The Nature Conservancy
Protecting nature. Preserving life.™


© Barry Truit, TNC


© Donna A. Dewhurst, U.S. Fish & Wildlife

Northwest Atlantic Marine Ecoregional Assessment: species, habitats and ecosystems

Phase One


© Hal Brindley

Acknowledgements

The Northwest Atlantic Marine Ecoregional Assessment (NAM ERA) was a major undertaking which could not have been successfully completed without the active engagement and hard work of many dedicated people. The help we received from numerous talented and dedicated individuals within state and federal government agencies, academic institutions, industry groups, and other non-governmental organizations was tremendous. We are deeply grateful to everyone who supported our work, gave us critical and sound advice, and spent long hours helping us to develop products designed to advance marine conservation in our region.

We are particularly grateful for the contributions by members of the eleven technical science teams who spent long hours working with us, sharing their expertise, recommendations, ideas, and methods on how best to organize and analyze data on important marine species, habitats and ocean conditions. Above all, we want to extend our gratitude to our three external science advisors, Dr. Peter Auster (University of Connecticut), Dr. Les Kaufman (Boston University) and Dr. Heather Leslie (Brown University), who supported the NAM ERA from its inception and who made themselves available throughout the two year process, providing helpful advice, answering questions, clarifying technical points and offering insights as the work progressed. We tried to faithfully transfer suggestions, advice and knowledge to these pages but any mistakes or errors in this report are owned by us alone.

The Conservancy owes a huge debt of gratitude to Sally Yozell whose bold vision and enthusiastic leadership guided and propelled this project from its inception until shortly before it was completed. We wish her the best of success in her new position and hope that she will be proud of what she accomplished for The Nature Conservancy while she was with us. We relied on an enthusiastic Core Team to provide vision, leadership and innovative thinking throughout the development and production of the NAM ERA. The Conservancy's rock-solid GIS Team (Chris Bruce, Juanmin Chen, Melissa Clark, Dan Coker, Ryan Gordon, Alex Jospe, Erik Martin, Dan Morse, Kevin Ruddock, and Arlene Olivero) did much of the heavy lifting and made sure the analysis, maps, and metadata were complete, accurate and professional. Pam Crosby and Chelsea Todd provided outstanding service as they attended to complex logistical requirements for planning and holding two large two-day peer review workshops. We are grateful for the hard work and support of our graphic designer, Scott Hancock. We are also grateful for the patience, support and guidance from our senior manager sponsors -- Janet Coit, Lise Hanners and Michael Lipford. Finally, we are extremely grateful to all of The Nature Conservancy's members and especially the Gordon and Betty Moore Foundation and the Forrest and Frances Lattner Foundation

Assessment Core Team

Sally Yozell	Project Lead
Jennifer Greene	Project Manager
Geoffrey Smith	Gulf of Maine Subregional Team Lead
Marci Bortman	Southern New England Subregional Team Lead
Jay Odell	Mid-Atlantic Subregional Team Lead
Mark Anderson	Science Team Co-Lead
Caroly Shumway	Science Team Co-Lead
Lise Hanners	Eastern U.S. Conservation Region Coordinator
Zach Ferdana	Technical Science and Planning Advisor
Kate Killerlain Morrison	Communications Team Lead
Melissa Clark	Data Management Team Lead

Science Advisory Committee

Les Kaufman	Boston University
Peter Auster	University of Connecticut
Heather Leslie	Brown University

Please cite as:
Greene, J.K., M.G. Anderson, J. Odell, and N. Steinberg, eds. 2010. The Northwest Atlantic Marine Ecoregional Assessment: Species, Habitats and Ecosystems. Phase One. The Nature Conservancy, Eastern U.S. Division, Boston, MA.

CHAPTER

1

Introduction

Mark Anderson, Jay Odell, and Caroly Shumway

Introduction to Ecoregional Assessments

The ocean provides the largest living environment on Earth and is home to millions of species, some as yet undiscovered. All of Earth's biodiversity depends on the ocean's life-support services. The ocean regulates climate, mediates global nutrient and sediment cycles, and powers food-webs that span the poles. Humans depend on the ocean for transportation, recreation, energy, and food. Human survival and well-being is tightly linked to the condition of coastal and ocean ecosystems. For example, more than three billion people derive at least one-fifth of their needed protein from fresh and saltwater fish. The United States commercial fishing industry is valued at $28 billion and the recreational saltwater fishing industry at about $20 billion (USCOP 2004).

© Hal Brindley

Recognizing the vital role of marine ecosystems to the health of the planet and the increasingly strong human dependency on ocean resources, The Nature Conservancy (TNC) has endeavored to synthesize data on species distributions, geology, oceanography, chemistry, biology and social science to create maps and other tools that reveal conservation priorities and inform management decisions to help sustain coastal and marine ecosystems and the people that depend on them. This process, known as an **ecoregional assessment,** is part of a TNC wide effort supported by its Global Marine Initiative to protect and restore ocean and coastal ecosystems. Since the early 1990s, TNC has focused on expanding expertise in the marine realm, and now has about 130 staff members working on marine conservation around the world. To date, TNC has completed 10 marine ecoregional assessments, and many more are pending.

The Ecoregional Assessment Process

Ecoregional assessments provide a vision of success for conserving the biodiversity of an ecoregion, a large, relatively distinct area that shares similar climate, topography or assemblages of species. TNC is working with partners to develop ecoregional assessments for every ecoregion in North America, from the Central California Coast to the Northern Appalachians of New England and Maritime Canada.

Important steps in the ecoregional planning process, whether applied to terrestrial or marine and coastal ecosystems, include (Groves et al. 2002):

1. Identification of the species, habitats and ecological processes (conservation targets) that best represent the biodiversity of the ecoregion.
2. Collection of data and information on the targets' ecology, distribution, current condition and vulnerability to human uses and/or environmental changes (threats).
3. Determination of conservation goals for the targets (e.g. population size, areal coverage, distribution).
4. Identification of a set of sites and strategies for meeting conservation goals for the targets.

Introduction to this Assessment

The Northwest Atlantic region is known for its cold, nutrient-rich, and highly productive waters that have sustained regional economies for centuries. With its strong tidal flows, complex circulation patterns, and varied seafloor topography the region supports large diverse populations of bottom dwelling fish and an array of benthic communities. The deep basins and shallow banks of the Gulf of Maine, with seasonal concentrations of plankton and forage fish, attract an impressive number of marine mammals. Farther south, the broad continental margin, large estuaries, and deep submarine canyons function as nursery areas for estuary dependent fishes, critical stopover sites for millions of seabirds, migratory pathways for large pelagic species, and key habitat for coldwater corals.

While the accumulated pressures of population growth and human use of the coasts and oceans have resulted in widespread damage and loss to marine and coastal habitats and species, there is nonetheless, significant evidence of resilience and opportunity for actions to conserve and restore the Northwest Atlantic's marine biodiversity and ecosystem services. This assessment highlights the areas in this region where significant species, natural communities and ecological processes hold the greatest promise for conservation success. This information, in turn, will provide the basis for developing a suite of strategies, from resource management to marine spatial planning, for achieving that success.

This assessment is intended to support regional ecosystem-based management (EBM), an approach previously endorsed by several blue-ribbon panels and recently by the United States Ocean Policy Task Force. Ecosystem based management approaches acknowledge the interconnections between air, land, sea, marine organisms and people, and the dynamic interactions between living resources and their environments. Such approaches are most effective when management of multiple human activities is integrated rather than conducted in sector specific isolation (see Pew Oceans Commission 2003; USCOP 2004; JOCI 2006; OPTF 2009). Around the world, marine resource managers are now seeking to implement EBM to improve conservation of coastal and marine environments. In recognition that political boundaries are essentially irrelevant to marine ecosystem function, EBM planning areas are defined by biogeographic rather than political boundaries.

In order to advance these overarching goals, this assessment integrates information about multiple species and their habitats. The results summarized in this report include maps and data on concentrations of high biodiversity and critical species specific areas for refuge, forage and spawning, and also some of the limited available spatial data for human uses such as shipping lanes, port facilities, energy development, fishing effort, dredge sites and locations of shoreline armoring. The Northwest Atlantic Marine Ecoregional Assessment is designed to be used by diverse stakeholders to inform diverse decisions, to be freely available online for public use. For direct access to assessment data, please visit www.nature.org/namera/.

The Nature Conservancy's goals in conducting the Northwest Atlantic Marine Ecoregional Assessment were to produce a baseline of scientific information on the distribution and status of key habitats and species (Phase One), and a map and report of priority conservation areas for the region's marine biodiversity (Phase Two). The latter used information collected in the first phase to identify areas important to myriad species including seagrass, oysters, diverse migratory and resident fishes, sea turtles, marine mammals, and coldwater corals.

The products of the two phases include:

Phase One:

- A database of information on marine ecosystems, habitats and target species at the Northwest Atlantic regional scale.
- Maps that synthesize diverse spatial data, designed to meet multiple objectives for a variety of users, including support of decisions about conservation and resource use.
- A narrative report of the approach and methods used to build the decision support database, as well as a description of current conditions and trends in all the marine, habitats, species and human uses that were included in the analysis.

Phase Two:

- A narrative report that describes the priority places and strategies that TNC recommends for conservation action within the Northwest Atlantic region, based on analysis by teams of experts, of information gathered in Phase One.

Developing ecoregional assessments for the ocean is inherently more difficult than on land because ocean ecosystems are dominated by three dimensional and highly dynamic processes, and because precise data on the location of key habitats and species are often not available.

However, the authors of this assessment were fortunate to be working within one of the world's most well studied regions and grateful for the opportunity to integrate millions of records of data collected over several decades and graciously contributed by expert researchers from the National Oceanic and Atmospheric Administration (NOAA), the United States Geological Survey (USGS), and several other agencies and institutions listed elsewhere in this report. This rests on the foundation of data created by many scientists whose careers have been devoted to advancing knowledge of Northwest Atlantic marine ecosystems, and on the methodology from previous Conservancy assessment projects.

Over 1200 data files, from over 100 sources, were compiled for this assessment. Every effort was made to understand, and account for, the idiosyncrasies of each dataset, and to respect the value of each source. For each dataset, we contacted the source, met with the people responsible for the data to learn from their experience in collecting and processing the information, and shared our maps and analysis with them through written materials, meetings and phone calls. Any mistakes or oversights in the use of data are solely the responsibility of the authors. Moreover, the willingness of an organization or individual to contribute data to this assessment does not imply an endorsement of the final products.

Despite the availability of considerably more relevant data than is typically available for marine assessments, the challenges noted above persist, resulting in map products that contain more uncertainty, or are at coarser scales, than would be ideal. However, a balance must be struck between delaying actions because of imperfect data, and taking actions based on what we do know in the face of significant threats to marine biodiversity and associated ecosystem services. The results of this assessment are provided with caveats noted, and with the expectation that data gaps will help to inform and prioritize future survey efforts.

There is, and will continue to be, a healthy debate on many aspects of marine conservation. We hope however that we used each dataset appropriately, transparently, and in an unbiased manner. And that this work will aid others in coming to their own conclusions with respect to the conservation of marine biodiversity.

This assessment is envisioned as a mechanism to empower partners, resource users and governments to develop strategies for long-term sustainability of the Northwest Atlantic's ecological services, from the fisheries that feed human populations, to the reefs and barrier islands that absorb wave action and storm surges as sea level rises. The ultimate measure of its success is tangible effective marine conservation.

Northwest Atlantic Assessment Teams

The Northwest Atlantic Marine Assessment was led by a Core Team of Conservancy staff that included representatives from the three subregions in the study area. The Core Team conducted monthly meetings to direct the assessment process and other technical issues that arose. Separate teams were also developed to address the following issues:

- The Data Management Team identified existing data sources and produced maps and Geographic Information Systems that synthesize multiple data layers.
- The Communications Team coordinated public outreach and conducted a survey of stakeholders about their views of the region, and need for data and potential uses of the assessment.
- The Science Team established and organized eleven technical teams, composed of experts in the field, to review, compile and analyze data for each of the focal species and habitats. Each team had a TNC leader who was responsible for working external team members, and drafting and completing the chapters in this report.

The role of the technical teams was to provide guidance to the team leader on the selection of species and habitats, to review data products, provide critical review on the chapters, and ensure that the analyses used were appropriate to the data and species. Members of each technical science team are listed in each chapter.

The Conservancy is extremely grateful to the large number of scientific experts and representatives from government, industry and academia that provided assistance as technical team members or as participants in our peer review workshops.

