUM 46455 (2 specimens)

Management Unit: Raccoon - Symmes

(25) Contiguous population: Symmes Creek

State: Ohio
County: Lawrence
Year of last live or fresh dead observation: 2005, Hoggarth et al. 2007, p. 59
Estimated occupied length: Approx. 45 km
Notes: Appears restricted to Lawrence Co. (middle and lower reaches, Hoggarth et al, 2007) (11th of 40 spp.), only 1 collection from Gallia Co., in 1987, OSUM 59318. Surveys in 1987 and 2004-05; reported 4 live, 8 total L/D individuals reported from the stream. No collections of live individuals in Symmes Creek prior to 2004 (Hoggarth et al 2007, p. 59). Only 2 live individuals recorded, which were from middle and lower reaches of the Creek (p. 60). OSUM 59318, OSUM 59280, OSUM 61770, OSUM 61221, 61487, OSUM 46769.

Management Unit: Little Kanawaha

(26) Contiguous population: West Fork Little Kanawha River

State: West Virginia
County: Kanawha, Calhoun
Year of last live or fresh dead observation: 2003, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 45 km
Notes: Only 2 collections of the species from this stream, at 2 sites. 4 live individuals collected from 1 site in Calhoun Co. in 2003. Both collections limited to Calhoun Co. Collections widely separated, over 45 KM length.

Management Unit: Little Kanawaha

(27) Contiguous population: Little Kanawha River

State: West Virginia
County: Braxton, Gilmer, Calhoun, Wirt
Year of last live or fresh dead observation: 2017, EnviroScience; WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 190 km
Notes: Not found by Schmidt et at. 1983 in brail survey before 1st riffle at Site 29 RM 14.4 backwater from Ohio River (impoundment effects). Population is extensive but relatively small in terms of density. Only 53 Live collected over 200 KM of river since 2000 despite significant survey efforts in the river by WVDNR and others. Various collection methods (snorkel, scuba, hand picking, bank searches). No collections of the species above Burnsville Lake. Schmidt et al. (1983): ≥4 L @ 4 of 6 sites; RA = top 4 of 27 spp. Braxton Co.: OSUM 49835(2), Ortmann (1919), CM 61.5432; Gilmer Co.: MUMC 3338; Calhoun Co.: OSUM 75397, MUMC 3357, 3371, 3380; Ortmann (1919), CM 61.2050; ANSP 66577 (< 1895).

Management Unit: Little Kanawaha

(28) Contiguous population: Hughes River

State: West Virginia
County: Wirt
Year of last live or fresh dead observation: 2018, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 8 km
Notes: 2 live observed by WVDNR in 2018, one collection at one site. MUMC 3144, OSUM 14540, 14618 (1930).

Management Unit: Little Kanawaha

(29) Contiguous population: North Fork Hughes River

State: West Virginia
County: Ritchie
Year of last live or fresh dead observation: 2018, EnviroScience; WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 40 km, although most collections are concentrated below North Bend Dam
Notes: Collections limited to Ritchie County. Ortmann 1912 Carnegie record from Wirt Co., is likely Hughes River proper since NF Hughes does not flow through Wirt. 71 Collected live since 2000 at multiple sites; INHS 28459(7); OSUM 31562(2), 31576(R), 31583(1), 31594(R); Schmidt et al. (1983) ≥5 L @ 5 of 5 sites; OSUM 53364, 53373, 53380, 53385, 53418; MUMC 3154, 3166, 3812; OSUM 41583; OSUM 50092; CM 61.5950 (1912). Various collection methods (bank searches, snorkel, scuba).

Management Unit: Little Kanawaha

(30) Contiguous population: Fink Creek

State: West Virginia
County: Lewis, Gilmer
Year of last live or fresh dead observation: 2015, ESI; WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 10 km
Notes: Occupied reach is from mouth of Elk Lick to confluence with Leading Creek. 4 Live collected by ESI 2015, p. 13; 2 live individuals collected from 1 site in 2005 near Vadis, WV.

Management Unit: Little Kanawaha

(31) Contiguous population: Leading Creek

State: West Virginia
County: Gilmer
Year of last live or fresh dead observation: 2017, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 1 km
Notes: Collections limited to Gilmer County. 36 total reported from stream; 8 Live individuals collected from 4 sites since 2015; 3 of 5 sites sampled have been associated with pipeline construction activities. Schmidt et al. 1983 p. 136, sampled 1 site where the species was collected.

Management Unit: Little Kanawaha

(32) Contiguous population: Reedy Creek

State: West Virginia
County: Wirt
Year of last live or fresh dead observation: 2001, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 1 km
Notes: OSUM 12974; Only 1 live collection, 1 weathered dead collection, 1 historic museum record from OSUM (1961).

Management Unit: Little Kanawaha

(33) Contiguous population: Spring Creek

State: West Virginia
County: Wirt
Year of last live or fresh dead observation: 2015, EnviroScience; WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 1 km
Notes: OSUM 53464; Only recent live collection was associated with a pipeline construction project. Schmidt et al. 1983 p. 136, sampled 1 site where the species was collected.

Management Unit: Little Kanawaha

(34) Contiguous population: Middle Fork South Fork Hughes River

State: West Virginia
County: Ritchie
Year of last live or fresh dead observation: 2018, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 1 km
Notes: Only 1 collection of 3 live and 1 weathered dead individual collected approximately 100m US of mouth, collected in a pipeline crossing survey

Management Unit: Little Kanawaha

(35) Contiguous population: South Fork Hughes River

State: West Virginia
County: Ritchie/Wirt
Year of last live or fresh dead observation: 2018, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 70 km

Notes: All collections from Ritchie Co., OSUM 75402; OSUM 53392, 53408; MUMC 3187; 109L, 2FD in 2018

Management Unit: Upper Ohio - Shade

(36) Contiguous population: Middle Branch Shade River

State: Ohio
County: Meigs
Year of last live or fresh dead observation: 1987 (Watters 1992b)
Estimated occupied length: Approx. 5 km based on OSUM data
Notes: no recent data but listed as extant in Watters et al. 2009; Shade River and Middle Fork Salt Creek populations have not been assessed since the 1980s (Grabarkiewicz, 2014, p. 8). All records limited to Meigs Co.; 4 L/1 R @ 1 of 3 sites; QLTOT = 88; RA = 4.5% (3rd of 8 spp. L); OSUM 59351; Rare in several small southern Ohio streams (Watters et al 2009, p. 211).

Management Unit: Upper Ohio - Shade

(37) Contiguous population: East Branch Shade River

State: Ohio
County: Meigs
Year of last live or fresh dead observation: 1987 (Watters 1992b)
Estimated occupied length: Approx. 5 km based on OSUM data
Notes: no recent data but listed as extant in Watters et al. 2009; Shade River and Middle Fork Salt Creek populations have not been assessed since the 1980s (Grabarkiewicz, 2014, p. 8). OSUM 59204, OSUM 396, Rare in several small southern Ohio streams (Watters et al 2009, p. 211).

Management Unit: Upper Ohio - Shade

(38) Contiguous population: Ohio River (Belleville Pool)

State: West Virginia/Ohio
County: Wood/Washington
Year of last live or fresh dead observation: 2017, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Less than 5 km (concentrated around Neal & Muskingum Island)
Notes: 2 Live reported by WVDNR since 2000; singular individuals are located sporadically throughout the Belleville pool, not a result of stocking, typically very large old males. 43 individuals stocked in 2013 (WVDNR database 2017; Service 2019, unpublished data). 14 live reported from Belleville Pool, 1969-1999 (ESI 2000); Zeto et al. 1987 reported 5 individuals from Belleville Pool at 2 sites.

Management Unit: Upper Kanawha

(39) Contiguous population: Kanawha River

State: West Virginia
County: Fayette, Kanawha (upstream of Charleston, WV)
Year of last live or fresh dead observation: 2018, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 75 km
Notes: Although the species has been collected sporadically downstream in the Marmet, London, and Winfield pools of the Kanawha River since 2000, the best remaining mussel habitat is the 5 mi unimpounded reach between London Pool and Kanawha Falls upstream. Lewis 2014 found 18 live from RM 70.5-71.1 right bank Aged 3-6 years. Taylor 1983, p. 62, reported 274 L @ 9 of 14 sites; QLTOT = 2991; RA = 9.1% (3rd of 27 spp. L), he also reported 2 specimens of *O. subrotunda* as being collected above the falls (p. 54), but these may not be valid records since it was never collected above falls before

or since. Fayette Co.: MUMC 3429, 3439, 3456, 3478, 3507, 3527, 3532, 3597, 3620 (16 D at 6 sites), OSUM 52229, MUMC 1800; OSUM 45893(33), 48388(R), OSUM 44434, 44788, 45630, OSUM 38837, MUMC 1565, OSUM 26887, 26899, MCZ 272851, OSUM 25588, 27008(31), 43717(43), MCZ 267320, 267765, 267772; OSUM 22537, 22662(64), 22697, 23022(100), 26061, 26105(36), 43585. Winfield Pool 892 L (approximately 14 sites, 42 records) 2000 to 2018.

Management Unit: Lower Kanawha

(40) Contiguous population: Kanawha River

State: West Virginia
County: Kanawha, Putnam (downstream of Charleston, WV)
Year of last live or fresh dead observation: 2018, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 50 km
Notes: Stansbery (1972): one valve at the Buffalo Archaeological Site, RA = 0.2% (tied for last of 28 spp.); indicates the species may never have been abundant in the lower Kanawha River. 1 collected live by AEP in 2012, 21 individuals collected in 2018 by WVDNR, AllStar Ecology, TRC, Snavely, and Envrionmental Solutions and Innovations.

Management Unit: Elk River

(41) Contiguous population: Elk River

State: West Virginia
County: Braxton, Clay, Kanawha
Year of last live or fresh dead observation: 2018, Dinkins Biological, Environmental Solutions, WVDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 125 km
Notes: No recruitment documented for any species of mussels in the Sutton area of the Elk River since 2004. In 2015 at Queen Shoals WVDNR found 2 of 1631 juvenile individuals were *O. subrotunda* (Janet Clayton, 2018, pers. Comm.). ESI (2009) report 12 L @ 212 Sites; QLTOT = 4175; Clayton (1994) ≥6 L @ 6 of 22 sites, D @ 7 others; Taylor & Hughart (1981) ≥5 L/FD @ 5 of 15 sites; Braxton Co.: OSUM 45029, OSUM 24706, 27950(61), 45004, 44982, UMMZ 64068, Ortmann (1913, 1919); CM 61.5433, 61.5435; UMMZ 62364; Clay Co.: Dinkins and Ahlstedt (2007) 4 L @ 2 of 2 beds; QLTOT = 661; HE = 12.8; RA = 0.6%, 1 L @ 2 beds in 60 ¼ MSQ; MD = 0.02; QNTOT = 93; POP = 128, MUMC 4055, OSUM 47730; MUMC 1632, OSUM 43888(44), 44555(12), 44655(42), 44935, 45019, OSUM 7911; OSUM 6414, 6426, 6519, Ortmann (1913, 1919); CM 61.5436, 61.5437; Kanawha Co.: ESI (1993, p. 6 QN TOT = 11), INHS 28102(1), OSUM 47602, 47741, OSUM 44383(12), 44626, OSUM 23035, 23231, MCZ 288855; Dinkins et al. 2017: 14 Live QN + QL.

Management Unit: Upper Scioto River

(42) Contiguous population: Big Darby Creek

State: Ohio
County: Franklin, Pickaway
Year of last live or fresh dead observation: 2000, OSUM 69514
Estimated occupied length: Approx. 60 km
Notes: From Watters 1990, p. 29: This is a very uncommon species, limited to lower Big Darby Creek, from the confluence of Little Darby Creek to its mouth. Its range has been greatly reduced since 1986, and is absent for several miles below the mouth of Hellbranch Run. No evidence was found of recruitment since 1986. Uncommon in Big Darby Creek (Watters et al 2009, p. 211); OSUM 6863, OSUM 68080, OSUM 67710, OSUM 47907, OSUM 39660, OSUM 63518, OSUM 27212, OSUM 14764, OSUM 8251, OSUM 5524, OSUM 8042, 129, OSUM 7753, OSUM 3553, OSUM 3192, OSUM 69514, 69865, OSUM 31514, OSUM 1428, OSUM 67954, OSUM 1410(R), 53443(R), 67943(1), OSUM

43248, OSUM 41383, OSUM 76058, OSUM 32923, OSUM 25964(17), 23967, 25731, OSUM 24948, MCZ 268221, OSUM 14079, UMMZ 234242, USNM 1017769, OSUM 12342, 12571, 12788, OSUM 7802, 8407(14), 9177, OSUM 5874(57), 6018(42), 6098, 6920(69), 7441(46), 7518(76), 8500(85), OSUM 4453, 4615, 4864, 4889, 5398, 6902, OSUM 8151, 8755, 8848, 16909, OSUM 7939, 7959, 8090, 8112, 8183, 8285, 8351, 8379, OSUM 3590, 3603, 3662, 3677, 7737, 7776, 27891, 27917 OSUM 3466, 3563, 7828, 7840, 27904, OSUM 7814, 8048, ANSP 165989, FMNH 187858

Management Unit: Upper Scioto River
(43) Contiguous population: Walnut Creek
State: Ohio
County: Fairfield
Year of last live or fresh dead observation: 2013(a); Swecker and Garofolo
Estimated occupied length: Approx. 25 km, From St. Hwy 256 near Thurston downstream to Hwy 33 near Carroll (Documented from only 1 site in Fairfield Co., OSUM records from 1994 are a considerable distance downstream in Pickaway Co.).
Notes: Current status of Pickaway Co. unknown; negative data from 1 site in ESI 2013; Only 1 weathered shell reported from Franklin Co.; OSUM 61850; NO records for Fairfield Co. depicted in Watters et al 2009, p. 210 or in OSUM records database; 24 live collected by ESI 2013; OSUM 32391, 32413, 56025, 56058, 56102, 56330, 56935

Management Unit: Upper Scioto River
(44) Contiguous population: Big Walnut Creek
State: Ohio
County: Fairfield
Year of last live or fresh dead observation: 2013(a); Swecker and Garofolo
Estimated occupied length: Approx. 25 km, From St. Hwy 256 near Thurston downstream to Hwy 33 near Carroll (Documented from only 1 site in Fairfield Co., OSUM records from 1994 are a considerable distance downstream in Pickaway Co.).
Notes: Current status of Pickaway Co. unknown; negative data from 1 site in ESI 2013; Only 1 weathered shell reported from Franklin Co.; OSUM 61850; NO records for Fairfield Co. depicted in Watters et al 2009, p. 210 or in OSUM records database; 24 live collected by ESI 2013; OSUM 32391, 32413, 56025, 56058, 56102, 56330, 56935

Management Unit: Lower Scioto
(45) Contiguous population: Middle Fork Salt Creek
State: Ohio
County: Vinton (Ross Co. listed in OSUM but this stream does not flow through that Co.)
Year of last live or fresh dead observation: 1987 (Watters 1992b)
Estimated occupied length: Approx. 5 km
Notes: No recent records, but listed as extant but uncommon by Watters et al. 2009, p. 211; Shade River and Middle Fork Salt Creek populations have not been assessed since the 1980s (Grabarkiewicz, 2014, p. 8); 42 FD/5 R @ 1 of 3 sites; 4 L/138 FD/35 R @ Site 70; QLTOT = 45; RA = 8.9% (3rd of 7 spp. L); OSUM 59483 (6), OSUM 65303 (82)

Management Unit: Lower Scioto
(46) Contiguous population: Scioto River
State: Ohio
County: Ross
Year of last live or fresh dead observation: 2014, Stantec
Estimated occupied length: Approx. 30 km

Notes: Formerly occurred in Pickaway, Pike, Scioto Co.; Watters et al. 2009: historically throughout the Scioto River. OSUM 67221, OSUM 47822, OSUM 8587, Bogan (1990); OSUM 50133, OSUM 46781, OSUM 64039, UMMZ 107532, UMMZ 106278, INHS 22837, USNM 514979, USNM 30000, USNM 85742, OSUM 5000, 38139, 38140, 58580, 68602, FLMNH 66325; USNM 58283, 85738; UMMZ 23, 33

Management Unit: Licking

(47) Contiguous population: Licking River

State: Kentucky
County: Bath/Fleming, Nicholas/Rowan, Robertson, Pendleton
Year of last live or fresh dead observation: 2016, KYFW database records; Service 2019, unpublished data
Estimated occupied length: Approx. 150 km
Notes: No longer occurs in Campbell/Kenton, Morgan Co.; Occasional and localized; uncommon (Haag and Cicerello 2016, p. 179). Listed as occasional in the Licking River by Laudermilk 1993, p. 49. Considered to be most dense in the middle Licking (A. Sheperd 2017, KYFW, pers. comm.). MFM 22922, MCZ 289447, MCZ 278724, MFM 12743, USNM 853679, Laudermilk (1993), EKU 893, 896, 913, 915, 916, 921, 922, 923, 924, 925, 926, 929, 932, 933, 939, 950, 972, EKU 25, OSUM 54691, EKU 341, OSUM 34301, EKU 98(10), 173, OSUM 20099, OSUM 10834, Ortmann (1913, 1919), Schuster (1988, p. 668-683), EKU 88, 190, EKU 874, OSUM 32870, OSUM 12904, OSUM 8429, 16457

Management Unit: Middle Fork Kentucky

(48) Contiguous population: Middle Fork Kentucky River

State: Kentucky
County: Leslie
Year of last live or fresh dead observation: Haag and Cicerello 2016 depict record since 1990 in Leslie Co. (p. 178), likely based on R. Cicerello collection in 1996.
Estimated occupied length: Approx. 10 km
Notes: No longer occurs in Breathitt, Lee Co.; limited to Leslie Co.; uncommon in the upper Kentucky River system (Haag and Cicerello 2016, p. 179). Listed as Occasional throughout the KY River Basin in 1922 (Danglade 1922, p. 5). EKU 69, Schuster (1988, p. 668-683).