This assessment is built on the foundation laid by many previous assessments of all or part of the region (see NRDC 2001; Department of Navy 2005; NCCOS 2006; CLF/WWF 2007; Cook and Auster 2007; NMFS 2009). As our understanding of marine systems grows, and as tools for analyzing dynamic spatial processes increase in sophistication, we expect more refined and comprehensive assessments to emerge. Just as this assessment utilized earlier ecoregional plans and data where it existed, the Conservancy anticipates that future assessments will build upon this baseline as scientific knowledge advances and methods are further refined.

The Study Area: The Northwest Atlantic

As defined in this assessment, the Northwest Atlantic region spans the area from Cape Hatteras in North Carolina to the northern limit of the Gulf of Maine in Canadian waters, and extends from the mean high tide mark seaward to the foot of the continental slope (depth of 2500 m). The study area includes the shorelines of 11 states and two Canadian provinces inhabited by more than 65 million people.

The Northwest Atlantic Marine Ecoregional Assessment focuses on two distinct and well-documented marine ecoregions – the Acadian (Gulf of Maine/Bay of Fundy) and the Virginian (Briggs 1974; Spalding et al. 2007). These two ecoregions nest together within the larger Cold Temperate Northwest Atlantic Province, and the similarly bounded Northeast Continental Shelf Large Marine Ecosystem (Spalding et al. 2007; Sherman et al. 1988).

The 140,745 square mile Northwest Atlantic study area is divided into three ecological sub-regions (Figure 1-1). These subregions were also based on biogeographic rather than political considerations to enable geographically appropriate analytical approaches to produce maps and tools to guide ecosystem based conservation. The three subregions described below have distinct and unique characteristics; stratifying our analyses by subregions enabled more meaningful and robust analysis of each subregion's characteristic habitats and species.

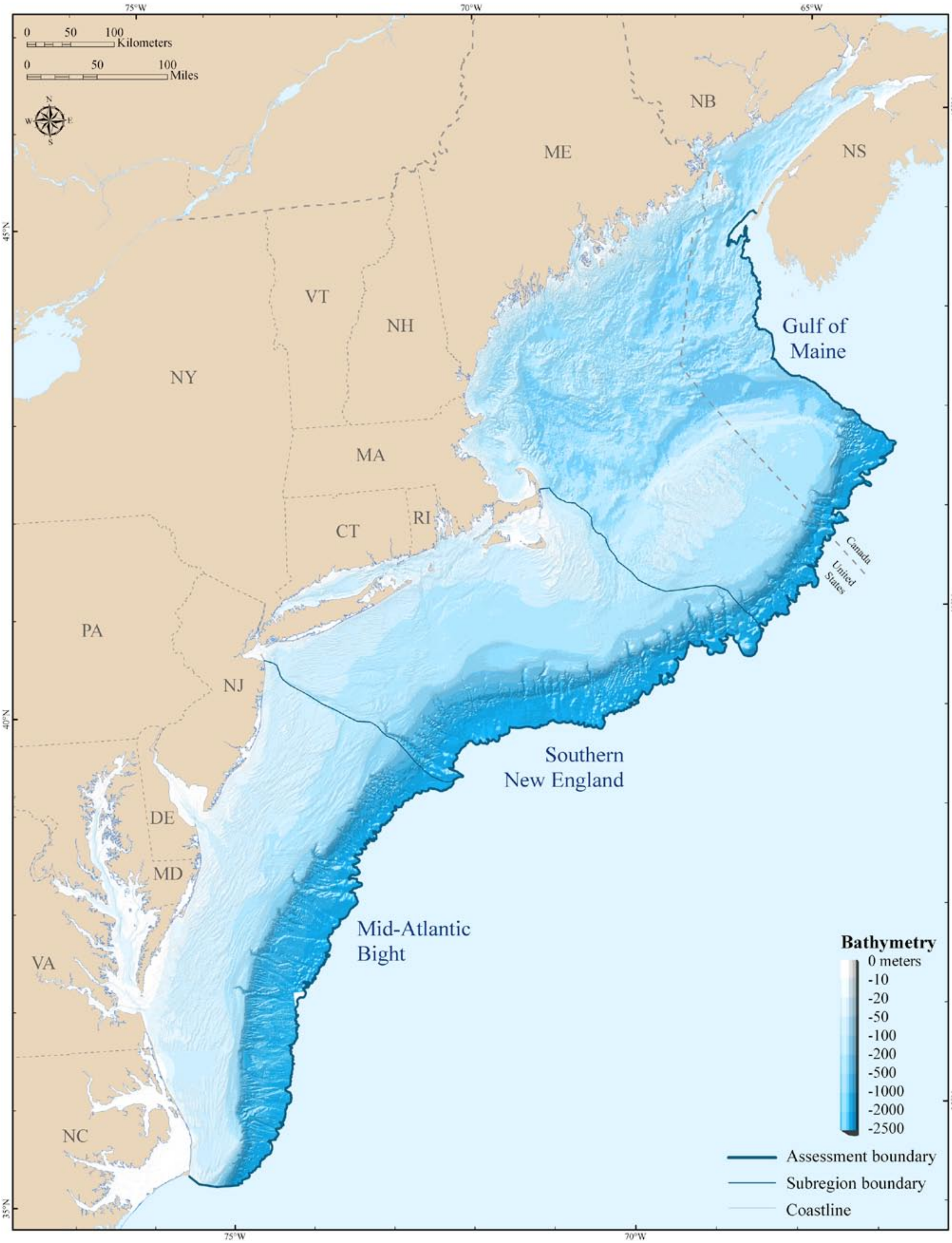


Figure 1-1. The Northwest Atlantic Marine Ecoregional Assessment study area.

1) Gulf of Maine, from Nova Scotia's Bay of Fundy to the tip of Cape Cod, including Georges Bank;
2) Southern New England, ranging from the base of Cape Cod to the southern coast of Long Island;
3) Mid-Atlantic Bight, from Sandy Hook, New Jersey south to Cape Hatteras, North Carolina.

Gulf of Maine Biogeography

The Gulf of Maine is a semi-enclosed sea located in the Gulf of Maine/Bay of Fundy ecoregion of the Cold Temperate Northwest Atlantic marine province (Spalding et al. 2007). The Gulf is bounded by Georges Bank and Browns Bank to the east and the coastlines and near-shore estuarine waters of Massachusetts, New Hampshire, Maine, New Brunswick, and Nova Scotia to the west and north. The Gulf spans over 90,000 square kilometers and has average depth of 150 meters.

The geology of the Gulf has been shaped by glaciation, volcanism, erosion, subsidence, and sea level rise and features prominent banks, basins and channels. The most notable seafloor features include: Georges Bank, Browns Bank, Georges Basin, and the Northeast Channel to the east; Stellwagen Bank, Jeffreys Ledge, Cashes Ledge, and Wilkinson Basin to the west; the Great South Channel to the south; and Jordan basin to the north. There are four hydrographically distinct sub-regions in the Gulf of Maine each having unique physical, hydrographic, and oceanographic conditions: estuarine areas, coastal regions, the central Gulf, and shallow offshore banks (NCCOS 2006).

The Gulf of Maine is one of the most productive marine systems on the planet. The Gulf's high productivity is heavily influenced by interactions between the Labrador Current from the north and the Gulf Stream from the south. When these currents meet, cold nutrient-rich water enters the Gulf through the Northeast Channel. These currents and tidal action in the Bay of Fundy create a counter-clockwise gyre that delivers nutrient-rich waters to the Gulf's banks and ledges, and along the coastal shelf. These nutrient-rich waters rise to the surface and enter the euphotic zone, creating optimal conditions for phytoplankton production, with primary productivity levels ranging from 270 gC m-2 yr-l in the offshore waters of the Gulf to over 400 gC m-2 yr-l on Georges Bank (Townsend et al. 2006). These high levels of primary productivity support a wide diversity of zooplankton species (predominantly copepods) and planktivorous fishes that form the base of the Gulf of Maine food web.

High rates of primary and secondary productivity in the Gulf of Maine support a wide diversity of marine life. Planktivorous fish including herring, mackerel, sand lance, and menhaden that thrive in the Gulf provide a critical forage base for a variety of species including demersal fishes, tunas, whales, marine mammals, and birds. The diversity of marine life in the Gulf if also characterized by a diversity of organisms including anemones, sea stars, sponges, kelp forests, and deep water corals.

Southern New England Biogeography

The Southern New England bays, beaches and rivers stretch from the mouth of the Hudson River to the tip of Cape Cod, and include four National Estuarine Reserves (Peconic Bay, Long Island Sound, Narragansett Bay, and Buzzard's Bay). The region shares a glacial moraine that creates the east-west archipelago of Long Island-Block Island-Martha's Vineyard (USFWS 1997). The subregion's rivers historically supported vast American shad runs, eel populations, and even Atlantic salmon, all of which have severely declined and are now highly managed. This subregion includes parts of what is often referred to as the American "megalopolis" from Boston to Washington that is home to one-in-five Americans although it only makes up 1.5% of the United States' landmass (Gottman 1961). Roughly 12.25 million people live in the subregion, with roughly 7.5 million on Long Island alone (US Census 2001).

This landscape encompasses several highly productive ecosystems situated in the most densely populated region of the Unites States. The coastal stretches of this region are comprised of beaches, bluffs, dunes, rocky shores, bays, estuaries, mud flats, tidal wetlands, and maritime forests. These coastal wetlands and beaches are home to a variety of shorebirds such as osprey, herons, egrets, oyster catchers, plovers, terns, sandpipers and gulls.

The shallow estuaries and embayments are home to a wide variety of migratory marine species that give this temperate region its unique character (Weiss 1995). Large mammals such as harbor seals and harbor porpoises have been frequently documented migrating close to shore. The region is also home to a variety of migratory fishes, many of which are commercially and recreationally important species including bluefish, bass, toadfish, flounder, shad, herring, menhaden and mackerel.

The subregion is well known for its productive estuaries that have historically supported thriving shellfish industries and a cultural history centering around the productive maritime industry. Subregional favorites include oysters, hard and soft shell clams, razor clams, bay scallops, and quahogs. Horseshoe crabs can be found on the shorelines throughout the landscape, as well as blue crabs, spider crabs, and fiddler crabs.

Mid-Atlantic Bight Biogeography

The Mid-Atlantic Bight extends from Cape Hatteras in North Carolina to Sandy Hook, New Jersey and is a transitional area between the rocky shores of New England and gently sloping, warmer South Atlantic. The Mid-Atlantic's oceanographic features, diversity and ecology are strongly influenced by two very large estuaries - Chesapeake Bay and Delaware Bay. Like the Gulf of Maine and Southern New England, the Mid-Atlantic is a highly productive region of one of the world's most productive large marine ecosystems.

The topography of the Mid-Atlantic is characterized as mostly flat, with low relief features such as sandy shoals and swales, sand wedges and waves, and relict coastal features with major submarine canyons at the shelf-slope break. The complex of shoals and swales are important structural features supporting biologically diverse and abundant benthic macrofauna, demersal fish, and foraging concentrations of sea birds, sea ducks and bottlenose dolphins. The shelf is typically covered by a sheet of medium-to-coarse grained sands with occasional pockets of sand-shell and sand-gravel sediments (Wigley and Theroux 1981). Natural hard bottom habitat is relatively scarce compared to the Southern New England and Gulf of Maine subregions. However, coldwater coral patch reef communities with associated structure oriented fish like black seabass and tautog are present, though poorly mapped at this time.

Warm core rings, filaments and mid-water intrusions peel off the meanders in the Gulf Stream, moving warmer, higher salinity pockets of waters from the slope westward across the shelf towards the coast. When these currents cross over topographic highs such as shoals or ridges - and notably canyon heads - they create significant cold-water upwellings and extremely productive biological events (Walsh et al. 1978). The freshwater outputs of the Chesapeake and Delaware bays function similarly to the Gulf Stream through their large plumes which collide with tidal forces to create highly productive nearshore upwelling events that support diverse marine life.

Due to its intermediate position between the cool New England and warm southeastern United States waters, the Mid-Atlantic subregion provides a critical migratory pathway with abundant forage resources for many migratory species from striped bass to right whales.

The Mid-Atlantic's chain of barrier islands includes roughly 30 inlets, formed by the interaction action of waves and currents with mainland drainages and underlying ancient river valleys. These inlets are important ecological systems in the Mid-Atlantic as well, functioning as corridors between the coastal lagoons and the shelf waters. The Mid-Atlantic's inlets and lagoons provide critical spawning areas for sciaenids such as drum, spot, croaker and sea trout, pupping grounds for coastal elasmobranches like sandbar shark, dusky sharks and sand tiger, foraging and nursery habitat for all life stages of the bottlenose dolphin, juvenile habitat for loggerhead turtles and low energy beaches for horseshoe crab spawning.

Species and Habitats Selection

A suite of habitats and species, characteristic and representative of the full diversity of the region were selected in consultation with external technical advisors. The Conservancy's standard conservation planning methods usually refers to the habitats and species one seeks to conserve as **conservation targets**. Although this methodology has been adopted or modified by many groups around the world, the terminology can be confusing. In this report, conservation targets are simply the habitats, species, and processes we focused on and not targets in the sense of numerical goals.

The concept of coarse and fine filters was used in selecting conservation targets in this assessment. The "coarse filter" approach is based on the efficiency of using large-scale habitat conservation strategies to benefit many species at once. Two habitat targets, coastal shorelines and benthic habitats, were indentified to serve as coarse filters to account for all the species and processes that they support. Both of these habitats were mapped comprehensively across the region, classified into many subtypes based on structure and composition, and characterized in detail. This analysis was designed to facilitate selection of a suite of priority conservation areas representing some of the best examples of each habitat type for the second phase of this assessment.

However, habitat conservation alone is not sufficient for conserving all species and so with guidance from each technical team, a "fine filter" approach was used to select a subset of the thousands of species found within the study area. Because it is not practical or feasible to produce a detailed and spatially explicit analysis for every species in the region, the teams identified focal species in consideration of representation, ecological guilds and processes, and rarity. For each species team, a set of 8 to 50 individual species were identified and a set of individual analyses were done for each species.

Phase Two of this assessment integrates the individual spatial data for all conservation targets to identify high priority conservation areas. In a few instances, such as seabirds, species concentration areas were identified as targets in their own right. All of the conservation targets are listed below and described in detail in the chapters of this report.

Coastal Ecosystems

The fringing ribbons of habitats that make up the land-sea interface help maintain marine diversity and play critical roles for both nearshore and offshore plants and animals. The Northwest Atlantic coastline is particularly well known for several large and hundreds of small productive estuaries that provide juvenile nursery and spawning grounds for fish, mollusks, seabirds, and crabs. Recognizing the heterogeneity and ever-changing nature of the coastline, this section of the assessment reviews the history of coastal systems in the region, provides an overview of coastal habitats such as salt marshes, seagrass beds, and oyster reefs, examines some of the threats and human interactions with these systems, provides an in-depth look at sea level rise and reviews potential strategies for enhancing resilience of coastal systems. This report focuses specifically on the contributions that coastal ecosystems make to marine diversity.

Benthic Habitats

In Northwest Atlantic region, benthic (or seafloor) habitats contain over 2000 species of invertebrates such as marine worms, sponges, shrimp, crab, clams, scallops, snails, sea stars, corals, anemone. , and. Because individual species are adapted to variations in the environment such as sediment grain size, topography and depth, a benthic habitat type is defined as a group of organisms repeatedly found together within a specific environmental setting. For example, silt flats in shallow water are characterized by specific amphipods, clams, whelks and snails. In this assessment, we identified and mapped over 90 of the most common habitats with characteristic benthic communities distributed throughout each subregion.

Diadromous Fish

Diadromous fish are species that utilize both freshwater and salt water habitats during their life cycle. These species have great cultural and ecological significance in the region, and they provide an important energy link among freshwater, estuarine, and marine food webs. The Northwest Atlantic populations of some of these species are particularly important because the global range of seven of the eleven target diadromous species (alewife, American eel, American shad, Atlantic salmon, Atlantic sturgeon, Atlantic tomcod, blueback herring, hickory shad rainbow smelt, sea-run brook trout, and shortnose sturgeon) is limited to the Atlantic coast of the United States and Canada. The species included as primary targets show evidence of significant decline or are already recognized as globally rare.

Demersal Fish

Demersal fish (or groundfish) are characterized by their close association with the seafloor for feeding, spawning, and juvenile nursery areas. This region is particularly productive for demersal fish with some such as cod, haddock, halibut, and hake believed to be largely responsible for initial waves of European settlement in North America. Six groups of demersal fish were analyzed in the report: 1) gadids (cod, haddock, pollock, cusk, white hake, red hake, and silver hake), 2) pleuronectids (American plaice, witch flounder, winter flounder, and yellowtail flounder), 3) elasmobranchs (clearnose skate, little skate, rosette skate, thorny skate, and spiny dogfish), 4) offshore wintering species (summer flounder, scup, black sea bass, and northern sea robin), 5) estuarine species (spot, croaker, weakfish, and tautog), and 6) other species of interest (halibut, wolffish, ocean pout, monkfish, tilefish, redfish, and longhorn sculpin). These species were chosen to represent a wide range of preferred habitats, life history patterns, food habits, population trends, and ecological roles.

Small Pelagic Fish

Small pelagic fish (such as herring and mackerel) are the dominant food source for top marine predators like marine mammals, sea birds, and larger fish. Because of their migration patterns and life histories, these species transfer energy and biomass seasonally from coastal embayments to offshore habitats, thereby providing a significant link between coastal and pelagic systems. The eight species (American sand lance, Atlantic herring, Atlantic mackerel, Atlantic menhaden, butterfish, longfin inshore squid, northern sand lance, and northern shortfin squid) studied represent the guilds of prey species most important to the food webs of the Northwest Atlantic region.

Large Pelagic Fish

Large pelagic fish are highly migratory fish species that are typically found well above the seafloor in the water column. Pelagic species play a key ecological role as predators that regulate their prey communities and structure marine food webs. Some inhabit the region only seasonally and many of the details of their life history are not known. The fourteen species selected as targets include five bony fishes and nine sharks (albacore tuna, Atlantic bluefin tuna, bigeye thresher, blue marlin, dusky shark, great hammerhead, porbeagle, sand tiger, sandbar shark, scalloped hammerhead, shortfin mako, swordfish, thresher shark, and white marlin). The wide ranging distribution of these species across diverse habitat types, their roles as apex predators, and their threatened population status make them prime candidates for inclusion in this assessment.

Cetaceans

Cetaceans (dolphins, porpoises, and whales) are large migratory species that use this region primarily in spring and summer when there is an abundance of food resources associated with cool nutrient-rich waters. As predators, cetaceans are major consumers at most trophic levels, specifically targeting organisms like zooplankton, invertebrates, and small pelagic fish such as sand lance or Atlantic herring. Due to their seasonal abundance and charismatic nature, marine mammals have a long-standing, complex relationship with humans in this region. Ten marine mammals (Atlantic white-sided dolphin, bottlenose dolphin, fin whale, harbor porpoise, humpback whale, minke whale, North Atlantic right whale, sei whale, sperm whale, striped dolphin) were chosen for this study based on their population status and distribution throughout the region.

Sea Turtles

Sea turtles are large, air-breathing reptiles that utilize both oceanic (inner shelf region and offshore) and terrestrial (beach) ecosystems. Their highly migratory and long-lived life history characteristics present unique challenges to their continued protection and recovery. Sea turtles may have once comprised an important component of the region's coastal food webs, consuming prey including fish, invertebrates, and sea grasses. Three species of sea turtle (green, leatherback and loggerhead) were selected based upon their status as endangered species and distribution within the region.

Coastal and Marine Birds

Birds are creatures of both land and sea. Seabirds spend the majority of their life at sea, but return to coastal areas to breed, while shorebirds spend their lives on the coastal land edge, but forage in marine environments. In some cases, these birds may connect geographically disparate marine environments, from southern South America to the Arctic. World-wide, a higher percentage of seabird species are at risk of extinction than any other bird group. Within this region, a number of coastal and marine bird species are listed as state and federally threatened or endangered and nine were chosen for this study (Arctic Tern, Audubon's Shearwater, Barrow's Goldeneye, Harlequin Duck, Least Tern, Piping Plover, Razorbill, Red Knot, and Roseate Tern).

Biodiversity Threats

Pollution and Nutrient Runoff

The Northwest Atlantic's major estuaries of Albemarle and Pamlico Sounds, Chesapeake Bay, Delaware Bay, Long Island Sound, Narragansett Bay, Massachusetts Bay, Penobscot Bay and the Bay of Fundy support enormous biodiversity, but also introduce runoff of nutrients (nitrogen and phosphorus) to the sea from land-based human activities such as agriculture and urban development.

In Chesapeake Bay, for example, nutrients from sewage treatment plant discharges and farming cause extensive blooms of algae. When the algae dies and decomposes, dissolved oxygen is removed from the water, creating a so-called dead zone of hypoxic, or oxygen-starved, water. In July 2003, the dead zone covered 40 percent of the Bay's main stem, the largest area in 20 years, causing stress and habitat loss for crabs, fish and oysters (Chesapeake Bay Foundation 2008).

Intensified occurrences of another phenomenon known as Sudden Wetland Dieback (SWD) have been reported to occur along the East Coast, including Delaware's inland bays, within the past decade. SWD is often characterized by rapid death, or failure to grow for a season or more, of the upper portion of marsh vegetation, primarily Saltmarsh cordgrass (*Spartina alterniflora*). Sometimes complete death occurs. The cause of marsh dieback is unknown, though the cumulative effect of multiple environmental factors are suspected (Bason et al. 2007).

Coastal Development and Population Trends

The Northeast region from Maine to Virginia is the most densely populated coastal region in the United States with 641 persons living per square mile in the coastal

© Reuven Walder/ Marine Photobank

counties of those states in 2003. The population density of Northeast coastal counties increased from 543 per square mile in 1980 and is expected to increase to 661 in 2008 (Crosset et al. 2004). While these growth rates are similar to those for the country as a whole, the level of density on the finite land area of coastal regions has resulted in environmental stresses.

TNC's 2006 North Atlantic Coast Ecoregional Assessment (portions of which overlap the Northwest Atlantic study region), found that 40 percent of that ecoregion has been lost to conversion to development (3 percent is secured primarily for nature and 14 percent is secured from development while allowing multiple uses). An index of Housing Density Pressure based on census data trends from 1940 through 2050, indicate that 20 percent of the North Atlantic Coast area is predicted to have urban level housing densities by 2050.


© Cecilia Talopp/ Marine Photobank

Sea Level Rise

The combined effect of rising sea level and stronger storms related to climate change is expected to accelerate shoreline retreat in certain areas of the ecoregion. The coastal plains from northern New Jersey to northeastern North Carolina, in particular, are expected to experience significant shoreline changes over the next century. Coastal wetlands and beaches that provide important feeding grounds for global bird migrations, as well as nursery grounds for fish and other aquatic species, are at risk from inundation due to sea level rise.

A committee of coastal scientists convened to discuss the potential effects of sea level rise on the mid-Atlantic coastal plain identified an increased likelihood for 1) erosion and shoreline retreat for spits, headlands, wave-dominated barriers and "mixed-energy" or tide-dominated barrier islands; 2) increased likelihood for erosion, overwash and inlet breaching for barrier islands, and 3) the possibility of segmentation or disintegration for some barrier island systems (Gutierrez et al. 2007). The committee also concluded that factors such as human engineering to protect property by building seawalls and jetties can interact with geologic and physical processes to alter sediment dynamics, making it difficult to predict the ultimate response of shorelines to sea level rise (Gutierrez et al. 2007).

Unsustainable Fisheries

The Northwest Atlantic includes Georges Bank, historically one of the richest fishing sites in the world. This plateau in relatively shallow ocean water is located on the eastern rim of the Gulf of Maine where the collision of the Labrador Current with the Gulf Stream creates a nutrient rich upwelling that nourishes plankton and fuels the marine food chain to support exceptionally high fish productivity. Overfishing in the Georges Bank, competed over by United States, Canadian and international fleets over the past century, has taken a toll on ground fish such as Atlantic cod, haddock and flounder, and portions are now closed to commercial fishing (Boreman et al.1997; Murawski et al. 2005).

Species and Resources at Risk

Numerous iconic species of the Northwest Atlantic region face challenges caused by loss or damage to habitat and other environmental stresses. For example:

- Habitat for lobster that support coastal fishing communities throughout New England, may be affected by increased ocean temperatures caused by global climate change, with populations potentially shifting from current locations

(NECIA 2007).

- Dams and other development create barriers to migration for anadromous species such as Atlantic salmon, which hatch in rivers and migrate to the sea for two years of extensive feeding before re turning two to three years later to spawn. Once native to nearly every river north of the Hudson, wild populations of Atlantic salmon are now known to persist on only eight rivers and certain population segments are federally listed as endangered species (NOAA 2008a).
- Juvenile loggerhead sea turtles forage for food from Cape Cod south along the continental shelf of the Eastern United States. A petition was filed in 2007 to change the status of the Western North Atlantic population from threatened to Endangered (NOAA 2008b).
- North Atlantic right whales, the rarest of all large whale species, arrive in the Bay of Fundy, Scotian shelf and waters off New England in the summer to feed. Numbering only about 400, the Western North Atlantic population of these baleen whales has been listed as federally endangered since 1973. Ship collisions followed by entanglement in fishing gear are the most common causes of injury and mortality (NOAA 2008c).