Management Unit: South Fork Kentucky

(49) Contiguous population: South Fork Kentucky River

State: Kentucky
County: Clay, Owsley
Year of last live or fresh dead observation: 2015, KYSNPC database records; Service 2019, unpublished data
Estimated occupied length: Approx. 30 km
Notes: Uncommon in the upper Kentucky River system (Haag and Cicerello 2016, p. 179). Limited to Clay and Owsley Co., Evans 2010, p. 45; 5 total reported Live by Evans, 2010, p. 24; 4 other relic records; Schuster (1988, p. 668-683), EKU 27, 45, EKU 51, 65, 398, EKU 44, 50, 586, MCZ 220874

Management Unit: South Fork Kentucky

(50) Contiguous population: Red Bird River

State: Kentucky
County: Clay
Year of last live or fresh dead observation: 2009, Evans 2010, p. 24
Estimated occupied length: Approx. 25 km

Notes: Uncommon in the upper Kentucky River system (Haag and Cicerello 2016, p. 179). Limited to Clay Co., Evans 2010, p. 45; 2 Live reported by Evans 2010, p. 24; 2 other relic records; Schuster (1988, p. 668-683); EKU 647, INHS 5664, EKU 64, EKU 63, MCZ 210958

Management Unit: Upper Kentucky

(51) Contiguous population: Red River

State: Kentucky
County: Menifee/Powell
Year of last live or fresh dead observation: 2003, KYFW database records; Service 2019, unpublished data
Estimated occupied length: Approx. 8 km
Notes: Uncommon in the upper Kentucky River system (Haag and Cicerello 2016, p. 179). Limited to Menifee and Powell Co., Recent collections by KYFW in vicinity of mouth of Edwards Branch; considered very rare or rare; Schuster (1988, p. 668-683); OSUM 33199, EKU 4, EKU 3, 6, UMMZ 234354, 247844, OSUM 18035.
Management Unit: Upper Kentucky

(52) Contiguous population: Kentucky River

State: Kentucky
County: Estill
Year of last live or fresh dead observation: 2009, KYSNPC database records; Service 2019, unpublished data
Estimated occupied length: Approx. 20 km
Notes: No longer occurs in Lee Co.; uncommon in the upper Kentucky River system (Haag and Cicerello 2016, p. 179). Limited to Estill Co., Only 1 collection in KYFW and KYSNPC database since 2000, not depicted in Haag and Cicerello 2016, p. 179; Schuster (1988, p. 668-683); ANSP 20254, 334287, ANSP 20255aB, 20255aC; MCZ 5066.

Management Unit: Tippecanoe

(53) Contiguous population: Tippecanoe River

State: Indiana
County: Marshall, Fulton, Pulaski, Starke, potentially White
Year of last live or fresh dead observation: 2018, INDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 100 km
Notes: No longer extant in Kosciusko Co. (1 museum record), Carroll & Tippecanoe Co. - considered extirpated by ESI 2003 (p. 20); restricted to area upstream of Lake Shafer and Lake Freeman (B. Fisher INDNR 2019, pers. comm.); 42 Live/FD collected from multiple sites over a 4 county area since 2000 (INDNR database), juveniles encountered regularly (B. Fisher INDNR, 2019 pers. comm.). Kosciusko Co.: FMNH 281953 (1995); Marshall Co.: ESI 1995, p. 10; Fulton Co.: Cummings and Berlocher 1990 (p. 85), INHS 3473, 3543, 4064, 4083 (15 specimens); Pulaski Co.: INHS 28997, ESI (1993a, p. 28), OSUM 57057 R, Cummings and Berlocher 1990 (p. 85), INHS 3700, 4178, 4331, INHS 2186, UMMZ 246834; White Co.: ESI (2003, p. 9; 1993, p. 28), INHS 3897, USNM 676932, UMMZ 105731; Carroll Co.: ESI 1993a, p. 28, OSUM 56483, INHS 6600, Cummings and Berlocher 1990 (p. 85), INHS 3854; Tippecanoe Co.: ESI (1993a, p. 28), OSUM 56289, 56381

Management Unit: Eel (Wabash)

(54) Contiguous population: Eel River

State: Indiana
County: Cass

Year of last live or fresh dead observation: 2007, INDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 10 km
Notes: No longer occurs in Clay, Miami, Wabash Co.; Collections since 2000 limited to Cass Co., found in lowest section of river. Population is precarious at best, likely not reproducing anymore (B. Fisher INDNR, 2018 pers. comm.). Fisher 2006, p. 107: Many mussel species now restricted to the tributaries of the Wabash River have been gone from the mainstem for a long time, many of these species are now rare in the tributaries and most have incurred a substantial reduction in their historic distribution; OSUM 83198 (2)(1969), UMMZ 106224 (~1900)

Management Unit: Lower White
(55) Contiguous population: Richland Creek
State: Indiana
County: Greene
Year of last live or fresh dead observation: 2013, INDNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 25 km
Notes: All collections since 2000 in vicinity of Bloomfield and Tulip in Greene Co.; 14 Live, 5 FD collected from 3 sites since 2000, population was first discovered in 2001 and is likely still reproducing due to the presence of live and fresh dead specimens in the system over the last 15 years (B. Fisher INDNR 2019, pers. comm.).

Management Unit: Upper Green
(56) Contiguous population: Green River
State: Kentucky
County: Hart, Edmonson, Butler/Warren
Year of last live or fresh dead observation: 2012, Lewis Environmental Consulting; 2015 relic KYSNPC
Estimated occupied length: Approx. 100 km
Notes: No longer occurs in Green Co.; Locally Common in Green River (Haag and Cicerello 2016, p. 179); Cicerello (1999) reported 43 L @ 17 of 37 sites; OSUM 49871, OSUM 33282, MCZ 268211, EKU 396, OSUM 44911, OSUM 17503, OSUM 16540, 16598, Stansbery (1965). OSUM 12712, 13477, OSUM 11830, OSUM 6590, OSUM 6299, 5340, MCZ 103872, USNM 63162, MCZ 52896; UMMZ 32916, 106228, MCZ 70144, OSUM 27197, OSUM 5251, UMMZ 45101, USNM 677535, MCZ 5065, Gordon & Sherman (1995); INHS 13835(1), 15639(R), 15968(R), Cochran & Layzer (1993), INHS 14991, INHS 12869(1), 12922(5), 12957(1), 15729(R), 15748(5), 15766(9), 15786(3), 15804(7), 15857(9), OSUM 55952(2), 75407(R), OSUM 50981, EKU 35, OSUM 44617, OSUM 44279, OSUM 38550, 39186, MCZ 272818, OSUM 33776, OSUM 26844, 27171, OSUM 25511, 44101, OSUM 21708, 44410, Clench & van der Schalie (1944), MCZ 58400(13); UMMZ 44735(33), 66909(17), USNM 677667, FMNH 66376, Morey & Crothers (1998)

Management Unit: Barren
(57) Contiguous population: Barren River
State: Kentucky
County: Warren
Year of last live or fresh dead observation: 2002, KYFW database records; Service 2019, unpublished data
Estimated occupied length: Approx. 10 km

Notes: Limited to Warren Co.; locally common (Haag and Cicerello 2016, p. 179); INHS 17799, Gordon & Sherman (1995, p. 20), Cochran & Layzer (1993), INHS 13580(R), 13607(1), 13624, Weiss (1993), INHS 12824, MCZ 193271

CUMBERLAND RIVER BASIN

Management Unit: Upper Cumberland - Lake Cumberland

(58) Contiguous population: Buck Creek

State: Kentucky
County: Pulaski
Year of last live or fresh dead observation: 2007, KYFW database records; Service 2019, unpublished data
Estimated occupied length: Approx. 40 km
Notes: No longer occurs in Lincoln Co.; reported as very rare, rare, and uncommon by KYFW; Shepard 2006, p. 4 reports five males and one female; Hagman 2000, p. 22-23 reports live individuals at one site, with weathered specimens sporadically distributed throughout stream, and live individuals were rare; fresh dead specimens at 2 sites; rarely if ever found in lower mainstem (Schuster et al 1989, p. 80). EKU 869, 871(13), EKU 865, 866, EKU 39, EKU 117, EKU 125, 128, 132, 208, EKU 112, 114, 115, 129, 130(31), 443, EKU 32(R); OSUM 47989(1), 49414(R), OSUM 37723, 37733, 38062, OSUM 55216, OSUM 27018, EKU 119; Schuster 1988, p. 669-673.

Management Unit: Rockcastle

(59) Contiguous population: Rockcastle River

State: Kentucky
County: Laurel/Pulaski
Year of last live or fresh dead observation: 2004, KYFW database records; Service 2019, unpublished data
Estimated occupied length: Approx. 20 km
Notes: Large rapids potentially limit species distribution - possibly related with host fish movement (Haag and Cicerello 2016, p. 50.); multiple surveys in this stream since 1980 have failed to detect the species, 1 recent (Ahlstedt et al. 2014); small population (Haag and Cicerello, 2016, p. 179); infrequently observed (Houp and Smathers 1995, p. 115); EKU 794, Neel & Allen (1964), UMMZ 172878; Schuster 1988, p. 671.

TENNESSEE RIVER BASIN

Management Unit: Wheeler Lake

(60) Contiguous population: Paint Rock River

State: Alabama
County: Jackson, Madison/Marshall
Year of last live or fresh dead observation: 2013, ADCNR database records; Service 2019, unpublished data
Estimated occupied length: Approx. 70 KM according to Fobian et al 2014, 253.
Notes: 2013 collections yielded 2 L @ 4 sites in 320 ¼ MSQ; MD = 0.03; POP = 200; QNTOT = 372; RA = 0.5%; (T. Fobian, ADCNR, 2017, pers. comm.); Fobian et al 2014: FD @ 4 of 41 sites, R @ 4 more; QLTOT = 1798+; RA < 1%; Ahlstedt 1995-1996 p. 72 found only 9 live individuals at 3 of 18 sites from PRRM 13.3 to 60.0 (1 % of community composition). Ahlstedt 1991, p. 155 reported 6 live at 5 of 25 sites from RM 24.5 to 60.0; Isom and Yokley 1973, p. 445, reported the species from 4 of 6 sites. McGregor & Shelton (1995); INHS 16485(1), 16496(5), Barr et al. (1993–94), Ahlstedt (1991a),

NCMNS 30251(1), 6774, INHS 16466, 16568; OSUM 38982, 40113, OSUM 38302, Isom & Yokley (1973); MCZ 274945; OSUM 38203, 38228, OSUM 18714(82), 20627, OSUM 38513, 38528, FMNH 299050, UMMZ 106273, UMMZ 62368, 62369, Ortmann (1925), Ortmann (1919), UMMZ 106274, CM 61.6960, 61.6961, 61.6962, 61.6963, FMNH 269797; MCZ 100148(13), FMNH 4126, UMMZ 68837, FMNH 90121, OSUM 33091, UMMZ 106267, UMMZ 4441

Management Unit: Lower Tennessee - Beech

(61) Contiguous population: Tennessee River

State: Tennessee
County: Hardin
Year of last live or fresh dead observation: 2019, TWRA (C. Lewis collector)
Estimated occupied length: Approx. 1 KM
Notes: 1 L @ ~ 22 sites in 3 reaches in 166+ h total dive time, below Wolf Island near TRM 191.0 (D. Hubbs, TWRA, 2019, pers. comm.). UT McClung has 2 lots of the speices from the vicinity of Camden, TN, a total of 13 valves (UTMM 9633, 223)

Management Unit: Upper Elk

(62) Contiguous population: Elk River (TN)

State: Tennessee
County: Lincoln
Year of last live or fresh dead observation: 2015, TVA heritage database records; Service 2019, unpublished data
Estimated occupied length: Approx. 25 km
Notes: No longer considered extant in Moore/Franklin, Giles Co.; collected live just upstream of I-65 bridge (RM 49) in 2015 TVA quantitative surveys (1 individual at 1 of 5 sites surveyed), weathered dead at RM 75.7 in 2009; only 1 live specimen recorded in 2015, UTMM 4629 (6 valves) from below Harms Mill, Ahlstedt et al 2005 reported relic only from 5 sites, Hubbs 1991 reported relic at 1 site upstream of Harms Mill, Ahlstedt (1983, 1991) reported 5 L @ 4

Management Unit: Upper Duck

(63) Contiguous population: Duck River

State: Tennessee
County: Bedford, Marshall, Maury
Year of last live or fresh dead observation: 2015, TWRA (2016, p. 34).
Estimated occupied length: Approx. 95 km
Notes: Limited to reach between Milltown and Columbia (D. Hubbs TWRA, 2019, pers. comm.) 3 mill dams interrupt distribution; only one collection of the species from Coffee Co., by Isom and Yokley 1968, p. 40 (OSUM 33096). Likely no longer occurs in Coffee Co.; overall density has increased in the Duck River over the past 30 y. In 1979 density was 0.05 mussels/m2. In 1988 none were collected in quadrat samples, but one individual was found in snorkel surveys (Jenkinson, 1988). Density increased to 0.31 mussels/m2 in 2002 (Ahlstedt et al., 2004), and in 2010, density was 0.89 mussels/m2 (Ehlo and Layzer 2014 p. 171); in 2015 was 3.66% of total catch across 3 of 5 sites surveyed (54 total; TWRA 2016, p. 34). OSUM 33096, OSUM 33865, 33888, MFM 21683, MFM 19817, MCZ 274840, OSUM 19682, OSUM 21608, OSUM 33104, 33119(10), 33179, MFM 11843, OSUM 15063, CM 61.11452(10), UMMZ 62365, MCZ 5073, NCMNS 35388(2), 38388(2), 40907(R), NCMNS 46470, INHS 27401, NCMNS 27052(1), 27097(1), 27127(R), NCSMNS 6146, INHS 13980, INHS 15363, ANSP 366818, OSUM 52502(2), INHS 14367, INHS 14513, 16760, NCMNS 6837, OSUM 38365, 39579, NCMNS 30503, 30544; OSUM 34880, OSUM 33333, OSUM 33913(29), 33950, 33971, ANSP 314029; MFM 15425; OSUM 12062, 12229(94), 14849, 15135(51), MFM 6922, MCZ 210930, MFM 4323, FMNH 120078, UMMZ 58344(45), MCZ 98536(29), INHS 22833; UMMZ 52735(34), 52736; ANSP 157142, CM 61.11629,

61.11630, 61.11631, UMMZ 246929, FMNH 66365, 66367; MCZ 93768(12), NCMNS 41077, 29301, 27073, OSUM 30526, MCZ 272784; OSUM 14492, 34031, 34064, 34147, UMMZ 128871, UMMZ 52767(18), 52768, CM 61.11453(3), 61.11223(8), 61.11451, 61.11633(2), 61.11634(4); UMMZ 62371, USNM 514950, INHS 22831, CM 61.13183, INHS 22832, ANSP 163045, INHS 8379, USNM 150457 L, UMMZ 106295, MFM 1323, 1836.