Conservation Action for the Northwest Atlantic

While the accumulated pressures of population growth and human use of the coasts and oceans has resulted in widespread degradation of marine and coastal resources. Nonetheless, significant resilience remains and it is not too late to take action to improve conservation of the Northwest Atlantic's biodiversity. This assessment highlights significant species, natural communities and ecological processes within the region, and specific areas that present compelling conservation opportunities for maintaining coastal and marine ecosystems that provide the goods and services that people want and need.

Literature Cited

Bason, C., A. Jacobs, A. Howard, and M. Tymes.2007. Status of Sudden Wetland Dieback in Saltmarshes of the Delaware Inland Bays. http://www.inlandbays.org/cib_pm/pdfs/uploads/swdwhitepaper07final.pdf.

Boreman, B. S. Nakashima, J. A. Wilson, and R. L. Kendall, eds.1997. Northwest Atlantic Groundfish: Perspectives on a Fishery Collapse, J. American Fisheries Society, eds. 242 pp.

Briggs, J. C. 1974. Marine Zoogeography. New York, USA: McGraw-Hill.

Chesapeake Bay Foundation. 2003. The Chesapeake Bay's Dead Zone. http://www.cbf.org/site/PageServer?pagename=resources_facts_deadzone. Accessed Feb. 22, 2008.

CLF/WWF (Conservation Law Foundation and World Wildlife Fund-Canada). 2006. Marine ecosystem conservation for New England and Maritime Canada; A science-based approach to identifying priority areas for conservation. CLF-US and WWF- Canada.

Cook, R. R. and P. J. Auster. 2007. A bioregional classification for the continental shelf of Northeastern North America for conservation analysis and planning based on representation. Marine Sanctuaries Conservation Series NMSP-07-03. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Sanctuary Program, Silver Spring, MD.

Crosset, K. M., T. J. Culliton, P. C. Wiley, and T. R. Goodspeed. 2004. Population Trends along the coastal United States. 1980-2008. National Oceanic & Atmospheric Administration. http://oceanservice.noaa.gov/programs/mb/pdfs/coastal_pop_trends_complete.pdf.

Department of Navy. 2005. Marine Resource Assessment for the Northeast Operating Areas: Atlantic City, Narragansett Bay, and Boston. Naval Facilities Engineering Command, Atlantic; Norfolk, Virginia. Contract Number N62470-02-D-9997, Task Order 0018. Prepared by Geo-Marine, Inc. Newport News, Virginia.

Gottman, J. 1961. Megalopolis: The Urbanized Northeastern Seaboard of the United States. The Twentieth Century Fund, New York.

Groves, C. R., D. B. Jensen, L.L. Valutis, K.H. Redford, M. L. Shaffer, J. M. Scott, J. V. Baumgartner, J. V. Higgins, M. W. Beck, and M. G. Anderson. 2002. Planning for biodiversity conservation: putting conservation science into practice. Bioscience. 52: 499-512.

Gutierrez, B. T., S. J. Williams, and E. R. Thieler. 2007. Potential for shoreline changes due to sea-level rise along the U.S. Mid-Atlantic Region. U.S. Geological Survey Open-File Report 2007-1278. http://pubs.usgs.gov/of/2007/1278.

JOCI (Joint Ocean Commission Initiative). 2006. From Sea to Shining Sea: Priorities for Ocean Policy Reform. Report to the United States Senate. Washington, D.C.

Murawski, S. A., S. E. Wigley, M. J. Fogarty, P. J. Rago, and D. G. Mountain. 2005.
Effort distribution and catch patterns adjacent to temperate MPAs. ICES Journal of Marine Science. 62:1150-1167.

NECIA (Northeast Climate Impacts Assessment). 2007. Confronting Climate Change in the U.S. Northeast: Science, Impacts and Solutions.

NCCOS (NOAA Centers for Coastal Ocean Science) 2006. An ecological characterization of the Stellwagen Bank National Marine Sanctuary Region: Oceanographic, Biogeographic, and Contaminants Assessment. Prepared by NCCOS's Biogeography Team in cooperation with the National Marine Sanctuary Program. Silver Spring, MD. NOAA Technical Memorandum NOS NCCOS 45. 356 pp.

NMFS (National Marine Fisheries Service). 2009. Ecosystem Assessment Report for the Northeast U.S. Continental Shelf Large Marine Ecosystem. Ecosystem Assessment Program. US Department of Commerce, Northeast Fisheries Science Center. Ref Doc. 09-11; 61 pp.
http://www.nefsc.noaa.gov/nefsc/publications/

NOAA (National Oceanic and Atmospheric Commission). 2008a. Atlantic salmon *(Salmo salar)*. Office of Protected Resources. http://www.nmfs.noaa.gov/pr/species/fish/atlanticsalmon.htm. Accessed Feb. 22, 2008

NOAA (National Oceanic and Atmospheric Commission). 2008b. Marine Turtles. Office of Protected Resources. http://www.nmfs.noaa.gov/pr/species/turtles/. Accessed Feb. 22, 2008

NOAA (National Oceanic and Atmospheric Commission). Office of Protected Resources. 2008c. Northern Right Whale (*Eubalaena glacialis*). http://www.nmfs.noaa.gov/pr/species/mammals/cetaceans/rightwhale_northern.htm. Accessed Feb. 22, 2008

NRDC (Natural Resource Defense Council). 2001. NRDC Priority Ocean Areas for Protection in the Mid-Atlantic: Findings of NRDC's Marine Habitat Workshop. http://www.nrdc.org/water/oceans/priority/recwatl.asp

OPTF (Ocean Policy Task Force). 2009. Interim framework for effective coastal and marine spatial planning. The White House Council on Environmental Quality. December 9, 2009. Washington, D.C.

Sherman, K. M., M. Grosslein. D. Mountain, J. O'Reilly, and R. Theroux. 1988. The continental shelf ecosystem off the northeast coast of the United States. p. 279-337 in: Postma, H. and J.J. Zijlstra, eds. Ecosystems of the World 27: Continental Shelves. Elsevier. Amsterdam, The Netherlands.

Spalding M., H. Fox, N. Davidson, Z. Ferdana, M. Finlayson, B. Halpern, M. Jorge, A. Lombana, S. Lourie, K. Martin, E. McManus, J. Molnar, K. Newman, C. Recchia, and J. Robertson. 2007. Marine Ecoregions of the World: A Bioregionalization of Coastal and Shelf Areas. Bioscience. 57 (7):573-583.

Stevenson D., L. Chiarella, D. Stephan, R. Reid, K. Wilhelm, J. McCarthy, and M. Pentony. 2004. Characterization of the fishing practices and marine benthic ecosystems of the northeast US shelf, and an evaluation of the potential effects of fishing on essential habitat. NOAA Technical Memorandum. NMFS NE 181; 179 p.

Townsend, D. W., A. C. Thomas, L. M. Mayer, M. A. Thomas, and J. A. Quinlan. 2006. Oceanography of the Northwest Atlantic continental shelf. In: A.R. Robinson and K.H. Brink, eds. The Sea: the Global Coastal Ocean: Interdisciplinary Regional Studies and Syntheses. Harvard University Press, Cambridge, Massachusetts.

Pew Oceans Commission. 2003. America's Living Oceans: Charting a Course for Sea Change, Philadelphia, PA. Pew Charitable Trust.

USCOP (United States Commission on Ocean Policy). 2004. An Ocean Blueprint for the 21st Century: Final Report of the U.S. Commission on Ocean Policy. Washington, DC.

USFWS (United States Fish and Wildlife Service). 1997. Significant Habitats and Habitat Complexes of the New York Bight Region. Southern New England-New York Bight Coastal Ecosystems Program. Charlestown, Rhode Island.

U.S. Census Bureau. 2000. http://www.census.gov/prod/cen2000/index.html. Accessed January 9, 2009.

Walsh J. J., T. E. Whitledge, F. W. Barvenik, C. D. Wirick, S. O. Howe, W. E. Esaias, and J. T. Scott. 1978. Wind events and food chain dynamics within the New York Bight. Limnology and Oceanography. 23:659–683.

Weiss, H. M. 1995. Marine animals of southern New England and New York. Bulletin 115 of the State Geological and Natural History Survey of Connecticut. Hartford, Connecticut: Connecticut Department of Environmental Protection.

Wigley, R. L. and R. B. Theroux. 1981. Atlantic Continental Shelf and Slope of Faunal Composition and Quantitative Distribution. U.S. Geological Survey Professional Paper 529-N, pp. 1–198.

CHAPTER

2

Coastal Ecosystems

Barbara Vickery, Marci Bortman, Carl Lobue, Ray Konisky, Jay Odell, and Arlene Olivero

Introduction: Coastal Communities at the Land-Sea Interface

The fringing ribbons of habitats that make up the land-sea interface maintain marine diversity and play critical roles for both nearshore and offshore plants and animals. The Northwest Atlantic coastline is particularly well known for its hundreds of productive estuaries that provide juvenile nursery and spawning grounds for fish, mollusks, seabirds, and crabs. This report focuses specifically on the contributions that coastal ecosystems make to marine diversity.

© Mark Godfrey, TNC

The edge of earth that meets the sea – what we call coastline – is the ultimate ecotone, a critical ecological transition, as dramatic and obvious a natural boundary as one can find on Earth. While well defined, coastlines are very dynamic over geologic time. Over millennia, estuarine and ocean shorelines have advanced and retreated thousands of kilometers inland and seaward, and back again in cycles. The zone where ocean meets earth includes diverse landforms that are cut and shaped by waves and tides and by the continuous flow of new sediments carried by freshwater in coastal watersheds. The adjacent shallow, well-lit, and productive coastal waters give rise to habitats like the salt marshes, oyster reefs, and seagrass meadows discussed in this chapter, critical habitats that directly and indirectly support many of the species mentioned throughout this report.

The coasts and estuaries in this region are also of great importance to humans. Tremendous material, aesthetic, and spiritual resources associated with shorelines have attracted and sustained humans for thousands of years. Our coasts and estuaries are where we live, recreate, work, and gather. They help support the economy and sustain us in many ways, including providing places to live, opportunities for tourism, shipping and transportation routes, commercial fishing, and seafood processing. Conversely, the malfunctioning of these systems in the form of pollution, habitat destruction, hypoxia, harmful algal blooms, fishery collapses, and increased coastal erosion can have devastating social and financial impacts for coastal communities.

Coasts and estuaries and their component organisms and habitats provide ecosystem services at multiple scales. For example, at the scale of meters, estuarine bivalves such as the Eastern oyster convert pelagic primary production into food and habitat for benthic organisms and clear water for submerged vascular plants. At the kilometer scale, tidal wetland vegetation cycles nutrients, sequesters carbon, and serves as a marine nursery. At the coast-wide scale, each estuary supports a wide array of coastal migratory fishes, and at the global scale the network of estuaries in this region produces the food that fuels shorebirds flying to Alaska and tuna swimming to the Mediterranean Sea.

Recognizing the heterogeneity and ever-changing nature of the coastline, this section of the assessment reviews the history of coastal systems in the region, provides an overview of coastal habitats such as salt marshes, seagrass beds, and oyster reefs, examines some of the threats and human interactions with these systems, provides an in-depth look at sea level rise and reviews potential strategies for enhancing resilience of coastal systems.

Technical Teams Members

Historical context sub-team

Jay Odell, The Nature Conservancy, Virginia

Coastal systems sub-team

Mark Anderson, Ph.D., The Nature Conservancy, Eastern Division
Marci Bortman, Ph.D., The Nature Conservancy, Long Island
Mark Bryer, The Nature Conservancy, Maryland
Chris Clapp, The Nature Conservancy, Long Island
Jennifer Greene, The Nature Conservancy, Eastern Division
Alexandra Jospe, The Nature Conservancy, Eastern Division
Heather Leslie, Ph.D., Brown University
Kathleen Leyden, Maine Coastal Program
Carl Lobue, The Nature Conservancy, Long Island
Nicole Maher, Ph.D., The Nature Conservancy, Long Island
Dan Morse, The Nature Conservancy, Eastern Division
Jay Odell, The Nature Conservancy, Virginia
Arlene Olivero, The Nature Conservancy, Eastern Division
Caroly Shumway, Ph.D., Visiting Researcher, Boston University
Peter Slovinsky, Maine Geological Survey
Barbara Vickery, The Nature Conservancy, Maine

Shellfish sub-team

Robert Brumbaugh, Ph.D., The Nature Conservancy, Global Marine Initiative
Mark Bryer, The Nature Conservancy, Maryland
Loren Coen, Ph.D., Sanibel Captiva Conservation Foundation
Jonathan Grabowski, Ph.D., Gulf of Maine Research Institute
Ray Grizzle, Ph.D., University of New Hampshire
Boze Hancock, Ph.D., The Nature Conservancy, Global Marine Initiative
Sally Harold, The Nature Conservancy, Connecticut
Ray Konisky, Ph.D., The Nature Conservancy, New Hampshire
Jay Leverone, Ph.D., Sarasota Bay Estuary Program
Carl Lobue, The Nature Conservancy, Long Island
Jay Odell, The Nature Conservancy, Virginia
Marc Ouellette, Division of Fisheries and Oceans Canada
Stephen Tettlebach, Ph.D., Long Island University
Barry Truitt, The Nature Conservancy, Virginia

Sea level rise sub-team

Dan Coker The Nature Conservancy, Maine
Zach Ferdana, The Nature Conservancy, Global Marine Initiative
Sarah Newkirk, The Nature Conservancy, Long Island
Jay Odell, The Nature Conservancy, Virginia
Barbara Vickery, The Nature Conservancy, Maine

Selection of Target Coastal Habitats

For coastal habitats, the team chose to focus on a limited number of targets. These are most simply summarized in three categories; the various types of habitats that make up the land-sea interface (e.g., salt marsh, beach), seagrass meadows (beds of submerged marine rooted vascular plants), and nearshore shellfish assemblages.