Management Unit: Buffalo

(64) Contiguous population: Buffalo River

State: Tennessee
County: Wayne, Perry
Year of last live or fresh dead observation: 2014, UT McClung Museum (Reed 2014, p. 28)
Estimated occupied length: Approx. 5 km according to Reed 2014 (p. 29)
Notes: Reed, 2014, p. 49 considered the species "possibly extirpated" from the Buffalo River, despite collecting a fresh dead individual. Formerly distributed from over 60 River Miles of the Buffalo River (Reed 2014, p. 9). Reported from 4 sites by van der Schalie 1973, 3 live at 3 of 3 sites; 1 site by Isom and Yokley 1968; CM 61.11454; OSUM 34240; UMMZ 52845; UMMZ 246927; ANSP 157153; MCZ 93776(11), 93778(14); UMMZ 52853, 52858, 52819(47), 52820(54); UMMZ 246928; FLMNH 66374

LOWER MISSISSIPPI RIVER BASIN

Management Unit: Upper Big Black

(65) Contiguous population: Big Black River

State: Mississippi
County: Montgomery
Year of last live or fresh dead observation: 2010, MMNS database records; Service 2019, unpublished data
Estimated occupied length: Approx. 10 km
Notes: No longer occurs in Hinds Co.; all live collections limited to Montgomery Co. where it is locally common but restricted to a small reach of the river; 40 individuals collected since 2000 but all from 2 sites (R. Jones, MSMNS, 2018, pers. comm.); last remaining population in the MS river drainage, severely fragmented from other populations. Hartfield & Rummel (1985); MMNS 1659, 1751, 1763; OSUM 52170; MMNS 1654(1), 1792(4R); OSUM 52167(R); Peacock & James (2002), p. 123 RA = 11.4% (3rd among identifiable valves); from Hartfield and Rummel 1985, p. 119: the richest section of the Big Black River in terms of unionid diversity is in the Loess Hills physiographic region, roughly that stretch of river flowing between Highway 61 and Highway 49; however, there are no *O. subrotunda* collections from that reach of the Big Black River.

APPENDIX B—FORMER CONTIGUOUS POPULATIONS AND MANAGEMENT UNITS, NOW CONSIDERED EXTIRPATED, ACROSS THE ROUND HICKORYNUT RANGE

GREAT LAKES BASIN (US)= 33; OHIO RIVER BASIN = 160; CUMBERLAND RIVER BASIN = 25; TENNESSEE RIVER BASIN = 29; MISSISSIPPI RIVER BASIN = 8; TOTAL US EXTIRPATED = 255

**Shaded rows indicate those management areas still containing extant Round Hickorynut populations.*

Management Unit	**Record State/Province**	**Former Contiguous Population**	**Source**
Great Lakes (Canada)			
Lake Erie	Ontario	Lake Erie	COSEWIC Database records; Service 2019, unpublished data
Syndenham	Ontario	North Sydenham River	Mackie and Topping 1988
	Ontario	Hardy Creek	Metcalfe-Smith *et al*. 2003
Grand	Ontario	Grand River	Mackie 1996, p. 13
Thames	Ontario	Thames River	COSEWIC Database records; May be extirpated from the Thames River watershed (Cudmore et al 2004, p. 14); Service 2019, unpublished data
Detroit	Ontario	Detroit River	Schloesser et al 1998
Great Lakes (US)			
Niagra	NY / Canada	Niagra River (Erie/Niagra Co. NY/Ont)	FMNH 269803; This specimen may represent *Obovaria olivaria* (Maury 1917, p. 30)
Chatauqua-Conneaut	NY	Lake Erie (Chautauqua/Erie Co.)	Strayer et al. 1991, p. 70; Letson 1905, p. 84
Clinton	MI	Clinton River, Macomb Co.	UMMZ 255028; Strayer 1980 p. 147: apparently extinct in the Clinton, having been restricted to the lower mainstem. UMMZ 56851, 106232
	MI	North Branch Clinton River, Macomb Co.	OSUM 21453
Huron	MI	Huron River, Monroe/Wayne Co.	UMMZ 106233; van der Schalie 1938, p. 29, UMMZ 60037
Ottowa - Stony	MI	Lake Erie, Monroe Co.	MCZ 193272, NCSMNS 40631, OSUM 52732, USNM 809541, Kovalak et al. (1986), OSUM 25402, CM 61.4770, 61.7827, FMNH 299048; UMMZ 106259(12), 106261, 106262(19), 106265, 164109, MCZ 193273, UMMZ 45009, UMMZ 106258, OSUM 51712, CM 61.5698, UMMZ 22763, USNM 168970, USNM 84425 (L), OSUM 10219, FLMNH 66320; INHS 22834; MCZ 193276, 193278; UMMZ 163067; USNM 25297, 123187. Shells were "most

Management Unit	Record State/Province	Former Contiguous Population	Source
			common" in Michigan on the beaches of the S part of the county in 1930, according to Goodrich. There are 27 valves from this area in the USNM. (MNFI database; Service 2019, unpublished data).
Detroit	MI	River Rouge, Wayne Co.	INHS 1554, CM 61.9289, MCZ 14953, USNM 512301, 515009, INHS 22836, USNM 29997
	MI	Middle River Rouge, Wayne Co.	UMMZ 56962
	MI / Canada	Detroit River, Wayne Co.	Badra 2009; Schloesser et al. 1998 (3 L/5 D @ 5 of 15 Sites); Freitag (1984) p. 105 (2 L/1 D @ ≤3 of 13 sites), OSUM 53212, UMMZ 106253, 106257, 106260, UMMZ 7666
Lake St. Clair	MI	Lake St. Clair (west bank - Wayne, Macomb Co.)	MNFI database (Badra); Service 2019, unpublished data; Only recent collection is 3 individuals by Badra; NCSMNS 28131, UMMZ 106264, Goodrich (1932), Goodrich & van der Schalie (1932), UMMZ 51859, INHS 22835; Wayne Co.: UMMZ 106263, UMMZ 4266
Raisin	MI	River Raisin (Lenawee, Monroe Co.)	OSUM 53001; UMMZ 42156, OSUM 53001, UMMZ 106231 (8 specimens), UMMZ 51957, UMMZ 164023
Cedar - Portage	OH	Lake Erie, Lucas Co.	OSUM 46134; CM 61.11510; Clark & Wilson (1913): "Common" at put-in, Bay Island, Maumee Bay
	OH	Lake Erie, Ottowa Co.	OSUM 57482; OSUM 58269, OSUM 60050, FMNH 282700, FMNH 282119, OSUM 44321, 45991, OSUM 41170, 46038, 49017, OSUM 33409, OSUM 56075, OSUM 22326, 22441, 26214, 26286, 26294, 26303, OSUM 24513, 28375, OSUM 17763, 19568, 19622, 19652, 19659, 27666, OSUM 35500, 15830, 17133, 17160, 27612, 27759, USNM 853645, OSUM 14171, OSUM 27699, 27645, 27716, OSUM 15288, OSUM 4742, 4709, 6994, 7161, OSUM 3966, 3953, 3929, 9685, OSUM 3794,OSUM 3036, 3074, OSUM 1589, 1608, OSUM 658, 1142, 1283, 1346, OSUM 86, UMMZ 246925, OSUM 2067, CM 69960, Brown et al. (1938), UMMZ 128774, OSUM 28185, CM 61.13231, UMMZ 106256, UMMZ 56523, OSUM 6830, 10691, 25236, 45937, CM 61.11557, UMMZ 7665, MCZ 193275, FMNH 269801, OSUM 59901
Sandusky	OH	Lake Erie, Sandusky Co.	Simpson 1914
	OH	Lake Erie, Erie Co.	OSUM 5055, 7401; OSUM 5055, 7401, OSUM 2063, UMMZ 106254, CM 61.9415, CM 61.4764, CM 61.10802, USNM 159949

Management Unit	Record State/Province	Former Contiguous Population	Source
	OH	Sandusky River (Wyandot, Seneca, Sandusky Co.)	OSUM 61558; OSUM 61558, OSUM 9917, OSUM 46233, UMMZ 106285, OSUM 62427, OSUM 28433, Kirsch (1894), OSUM 39390, OSUM 38597
	OH	Wolf Creek, Sandusky Co.	OSUM 62466
Cuyahoga	OH	Lake Erie, Cuyahoga Co.	OSUM 57590; OSUM 2062, OSUM 2060, 2064, 2065, 2066, USNM 25889, USNM 25889 (the exact Co. is unknown for these collections and assumed to be Cuyahoga Co.)
	OH	Cuyahoga River (Cuyahoga/Summit Co.)	Tevesz et al 2002; MCZ 5063; Murphy 1971, p. 23, reports 5 shells from 2 arch sites on the W side of the river
St. Joseph	OH	St. Joseph River (Williams Co.)	Watters 1998; OSUM 62281, 62337, Clark (1977), OSUM 7350, 10912, UMMZ 169204, 169226, UMMZ 163953, UMMZ 163914; Watters 1988, p. 12 indicated that when found it was fairly common and occurred in firm sand in good current.
	IN	St. Joseph River (Defiance, Dekalb, Allen Co.)	Fisher 2006; OSUM 11856, OSUM 46596 (17), OSUM 22286, OSUM 11655, 11720, OSUM 9886, OSUM 9537, 10994, UMMZ 150829, OSUM 7538, 10886
	OH	East Branch St. Joseph River, Williams Co.	Watters 1988; OSUM 65540, OSUM 29819,UMMZ 156379; Clark 1977; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	West Branch St. Joseph River, Williams Co.	Clark (1977); UMMZ 163961, MCZ 149455; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	IN	St. Joseph River Feeder Canal, Allen Co.	Clark & Wilson 1913, 7 L/FD @ 2 of 3 sites (E & FF); 11 L in 1 one MSQ; QNTOT = 81
	IN	Cedar Creek, Allen Co.	Watters 1988; OSUM 83360 (1 WD)
	IN	Metcalf Ditch, Dekalb Co.	Clark 1977, p. 29 (trib. In Dekalb Co. N of Newville)
Upper Maumee	OH	Maumee River (Paulding, Defiance Co.)	Clarke & Wilson 1912, 30 @ 9 of 15 sites; CM 61.10800; From Grabarkiewicz and Crail 2006, p. 35: Subfossil and weathered valves indicate that this species was once more common. Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	IN	Maumee River (Allen Co.)	Watters 1988; OSUM 24050 (1934); Clark & Wilson (1912) ~25 L @ 8 of 9 sites

Management Unit	Record State/Province	Former Contiguous Population	Source
Auglaize	OH	Auglaize River, Defiance Co.	OSUM 68357; Clark & Wilson (1912): 7 L/FD @ 2 of 3 sites (E & FF), 11 L in 1 one MSQ; QNTOT = 81; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Ottowa River, Allen Co.	OSUM 66827, 67009; Kirsch (1894); Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
Blanchard	OH	Blanchard River, Hancock Co.	Hoggarth 2012; USNM 132660; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
Huron-Vermilion	OH	Vermilion River, Lorain Co.	OSUM 3350, 3381; Considered extirpated by Krebs 2010, p. 512; CM 61.10801; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
Saint Marys	IN	St. Marys River, Allen Co.	Clark & Wilson 1912; Call (1896, 1897, 1900) <1895
Ohio			
Conewango	NY	Conewango Creek (Chautauqua Co.)	Strayer et al. 1991, p. 67
Middle Allegheny - Redbank	PA	Allegheny River (Armstrong Co.)	Ortmann 1919, p. 223-229; CM 61.9174, Ortmann 1913, p. 292, CMNH 61.4116
	PA	Crooked Creek (Indiana, Armstrong Co.)	Ortmann 1919 p. 223-229; CM 61.3269, 61.4115, 61.3028, Ortmann 1909a, p. 13, Ortmann 1913, p. 298-299, CM 61.2940; "Fully preserved mussel fauna", Ortmann 1913, p. 298.
Lower Allegheny	PA	Allegheny River (Allegheny, Westmoreland Co)	Ortmann (1919 p. 223-229, 1913), CM 61.4116, Ortmann 1913, p. 292, CM 61.4116, 61.9174, Ortmann (1909a) described seeing many dead shells of the Round Hickorynut in the Allegheny County portion of the Ohio River.
Lower Monongahela	PA	Monongahela River (Fayette, Washington, Westmoreland, Allegheny Co.)	ANSP 126395; Ortmann 1919, p. 223-229; Ortmann 1913, p. 292, CM 61.2840, USNM 152084; ANSP 126395, CM 61.2841, 79745
Shenango	PA	Little Shenango River, Mercer Co.	Considered extirpated (Welte 2012, p. 3).
		Pymatuning Creek, Mercer Co.	Ortmann 1919, p. 223-229; Ortmann 1909a, CM 61.3557
Mahoning	PA	Mahoning River (Lawrence Co.)	CM 61.2166; Ortmann 1919, p. 223-229; Ortmann 1909a, CM 61.2166
	OH	Mahoning River (Mahoning Co.)	USNM 514940, No collector information, 8 individuals in lot; not illustrated in Watters et al 2009; UMMZ 106279, UMMZ 107530, USNM

Management Unit	Record State/Province	Former Contiguous Population	Source
			894520(11), USNM 514970; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	West Branch Mahoning River (Portage, Trumbull Co.)	Swart 1940 reported 93 L @ 3 of 9 sites; QLTOT = 246; RA = 38% (1st of 5 spp. ID L); Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
Beaver	PA	Beaver River (Lawrence, Beaver Co.)	Ortmann 1919, p. 223-229, 6 individuals from 4 localities; Rhoads 1899, p. 136; CM61.2842, 76092, UMMZ 105726, 106269 (14), FLMNH 66375, NCMNS 56282, USNM 152075, MCZ 69832, 192473
Upper Monongahela	WV	Buffalo Creek, Marion Co.	Zeto 1982; WVDNR data; "Abundant in the upper Monongahela", Ortmann 1919, p. 228
Little Kanawha	WV	Steer Creek (Calhoun Co.)	Schmidt et al. 1983; OSUM 53501
	WV	Left Fork Steer Creek (Gilmer Co.)	WVDNR database, 1 collection of 1 WD individual; Service 2019, unpublished data
	WV	Left Fork Reedy Creek (Roane Co.)	WVDNR database, EnviroScience, 1 collection of 1 WD individual; Service 2019, unpublished data
	WV	Bonds Creek, Ritchie Co.	Schmidt et al. 1983
	WV	Spruce Creek, Ritchie Co.	Schmidt et al. 1983
	WV	Cedar Creek, Gilmer Co.	Schmidt et al. 1983
	WV	Sand Fork, Gilmer Co.	(WVDNR database) Athearn record; Service 2019, unpublished data
Elk	WV	Big Sandy Creek, Kanawha Co.	(WVDNR database) Athearn record, 2 individuals collected as weathered dead; Service 2019, unpublished data
Coal	WV	Coal River (Kanawha, Lincoln Co.)	OSUM 22972, 23005 (Taylor 1983a)
	WV	Big Coal River (Boone, Kanawha Co.)	MUMC 1529
	WV	Little Coal River (Boone, Kanawha/Lincoln Co.)	WVDNR database (WVDEP collection); CM 70766 (44 individuals), UMMZ 130190 (22 individuals); Service 2019, unpublished data
Lower Kanawha	WV	Pocatalico River (Kanawha, Putnam Co.)	MUMC 1595, 1601 (Taylor 1983a)
	WV	Dick Branch (Kanawha Co.)	OSUM 23030
Lower Guyandotte	WV	Mud River, Cabell Co.	Schmidt and Zeto 1986, OSUM 55866
Twelvepole	WV	Twelvepole Creek, Wayne Co.	WDVNR 309; Taylor (1983); MUMC 1831, 1834, 1836, 1854, 1858(101), 1864, 1869, 1875,

Management Unit	**Record State/Province**	**Former Contiguous Population**	**Source**
			1881, 1884, 1885, 1892, 1897, 1901, 1948 (1980)
	WV	West Fork Twelvepole Creek, Wayne Co.	MUMC 1984, 1992, 1995, 1999, 2004
	WV	Beech Fork Twelvepole Creek, Wayne Co.	MUMC 33
Big Sandy	WV	Big Sandy River, Wayne Co.	Tolin and Schettig 1984
	KY	Big Sandy River (Boyd/Lawrence Co.)	Tolin and Schettig 1984; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
	KY	Blaine Creek, Lawrence Co.	Tolin and Schettig 1984; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
Upper Ohio	OH	Middle Fork Little Beaver Creek, Columbiana Co.	UMMZ 249394; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
Little Muskingum - Middle Island	WV	Ohio River (Hannibal Pool) Marshall, Wetzel, Tyler, Pleasants Co. WV	ESI 2000, extant in Willow Island Pool
	OH	Ohio River (Hannibal Pool) Monroe, Washington Co., OH,	ESI 2000, extant in Willow Island Pool
	OH	Little Muskingum River, Washington Co.	OSUM 62229; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210; OSUM 61776(R), 61819(1), 61880(3), 61886(1), 61985(R), 62019(1), 62031(11), 62085(4), 62099(3), 62229(R); OSUM 51774, OSUM 45737, OSUM 39709, OSUM 6676, OSUM 46546
	OH	Duck Creek, Washington Co.	OSUM 46569, 46616(10), 46638; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
Tuscawaras	OH	Tuscarawas River (Stark, Tuscarawas, Coshocton Co.)	OSUM 65614; Sterki, 1894, p. 10 stated that the species was common in the river. OSUM 63223, OSUM 65614, OSUM 46199, CM 61.10794, 61.10798, CM 61.10797, CM 61.10796, UMMZ 63015(32), CM 61.10795, MCZ 114475(33), 169960; USNM 126925, 515013, 515014, OSUM 11193, CM 61.10793, FMNH 66234, UMMZ 62976(38), UMMZ 105717, Ortmann (1919), ANSP 61922, MCZ 103850, 169970
	OH	Sandy Creek (Carroll, Tuscarawas Co.)	OSUM 61522, 61382
	OH	Sugar Creek, Tuscarawas Co.	CM 61.10799; 1 specimen
Mohican	OH	Mohican River (Knox, Coshocton Co.)	OSUM 19151; OSUM 10938, 11048, OSUM 44217, MCZ 263150, OSUM 22746, OSUM 19335, OSUM 17871, 17971, OSUM 13012,

Management Unit	**Record State/Province**	**Former Contiguous Population**	**Source**
			OSUM 11105, OSUM 11130; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Lake Fork Mohican River, Holmes Co.	OSUM 66725; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
Muskingum	OH	Meigs Creek, Morgon Co.	OSUM 62170; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Olive Green Creek, Washington Co.	OSUM 46488; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Wolf Creek, Washington Co.	OSUM 8650; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
Hocking	OH	Federal Creek (Athens Co.)	Watters 1992b; OSUM Cat. No. 65396; 1 L/1 FD @ 1 of 3 sites; QLTOT = 108; RA = 0.9% (T 10th of 11 spp. L)
	OH	Hocking River (Hocking, Athens Co.)	Watters 1992b; 7 total individuals reported from Hocking River (1980-1997); OSUM 46737, OSUM 59164, OSUM 46745, OSUM 59183, 59274, OSUM 46737
Upper Ohio	PA	Ohio River (Dashields Pool, Elmsworth Pool, Montgomery Pool) Allegheny, Beaver Co.	Ortmann 1919 (CM 61.1798, CM 61.1598); One living specimen, taken August 1, 1906, was the last living unionid found in the Ohio in Allegheny County (Welte 2012, p. 5.)
	WV	Ohio River (New Cumberland Pool, Pike Island Pool, Hannibal Pool) Hancock Co. WV	INHS 22838; Considered extirpated from the Upper Ohio River (Taylor and Spurlock 1982, p. 5; There are various museum specimens of *O. subrotunda* that lack specific locality data from the Ohio River, where it was formerly considered common. These include: FLMNH 229419, MCZ 5062, USNM 25851, UMMZ 105707, UMMZ 106289, ANSP 20205, ANSP 20205, INHS 1708; FMNH 66322, 66327; UMMZ 26, 58739
	OH	Ohio River (New Cumberland Pool, Pike Island Pool, Hannibal Pool) Jefferson Co. OH	INHS 22838; Considered extirpated from the Upper Ohio River (Taylor and Spurlock 1982, p. 5; There are various museum specimens of *O. subrotunda* that lack specific locality data from the Ohio River, where it was formerly considered common. These include: FLMNH 229419, MCZ 5062, USNM 25851, UMMZ 105707, UMMZ 106289, ANSP 20205, ANSP 20205, INHS 1708; UFMNH 66322, 66327; UMMZ 26, 58739
Upper Ohio - Shade	WV	Ohio River (upper Gallapolis = Byrd Pool, Racine Pool) Wood, Jackson, Mason Co.	ESI 2000; OSUM 63928, Zeto et al. (1987); OSUM 53427, OSUM 6463, CM 61.4766,

Management Unit	**Record State/Province**	**Former Contiguous Population**	**Source**
	OH	Ohio River (upper Gallapolis = Byrd Pool, Racine Pool) Washington, Meigs, Gallia Co.	61.4767, 61.5434, CM 61.10788, 61.10790, OSUM 19249, CM 46988; There are various museum specimens of *O. subrotunda* that lack specific locality data from the Ohio River, where it was formerly considered common. These include: FLMNH 229419, MCZ 5062, USNM 25851, UMMZ 105707, UMMZ 106289, ANSP 20205, ANSP 20205, INHS 1708; UFMNH 66322, 66327; UMMZ 26, 58739
	WV	Ohio River Racine Pool Jackson Co.	Ortmann (1919); CM 61.4768, 61.5439; > 6 specimens; There are various museum specimens of *O. subrotunda* that lack specific locality data from the Ohio River, where it was formerly considered common. These include: FMNH 229419, MCZ 5062, USNM 25851, UMMZ 105707, UMMZ 106289, ANSP 20205, ANSP 20205, INHS 1708; FMNH 66322, 66327; UMMZ 26, 58739
	OH	Ohio River Racine Pool Meigs Co.	
Raccooon-Symmes	OH	Raccoon Creek (Meigs/Vinton, Gallia Co.)	UMMZ 70151
	WV	Ohio River (lower Gallapolis Pool, upper Greenup Pool) Gallia Co., OH; Mason Co., WV	ESI 2000, 2 individuals (Greenup Pool); There are various museum specimens of *O. subrotunda* that lack specific locality data from the Ohio River, where it was formerly considered common. These include: FLMNH 229419, MCZ 5062, USNM 25851, UMMZ 105707, UMMZ 106289, ANSP 20205, ANSP 20205, INHS 1708; FMNH 66322, 66327; UMMZ 26, 58739
Little Scioto - Tygarts	OH	Pine Creek (Lawrence/Scioto Co.)	Watters 1988, 1 FD @ 1 of 10 sites; QLTOT = 477; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Little Scioto River, Scioto Co.	OSUM 60094, 65129, Watters 1988: 12 L/3 FD/2 R @ 2 of 10 sites; QLTOT = 912; RA = 1.3%; OSUM 60094, 65129; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Rocky Fork Little Scioto River, Scioto Co.	OSUM 59371, Watters 1988: 1 L/1 R @ 1 of 5 sites; QLTOT = 323, OSUM 59371; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Ohio River (upper Meldahl Pool, lower Greenup Pool) Scioto Co.	OSUM 30191; Schuster (1988, p. 669), OSUM 46353, OSUM 213; There are various museum specimens of *O. subrotunda* that lack specific locality data from the Ohio River, where it was formerly considered common. These include: FLMNH 229419, MCZ 5062, USNM 25851, UMMZ 105707, UMMZ 106289, ANSP 20205, ANSP 20205, INHS 1708; FMNH 66322, 66327; UMMZ 26, 58739
	KY	Ohio River (upper Meldahl Pool, lower Greenup Pool) Greenup/Lewis Co.	

Management Unit	Record State/Province	Former Contiguous Population	Source
Upper Scioto	OH	Whetstone Creek, Delaware Co.	OSUM 5364; Stein 1963, p.109 reported 2 specs. @ 1 site, OSUM 46813, MCZ 5064; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Olentangy River (Delaware, Franklin Co.)	OSUM 58029; Stein 1963, p.109 reported 26 L @ 6 of 19 sites; QLTOT = 3387; RA = 0.8% (19th of 29 spp. L). OSUM 5808, OSUM 4530, 4645, OSUM 16856, UMMZ 168737, UMMZ 105708, USNM 512300, OSUM 58572, OSUM 58029, OSUM 30496, OSUM 5837, OSUM 4930, 4957, OSUM 4281, 4333, 13526, 13570, 16959, OSUM 4347, OSUM 4365, OSUM 10216, MCZ 193281, USNM 514964, USNM 514980. Formerly large population see Stein 1963 p. 106-109. Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Alum Creek (Delaware, Franklin Co.)	OSUM 59097; OSUM 31394, OSUM 63620, OSUM 26137, 26149, 26460, 27148, OSUM 60856, OSUM 22926, 22935, 23167(47), 62415(68), OSUM 20326, OSUM 17649, 17852, 21371, MCZ 260995; OSUM 13730, 13850, OSUM 5816, 5963, 6002, 7450, OSUM 4563, OSUM 9672, OSUM 7470, 9228, 9238, CM 67–54, MCZ 249304, OSUM 62290, OSUM 23133, 62360, OSUM 16900, OSUM 7463. Dramatic decline and extirpation (OSUM records), 304 individuals were found fresh dead in 1959 in Alum Creek. Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Blacklick Creek, Franklin Co.	OSUM 31669, 31702; OSUM 14156, OSUM 4519, 12412(12), OSUM 3870, OSUM 7112; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Scioto River (Delaware, Franklin, Pickaway)	OSUM 67221, 67289, 67240, 67343, 67362, OSUM 65259, OSUM 10215, 35677, OSUM 67123, 67289, 67240, 67343, 67362, OSUM 61339, 61966, OSUM 57031, 58892, OSUM 56517, OSUM 31872(5), OSUM 1898, OSUM 5705, 6173, OSUM 5656, 7276, 7377, 13158, OSUM 13324, 13374, OSUM 13351; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
Paint	OH	Paint Creek, Ross Co.	OSUM 21023; OSUM 20979, OSUM 22814, OSUM 10217; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
Lower Scioto	OH	Deer Creek, Fayette Co.	OSUM 5693; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Salt Creek, Ross Co.	OSUM 65084; OSUM 47016, OSUM 36503, 36577, 36762, 36892, OSUM 22755, OSUM

Management Unit	**Record State/Province**	**Former Contiguous Population**	**Source**
			14255, OSUM 11544, OSUM 8578, OSUM 7090, UMMZ 60885; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Little Salt Creek, Jackson Co.	OSUM 65534; OSUM 36882, OSUM 11990, 12676; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Buckeye Creek, Jackson Co.	Watters et al 2009; Scioto River trib., Illustrated on p. 210, Not reported live or fresh dead since 1980; Watters et al. 2009
Ohio Brush - Whiteoak	OH	Ohio Brush Creek, Adams Co.	OSUM 10432; OSUM 46364; Not reported live or fresh dead since 1996; Brown 2010, p. 41
	OH	White Oak Creek, Brown Co.	OSUM 59432, 11 specimens from 1930 collection; Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Ohio River (lower Meldahl Pool, upper Markland Pool) Brown Co.	OSUM 18937; Also Schuster 1988. There are various museum specimens of O. subrotunda that lack specific locality data from the Ohio River, where it was formerly considered common. These include: FMNH 229419, MCZ 5062, USNM 25851, UMMZ 105707, UMMZ 106289, ANSP 20205, ANSP 20205, INHS 1708; UFMNH 66322, 66327; UMMZ 26, 58739
	KY	Ohio River (lower Meldahl Pool, upper Markland Pool) Bracken Co.	OSUM 18937; Also Schuster 1988. There are various museum specimens of O. subrotunda that lack specific locality data from the Ohio River, where it was formerly considered common. These include: FMNH 229419, MCZ 5062, USNM 25851, UMMZ 105707, UMMZ 106289, ANSP 20205, ANSP 20205, INHS 1708; FMNH 66322, 66327; UMMZ 26, 58739
Lower Great Miami	OH	Little Miami River, Warren Co.	Swecker and Garafolo 2013b; OSUM 60198, 60219, OSUM 65759, OSUM 11564; UMMZ 106280; FMNH 229421, MCZ 193279; Hoggarth (1992), p. 259: 4 R; 1 Subfossil Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210
	OH	Great Miami River, Hamilton Co.	Museum of Comparative Zoology (No Catalog Number); 24 valves, locality info. Just states "at Miami" Isaac Lea collection.
	OH	Stillwater River, Montgomery Co.	OSUM 63825; only 1 record of the species (weathered, 1 valve) from this stream, in 1980. Not reported live or fresh dead since 1980; Watters et al. 2009 p. 210

Management Unit	Record State/Province	Former Contiguous Population	Source
Big Sandy	KY	Blaine Creek, Lawrence Co.	Bay and Winford 1984, Tolin and Schettig 1984, Preimpoundment records of mussels collected prior to construction of Yatesville Dam. 1, 900 individuals collected from 32 of 49 sites by Bay and Winford 1984, p. 19. This survey indicates that prior to construction of Yatesville Dam, that O. subrotunda was abundant in Blaine Creek, comprising 8 % of the mussel fauna above Fallsburg, KY, second most abundant of seven species collected (Tolin and Schettig 1984, p. 35). A large population existed in Blaine Creek, Lawrence Co., but this population appears extirpated by construction of Yatesville Dam in 1992 (Haag and Cicerello 2016, p. 179).
Lower Levisa	KY	Levisa Fork (Pike, Floyd, Johnson, Lawrence Co.)	USNM 677731; OSUM 10724; Ortmann (1913, 1919); UMMZ 134812; MUMC 3644; Tolin & Schettig (1984, p. 5), MUMC 3833. Not reported live or fresh dead since 1990, appears extirpated from Levisa Fork (Haag and Cicerello, 2016, p. 179).
Little Sandy	KY	Little Sandy River (Carter, Greenup Co.)	OSUM 36794 (19); OSUM 25348, USNM 853678; Not reported live or fresh dead since 1990; appears extirpated from the Little Sandy River (Haag and Cicerello, 2016, p. 179).
	KY	East Fork Little Sandy River, Boyd Co.	MUMC 2011; MUMC 1345; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
	KY	Tygarts Creek (Greenup, Carter Co.)	INHS 12860, MUMC 1175, Taylor (1980, p. 90); MUMC 799, 820, OSUM 29081, OSUM 30866, MUMC 1199, 1214, 1239, 1246(10), OSUM 48764, OSUM 42328, OSUM 17896; Schuster 1988, p. 669-670; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
Licking	KY	North Fork Licking River (Bracken/Harrison Co.)	EKU 920; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
South Fork Licking	KY	South Fork Licking River (Pendleton, Montgomery Co.)	Haag and Cicerello 2016, p. p. 178; Not reported live or fresh dead since 1990
	KY	Hinkston Creek (Bath/Montgomery Co.)	EKU 570; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
Lower Kentucky	KY	Kentucky River (Lee, Mercer/Woodford, Henry/Owen Co.)	Schuster 1988, p. 672; Call and Robinson, 1983, p. 33; UMMZ 105728, ANSP 20254, 334287, ANSP 20255aB , 20255aC ; MCZ 5066; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178. Kentucky River is neotype location.

Management Unit	Record State/Province	Former Contiguous Population	Source
	KY	Boone Creek (Clarke/Fayette Co.)	KYSNPC database records, Service 2019, unpublished data; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
	KY	Eagle Creek (Gallatin/Owen Co.)	KYSNPC database records, Service 2019, unpublished data; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
North Fork Kentucky	KY	North Fork Kentucky River, Breathitt Co.	Appears extirpated from the North Fork Kentucky River (Haag and Cicerello, 2016, p. 179).
	KY	Troublesome Creek, Breathitt Co.	Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
South Fork Kentucky	KY	Goose Creek, Clay Co.	Evans 2010, p. 24 (WD)
	KY	Cow Creek, Owsley Co.	EKU 68; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
Upper Kentucky	KY	Middle Fork Red River, Powell Co.	UMMZ 162497; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
Salt	KY	Salt River (Spencer, Nelson Co.)	KYSNPC database records, Service 2019, unpublished data; Not reported live or fresh dead since 1990, appears extirpated from the Salt River drainage (Haag and Cicerello, 2016, p. 179).
	KY	Brashears Creek, Spencer Co.	KYFW database (M. McGregor, J. Culp collectors), Service 2019, unpublished data; Not reported live or fresh dead since 1990, appears extirpated from the Salt River drainage (Haag and Cicerello, 2016, p. 179).
Rolling Fork	KY	Rolling Fork Salt River (Larue/Nelson Co.) Marion Co.	KYFW database (M. McGregor, T. Barbour, A. Shepard collectors), Service 2019, unpublished data; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
	KY	Beech Fork, Nelson Co.	KYSNPC database records, Service 2019, unpublished data; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
Upper Green	KY	Nolin River (Grayson/Hart Co.)	KYSNPC database records, Service 2019, unpublished data; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
Barren	KY	West Fork Drakes Creek, Warren Co.	Clench & van der Schalie (1944), UMMZ 44648; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
Middle Green	KY	Green River (Butler, McLean, Muhlenberg/Ohio Co.)	KYFW database records, Service 2019, unpublished data; Gordon and Sherman 1995, p. 13-14, MCZ 268570, OSUM 69638, OSUM 9617, OSUM 12754, Clench & van der Schalie