The land-sea targets discussed in this section are consistent with the initial charge to the group, which was to re-examine conservation targets already identified in TNC's adjacent terrestrial North Atlantic Coast (NAC) and Northern Appalachian (NAP) ecoregional plans from a marine perspective. Within the nearshore shellfish assemblage category, specific targets were selected based on general criteria of 1) need for specific conservation action, 2) wide historical distribution and significant abundance within the region, 3) relative importance of ecosystem services provided, and 4) cultural and economic value. The resulting list focuses on species located in closer proximity to human settlements, those for which there are economic markets, and bounded estuarine embayments that enhance ecological services. Other economically important shellfish species that occur in some nearshore areas but are more typically offshore were excluded as not currently overfished and likely having less coastal habitat value (ASMFC 2007).

The following targets were selected for this assessment:

- Land-sea interface
- Vegetated tidal wetlands (salt and brackish emergent marshes)
- Sandy beaches
- Cobble shores
- Non-vegetated sheltered coasts, including sand and mud flats
- Rocky headlands
- Coastal salt ponds
- Seagrass beds
- Nearshore shellfish assemblages
- Eastern oyster
- Hard clam
- Softshell clam
- Bay scallop
- Blue mussel
- Ribbed mussel

Population Status and the Importance of the Northwest Atlantic Region: A Historical Review of Key Coastal Habitats and Species

The purpose of this section is to help provide a historical context for conservation and restoration and a call to action for setting thoughtful and ambitious goals going forward. Restoration and conservation goals need to consider quantitative knowledge about the past and the environmental constraints of the present. They also need to be ambitious enough to make a difference – to affect the trajectory of ecosystem state conditions in ways that benefit nature and people. This section is not intended to be a comprehensive inventory of loss and damage to Northwest Atlantic coastal ecosystems. It is rather a sampling of available datasets that collectively can provide context for the assessment of current condition provided in the rest of this chapter.

Although quantitative data on historical conditions are relatively scarce, in recent years a large amount of qualitative and anecdotal historical data has become more readily available through internet sources. Some of the old stories ring true, and some may contain exaggeration or outright fiction. However, in total, these stories, frequently verified through comparisons with empirical data, strongly evoke the shifting baselines phenomenon (Pauly 1995). The condition of present day coastal ecosystems may be correctly perceived as being somewhat degraded in comparison to conditions a few generations ago, without full appreciation of the magnitude of damage and loss in comparison to conditions a few hundred years ago. Perhaps an inkling of baseline conditions from around the time of European settlement is revealed in this report from 1629, transcribed from Massachusetts Bay Colony reports in 1846.

> *The abundance of sea-fish are almost beyond believing; and sure I should scarce have believed it except I had seen it with mine own eyes. I saw great store of whales, and grampuses, and such abundance of mackerels that it would astonish one to*

behold; likewise codfish, abundance on the coast, and in their season are plentifully taken. There is a fish called a bass, a most sweet and wholesome fish as ever I did eat; it is altogether as good as our fresh salmon; and the season of their coming was begun when we came first to New-England in June, and so continued about three months' space. Of this fish our fishers take many hundreds together, which I have seen lying on the shore, to my admiration. Yea, their nets ordinarily take more than they are able to haul to land, and for want of boats and men they are constrained to let a many go after they have taken them; and yet sometimes they fill two boats at a time with them. And besides bass, we take plenty of scate and thornback, and abun dance of lobsters, and the least boy in the Plantation may both catch and eat what he will of them. For my own part, I was soon cloyed with them, they were so great, and fat, and luscious. I have seen some myself that have weighed sixteen pound; but others have had divers times so great lobsters as have weighed twenty-five pound, as they assured me. (Young 1846).

Even a cursory review of the historical and current conditions of Northwest Atlantic coastal ecosystems reveals that tremendous changes, including significant resource depletion, have taken place since European settlement. At least four marine species in the Northwest Atlantic became extinct in historic times – Atlantic gray whale (early 1700s), sea mink (1880), great auk (1884), and in 1929 the eelgrass limpet was lost during the eelgrass wasting disease pandemic (Geerat 1993; Carlton et al. 1999). While total range-wide extinctions in marine ecosystems appear to be relatively uncommon or go unnoticed, local extirpations and sharp population reductions with associated loss of ecosystem services are quite evident.

Prior to 1900, thousands of rivers and streams were dammed, and as a result, many thousands of kilometers of spawning habitat for diadromous fish were lost. Intensive logging cleared entire watersheds, leading to erosion and delivery of excessive sediment to estuaries, dramatically changing bathymetry and impacting a variety of habitats and species. Silt and enormous quantities of sawdust and wood debris from mills were dumped in estuaries, smothering shellfish, eelgrass, and benthic communities. Meanwhile, urban centers like Boston and New York grew rapidly into their adjacent estuaries, filling coastal wetlands and hardening natural shorelines. Unregulated effluents from textile mills, tanneries, and other industries combined with untreated sewage to poison and degrade benthic and pelagic habitats (Jackson 1944; Buschbaum et al. 2005). Against this backdrop of estuarine habitat destruction, largely unregulated harvesting of marine resources proceeded with the illusory idea that the ocean's bounty was limitless (Huxley 1884). However, by the mid to late 1800s many authors began to describe the damage that had begun to accrue and some of their observations are excerpted below. Modern scientists are revisiting the same questions, equipped with better scientific understanding while also at a great disadvantage due to the long passage of time. To provide an historical context for several of the conservation targets, the following sections highlight changes in salt marshes, eelgrass, and oysters.

Salt Marshes

Salt marshes are intertidal wetlands typically located in low energy environments such as estuaries. They exist both as expansive meadow marshes and as narrow fringing marshes along shorelines. Considered one of the most productive ecosystems in the world, salt marshes provide numerous ecological functions, including shoreline stabilization, wildlife habitat, and nutrient cycling. Their critical role in providing breeding, refuge, nursery, and forage habitats for diverse marine fauna is well known. Salt marsh dependent species facilitate the export of nutrients and carbon from coastal to offshore food webs. The emerging field of valuing nature (calculating ecosystem services in economic terms) is sometimes controversial, but by any measure salt marsh is one of the most valuable habitat types on Earth. Bromberg Gedan et al. (2009) cautiously estimate that the ecosystem services of one hectare of salt marsh exceed a value of $14,000 per year (Table 2-1).

In the past few centuries, a large portion of the Northwest Atlantic's salt marsh habitat has been altered or destroyed. Soon after European settlement, salt marshes were ditched and drained to facilitate hay production, and subsequently to control mosquitoes. Over decades, various forms of coastal development (urban expansion, roadways,

Table 12-1 Valuation of salt marsh ecosystem services. Reprinted with permission from Bromberg Gedan et al. (2009).

Ecosystem Service	Examples of Human Benefits	Average Value (Adj. 2007 $[a] ha^{-1} year^{-1})
Disturbance regulation	Storm protectio and shoreline protection	$2824
Waste Treatment	Nutrient removal and transformation	$9565
Habitat/refugia	Fish and shrimp nurseries	$280
Food Production	Fishing, hunting, gathering, aquaculture	$421
Raw materials	Fur trapping	$136
Recreation	Hunting, fishing, birdwatching	$1171
TOTAL		**$14,397**

residential development, and industry) have altered and reduced the extent of marshes through diking, dredging, filling, and armoring.

A comprehensive estimate of salt marsh loss along the eastern seaboard has not yet been produced and is beyond the scope of this project. However, GIS methods are increasingly being used to examine historical maps to produce local and regional spatially explicit estimates. It has been estimated that Rhode Island salt marsh area has been reduced by 53% since 1832 and that, since 1777, 40% of Massachusetts salt marsh has been lost, with over 80% lost in the heavily filled Boston area estuary (Bromberg Gedan and Bertness 2005). At Great Bay, New Hampshire a comprehensive review of historical data identified likely locations of salt marsh loss (Figure 2-1). Results indicate that the current extent of salt marsh in the Great Bay estuary is about 400 hectares and the identified restoration opportunities total about 200 hectares (GBERC 2006).

Eelgrass

Eelgrass *(Zostera marina)* is the major seagrass in the western North Atlantic, a marine flowering plant that grows in subtidal and intertidal regions of coastal waters in both protected and exposed systems. In addition to providing food and critical spawning and refuge habitat for fish and invertebrates (Wyda et al. 2002; Heck et al. 2003), the complex networks of leaves, roots, and rhizomes serve to trap nutrients and sediments, protect shorelines from erosion, and filter pollution. In northern latitudes eelgrass typically exhibits a seasonal change in abundance, with low biomass in winter months followed by rapid increases in the spring and early summer (Short et al. 2007).

Oysters and other shellfish benefit from associations with eelgrass in several ways. Eelgrass meadows trap and sequester suspended sediments that might otherwise smother juvenile shellfish and reduce habitat quality for adults. The beds also create eddies in currents that can affect larval retention and settlement, and the plants provide potential attachment sites for planktonic stages of some shellfish, notably bay scallops *(Argopecten irradians)* (Newell and Koch 2004).

Figure 2-1. Estimated salt marsh loss at Great Bay, New Hampshire. This image shows the detail of a map from the Great Bay Estuarine Restoration Compendium (2006). Dark orange indicates areas of probable loss identified using comparison of maps from 1918 with modern survey data showing current salt marsh distribution (beige areas).

In the North Atlantic, a wasting disease first noted in the 1930s caused a rapid coastwide decline in the extent of eelgrass. The link between the disease and the marine slime mold *Labrynthula zosterae* is now well established (Den Hartog 1989; Muehlstein et al. 1991). It is thought that higher than average salinity and human impacts on seagrass systems facilitated the disease.

Despite the widespread loss of the great majority of the eelgrass along the Northwest Atlantic coast, many eelgrass beds recovered over the subsequent few decades. However, this recovery coincided with rapidly increasing nutrient and sediment loads to coastal ecosystems, minimizing recovery in some areas and leading to the eventual loss of thousands of hectares of eelgrass beds that had briefly returned following the disease outbreak (Orth et al. 2006; Wazniak et al. 2007). Because of its functional role