Management Unit	**Record State/Province**	**Former Contiguous Population**	**Source**
			(1944), UMMZ 44767, USNM 677309, Isom (1974); USNM 152001Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
		Mud River (Butler/Muhlenberg Co.)	Schuster 1988, p. 67; Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
Lower Green	KY	Green River	OSUM 12754; Clench & van der Schalie (1944), UMMZ 44767; USNM 677309. Not reported live or fresh dead since 1990; Haag and Cicerello 2016 p. 178
Vermilion	IL	Vermilion River, Vermilion Co.	considered extirpated (Stodola et al., 2014, p. 47); "Fairly common" at several places in the Big Vermilion River and its tributaries (Parmalee 1967, p. 80). NHS 31362, INHS 31070, INHS 26657, INHS 24326, INHS 21636, INHS 9665, INHS 30258, UMMZ 105716; Baker 1922, p. 127
	IL	North Fork Vermilion River, Vermilion Co.	considered extirpated (Stodola et al., 2014, p. 47); INHS 28543, INHS 25731, INHS 25096, INHS 19318, INHS 18106, INHS 7000, INHS 3394, INHS 5492, 8582, 8638
	IL	Middle Fork Vermilion River, Vermilion Co.	considered extirpated (Stodola et al., 2014, p. 47), Baker 1922, p. 48 "abundant in Middle Fork near its junction with Salt Fork". INHS 27257, INHS 25712, 25742, 27031, INHS 24917, INHS 23914, INHS 22279, INHS 14464, INHS 2052, INHS 2838, 5513, 8531, 8540, 8566, INHS 22804, INHS 22802
	IL	Salt Fork Vermilion River (Champaign, Vermilion Co.)	considered extirpated (Stodola et al., 2014, p. 47); INHS 24582, 25084, 25237, INHS 24283, INHS 17958, INHS 1535, INHS 22806, Baker (1922), INHS 22801, INHS 22807; van Cleave 1940, p. 366
Embarras	IL	Embarras River (Douglas, Coles, Cumberland, Jasper, Richland, Lawrence Co.)	INHS 27366; Cummings et al. 1988, p. 16: 132 individuals were collected from 12 sites in 1956, therefore it was formerly abundant component of Embarras River mussel assemblage; however, only shell remains were found in 1986-1987. Parmalee 1967, p. 80: Presently it is "locally numerous" in the Embarras River where it occurs on a sand or gravel bottom, in current, and at depths of several inches to 4-5 ft. INHS 2435, INHS 2384, INHS 26788, INHS 2507, 2564, 2978, INHS 2404, 2438, 2793(22), UMMZ 106284, INHS 27366, INHS 26077, INHS 23351, INHS 22608, 22621, INHS 18682, 19425, INHS 2522, INHS 25982, INHS 2574, 2851, 2881, INHS 2714, 3297(34), 3321, 3687,

Management Unit	**Record State/Province**	**Former Contiguous Population**	**Source**
			7378(36), 7404(13), INHS 7421, INHS 26106, Fechtner (1963, p. 100)
Skillet	IL	Horse Creek, Wayne Co.	INHS 28840; considered extirpated (Stodola et al., 2014, p. 47)
Middle Wabash - Busseron	IL	Wabash River (Crawford, Lawrence, Clark)	considered extirpated (Stodola et al., 2014, p. 47); Cummings et al. (1988, p. 154), INHS 6368, INHS 28966; Call 1900, p. 494 stated that the species was numerous in the lower Wabash; Goodrich & van der Schalie 1944, p. 261: common to this region; considered extirpated (Fisher 2006, p. 105); UMMZ 105710, USNM 118260, Cummings et al. (1988), INHS 6179, Bogan (1990) A
	IN	Wabash River (Knox, Sullivan, Vigo Co.)	
	IN	Brouilletts Creek (Vermilion, Vigo Co.)	considered extirpated (Stodola et al., 2014, p. 47); Tiemann 2005; INHS 29111, 29140, 29158, 29177
	IN	Otter Creek, Vigo Co.	INDNR Database Records, Subfossil
Lower Wabash	IL	Fox River, White Co.	INHS 22815; considered extirpated (Stodola et al., 2014, p. 47)
	IL	Wabash River (Wabash, White Co.)	INHS 41730; considered extirpated (Fisher 2006, p. 107); INHS 28966, 27348, 18927, 6702, 4788, 6707, 22805, 22816 (15), USNM 521408, 540298, Cummings et al. (1987), INHS 4763, UMMZ 66889, MCZ 64417, UMMZ 46066, Ortmann (1919), FMNH 66373, INHS 22814, FLMNH 66370, FMNH 59232, INHS 22813, 22817 (27 Specimens), UMMZ 106225, INHS 22799, OSUM 57227, INHS 1709, 22809; MCZ 89210, USNM 540384
	IN	Wabash River (Gibson, Posey Co.)	
Little Wabash	IL	Little Wabash River, Shelby Co.	FMNH 54855; considered extirpated (Stodola et al., 2014, p. 47)
Middle Wabash - Little Vermillion	IN	Wabash River (Tippecanoe, Fountain/Warren, Parke/Vermilion, Posey Co.)	considered extirpated (Fisher 2006, p. 105); Cummings et al. (1988). OSUM 31240, INHS 6214, 6405, 6643, OSUM 55070, OSUM 44196, OSUM 45655, OSUM 13071(15); UMMZ 240066, 246835, UMMZ 227337, OSUM 5145, UMMZ 253673, UMMZ 150790, INHS 1243, 4905, INHS 1379, 1432, 1706, INHS 22808(10), MCZ 63305, UMMZ 106226, INHS 5043, 5110, 5252, 5310, 5931, 6125, 6151, INHS 4943, UMMZ 183307, UMMZ 44951. Goodrich & van der Schalie 1944, p. 261: "common to this region", then Listed as rare in the upper Wabash river by Krumholz et al 1969, p. 214.
	IN	Mud Pine Creek, Warren Co.	INDNR Database Records, Weathered Dead

Management Unit	Record State/Province	Former Contiguous Population	Source
	IN	Coal Creek (Fountain, Parke Co.)	INDNR Database Records, Subfossil & Weathered Dead shells
	IN	Little Vermillion River, Vermillion Co.	INDNR Database Records, Weathered Dead
	IN	Big Raccoon Creek, Parke Co.	INDNR Database Records, Subfossil Shells
Middle Wabash-Deer	IN	Wabash River (Tippecanoe, Carroll Co.)	considered extirpated (Fisher 2006, p. 105), INHS 8249, Cummings et al. (1988); INHS 5185, 5218, USNM 149368, 149375, MCZ 19278. Goodrich & van der Schalie 1944, p. 261: "common to this region", then Listed as rare in the upper Wabash river by Krumholz et al 1969, p. 214.
Upper Wabash	IN	Wabash River (Miami, Wabash Co.)	considered extirpated (Fisher 2006, p. 105); Cummings et al. (1988); UMMZ 129828, FLMNH 229418, OSUM 41427, INHS 5087, OSUM 22953, OSUM 24057
Middle Ohio - Laughery	IN	Laughery Creek, Ripley/Ohio Co.	OSUM 57584
	OH	Ohio River (lower Markland Pool, upper McAlpine Pool), Hamilton Co.	OSUM 45549, Schuster 1988, p. 668; USNM 85741, USNM 85734, USNM 35734, FMNH 66321, 269780, 269798, 269799, 269802; MCZ 5061; OSUM 58573; UMMZ 232558, USNM 620145. Collections of 10 & 20 specimens in USNM from mid-1800s in vicinity of Cincinatti, OH.
	KY	Ohio River (lower Markland Pool, upper McAlpine Pool), Kenton Co.	
Salamonie	IN	Salamonie River, Huntington Co.	ESI 1995 Weathered Dead (3 sites)
Mississinewa	IN	Mississinewa River (Delaware, Grant, Miami, Wabash Co.)	WD reported by ESI 1995, p. 8 (1 site Miami Co.); OSUM 31611, USNM 420784, UMMZ 106291, INHS 30198
Tippecanoe	IN	Big Monon Creek (Pulaski, White Co.)	OSUM 66982 (Weathered Dead shells from 2 sites)
Wildcat	IN	Wildcat Creek, Tippecanoe Co.	INDNR Database Records, Subfossil Shell
	IN	South Fork Wildcat Creek, Tippecanoe Co.	INDNR Database Records, Subfossil Shells (3 Sites)
Sugar	IN	Sugar Creek, Montgomery Co.	INHS 22803, 1 specimen, relic
Lower White	IN	White River (Gibson/Knox/Pike Co.)	considered extirpated (Fisher 2006, p. 105); INHS 12412, UMMZ 106266, 107528, UMMZ 106296, ANSP 48210, UMMZ 67834, USNM 677601, USNM 85736, INHS 1707; USNM 29998, 29999, 118293, 514943, 514960, 521299; FLMNH 66363. From Cummings et al 1991, p. 29: Both Call (1900) and Goodrich and van der Schalie (1944) reported the round hickorynut from the White River. It was considered rare in the White River with a few specimens collected

Management Unit	**Record State/Province**	**Former Contiguous Population**	**Source**
			in East Fork between Tunnelton and Hayesville in July of 1967. No live *O. subrotunda* were collected in 1989-91, but weathered dead and sub-fossil shells were common throughout the river, indicating its former abundance in the drainage.
Upper East Fork White	IN	East Fork White River (Bartholomew, Jackson)	considered extirpated (Fisher 2006, p. 105); INHS 11603, INHS 12322(2), 12335, OSUM 11750, 12960, UMMZ 107525, UMMZ 44886, 44901, OSUM 8078, MCZ 5060; UMMZ 24(15), 105714
	IN	Clifty Creek, Bartholomew Co.	INHS 17115; INDNR Database Records, Weathered Dead
Lower East Fork White	IN	East Fork White River (Lawrence, DuBois/Martin, Daviess/Pike Co.)	considered extirpated (Fisher 2006, p. 105); INHS 12521, INHS 10576, 11581, UMMZ 44934, INHS 11305, UMMZ 50940
	IN	Lost River, Martin Co.	INDNR Database Records (may not be valid record – B. Fisher INDNR 2019, pers. comm.)
Driftwood	IN	Driftwood River, Bartholomew Co.	INDNR Database Records, Subfossil, Weathered Dead
	IN	Sugar Creek, Johnson Co.	Harmon 1992, p. 41, INHS 11198, 11218, 11240, 11260, 22803
	IN	Youngs Creek, Johnson Co.	Harmon 1992, INHS 10842
Flatrock-Haw	IN	Flatrock River, Bartholomew Co.	INDNR Database Records, Weathered dead shell not retained by JL Harmon but recorded by INHS (4 mi N Columbus, Co. Rd. 900N bridge)
Muscatatuck	IN	Muscatatuck River, Jefferson Co.	OSUM 29920
	IN	Big Creek, Jefferson Co.	INHS 13772
	IN	Graham Creek, Jennings Co.	OSUM 29942; Harmon 1989
Upper White	IN	West Fork White River (Hamilton, Marion, Morgan Co.)	considered extirpated (Fisher 2006, p. 105); INHS 8159, FMNH 11246, UMMZ 105709, USNM 677669, INHS 8452
	IN	Canal, Marion Co.	MCZ 5072
	IN	White Lick Creek, Morgan Co.	INDNR Database Records, Subfossil
Lower White	IN	West Fork White River (Owen, Green, Daviess/Knox Co.)	considered extirpated (Fisher 2006, p. 105); INHS 12590, Ortmann (1919), MCZ 193277, INHS 12372, 12442, INHS 11620, MCZ 58368, OSUM 23979
	IN	Black Creek, Knox Co.	INDNR Database Records, Subfossil

Management Unit	Record State/Province	Former Contiguous Population	Source
Eel	IN	Eel River - White River trib., Clay Co.	INDNR Database Records; considered extirpated (Fisher 2006, p. 105); weathered dead 6 sites
	IN	Big Walnut Creek, Putnam Co.	INDNR Database Records, Subfossil, Weathered Dead (3 sites)
Patoka	IN	Patoka River (Orange, Gibson Co.)	INDNR Database Records, Subfossil, Weathered Dead (4 sites) (Orange Co. record may not be valid– B. Fisher INDNR 2019, pers. comm.)
Silver-Little Kentucky	IN	Ohio River (Lower McAlpine Pool, Upper Cannelton Pool) (Harrison, Clark Co.)	INDNR Database Records, Way and Shelton 1997, p. 66 (D); Call 1900, p. 494, stated that the species was very common thoughout the Ohio all along the Indiana shores.
	KY	Ohio River (Lower McAlpine Pool, Upper Cannelton Pool) (Oldham Co.)	OSUM 30034 (1988), Way and Shelton 1997, p. 66 (D); Call 1900, p. 494, stated that the species was very common thoughout the Ohio all along the Indiana shores.
Blue - Sinking	IN	South Fork Blue River, Washington Co.	Weilbaker et al. 1985 (may not represent valid identification – B. Fisher INDNR 2019, pers. comm.)
Highland - Pigeon	KY	Ohio River (Myers Pool) Henderson Co.	Casey 1986; Parmalee 1960; Call 1900, p. 494, stated that the species was very common thoughout the Ohio all along the Indiana shores. Casey 1986, p. 129: recovered from the Angel Site on the North Bank of the Ohio River, 2.5 miles west of Newburgh OH, where it constituted 0.7% of the assemblage (40 valves).
	IN	Ohio River (Myers Pool) Vanderburgh Co.	
Cumberland			
Upper Cumberland - Lake Cumberland	KY	Cumberland River (Pulaski, Wayne, Cumberland/Monroe & Russell Co.)	EKU 95(10), 431; Ortmann (1925, p. 348), UMMZ 105718, Wilson & Clark (1914, p. 18), USNM 150469, UMMZ 105718, Wilson & Clark (1914), UMMZ 105719, Neel & Allen (1964), UMMZ 167132, EKU 95(10), 431; FMNH 29107, 36052; MCZ 184566; UMMZ 167054, 167075, 167147(17), 168072, 172797, 173686; USNM 595007, MCZ 56024, UMMZ 40726, Wilson & Clark (1914); UMMZ 105720, 105721, 105723, 105726, 105727; UT McClung 237. "Very common" in the Cumberland below the falls (Neel and Allen 1964, p. 442).
	KY	Beaver Creek, Russell Co.	Neel & Allen (1964p. 442); UMMZ 167106(34), 172749(11); USNM 592107, Wilson & Clark (1914, p. 18), MCZ 159743
Lower Cumberland	KY	Cumberland River (Livingston & Lyon Co.)	Wilson and Clark 1914; Casey 1986; Sickel and Chandler 1996; Blalock and Sickel 1996
South Fork Cumberland	KY	Little South Fork Cumberland River (McCreary/Wayne Co.)	Ahlstedt et al. 2014 (p. 11); Warren & Haag (2005, p. 1392), Starnes & Bogan (1982, p. 109),

Management Unit	Record State/Province	Former Contiguous Population	Source
			INHS 9821, 13989, Layzer & Anderson (1992, p. 46), Anderson et al. (1991, p. 4), EKU 442, Ahlstedt & Saylor (1995–96, p. 104), EKU 306, EKU 138(21), 434, NCSMNS 7331, OSUM 49946, EKU 33(1), 142(R), 143(R), 144(R), 422(R), 473(R); OSUM 47505(R), EKU 466; OSUM 45370, 45426, 45438, NCMNS 7289, OSUM 43005, NCMNS 6839, 7288
	TN	Big South Fork Cumberland River, Scott Co.	UMMZ 106290; Ahlstedt et al 2004, p. 62. The round hickorynut was reported as common at Burnside, Kentucky (Wilson & Clark, 1914). The mussel was collected in 1924 by Ortmann from the Cumberland River at Burnside (UMMZ 105718) and in 1948 by Neel two miles upstream from Burnside (UMMZ 172832) (Schuster, 1988, p. 674).
	KY	Big South Fork Cumberland River (McCreary, Pulaski Co.)	Neel & Allen (1964, p. 442), UMMZ 172832
	KY	Kennedy Creek, Wayne Co.	OSUM 45558
Upper Cumberland - Cordell Hull Reservoir	TN	Cumberland River (Jackson, Clay Co.)	Shoup et al 1941 (p. 67-68); UMMZ 134827, UMMZ 134848; Wilson & Clark (1914, p. 18)
Lower Cumberland-Old Hickory Lake	TN	Cumberland River (Smith Co.)	Parmalee et al. 1980, p. 101, UTMM 227, 228 (8 total specimens from 2 sites)
Lower Cumberland - Sycamore	TN	Cumberland River (Davidson, Cheatam Co.)	UMMZ 105729; USNM 514957, INHS 22830, USNM 85735, OSUM 68045, MCZ 5068, 5243; Wilson & Clark (1914, p. 18).
Obey	TN	Obey River (Pickett, Clay Co.)	FLMNH 4178; Shoup et al. (1941, p. 67-68); UMMZ 134742, 134749, 134755, 34764, 134771, UMMZ 107527, UMMZ 58503, FMNH 68448, 120269; MCZ 193283, 193284, UMMZ 46457, 46458, 46459, 46460, 46461, 49621, 49645, 49595; USNM 382394, 382422, 522519, ANSP 144856, ANSP 341258; FMNH 23028; FMNH 233277; UMMZ 246926, UMMZ 134819, FLMNH 229416
	TN	East Fork Obey River, Fentress Co.	UMMZ 49610
	KY	Wolf River, Clinton Co.	UMMZ 49695; MCZ 70974
	TN	Wolf River, Pickett Co.	MCZ 70974; No information, 10 valves recorded
Caney	TN	Caney Fork (Dekalb/Putnam/Smith Co.)	Layzer & Anderson 1992 (p. 46); OSUM 29710, OSUM 50047, 54279, FMNH 23027, MFM 8782, MCZ 56064, UMMZ 107526, UMMZ 50957

Management Unit	Record State/Province	Former Contiguous Population	Source
Stones	TN	Stones River (Rutherford, Davidson Co.)	MFM 14327 (Athearn); OSUM 18879, OSUM 14360, 15162, FMNH 154402(25); MFM 14660ZZ, OSUM 15578(343), 18890, 18903, 20193(402); USNM 1018026, OSUM 14282(19), MUMC 896, UMMZ 50924, UTMM 232. OSUM 20193 lot is of 400 individuals, and 15578 is of 327 individuals, collections were made in Sept. and Oct. of 1965, indicating a once very robust population of *O. subrotunda* in the vicinity of Couchville, TN.
	TN	East Fork Stones River, Rutherford Co.	INHS 15355, Schmidt et al. (1989, p. 58), OSUM 44726, OSUM 52065, MCZ 274839, OSUM 52052, OSUM 19462, 19485, OSUM 20270, OSUM 14212, 14474(38), 14572(21), UMMZ 58257, MCZ 98451, 98466, Wilson & Clark (1914, p. 18). D. Hubbs, TWRA, in 2002 found 2 relic shells at 1 site downstream of TN Hwy 231 (Hubbs. 2019 Pers. Comm.). OSUM lots 19462, 199485 from 1966 contain 75 specimens and 20270 from 1965 contains 64 specimens, indicating that a large population of the species occurred in vicinity of US Hwy 231.
	TN	West Fork Stones River, Rutherford Co.	OSUM 19962; OSUM 14550
Harpeth	TN	Harpeth River (Williamson, Davidson, Dixon, Cheatam Co.)	UTMM 3664; INHS 22827, ANSP 68355, 68381, UMMZ 52649, UMMZ 106294, OSUM 57707; Pilsbry and Rhoads 1896, p. 501. Relic individuals were collected from the lower Harpeth River in 2002 (D. Hubbs, TWRA 2019 Pers. Comm).
Red	KY	Red River (Logan Co.)	INHS 12746; MUMZ 61.7, OSUM 21671
	TN	Red River (Robertson / Montgomery Co.)	OSUM 16985(44), 17012(420), 17086; OSUM 23071, 23149(11), FMNH 156013, OSUM 22026, USNM 745400, Wilson & Clark (1914, p. 18). Over 465 specimens in these lots from 1966, indicating the species was formerly a major component of the Red River mussel fauna. Last collected in 2002 D. Hubbs TWRA (Hubbs 2019 Pers. Comm.).
	KY	South Fork Red River, Logan Co.	OSUM 82215
	KY	Whippoorwhill Creek, Logan Co.	OSUM 82610; KYSNPC Database records
	KY	West Fork Red River, Todd Co.	OSUM 7388
	TN	Sulphur Fork Red River, Robertson Co.	OSUM 20542
Tennessee			
Watts Bar Lake	TN	Tennessee River (Loudon Dam Tailwater, Watts Bar Reservoir)	Ortmann 1925, Hughes and Parmalee 1999; Parmalee et al. 1982; Parmalee et al. (1982);

Management Unit	Record State/Province	Former Contiguous Population	Source
			Lewis (1870), UMMZ 105712; MCZ 193280; Pilsbry & Rhoads (1896), ANSP 68362
Holston	TN	Holston River (Grainger/Hamblen, Jefferson, Knox Co.)	Parmalee and Faust 2006, CM 61.6650; OSUM 35159, FLMNH 269778, MCZ 46667, ANSP 48302, CM 61.7536, FLMNH 269779, USNM 24996, USNM 25404, FLMNH 66362
Lower French Broad	TN	French Broad River, Sevier Co.	UTMM 9572, Layzer and Scott 2006, p. 481 (McCrosky Island)
	TN	West Prong Little Pigeon River, Sevier Co.	Parmalee 1988, p. 168
Upper Clinch	TN	Clinch River (Hancock, Union Co.)	OSUM 67673; MCZ 5069
Powell	TN	Clinch River (Roane, Anderson Co.)	UMMZ 107529, USNM 172698; Parmalee and Bogan 1986
Emory	TN	Obed River, Morgan Co.	NCMNS 41035 (Athearn)
Lower Little Tennessee	TN	Little Tennessee River, Monroe Co.	Bogan 1990, p. 135
Upper Duck	TN	Big Rock Creek, Marshall Co.	OSUM 30755
Upper Elk	TN	Cane Creek, Lincoln Co.	UTMM 6405
	TN	Richland Creek, Giles Co.	Ortmann (1925), CM 61.11632; INHS 22828
Sequatchie	TN	Sequatchie River (Bledsoe, Sequatchie, Marion Co.)	Gordon 1991; CM 61.11687, USNM 133435, USNM 894518, OSUM 15667, UMMZ 106282; UTMM 224
Middle Tennessee-Chickamauga	TN	Tennessee River (Chickamauga Tailwater & Reservoir, Watts Bar Tailwater) (Rhea and Meigs Co., TN)	Parmalee et al. (1982): p. 83, 178 valves (64% of total) from 14 prehistoric aboriginal sites
	TN	Tennessee River (Nickajack Reservoir)	Bogan (1990)
	GA	South Chickamauga Creek, Catoosa Co.	Ortmann (1918, 1919), CM 61.8086
Wheeler Lake	AL	Tennessee River (Guntersville Dam tailwaters) (Jackson Co.)	Hughes & Parmalee (1999), NCMNS 45139(10); OSUM 57643; considered extirpated, Williams et al. 2008, p. 324
	AL	Hurricane Creek, Jackson Co.	Ahlstedt 1991b; considered extirpated, Williams et al. 2008, p. 324
	AL	Estill Fork, Jackson Co.	OSUM 39199, 40518, MCZ 275109, OSUM 19409, OSUM 18734; OSUM 75408 (Ahlstedt 1991b); considered extirpated, Williams et al. 2008, p. 324

Management Unit	Record State/Province	Former Contiguous Population	Source
	AL	Larkin Fork, Jackson Co.	OSUM 38392 (Isom and Yokley 1973); MFM 14327C Athearn record; considered extirpated, Williams et al. 2008, p. 324
	AL	Flint River, Madison Co.	Ortmann (1919, 1925), CM 61.6964, UMMZ 106276; considered extirpated, Williams et al. 2008, p. 324
	AL	Hurricane Creek, Madison Co.	Ortmann (1919, 1925), CM 61.6965, UMMZ 106275; considered extirpated, Williams et al. 2008, p. 324
	AL	Flint Creek, Morgan Co.	Ortmann (1925), CM 61.12056(12), UMMZ 62370; considered extirpated, Williams et al. 2008, p. 324
	AL	Limestone Creek, Limestone Co.	Ortmann (1925), UMMZ 106283; considered extirpated, Williams et al. 2008, p. 324
Lower Elk	AL	Elk River, Limestone Co.	Isom et al 1973, considered extirpated, Williams et al. 2008, p. 324
Pickwick Lake	AL	Tennessee River (Wilson Dam Tailwaters) (Lauderdale Co.)	USNM 85789; Hughes and Parmalee 1999; Morrison 1942, p. 360; considered extirpated, Williams et al. 2008, p. 324
	AL	Shoal Creek, Lauderdale Co.	considered extirpated, Williams et al. 2008, p. 324
Bear	AL	Bear Creek (Franklin, Colbert Co.)	UMMZ 157181; CM 61.7275; FMNH 66331; MCZ 30063; Ortmann 1925 p. 348 reported 11 specimens at Old Burleson
	AL	Little Bear Creek (Franklin Co.)	INHS 16167
Kentucky Lake	KY	Tennessee River (Kentucky Lake & Kentucky Dam tailwater)	Casey 1986, p. 129; Dyke Site, below Kentucky Dam on lower TN River, Casey also references the presence of the species at the Eva site in Benton Co., TN, which is now impounded by Kentucky Reservoir.
Lower Mississippi			
Lower Mississippi - Memphis	KY	Mississippi River, Ballard Co.	Wesler 2001, p. 115, excavations at the Wickliffe Mounds, which is a Native American site. These mounds are located on the East side of the Mississippi River, Ballard Co., KY, just upstream of the junction with the Ohio River.
Upper Yazoo	MS	Yazoo River, Yazoo Co.	MMNS 9200; Also Bogan 1990
Tallahatchie	MS	Tallahatchie River, Leflore Co.	Peacock et al. 2016, 663 shells from 3 sites, RA = 2.3 %
Big Sunflower	MS	Big Sunflower River, Sunflower Co.	MMNS 5951

Management Unit	**Record State/Province**	**Former Contiguous Population**	**Source**
Lower Big Black	MS	Fourteen Mile Creek, Hinds Co.	MMNS 47, 250
	MS	Big Black River, Madison Co.	MMNS 1654
Bayou Pierre	MS	Bayou Pierre, Copiah Co.	MMNS 5507; Hartfield & Ebert (1986), p. 26 L/FD, 2 R; MMNS 1822, 1892, 1912, 1924; UTMM 5954
Homochitto	MS	Homochitto River, Lincoln Co.	MMNS 1855
	MS	McCall Creek, Franklin Co.	MMNS 1854

APPENDIX C—MAPS DEPICTING THE 62 ROUND HICKORYNUT MUSSEL POPULATIONS WITHIN MANAGEMENT UNITS ACROSS THEIR CURRENT RANGE

**See supplemental/attached document for Appendix C.

APPENDIX D—ESTIMATES OF MAGNITUDE AND IMMEDIACY OF POTENTIAL THREATS NEGATIVELY INFLUENCING THE VIABILITY OF ROUND HICKORYNUT.

Population	Threat Level Category	Threats	References
GREAT LAKES BASIN (CANADA)			
(Canada 1) Lake St. Clair	High	Nonnative species, agriculture	Zebra Mussel and Round Goby are major threats (Nonnative species).
(Canada 2) East Sydenham River	High	Nonnative species, agriculture	Eighty-four percent of the watershed is agricultural, primarily in row crops (Metcalfe-Smith et al. 2003). Siltation, nutrient over-enrichment, exposure to agricultural pesticides and fertilizers, and runoff from highways, municipal, and industrial sources are threats. The drainage system of ditches around towns in the watershed also contributes sediment and runoff (Mackie and Topping 1988).
GREAT LAKES BASIN (USA)			
(1) Pine River	Moderate	nonnative species such as Zebra Mussel. The Belle is located in a primarily agricultural watershed, and impacted by sedimentation and runoff (Butler 2007, p. 27).	Badra and Goforth 2003 p. 35 cite Beaver Dams which have altered stream hydrology and agricultural land use resulting in increased silt levels. Also, Zebra Mussel occurs in surrounding watersheds.
(2) Belle River	Moderate	nonnative species such as Zebra Mussel. Located in an agricultural watershed threatened by sedimentation and runoff (Butler 2007, p. 26).	Badra and Goforth 2003 p. 35 cite Beaver Dams which have altered stream hydrology and agricultural land use resulting in increased silt levels. Also, Zebra Mussel occurs in surrounding watersheds.

Population	Threat Level Category	Threats	References
(3) Black River (MI)	Moderate	agriculture, human development	Haas, 2009, p. 42: Deforestation, agriculture, and industrial/residential development have been major factors changing landscape, channel characteristics, hydrology, water quality, and biological communities of the river.
(4) Grand River	Low	Impoundment, human development; potential for nonnative species	(Huehner et al. 2005). Painesville (a suburb of Cleveland) near the mouth. Harpersfield Dam in the lower reaches fragments habitat, and Huehner et al. 2005 p. 61 noted a decline in abundance of *O. subrotunda* in the middle and lower reaches.
(5) Mill Creek (Grand)	Moderate	Impoundment (beaver dams), human development; potential for nonnative species	Grabarkiewicz 2014, p. 2; Physical habitat in Mill Creek varies greatly longitudinally from the headwaters to the mouth. The Middle Reach extends from RM 3.1 to RM 18.0. Within this reach, extensive stretches of exposed bedrock and angular rubble are present. Suitable mussel habitat is intermittent, located in channel margins or backwaters, or absent for extensive stretches.
(6) Black River (OH)	High	nonnative species, human development, impoundments	dredged harbor at mouth of Black River, decimation of lake Erie's unionid fauna, anthropogenic changes to landscape, Lyons et al. 2007, p. 9; upstream impoundments, nonnative species (Zebra Mussel in Lake Erie).
(7) Fish Creek	Moderate	agriculture; anthropogenic impacts such as water quality degradation due to contaminants	The Fish Creek watershed is mostly in agriculture. A mussel kill at a site well upstream of the extant *O. subrotunda* reach was possibly the result of manure runoff from a hog farm (Watters 1998). A swamp-like area around river mile (RM) 12 separates the highly imperiled faunal elements found only in lower Fish Creek from the upper system. A major diesel fuel spill from a ruptured pipeline in DeKalb County, Indiana, in 1993 resulted in a mussel kill in the lower portion of the stream (Sparks et al. 1999).
OHIO RIVER BASIN			

Population	Threat Level Category	Threats	References
(8) Shenango River	High	impoundment, genetic isolation, climate change vulnerability, pollution	Bursey 1987, p. 43 cites domestic and industrial pollution and fertilizer and pesticide run-off, flood control dams reduced mussel habitat by completely inundating Pymatuning Creek. Furedi 2013, p. 14 ranked the species in PA as Extremely Vulnerable to climate change (flooding and potential hydropower development). The completion of the Pymatuning Reservoir dam (near Jamestown) in 1934 eliminated 27.4 km (17 miles) of free-flowing river habitat. The completion of the Shenango River Lake dam in 1965 (near Sharpsville) inundated 17.7 km (11 miles) of historically occupied habitat, including an occupied portion of Pymatuning Creek (Ortmann 1909). Pollution from the steel mills at Sharon and Farrell likely contributed to the demise of this species downstream of these communities.
(9) West Fork River	High	Agriculture, Resource Extraction, Forestry, Nonnative species (Corbicula); Impoundment (Stonewall Jackson Lake); sedimentation	Marcellus gas exploration may be impacting the watershed. Recent activities have included open trench pipeline crossings and water withdrawals for hydrostatic testing and well fracking. Coal mining played a significant role in the regional economy from the 1800's until a decline in coal production in the 1970's. As the production of coal mining declined, forestry, agriculture, oil and gas production, as well as sandstone, shale, and limestone extraction have become increasingly important economic factors (USDA 2010, p. 8). USDA (2010), p. 8: Agriculture is an important part of the economy in the West Fork watershed. Total number of farms have increased from 2,309 to 2,396 (approximately 8.5 percent) in recent years. Farms in this region are generally 150 to 200 acres in size and comprise approximately 25 percent of the land use area in the West Fork watershed.
(10) Right Fork West Fork River	High	Agriculture, Resource Extraction, Forestry, Nonnative species (Corbicula); Impoundment (Stonewall Jackson Lake) ; sedimentation	population is isolated above Stonewall Jackson Lake on West Fork River. Coal mining played a significant role in the regional economy from the 1800's until a decline in coal production in the 1970's. As the production of coal mining declined, forestry, agriculture, oil and gas production, as well as sandstone, shale, and limestone extraction have become increasingly important economic factors (USDA 2010, p. 8). USDA (2010), p. 8: Agriculture is an important part of the economy in the West Fork watershed. Total number of farms have increased from 2,309 to 2,396 (approximately 8.5 percent) in recent years. Farms in this region are generally 150 to 200 acres in size and comprise approximately 25 percent of the land use area in the West Fork watershed.

Population	Threat Level Category	Threats	References
(11) Kincheloe Creek	High	Agriculture, Resource Extraction, Forestry, Nonnative species (Corbicula) ; sedimentation	Stream is being impacted by Marcellus gas exploration. Increased sediment and pipeline crossings. Decline in overall mussel populations have been observed over the last 15 years. Coal mining played a significant role in the regional economy from the 1800's until a decline in coal production in the 1970's. As the production of coal mining declined, forestry, agriculture, oil and gas production, as well as sandstone, shale, and limestone extraction have become increasingly important economic factors (USDA 2010, p. 8). USDA (2010), p. 8: Agriculture is an important part of the economy in the West Fork watershed. Total number of farms have increased from 2,309 to 2,396 (approximately 8.5 percent) in recent years. Farms in this region are generally 150 to 200 acres in size and comprise approximately 25 percent of the land use area in the West Fork watershed.

(12) Hackers Creek	High	Agriculture, Resource Extraction, Forestry, Nonnative species (Corbicula) - At some point in the mid to late 1990s a significant mussel kill occurred within the stream. Though not confirmed, it is believed the kill resulted when an abandoned underground mine had a blowout at the head of the watershed. Many species were lost. Populations so decimated and with continued loss of riparian habitat and use of herbicides and pesticides, little chance of recovery (Clayton 2019, pers. comm.), sedimentation	Coal mining played a significant role in the regional economy from the 1800's until a decline in coal production in the 1970's. As the production of coal mining declined, forestry, agriculture, oil and gas production, as well as sandstone, shale, and limestone extraction have become increasingly important economic factors (USDA 2010, p. 8). USDA (2010), p. 8: Agriculture is an important part of the economy in the West Fork watershed. Total number of farms have increased from 2,309 to 2,396 (approximately 8.5 percent) in recent years. Farms in this region are generally 150 to 200 acres in size and comprise approximately 25 percent of the land use area in the West Fork watershed.