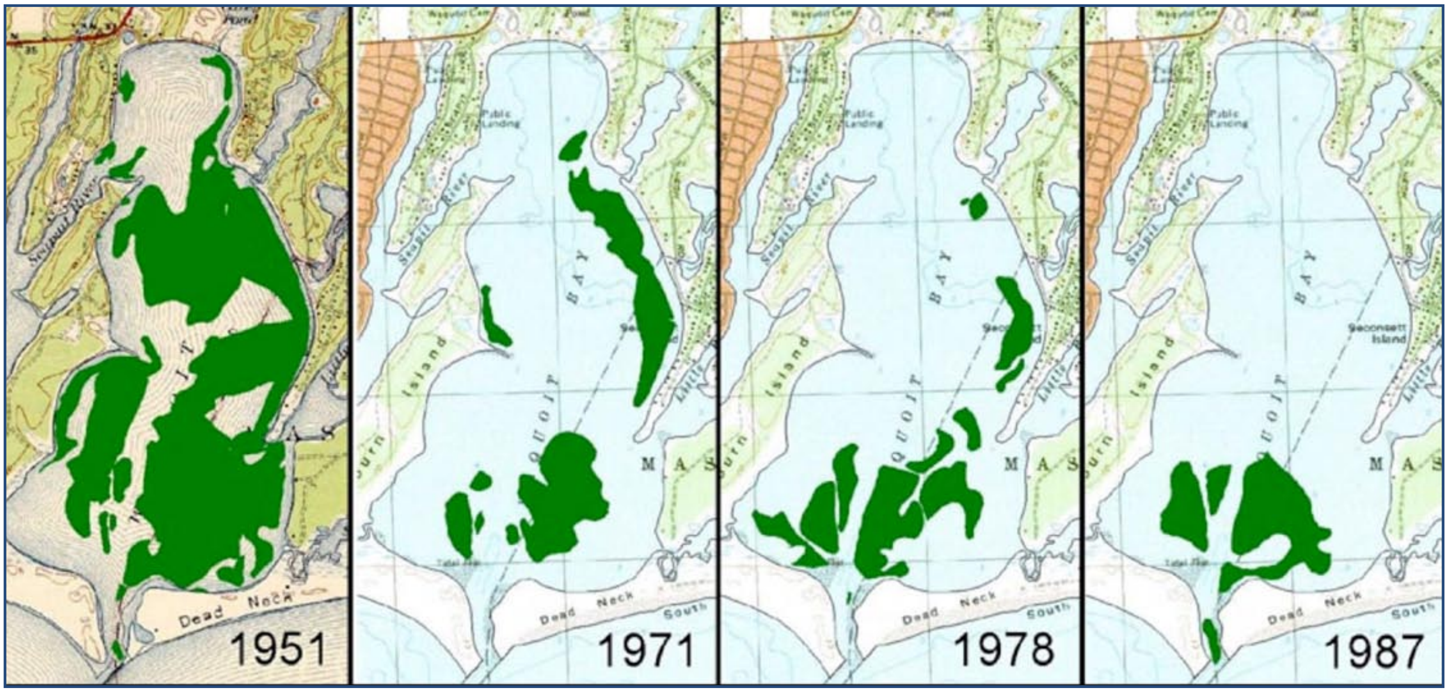


Figure 2-2. Eelgrass (Zostera marina) loss at Waquoit Bay, Massachusetts. This image shows post-disease re-growth followed by loss due to eutrophication (Costa et al. 1992). Nitrogen oncentrations in this embayment doubled between 1938 and 1990 (Bowen and Valiela 2001).

within coastal ecosystems, the loss of eelgrass has secondary impact on dependant fauna, from waterfowl such as brant *(Branta bernicla)* to bay scallops, and myriad other fish and invertebrate species (Bowen and Valiela 2001; Deegan et al. 2002; Kennish et al. 2007).

A comprehensive estimate of eelgrass loss and restoration opportunities for the project area has not yet been completed. However, estimates for some locations (Figure 2-2 and 2-3), have been produced through comparison of aerial photography with old maps and the use of habitat models (Orth and Moore 1983; Orth and Moore 1984; GBERC 2006). The greatest amount of eelgrass loss in the Northwest Atlantic has occurred within Chesapeake Bay, where more than half the area historically covered by eelgrass was lost by the 1970s (Robert Orth, personal communication).

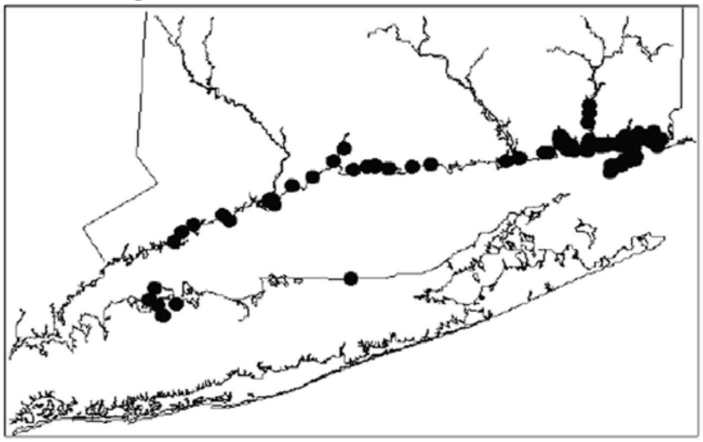
Eelgrass restoration efforts are picking up steam throughout the region, including at locations in Great Bay, New Hampshire, in Long Island Sound, and the seaside lagoons of the eastern shore of Virginia. As an example, the Conservancy is working with the Virginia Institute of Marine Science, Virginia's Coastal Zone Management Program, and NOAA to expand the world's largest successful seagrass restoration project. This landscape scale restoration project is being monitored to evaluate benefits for diverse eelgrass community fauna and includes re-introduction of eelgrass dependant bay-scallops and oyster settlement substrate.

Oysters

Eastern oysters *(Crassostrea virginica)* are found in shallow subtidal and intertidal areas throughout the Northwest Atlantic, providing substantial ecosystem services including water filtration, provision of fish habitat, and erosion control (Coen et al. 2007).

Much attention and resources have been brought to bear on protecting and conserving coral reef systems around the world. In temperate waters, reefs formed by oysters and other shellfish provide similar critical habitat and

Historical Eelgrass Distribution



Current Eelgrass Distribution

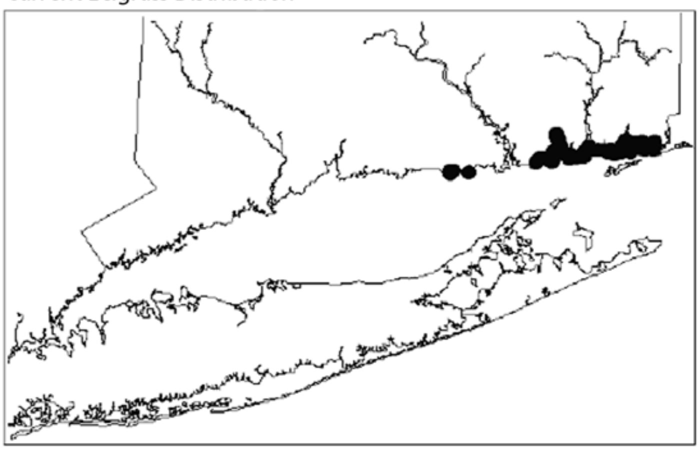


Figure 2-3. Long Island Sound Eelgrass Distribution. Comparison of historic and 2003 eelgrass (Zostera marina) bed locations (from LISHRI 2003).

ecosystem benefits as their tropical reef brethren. Globally, native shellfish are not just highly threatened, they are *functionally extinct* in most bays (Beck et al. in review). It is difficult to identify intact oyster reefs or shellfish beds anywhere in the northern hemisphere, including the major estuaries, tidal rivers, coastal bays, and lagoons of the Northwest Atlantic.

Many oyster shell middens along the Atlantic coast's estuaries and tidal rivers have been located and studied. These data-rich shell piles are monuments to the persistence of both abundant shellfish resources and human harvesters for thousands of years before European settlers stepped ashore.

Drake (1875) made many observations regarding the condition of oysters and other natural resources along the New England coast in the late 1800s. In reference to the famous thirty foot high oyster shell middens along the shores of the Damariscotta River in southern Maine and the abundance and large size of oysters in Massachusetts, he wrote:

> *The shell heaps are of common occurrence all along the coast. The reader knows them for the feeding-places of the hordes preceding European civilization. Here they regaled themselves on a delicacy that disappeared when they vanished from the land. The Indians not only satisfied present hunger, but dried the oyster for winter consumption...Josselyn mentions the long-shelled oysters peculiar to these deposits. He notes them of nine inches in length from the joint to the toe, that were to be cut in three pieces before they could be eaten. ... The problem of the oyster's disappearance is yet to be solved.*

Ingersoll (1881) published a comprehensive review of oyster distribution and associated industry for the United States Bureau of Fisheries. Substantial oyster reefs, consisting of much larger oysters than are typically found today, were noted in nearly every estuary and tidal river in the region. His 1881 review stated:

> *In 1634 William Wood, in his New England's Prospect, speaks of "a great oyster bank" in Charles river, and another in the "Misticke", each of which obstructed the navigation of its river. Ships of small burden, he says, were able to go up as far as Watertown and Newton, "but the Oyster-bankes do barre out the bigger Ships."... "Ships without either Ballast or loading, may floate downe this River; otherwise the Oyster-banke would hinder them which crosseth the Channell."*
>
> *"The Oysters," adds Wood, "be great ones in form of a Shoehorne; some be a foot long; these breed on certain banks that are bare every spring tide. This fish without shell is so big, that it must admit of a division before you can well get it into your mouth."*

This bank appears to have been a very well-known and prominent feature in those days, though no popular tradition of it remains. For example, Winthrop's History of New England, edited by the Rev. John Savage, p. 106, contains under date of August 6, 1633, the following statement: "Two men servants to one Moodye, of Roxbury, returning in a boat from the windmill, struck upon the oyster-bank. They went out to gather 'oysters, and, not making fast their boat, when the flood came, it floated away, and they were both drowned, although they might have waded out on either side; but it was an evident judgment of God upon them, for they were wicked persons.

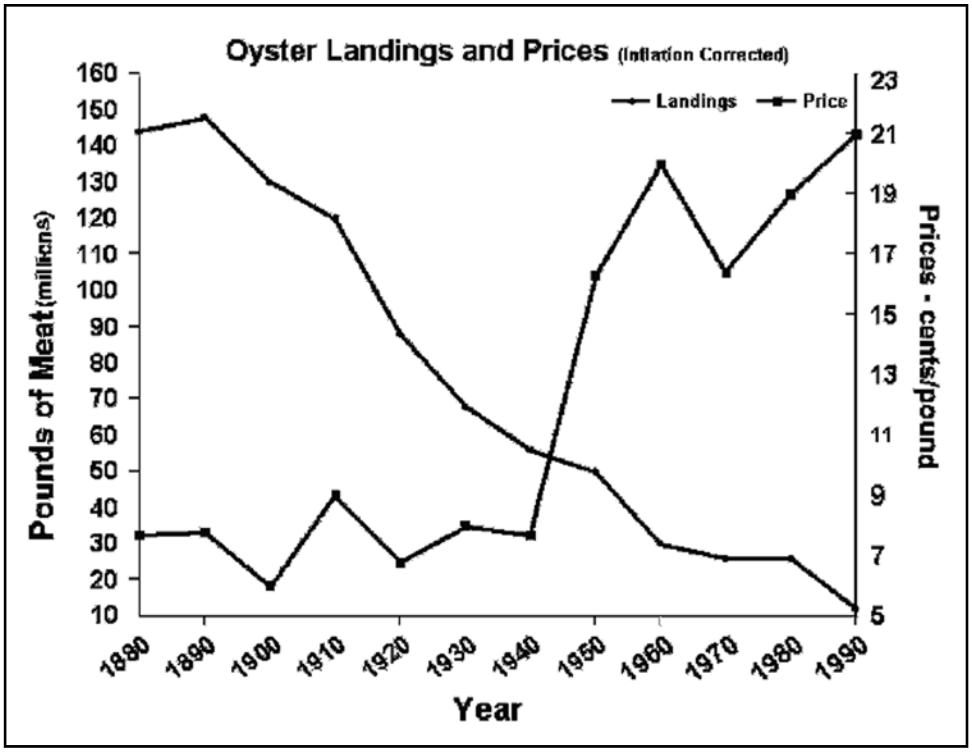


Figure 2-4. East Coast oyster landings and prices (inflation-corrected) of oysters, 1880 to 1990. Reprinted with permission from Mackenzie (2007).

The loss of oyster populations throughout the Northwest Atlantic is chronicled in many of the annual reports of the United States Bureau of Fisheries (USCF 1916). There is a wealth of credible historic information and maps indicating that oysters were formerly much more abundant than in modern times. East coast annual oyster harvests peaked at nearly 27 million bushels during the 1890s, declined to about 12 million bushels by 1940, and have been well below 0.5 million bushels in recent years (Figure 2- 4). Intense market demand and increasingly effective fishing methods fueled oyster fishery growth during the 1800s even though oyster populations had already been sharply reduced during the 17th and 18th centuries due to pollution and sedimentation from mills and logging.

Chesapeake Bay, the nation's largest estuary, has historically produced the highest oyster landings in the Northwest Atlantic. Ingersoll (1881) reports that in 1880 total Chesapeake Bay oyster production exceeded 17 million bushels. In Maryland and Virginia, the oyster industry employed at least 32,000 people in harvesting, processing, and marketing operations. Additional Chesapeake Bay production included millions of seed oysters sold and transported to help augment diminished oyster resources at many locations from Delaware to Maine. However, even during these times of extraordinary abundance, there were warning signs that these harvest levels were unsustainable (Ingersoll 1881; USBCF 1893).