Population	Threat Level Category	Threats	References
(13) Stonecoal Creek	High	Impoundment, hypolimnetic release, Agriculture, Resource Extraction, Forestry, Nonnative species (Corbicula); sedimentation	Stonecoal Dam, coldwater release. Coal mining played a significant role in the regional economy from the 1800's until a decline in coal production in the 1970's. As the production of coal mining declined, forestry, agriculture, oil and gas production, as well as sandstone, shale, and limestone extraction have become increasingly important economic factors (USDA 2010, p. 8). USDA (2010), p. 8: Agriculture is an important part of the economy in the West Fork watershed. Total number of farms have increased from 2,309 to 2,396 (approximately 8.5 percent) in recent years. Farms in this region are generally 150 to 200 acres in size and comprise approximately 25 percent of the land use area in the West Fork watershed.
(14) Jesse Run	High	Agriculture, Resource Extraction, Forestry; sedimentation	Coal mining played a significant role in the regional economy from the 1800's until a decline in coal production in the 1970's. As the production of coal mining declined, forestry, agriculture, oil and gas production, as well as sandstone, shale, and limestone extraction have become increasingly important economic factors (USDA 2010, p. 8). USDA (2010), p. 8: Agriculture is an important part of the economy in the West Fork watershed. Total number of farms have increased from 2,309 to 2,396 (approximately 8.5 percent) in recent years. Farms in this region are generally 150 to 200 acres in size and comprise approximately 25 percent of the land use area in the West Fork watershed.
(15) Middle Island Creek	High	Resource Extraction issues; Habitat alteration, Water quality degradation, Agriculture; sedimentation	This stream receives large input of sediment from infrastructure development for the Marcellus gas industry. Gas and water pipeline construction, access road and wellpad construction. Water is used for fracking, dust control on roads, and hydrostatic testing of pipes. In 2010, water withdrawals from the stream during drought conditions lead to stranding and subsequent mortality of mussels (WVDNR, unpublished data; J. Clayton, WVDNR, 2018, pers. comm.). At least one mill dam persists on the stream, although a side channel, The Jug, continues to provide unrestricted flow for fish movement.

Population	Threat Level Category	Threats	References
(16) Meathouse Fork	High	Resource Extraction issues; Habitat alteration, Water quality degradation; sedimentation	Due to significant habitat degradation from oil and gas drilling, Meathouse Fork existing mussel populations are imperiled. There is still habitat there but degraded from sedimentation, bed load movement, and water quality (Clayton, 2019, pers. comm.). Stream has been significantly impacted by Marcellus gas activities. Increased sediment load due to pipeline, well pad, and access road construction. Numerous pipeline crossings, open trench, of stream. Another compressor station is being built within the streams floodplain. County road along stream has been seriously degraded and has required bank stabilization activities due to heavy water and brine truck traffic. At least one truck has rolled into the stream. Landowners talk about brown surface film being evident over the weekends. Heavy oil sheen observed. Cattle access to stream and agricultural impacts, as well as significant bedload movement (WVDNR 2012, p. 41).
(17) McElroy Creek	High	Resource Extraction issues; Habitat alteration, Water quality degradation; sedimentation	WVDNR 2012, p. 52: water withdrawals during low flows to be used for Marcellus Shale gas drilling operations, Numerous pipeline crossings for the Marcellus industry.
(18) Buckeye Creek	High	Resource Extraction issues; Habitat alteration, Water quality degradation; sedimentation	Two of 4 sites surveyed were related to pipeline crossings; WVDEP 2009, p. 1 reported on a Tapo Energy oil spill which occurred in Buckeye Run, a direct tributary to Buckeye Creek, 50-70 barrels of contaminates were used for the cleanup and 9 industrial bags of leaves and debris. This report also indicates high total coliform, fecal coliform, bacteria and organic content levels in Buckeye Creek (p. 7-8).

Population	Threat Level Category	Threats	References
(19) Ohio River (Willow Island Pool)	High	Impoundment, non-native species, anthropogenic impacts such as spills and contaminants as well as navigation	From Watters and Flaute 2010, p. 1: the most dramatic declines in mussels were associated with the arrival of zebra mussels in the Ohio River in 1991. Pools with signifi cant urban centers often had a loss of diversity well before the construction of dams or the arrival of zebra mussels; these losses are attributed to water quality problems associated with urban centers. Mussel diversity has thus declined in the Ohio River as the result of a three-fold problem: loss of water quality, existing dams, and zebra mussels.
(20) Killbuck Creek	High	Forest conversion, oil and gas development, agricultural impacts	Ahlstedt 2012, p. 4 mentions clear-cutting of trees upstream and downstream of location where the only live O. subrotunda were collected. From USFWS 2007b: Ahlstedt reported that mussel habitat in Killbuck Creek is "severely degraded." The substrate is severely embedded and largely comprised of hard pan, which doesn't allow for mussel colonization. The riparian zone is impacted by timber removal, field crops, and cattle accessing the stream. Ahlstedt (2007) also noted that "fish are noticeably absent and Asian Clams were abundant" in Killbuck Creek. Ahlstedt (2014) reported that Asian Clams (Corbicula fluminea) appeared to have a massive die-off in 2011 but have appeared to rebound and are currently relatively common in the stream. It is interesting to note that the 2011 die-off correlates with the timing of the recent recruitment of purple cat's paw in Killbuck Creek. When Asian Clam numbers were very low the purple cat's paw had successful recruitment. However, it is not known if these two events are related. The Killbuck watershed also contains many operating oil and gas wells, though it is unknown if these wells are affecting the creek.
(21) Walhonding River	High	Impoundment, gravel mining, small, linear population limited in extent susceptible to stochastic events	Six Mile Dam is a lowhead dam at approximately RM 9 that impounds a 0.5-mile reach of the Walhonding. Six Mile Dam is scheduled for removal in 2020. Gravel mining also occurs in the lower portion of river below Six Mile Dam. An upstream impoundment on the Walhonding River, Mohawk Dam (~RM 17.5), was built on the main stem in 1936 and operates as a "dry dam" to temporarily control flood waters. Some developmental and agricultural pressure occurs, particularly upstream of Mohawk Dam.

Population	Threat Level Category	Threats	References
(22) Mill Creek (Walhonding)	Moderate	Impoundment; habitat fragmentation, Agriculture	Hoggarth (1995-96): Mohawk Dam (~RM 17.5) was built on the main stem Walhonding in 1936 and operates as a retarding basin to temporarily control flood waters. A low head dam (~RM 9) impounds a 0.5-mile reach of stream. There are active sand and gravel companies in the drainage (Walhonding Sand and Gravel and Smith Concrete) but neither are mining directly from the rivers.
(23) Muskingum River	High	Hydropower development, impoundment, dredging, genetic isolation; past threats include commercial harvest	The occupied reach of the Muskingum river is highly fragmented by impoundments, and Watters and Dunn 1993-1994 p. 258 state: It is foreseeable that a single major environmental accident upstream, such as an oil or pesticide spill, could irreparably damage or even eliminate this fauna. One such spill, although apparently minor and well contained occurred in 1992. They also cite potential dam removal and associated silt and sediment loads, dredging activities and harvesting pressure as long-term impacts on the mussel fauna in the Muskingum River. Additionally, ESI 2011 did extensive surveys related to proposed hydropower development at existing dams, and cite changes in shear velocity as potentially affecting substrate and unionid communities. Eleven Locks & Dams have been constructed on the Muskingum from Zanesville downstream.
(24) Wakatomika Creek	High	anthropogenic impacts (pollution); agriculture	Ahlstedt 2009 p. 6: Stream habitat is severely affected by heavy sedimentation and dump sites adjoining the road and stream banks.
(25) Symmes Creek	Moderate	anthropogenic impacts (Agriculture), habitat alteration	Hoggarth et al, 2007, p. 62: lists land use practices and decline of water and habitat quality. Also scour and habitat impacts from flood events. p. 60 cites a severe decline in mussel abundance in the smaller tributaries of Symmes Creek watershed.
(26) West Fork Little Kanawha River	Moderate	resource extraction (oil & gas); habitat alteration and water quality degradation; sedimentation - logging, inadequate wastewater treatment (domestic pollution); impoundment	From Schmidt et al 1983, p. 132: The streams and rivers of the basin are turbid the majority of the year. Major problems include sedimentation due to soil conditions aggravated by timbering and oil and gas exploration and elevated fecal coliforms due to inadequate domestic wastewater treatment. Rail and vehicular transportation routes follow the meandering streams, occupying most of the level land of the narrow stream flood plains.

Population	Threat Level Category	Threats	References
(27) Little Kanawha River	Moderate	resource extraction (oil & gas); habitat alteration and water quality degradation; sedimentation - logging, inadequate wastewater treatment (domestic pollution); impoundment	Schmidt et al 1983, p. 132: The streams and rivers of the basin are turbid the majority of the year. Major problems include sedimentation due to soil conditions aggravated by timbering and oil and gas exploration and elevated fecal coliforms due to inadequate domestic wastewater treatment. Rail and vehicular transportation routes follow the meandering streams, occupying most of the level land of the narrow stream flood plains. From J. Clayton 2018 (pers. comm.): Although the stream tends to be turbid due to the soils and land use within the area, since 2010 the stream is even more sediment laden, almost appearing as a mud flow at times. This is primarily due to the extensive Marcellus gas activities in the area. While the well pad and drilling in of itself has not been that detrimental, the needed transmission lines (both gas and water) and access roads have significantly impacted the area. While much of this activity has not directly affected the mainstem Little Kanawha (pipeline crossings), it has significantly impacted the watershed. Over 30 open trench pipeline crossings have occurred or close to construction since 2011. Six major FERC regulated gas lines are currently being constructed across WV. The oil and gas coalition projects drilling for the next 50 years is expected to be significant (J. Clayton, WVDNR, 2018, Pers. comm.).
(28) Hughes River	High	impoundment, oil & gas activities	habitat and water quality degradation due to resource extraction activities would be same as that listed for South Fork and North Fork Hughes
(29) North Fork Hughes River	High	impoundment, oil & gas activities, logging (forest conversion)	From Miller and Payne 1999, p. 2: sedimentation from eroding soils is often a problem. ESI 1993, p. 19 cite water quality problems in the river associated with land use (Ag runoff, livestock in and near stream, oil development and sewage treatment) as potential reasons for lack of unionids at survey sites. Extensive Marcellus gas activities in the area. While the well pad and drilling in of itself has not been that detrimental, the needed transmission lines (both gas and water) and access roads have significantly impacted the area. Much of this activity has been upstream of the Dam which actually may help retain a small portion of the sediment load. There has been a new frack fluid processing plant placed above the lake. Associated with this is a salt landfill that is supposed to have 0 discharge. It is located on a

Population	Threat Level Category	Threats	References
			small tributary of the North Fork so if there are issues, they can be addressed before reaching the North Fork (J. Clayton, WVDNR, 2018, pers. comm.).
(30) Fink Creek	Moderate	resource extraction (oil & gas); habitat alteration and water quality degradation	An oil slick on water was noted at the only locality where the species was collected (WVDNR database 2018, Service 2019, unpublished data).
(31) Leading Creek	Moderate	resource extraction (oil & gas); habitat alteration and water quality degradation	3 of 5 sites sampled have been associated with pipeline construction activities. Schmidt et al. 1983 p. 136, sampled 1 site where the species was collected.
(32) Reedy Creek	Moderate	resource extraction (oil & gas); habitat alteration and water quality degradation	Only 1 live collection, 1 weathered dead collection, 1 historic museum record from OSUM (1961).
(33) Spring Creek	Moderate	resource extraction (oil & gas); habitat alteration and water quality degradation	Only recent live collection was associated with a pipeline construction project. Schmidt et al. 1983 p. 136, sampled 1 site where the species was collected.
(34) Middle Fork South Fork Hughes River	High	resource extraction (oil & gas); habitat alteration and water quality degradation	Only recent live collection was associated with a pipeline construction project
(35) South Fork Hughes River	High	resource extraction (oil & gas); habitat alteration and water quality degradation	From Miller and Payne 2000, p. 2: Sedimentation from eroding soils is often a problem. ESI 1993, p. 19 cite water quality problems in the river associated with land use (Ag runoff, livestock in and near stream, oil development and sewage treatment) as potential reasons for lack of unionids at survey sites. Extensive Marcellus gas activities in the area. While the

Population	Threat Level Category	Threats	References
			well pad and drilling in of itself has not been that detrimental, the needed transmission lines (both gas and water) and access roads have significantly impacted the area.
(36) Middle Branch Shade River	Moderate	resource extraction impacts, degradation of water quality and habitat; agriculture	Watters 1992b, p. 80 cites unstable substrates; Gbolo and Lopez 2013: The watershed was once mined for coal and has history of AMD. Treatment of this contamination is still being addressed by federal and local organizations. Sediment analyses indicated that iron, aluminum, and manganese, which are primary AMD species, are dominant within the sediments. Pollution indices indicated that the sediments were moderately to extremely polluted, with iron dominating. Intense remediation or treatment of mine drainage. The relationship between iron and other trace elements indicates that alkaline pH and redox conditions can influence the neutralization of AMD, and also result in the precipitation of iron and manganese oxide/hydroxides. This may have caused the contamination of the streambed sediment apart from factors including local geology, erosion of agricultural soil, mine discharge, and other anthropogenic input into the watershed.

Population	Threat Level Category	Threats	References
(37) East Branch Shade River	Moderate	resource extraction impacts, degradation of water quality and habitat	Gbolo and Lopez 2013: The watershed was once mined for coal and has history of AMD. Treatment of this contamination is still being addressed by federal and local organizations. Sediment analyses indicated that iron, aluminum, and manganese, which are primary AMD species, are dominant within the sediments. Pollution indices indicated that the sediments were moderately to extremely polluted, with iron dominating. The relationship between iron and other trace elements indicates that alkaline pH and redox conditions can influence the neutralization of AMD, and also result in the precipitation of iron and manganese oxide/hydroxides. This may have caused the contamination of the streambed sediment apart from factors including local geology, erosion of agricultural soil, mine discharge, and other anthropogenic input into the watershed.

Population	Threat Level Category	Threats	References
(38) Ohio River (Belleville Pool)	High	habitat loss and fragmentation due to impoundment, nonnative species (Zebra Mussel); anthropogenic impacts such as spills and contaminants as well as dredging & navigation	Only known extant occurrence in the Ohio River. From Watters and Flaute 2010, p. 1: the most dramatic declines in mussels were associated with the arrival of Zebra Mussels in the Ohio River in 1991. Pools with significant urban centers often had a loss of diversity well before the construction of dams or the arrival of Zebra Mussels; these losses are attributed to water quality problems associated with urban centers. Mussel diversity has thus declined in the Ohio River as the result of a three-fold problem: loss of water quality, existing dams, and Zebra Mussels. From J. Clayton, WVDNR 2019; pers. Comm.: Belleville Pool had a significant mussel kill in 1999 which impacted over 30 miles of river into pools downstream. At the source 100% mortality in right half of river. At bend in river, more mixing occurred and eventually impact width of river, still significant mortality but declined further away from outfall. In 2000 approximately 25% mortality of native mussels in the Belleville Pool died as a result of the Zebra Mussel levels.

Population	Threat Level Category	Threats	References
(39) Kanawha River (upper)	High	Resource extraction; Chemical releases, agriculture, nonnative species (Corbicula); anthropogenic impacts such as contaminants & spills; impoundment, dredging for navigation, and legacy commercial sand and gravel dredging.	Morris and Taylor (1978, p. 153) state that timbering and surface mining in the upper Kanawaha river contributes sizable sediment loads, and that the river for decades has had low water quality resulting from industrial, urban organic sewage, and acid mine runoff pollution. P. 155: Limiting factors for absence of unionids at lower sites may include industrial wastes, urban organic enrichment, and habitat destruction resulting from navigational impoundment, as well as the presence of the introduced Asian Clam, Corbicula. On 12 June 2014, a closed fly ash landfill discharged ash into the Kanawha River at Deepwater, London Pool, Fayette County, West Virginia. Current dredging only associated with lower and upper approaches to the lock chambers for navigation and associated with industry mooring and loading facilities. The Kanawha River valley contains significant deposits of coal and natural gas, and is dredged for navigation. From Clayton (2018, pers. comm.): In The Kanawha River, bulk of population is within the 5 mi reach of non-impounded riverine habitat from Kanawha Falls downstream to Deepwater near the head of the London Pool. Smaller densities occur within the Winfield, London and Marmet Pools. Threats include commercial fleeting attempting to expand to the head of navigation, and spills from vehicle transport along State Route 60 and CSX railroad. There is the possibility of future events that could result in toxic spills as railroad traverses both sides of the river.