Comprehensive and detailed estimates of oyster loss and current restoration opportunities for the project area have not been produced. However, loss and restoration potential have been estimated for some locations using both historic maps and habitat models. At Great Bay, New Hampshire the extent of oysters before significant losses occurred between the 1700s and about 1970 remains unknown. However, GIS analysis of available map data (Figure 2-5) indicates that oysters covered at least 365 hectares, and perhaps as much as 525 hectares, compared to the current extent of live oyster bottom of 20 to 40 hectares. It should be noted that although disease has taken a heavy toll on oysters within the Great Bay

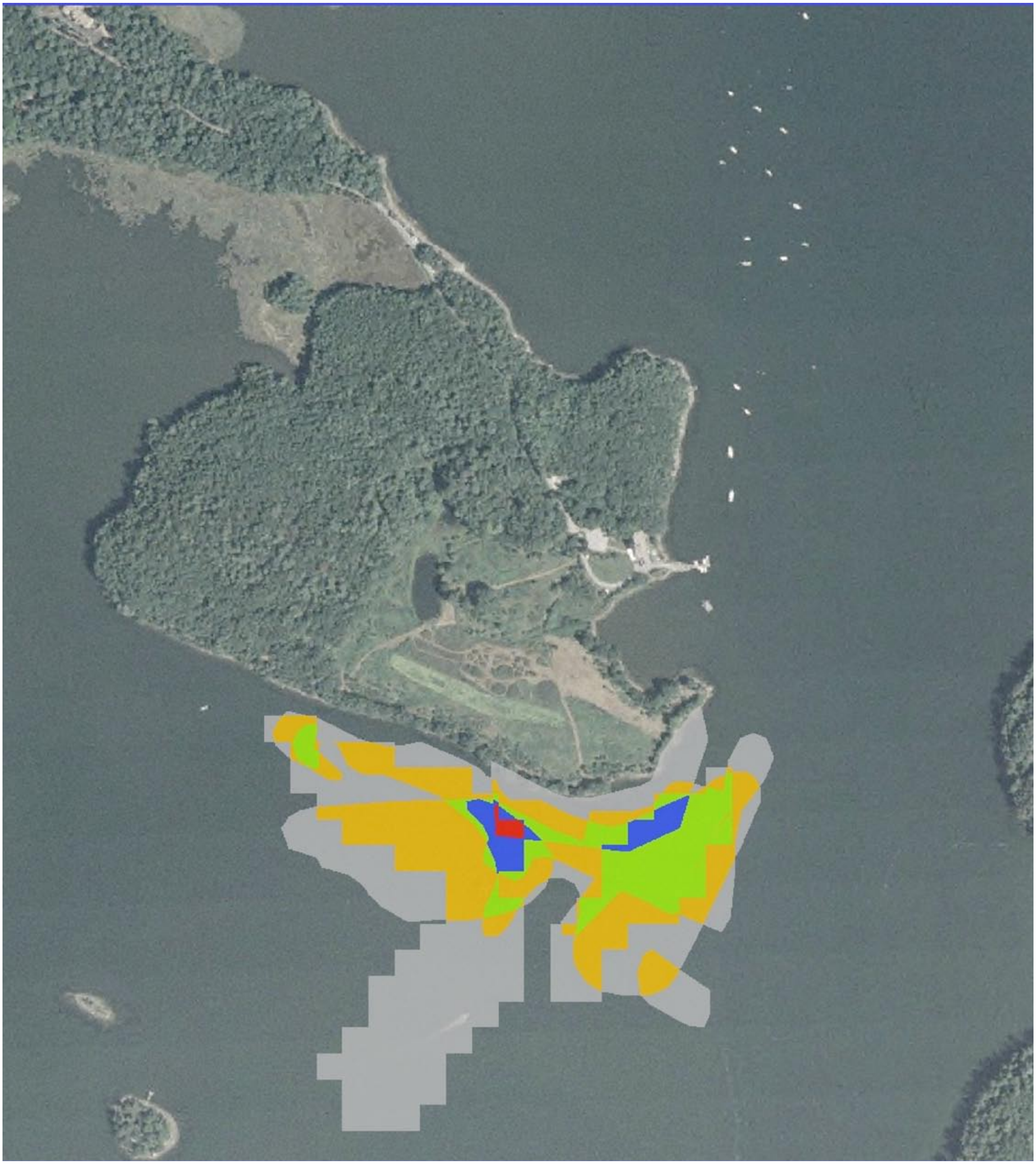


Figure 2-5. Overlay of seven oyster distribution maps from Great Bay, New Hampshire. Colors indicate number of coincident survey footprints (gray = 1, yellow = 2, green = 3, blue = 4, and red = 5). This analysis was used in preparation of the Great Bay Estuarine Restoration Compendium to inform confidence levels regarding the validity of historic maps.

estuary, oysters in an area closed to harvest due to pollution concerns are thriving and forming a three-dimensional reef structure.

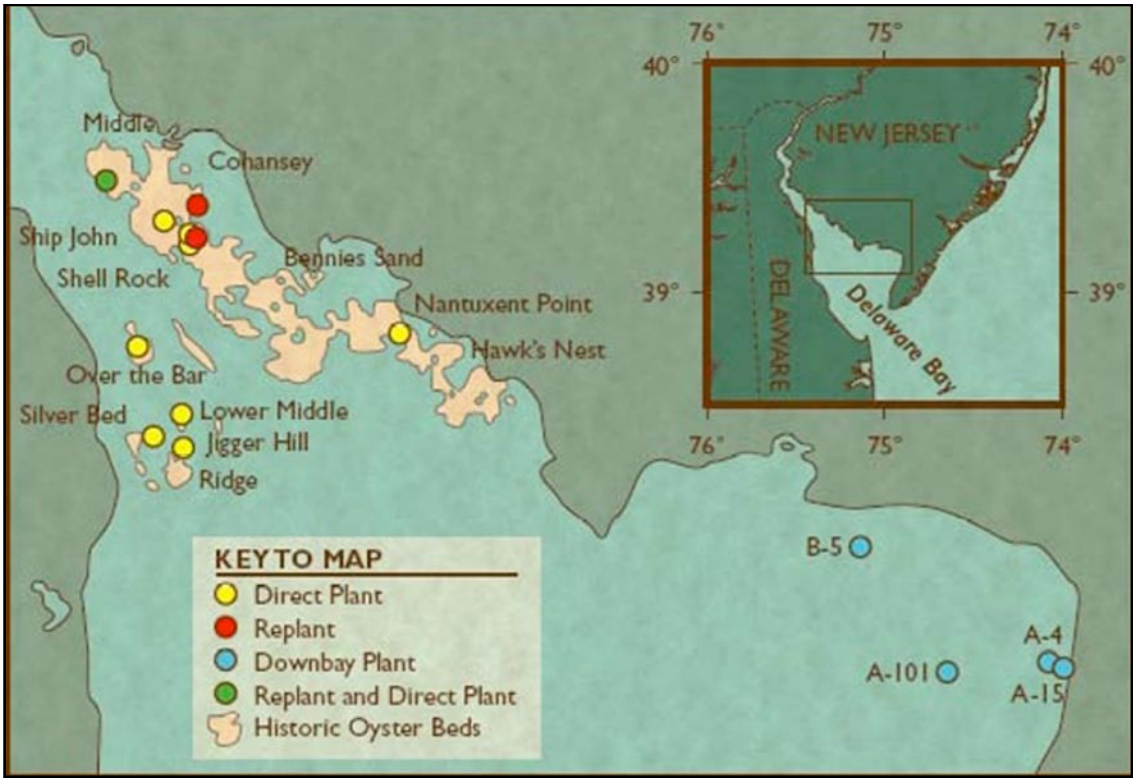


Figure 2-6. Delaware Bay's historic oyster reefs and restoration sites. This map image is reprinted courtesy of the Delaware Bay Oyster Restoration Task Force.

Since 2005, the Delaware Bay Oyster Restoration Task Force has strategically planted millions of bushels of shell material onto historic reef sites in Delaware Bay (Figure 2-6), attaining initial goals of equilibrium conditions for settlement habitat. Recent observations suggest that restoration efforts are leading to a substantial increase in juvenile oyster survival (DBOP 2009).

These are only two examples; additional oyster restoration projects are proceeding or being initiated in many states of the Northwest Atlantic region (MDNR 2009; NJB 2009; VIMS 2009).

Throughout the Northwest Atlantic, a combination of factors continues to limit prospects for effective oyster restoration. These factors include continued recreational and commercial oyster harvest pressure, two oyster diseases (MSX and Dermo), excess sediments, reduced freshwater flows, and dredging for navigation. The relative importance and nature of these stresses varies substantially geographically. However, the long-held notion that oyster diseases present an insurmountable barrier to effective restoration is yielding to increasing evidence that, with appropriate investment and protection of sufficient numbers of oysters within sanctuaries, native oyster restoration can be very successful (Powers et al. in press).

Lessons Learned

The historical anecdotes and data summarized above provide evidence that the condition and geographic extent of coastal habitats and populations of key species are greatly diminished compared to past times. At the same time, the outdated notion that undisturbed nature represents an ideal state has given way to a more realistic view - that ecosystems are dynamic, with multiple potential stable states and ever-changing mosaics of diverse habitats. It is not realistic to set restoration goals that attempt to recreate the exact conditions of the past.

With that caveat in mind, we also recognize that human activities have unintentionally altered many ecological processes necessary for the long term persistence of estuarine habitats and the species that depend on them (Lotze et al. 2006; UNEP 2006). Left unchecked, these alterations can drive ecosystems into alternate and relatively stable states that are clearly undesirable, possibly including hypoxic or anoxic "dead zones," food webs simplified by the loss of formerly dominant species, and a loss of natural resources and ecological services desired and required by human communities (Leslie and Kinzig 2009). These undesirable states are now being observed in coastal ecosystems around the world.

Our challenge is to set ambitious and achievable conservation and restoration goals, in clear recognition of all the threats that degrade coastal ecosystems. At many locations, habitat and species-focused restoration will not be successful without prior substantial and successful work to conserve land within coastal watersheds and to abate point and non-point pollution impacts. Policy-focused strategies to reduce water pollution, habitat loss and harvest of threatened species, as well as place-based projects to plant eelgrass and oysters, to restore salt marshes, and to improve fish passage are urgently needed. An invigorated whole-ecosystem approach offers much promise for increasing ecological resilience - the ability of an ecosystem to rebound from disturbances (Leslie and Kinzig 2009). We have an opportunity now to learn from history and move forward with coordinated science and policy to avoid and reverse undesirable ecosystem state conditions so that our coastal habitats continue to support life and produce the material and aesthetic goods and services that people want and need.

> *Human impacts have pushed estuarine and coastal ecosystems far from their historical baseline of rich, diverse, and productive ecosystems. The severity and synchrony of degradation trends and the commonality of causes and consequences of change provide reference points and quantitative targets for ecosystem based management and restoration. Overexploitation and habitat destruction have been responsible for the large majority of historical changes, and their reduction should be a major management priority. Eutrophication, although severe in the last phase of estuarine history, largely followed rather than drove observed declines in diversity, structure, and functioning. Despite some extinctions, most species and functional groups persist, albeit in greatly reduced numbers. Thus, the potential for recovery remains, and where human efforts have focused on protection and restoration, recovery has occurred, although often with significant lag times.* (Lotze et al. 2006)

Ecosystem Interactions and Ecological Dependencies

Natural Shorelines

Vegetated Tidal Wetlands – Salt, Brackish, and Freshwater Emergent Marshes

Among the most biologically productive ecosystems on earth (Teal 1962; Odum 1970; Valiela et al. 1976; Nixon 1980), salt marshes perform many ecosystem services that are highly valued by society. Salt marshes protect estuarine water quality by acting as a sink for land-derived nutrients and contaminants (Valiela et al. 2004; O'Connor and Terry 1972; Teal and Howes 2000). They are also an important component of the estuarine food web: there is a strong positive relationship between the productivity of salt marshes and the productivity of coastal fisheries (Peterson et al. 2000). During high tide, salt marshes and the network of tidal creeks and pools within them provide food and important nursery grounds for shellfish and finfish, including many commercially harvested species (Teal 1962; Weisburg and Lotrich 1982; Dionne et al. 1999; Able et al. 2000; Cicchetti and Diaz 2000). Juvenile menhaden, for example, derive much of their energy from marsh plant detritus rather than from a phytoplankton–based food web (Pernell and Peters 1984). Able et al. (2000) found that the guts of striped bass *(Morone saxatilis)* caught in marsh creeks were full of killifish *(Fundulus heteroclitus),* a common marsh resident. During low tide, salt marshes provide foraging opportunities for terrestrial species, including songbirds and shorebirds. Salt marshes also provide valuable wildlife habitat and nesting areas for osprey, the sharp-tailed sparrow and the clapper rail.