Population	Threat Level Category	Threats	References
(40) Kanawha River (lower)	High	impoundment, agricultural activities, resource extraction; anthropogenic impacts such as chemical releases, contaminants & spills	The Kanawha River valley contains significant deposits of coal and natural gas, and is dredged for navigation. Most navigation traffic is related to the coal industry and as that declines so will the traffic. Commercial barge traffic and fleeting areas where coal is loaded and off-loaded. Dredging occurs at fleeting areas and the upstream and downstream approaches of the lock chambers. The potential for chronic impacts associated with the ash spill to mussel resources continues, and fly ash still covers the Kanawha River substrate (WVDNR 2015).In the impounded sections in the lower ends of the navigational pools, there is a large amount of coal fines evident in the predominantly sandy/gravel substrate. Much of this from the commercial barge traffic and fleeting areas where coal is loaded and off-loaded. Taylor 1983, p. 6 cites: Habitat degradation through navigation improvements, impoundments, water quality, in addition to heavy pollution loads from industrial and point source discharges, acid mine drainage, agricultural inputs.

(41) Elk River (WV)	High	1. Abandoned mine lands (metals associated with mining runoff). 2. Inadequate sewage treatment (unionized ammonia). 3. Erosion in the watershed - ESI 2009; Impoundment, industrial discharge timber treatment facility, combined sewer stormwater outfall. Water quality and habitat changes (erosion and subsequent sedimentation, scour) caused by sewage treatment problems and abandoned mine facilities, as well as, lack of best management practices during instream and riparian corridor construction and land use. Exposed pipeline construction led to localized changes in hydraulics which affected substrate stability.	In 1980 Sutton Dam was fitted with upper level discharge port. Per request of WVDNR fisheries biologist during high flows, water was all released from the bottom port to quickly reduce sediment within Sutton Lake. This resulted in significant cold water releases that most likely continued to impact mussel reproduction downstream. The Corps upon request agreed to modified discharge plan and began allowing as much water as possible through the upper port which reduced the temperature swings by about half. This is the limit of operational adjustments and any further attempts to restore natural temperature regime would require futher dam modification. Lack of reproduction and mussel die-offs are still occurring. Potential causes are harmful algal blooms, sewage discharges, timber treatment facility discharges, or others. From Butler 2007 - Primary threats include silvicultural activities, coal mining, and natural gas exploration and production. Riparian and floodplain roads and development raise concerns with contaminant runoff. Straight piping, sedimentation (especially from Big Sandy Creek in northeastern Kanawha County), and localized channel alterations are also threats. Sutton Dam impounds ~15 RMs and impacts tailwater habitat. ESI 2009, p. 19, cite abandoned mine lands, inadequate sewage treatment and erosion as being the primary factors currently affecting the Elk River unionid fauna, but also cold water releases from Sutton Dam between 1960-1980 contributed to lack of mussel recruitment and population densities. ESI 2009, p. 21: The changes in unionid abundances and distribution and lack of recruitment (cause of declines) seems to be water quality and habitat changes caused by sewage treatment problems and abandoned mine facility, as well as, lack of best management practices during instream and riparian corridor construction and land use.

Population	Threat Level Category	Threats	References
(42) Big Darby Creek	High	Enigmatic population declines, human development, agriculture, habitat and water quality degradation, resource extraction (gravel mining)	Threats to the mussel fauna include riparian deforestation, agricultural runoff, sedimentation, sand and gravel mining, heavy metals, and nutrient over-enrichment (agricultural and lawn care fertilizers) (Watters 1994). A mussel die-off event began in 2017 and is still unexplained, and the stream is in close proximity to the Columbus OH metropolitan area.
(43)Walnut Creek	Moderate	agriculture, human development	Swecker and Garofolo 2013a cite silt and sand substrates as part of open trench pipeline construction surveys
(44) Big Walnut Creek	High	impoundment, habitat and water quality degradation; resource extraction (sand and gravel mining)	Hoggarth and Grumney 2016, p. 57 lists impoundment, nutrient enrichment, and sand and gravel operations as threats. Hoover Dam also limits dispersal and host fish movement. Hoggarth and Grumney, 2016, p. 62: lists land use practices and decline of water and habitat quality. Also scour and habitat impacts from flood events.
(45) Middle Fork Salt Creek	Low	Impoundment, habitat fragmentation, agriculture	A series of system reservoirs on the mainstem Scioto River mostly north of Columbus reduced habitat and the location of the Columbus Metropolitan Area in the heart of the watershed has also likely contributed to fragmentation of populations of the species in the drainage.
(46) Scioto River	High	impoundment; water quality and habitat degradation as a result of human population growth in and around Columbus, OH	The Scioto River system has been one of the most routinely sampled watersheds for mussels over the past 50 years. The location of the Columbus Metropolitan Area in the heart of the watershed has undoubtedly contributed to the decline of the mussel fauna. The historical literature suggests that the fauna was negatively affected in the Scioto River main stem as far back as the 1850s, when major impacts appeared to include sawdust, and brewery and slaughterhouse wastes (Stansbery 1962). Stansbery (1962) noted the complete absence of mussels in the Scioto downstream of Columbus to Circleville (~40 RMs). A series of reservoirs in the watershed reduced habitat and probably contributed to the elimination of some populations in several streams (e.g., Olentangy, upper Scioto Rivers; Alum, Big Walnut, Deer Creek dams).

Population	Threat Level Category	Threats	References
(47) Licking River	Moderate	Impoundment, water quality degradation through hypolimnetic discharges, habitat degradation	A linear population distributed below Cave Run Lake Dam. Water quality problems in the Licking River drainage are nutrients, bacteria, and sediments. Also, lack of stream buffers, channelization, and wastewater discharge are cited as contributing to water quality problems (KYDOW 1998). Hardison and Layzer (2001, p. 79) indicate hydrological instability and specifically high shear stress and scour from high flows limits mussel distribution and recruitment in the Licking River, KY, where O. *subrotund*a is known to occur below a flood control dam operated by the Corps. Constructed in 1974, Cave Run Reservoir impounded 38 RMs of the upper Licking which impacted mussel habitat, and spikes in cold tailwater releases continue to impact the river. Other threats include sedimentation, agricultural runoff, and sewage pollution. (Butler 2007, p. 53).
(48) Middle Fork Kentucky River	High	Resource extraction, water quality degradation, human population growth	Haag & Cicerello 2016, p. 18: Coal mining has degraded water quality in many areas and several sizeable communities on the river or its tributaries further degrade water quality.

Population	Threat Level Category	Threats	References
(49) South Fork Kentucky River	High	water quality degradation from agricultural and mining impacts;	From Evans 2010: Threats observed to the mollusk fauna in the South Fork Kentucky basin are numerous. Overall, perturbations to the mollusk fauna of the basin likely stem from water quality and habitat conditions as opposed to a net hydrological alteration in the basin. In the Goose Creek watershed, coal mining and floodplain agriculture has taken a visible toll on the mussel fauna. Coal deposits, in the form of coal fines and coal pieces, were visible at many sites in mainstem Goose Creek. Further, several areas examined in Goose Creek were scoured down to bedrock, possibly as a result of long-term hydrological alterations in the watershed and a complete lack of riparian area along several stretches of the mainstem. Lower sections of Collins Fork (RK 4.0 to 10.5), is listed on the KY DOW 303(d) list as being impaired due to sedimentation. Acid drainage was noted on the South Fork Kentucky coming out of several tributaries; namely the confluences of Indian Creek, Fish Creek, Matton Creek, and in Booneville above KY 28 bridge. Coal and coal fines was present in the river in the Chestnut Gap area upstream of Booneville and acid seeps were seen coming into the river in the area west of Eversole in this river reach. At one of the lowermost sites on the Redbird River a new surface mining operation upstream of Laurel Branch was beginning operation during this study. From Butler 2005 p. 41 (rabbitsfoot): Threats in the system include coal mining, sedimentation, straight piping of untreated domestic effluents, municipal wastewater, and runoff of various other pollutants in the steep terrain characteristic of this Cumberland Plateau watershed.

Population	Threat Level Category	Threats	References
(50) Red Bird River	Moderate	water quality degradation from agricultural and mining impacts	From Haag and Cicerello 2016, p. 18: Coal mining has degraded water quality in many areas and several sizeable communities on the river or its tributaries further degrade water quality; impacts associated with population growth in the narrow stream valleys.
(51) Red River	High	Impoundment; habitat and water quality degradation due to agriculture (sedimentation)	Houp 1993 p. 93 long-term sedimentation, habitat and water quality degradation
(52) Kentucky River	High	impoundment; habitat and water quality degradation due to agriculture and mining impacts (sedimentation)	Listed as of commercial importance for button industry "good value" Danglade (1922, p. 5): Indicates overharvest as a past threat. Domestic and Municipal pollution, coal mining, oil drilling. A total of 259 RMs is pooled behind 14 locks and dams, which eliminated most shallow shoal habitats, and extensive agriculture in floodplains. From Haag and Cicerello 2016 p. 18: The Kentucky River downstream of the forks is a large stream. Three major reservoirs exist in the drainage: Herrington Lake (Dix River), Buckhorn Lake (Middle Fork Kentucky River), and Carr Fork Lake (Carr Fork).

Population	Threat Level Category	Threats	References
(53) Tippecanoe River	Moderate	Agriculture, Impoundment, nonnative species	Water withdrawal for irrigation, drought in 2012 (Fisher, INDNR, pers. comm. 2018). Mussel threats in the Tippecanoe River were noted by Cummings and Berlocher (1990) and Ecological Specialists, Inc. (1993a). They include evidence of nutrient enrichment manifest in abundance of filamentous algae in some reaches. Turbidity increases in downstream areas indicated that streambank and other sources of erosion were more prevalent than they were upstream. Unrestricted cattle access in some riparian areas is a sedimentation and nutrification concern. The extent of suitable habitat in the lower river has been compromised by two major reservoirs, Shafer and Freeman. Mussel populations in general below the impoundments are highly localized in deeper pools and comprised primarily of species indicative of slow water and soft substrate habitats generally associated with impoundments. This indicated riffle habitats may be impacted by tailwater conditions, such as temporary exposure during low flow releases. The Zebra Mussel has been documented from the watershed for over 20 years but never show up in high density in the Tippecane River itself (Fisher, 2019, pers. comm.).
(54) Eel River (Wabash)	Moderate	Impoundment; Habitat and water quality degradation; agriculture	A dam at the mouth of the Eel River precludes movement from the Wabash River into the Eel. Gammon and Gammon 1993, p. 78-79, mention stream channelization activities causing erosion and scoured banks, as well as lack of riparian vegetation, and non-point source pollution leading to measured high turbidity readings, and high levels of suspended sediment
(55) Richland Creek	Low	Contaminants, Agriculture, Human Development, Logging (forest conversion)	IDEM (2012), p. 9 lists: *E.coli*, Agricultural impacts, Bank Erosion, Flooding, human development, logging and other impacts such as garbage disposal and invasive species in the Plummer and Richland Creek watersheds. Contaminants have been a problem in the headwaters of Richland Creek (Fisher 2019, pers. comm.).

Population	Threat Level Category	Threats	References
(56) Green River (upper)	Moderate	impoundment - habitat loss & water quality degradation; resource extraction; past commercial harvest threat	There are multiple dams on the Green River mainstem, the largest of which is Green River dam which contributes to hydrological instability (Hardison and Layzer 2001, p. 77). The KY CWCS lists the following as threats to the species: Aquatic habitat degradation, loss of fish hosts, point and non-point source pollution, siltation and increased turbidity. Cochran and Layzer 1993, p. 64, determined that mussels in the middle Green and Lower Barren Rivers selected habitats that were less impacted by commercial harvest activities. This reach of the river was more heavily impacted by towboats before reduced commercial traffic. Miller *et al.* (1994, p. 53) also cite hypolimnetic discharges as an impact to the Green River mussel fauna.
(57) Barren River	Moderate	impoundment - habitat loss & water quality degradation; resource extraction; past commercial harvest threat	There are multiple dams on the Barren River mainstem. The KY CWCS (2015) lists the following as threats to the species: Aquatic habitat degradation, loss of fish hosts, point and non-point source pollution, siltation and increased turbidity. Cochran and Layzer (1993, p. 64) determined that mussels in the middle Green and Lower Barren Rivers selected habitats that were less impacted by commercial harvest activities. This reach of the river was more heavily impacted by towboats before reduced commercial traffic.
CUMBERLAND RIVER BASIN			
(58) Buck Creek	High	Habitat loss/alteration due to Resource Extraction (Coal Mining, Oil Drilling, gravel mining), Impoundment	Hagman 2000, p. 30 cites flow alteration though impoundment, non-point source pollution, and erosion/siltation through ATV usage, livestock access, row crops associated with agriculture, gravel dredging, lack of riparian buffer and bank instability as affecting Buck Creek water quality and mussel habitat. Haag and Cicerello, 2016, p. 14: The middle Cumberland River drainage has been completely transformed by Wolf Creek Dam.
(59) Rockcastle River	High	Resource Extraction (Coal Mining, Oil Drilling), Impoundment	Haag and Cicerello, 2016, p. 14: The middle Cumberland River drainage has been completely transformed by Wolf Creek Dam. Houp and Smathers 1995 cite surface mining in the headwaters and excessive sedimentation as affecting the mussel fauna in the Rockcastle drainage.

Population	Threat Level Category	Threats	References
TENNESSEE RIVER BASIN			
(60) Paint Rock River	High	Habitat loss through alteration (snag removal), habitat fragmentation – population isolation due to impoundment; agriculture	The Paint Rock River drainage was severely affected in past decades by small impoundments, stream channelization, erosion, and agricultural runoff. A major detrimental impact on habitat occurred with the channelization and removal of snags and riverbank timber in the upper drainage and the lower reaches of Larkin and Estill forks and Hurricane Creek by the Corps during the 1960s (Ahlstedt 1995-96). This direct headwater habitat manipulation was probably a large contributor to freshwater mussel loss in the drainage. Wheeler Dam was completed by the Tennessee Valley Authority (TVA) in 1936, resulting in loss of most of the mussel fauna and riverine habitat in the lower 21 km of the Paint Rock River (Ahlstedt 1995-96).
(61) Tennessee River (Kentucky Reservoir)	High	Impoundment, dredging/navigation impacts, agriculture	Commercial sand and gravel dredging, conducted on the Lower Tennessee River since at least the 1920's, and currently permitted on approximately 48 of the 95 river miles in this reach has degraded a significant portion of the available aquatic habitat. Significantly lower mussel abundance and diversity values have been observed at dredge sites indicating bottom substrates altered by dredging and resource extraction operations do not provide suitable habitat to support mussel populations similar to those found inhabiting non-dredged reaches (Hubbs et al. 2006)
(62) Elk River (TN)	Moderate	Impoundment, water quality degradation (hypolimnetic discharges suppressed recruitment for decades) agricultural impacts to habitat and water quality	The Elk River in Tennessee, which has significant agricultural activity throughout the watershed, irrigation impacts (Hoos *et al.* 2000). Additionally, construction and operation of Tims Ford Dam altered the fauna considerably above Harms Mill dam at Fayetteville TN. Although the operations have changed, the lack of mussel recruitment above Harms Mill Dam indicates that translocation or propagation for population restoration is likely needed.
(63) Duck River	Moderate	Water quality degradation through agriculture (conversion of pasture to row-crop) and increased human development (rapid expansion of	Rapidly increasing human development pressure (Hubbs, 2019, pers. comm.), agricultural impacts such as water withdrawals for irrigation and cattle. Small and large impoundment. Urban development is increasing rapidly throughout the Duck River drainage, resulting in the large-scale removal of riparian vegetation. Although improvements made at Normandy

Population	Threat Level Category	Threats	References
		metro-Nashville). Impoundment (Normandy Dam & 3 mill dams) fragment population	Dam regarding flows and dissolved oxygen, the presence of the impoundment limits colonization potential upstream.
(64) Buffalo River	Moderate	Human development; Water quality degradation through agriculture (conversion of pasture to row-crop); habitat degradation (hydrological alteration)	Reed 2014, p. 13 cites increases in human population and associated municipal effluent as the primary source of degradation in Buffalo River tributaries. Additional increased herbicide and pesticide use and changes to hydrology were also cited as contributors to mussel decline in the river.
LOWER MISSISSIPPI BASIN			
(65) Big Black River	High	Population isolation, reduced gene flow, agricultural impacts impoundment	Only remaining population in Lower Mississippi Basin, severely fragmented from populations in other basins. Restricted to small reach of stream in Montgomery Co., MS. Intensive agricultural activities have contributed substantial surface runoff within the Big Black River, which covers substrates used for settlement (Jones *et al.* 2005, p. 84). Hartfield 1993, p. 133 cites channel instability and localized channel adjustments as severe impacts to mussels in the Big Black River.