Typical northeastern salt marshes are described by Niering and Warren (1980), Edinger et al. (2002), Bertness (2006), and others. The low marsh zone, which is flooded on a daily basis by the tides, is dominated by the cordgrass, *Spartina alterniflora*. Low marsh grades into high salt marsh habitat. At slightly higher elevations, these are flooded periodically by spring and flood tides (Edinger et al. 2002). High salt marsh habitat occurs in a band from the mean high tide level to the landward limit of the highest spring tides. The dominant plant species in the high salt marsh community is the salt-meadow grass or marsh hay *(Spartina patens)*. Spikegrass *(Distichlis spicata),* black-grass (*Juncus gerardii*), and glassworts *(Salicornia* spp.) are also common in the high marsh. Characteristic invertebrates of the salt marsh include ribbed mussels *(Geukensia demissa)* and fiddler crabs *(Uca* spp.), both of which boost productivity of marsh plants.

As sea level has very gradually risen since the last glaciations period, salt marshes have grown both horizontally and vertically (Redfield 1965 and 1972). Horizontal growth occurs via migration into adjacent upland areas and vertical growth occurs through the accumulation of


© Robert H. Pos/USFWS

mineral and biologic sedimentary materials that form the peat substrate (Bertness 2006). Each year's new growth builds on these two types of sediments that form the marsh peat. Historically, this type of accretion has more or less kept pace with changing relative sea level in most parts of our region. However, human alterations such as shoreline hardening and development can impede this growth.

In regions where rivers bring large quantities of freshwater, salt water tidal marshes may grade to brackish and even completely fresh. Long bands of freshwater tidal marsh occur along the shores of the Hudson, Connecticut, and Kennebec River estuaries, for instance. Here, the graminoid (grass and grass-like) species shift from cordgrass to cattails, rushes, wild rice, and numerous forbs, many of which are restricted to this habitat and thus rare in the region. Brackish and freshwater tidal marshes are important for migrating waterfowl and anadromous fishes and, like salt marshes, contribute considerable carbon to the estuaries of which they are part. In some parts of the region, these wetlands have been heavily impacted by industrial development of major ports or by dams which have shifted the tidal flooding and salinity regimes. Rising sea level will be a particularly important factor in determining future trends in tidal marsh health and distribution.

A very small percentage of the overall shoreline in this region is classified by National Oceanic and Atmospheric Administration (NOAA) Environmental Sensitivity Index (ESI) as "swamp," mostly in the Southern New England and Mid-Atlantic subregions. According to ESI, freshwater tidal swamps are forested or shrub-dominated tidal wetlands, a classification used in the United States Fish and Wildlife Service (USFWS) National Wetlands Inventory (NWI), that occur along freshwater tidal portions of large river systems characterized by gentle slope gradients coupled with tidal influence over considerable distances. The swamp substrate is always wet and is subject to semidiurnal flooding by fresh tidal water (salinity less than 0.5 ppt). The characteristic trees are ash *(Fraxinus)* and tupelo *(Nyssa* and *Taxodium* species) (Reschke 1990).

Sandy Beach and Dune systems

There are three primary types of sandy beach systems found within the region: barrier island and barrier beaches, primarily found in the south, and pocket beaches, generally found in the north at the head of small bays.

Sandy ocean beaches especially in the southern half of the region are often associated with barrier island systems. In their natural state, sand-derived barrier islands and barrier beaches attached to the mainland are highly dynamic systems, constantly shaped and reshaped by winds, storms and ocean currents. Generally speaking, prevailing winds and nearshore currents cause North Atlantic barrier islands to migrate slowly southward (westward on Long Island), with sand lost from the north (east) end often transported to build new beaches and dunes at the south (west) end. Hurricanes and nor'easters episodically move tremendous quantities of sand, both onshore and offshore, as well as along the main axis of the islands. Barrier beaches typically protect tidal lagoons, coastal salt ponds, or salt marshes behind them. Breaches or blowouts of the beach/dune systems can occur during major storms, creating new channels for flow between the ocean and back bays, and flood plain deltas which eventually submerge to create sand flats, or become vegetated to create wetlands.

In the more northern part of the region sandy beaches tend to be pocket beaches at the head of small bays or fringing beaches at the base of bluffs. These are much smaller than barrier beaches but cumulatively still figure in the overall sediment budget and habitat dynamics of estuaries.

All types of sandy beaches in this region are breeding grounds for endangered and threatened species such as the piping plover, least terns, Arctic terns, roseate terns as well as several species of sea turtles (see Chapter 11 and 12 for more information). They also provide critical roost sites for migrant shorebirds. The sand of an open beach may appear relatively devoid of marine life, but a variety of species live in the sand as infauna, often serving as important food sources (Bertness 2006). The value of sandy beaches to marine species is enhanced by their functional relationship to the habitats behind them (e.g. dune systems) and to the productive sand and mud flats (see below) often associated with them.

Sandy ocean beaches have been long been valued for their recreation and tourism value and billions of dollars are spent to maintain these resources. This maintenance can include artificial stabilization to minimize erosion. However, in some cases the very techniques designed to secure the beach for human uses, such as groins, beach walls, and beach fill, actually interfere with the dynamics necessary for sandy shorelines and barrier islands to persist. This is particularly relevant in the face of rising sea level and storm surges. Thus, these shoreline armoring measures are actually detrimental to the ecological communities that rely on the beaches and adjacent habitats (Pilkey and Dixon 1996).

Cobble Shores

Cobble shores range from the mid to high energy cobble-filled nooks among the rocky headlands to stretches of cobble-lined shoreline adjacent to sandy beaches. More common in the northern half of the region, they support a different suite of species than the rocky headlands, as the cobble provides a less stable substrate for attachment. Cobble stones roll about in the surf, and are shoved into piles during one storm event and spread out again in another. Species associated with the cobble shore tend to be small, mobile, and short-lived (Tyrrell 2005), commonly including Irish moss, barnacles, periwinkles, and other invertebrates and the shorebird species that feed on them. The large algae species of the rocky headlands are mostly absent here but may be present on larger boulders.

Sand and Mud Flats

Non-vegetated sheltered coasts, usually sand and mud flats, have received less attention by resource managers than sandy ocean beaches or vegetated tidal wetlands, and therefore their importance to wildlife and humans has often been overlooked. Recently, however, the focus on the relationship between endangered shorebirds and sheltered beach-nesting horseshoe crabs has brought to light the ecological importance of these often under-protected coastlines. Intertidal sand and mud flats of the sheltered coasts can be fringing or expansive, depending on bathymetry and tidal amplitude.

Sediment size, sediment chemistry, inundation cycle, salinity, frequency of disturbance, and latitude are all determinants of the biotic community within flats. These flats are habitat for shellfish such as blue mussel *(Mytilus edulis),* Eastern oyster *(Crassostrea virginica),* hard clam (*Mercenaria mercenaria*) and soft shell clam *(Mya arenaria).* In addition to the typical resident invertebrate communities of annelids, crustaceans, and bivalves, tidal flats are foraging grounds for marine organisms such as eels, crabs, fish, snails, and shrimp at high tide and terrestrial organisms, particularly shorebirds, at low tide.

A variety of algal species often grow or float among the shells, rocks, and other structures present in the intertidal areas. The algae and bacteria that grow here provide additional food for fish, shellfish, and other animals using this habitat. However, in some areas of anthropogenic eutrophication excessive growth of certain green algae species can actually suffocate the infauna of the mudflats below.

Rocky Headlands

The organisms of the stable bedrock and boulder seacoast include those capable of attaching to rock and withstanding intense wave impact and periodic desiccation. These include attached macroalgae such as rockweeds *(Ascophyllum nodosum, Fucus spp.)*, kelp *(Laminaria spp.)*, *Enteromorpha* spp., and *Rhizoclonium* spp., and invertebrates such as blue mussel *(Mytilus edulis)*, rock barnacle *(Balanus balanoides)*, sea star *(Asterias spp.)*, and sea urchin *(Arbacia punctulata)*. As the environment is high energy, rocky shore communities may be less vulnerable to human caused degradation, although eutrophication, sedimentation, overexploitation, and trampling can still pose problems (Menge and Branch 2001). Like large intertidal cobble and boulders, rocky headlands also provide habitat for juvenile lobsters (Cowan 1999) and fishes. Island occurrences of rocky headlands provide haul out areas for seals and nesting areas for seabirds.

Coastal Salt Ponds

Coastal salt ponds, found mostly in southern New England (according to the NWI), are marine shoreline lakes or ponds formed when sandspits or barrier beaches close off a lagoon or bay from the surrounding estuarine or oceanic waters. These ponds can be permanent, transient, or periodic. The salt pond water is often less saline that the surrounding embayment and its volume is dependent upon the rates of freshwater input, evaporation, and the frequency of breaching or flooding. Some ponds have been modified to have permanent inlets, and some are managed by opening and closing inlets. Salt pond species are usually the same as those found in adjacent sheltered brackish embayments; however, unique community assemblages can arise within ponds that are only periodically breached. Species which can tolerate salinity and temperature changes such as the killifish (*Fundulus heteroclitus*), Eastern oyster (*Crassostrea virginica*), and American eel (*Anguilla rostrata*) can thrive in salt ponds. Isolation within a salt pond can protect species, at least temporarily, from migratory marine predators. In winter, coastal salt ponds provide migratory refuge for a broad variety of waterfowl including canvasback duck *(Aythya valisneria)*, pintail *(Anas acuta)*, scaup *(Aythya affinis)*, and common loon *(Gavia immer).*

Seagrass Beds

Seagrasses are marine, subtidal, rooted vascular plants found in shallow coastal waters in various types of sediment substrate from sand to mud. Eelgrass *(Zostera marina),* the major seagrass species in the region, grows in perennial beds that form highly diverse and productive

© Jerry Monkman

ecosystems providing a wide range of services. Widgeon grass *(Ruppia maritima)* is an annual seagrass species that also grows in the region but tends not to form extensive bed structures. Eelgrass beds serve as shelter and nursery grounds for hundreds of species from all phyla, including juvenile and adult fishes, shellfish, and invertebrates.

The plants can contribute significantly to the overall primary productivity of an estuary; energy present in seagrass enters the estuarine food web as detritus. In addition, numerous animals feed directly on seagrasses, including fishes, geese, swans, sea turtles, and crabs. Seagrass provides structure for benthic (seabed) communities and can slow down currents, thereby increasing sediment trapping. The seabed is stabilized by seagrass roots and rhizomes. Seagrass provides oxygen to the water column and shallow benthos, and takes up nutrients (e.g. nitrogen and phosphorus) during its growing season (spring to fall), re-releasing the nutrients through organic decay.

Seagrasses support a diverse epiphyte (plants that grow on the surface of another plant) community, including benthic diatoms and other algae, and free-floating macro and microalgae. Other organisms living on blades of eelgrass include protozoans (ciliates, flagellates, and foraminifera), nematodes, and copepods (Perry 1985). Sessile (attached) animals living on the blades and at the base of eelgrass shoots include bay scallops, crustaceans, sponges, anemones, bryozoans, tube worms, polychaetes, barnacles, and other arthropods and tunicates (Perry 1985).

Seagrass beds can occur in association with a variety of natural shoreline types. Ecological factors contributing to the distribution and continued health of seagrasses include water quality, depth, substrate type, light and nutrient regime, existing meadow size, germination and growth, water temperature, pore water chemistry, salinity, sediment dynamics, and wave energy. Many of these attributes are site specific. Although in many parts of the region seagrass beds have significantly declined, computer models (Short and Burdick 2005) have recently become available to help determine the most suitable places for eelgrass within some estuaries.

Nearshore Shellfish Assemblages

Dense beds of oysters, clams, scallops, and mussels once populated the bays and estuaries of the Atlantic coast, providing a wide array of ecological services. For instance, oysters develop vertical reef structures that provide fish habitat, filter the water and modify patterns of estuarine circulation, sediment transport, and wave energy. The viability of nearshore shellfish populations is highly dependent on sustainable harvest levels and presence of high quality settlement substrate, as well as estuarine water quality and salinity regimes. Although many shellfish species are found in abundance in the region, populations of some formerly dominant bivalve species are dwindling.

Prominence as a food source often overshadows the critical roles that shellfish assemblages play in ecosystem function (Grabowski and Peterson 2007). Bivalves are suspension feeders that, in abundant colonies, have the capacity to filter volumes of water equivalent to entire bays in a matter of days (Newell 2004). Filter feeders exert controls on harmful algal blooms and may facilitate eelgrass productivity (Peterson and Heck 1999; Wall et al. 2008). Reefs formed by oysters and blue mussels provide refuge and structure for many marine plants, animals, and invertebrates (ASMFC 2007), including economically valuable fish (Peterson et al. 2003). Once established, shellfish form dense colonies that provide many services, especially water filtration that directly benefits other species and habitats like eelgrass. In intertidal areas, shellfish beds trap sediments and stabilize shorelines against wave and storm erosion (Piazza et al. 2005; Meyer et al. 1997). The loss of shellfish habitat therefore has wide-ranging and serious implications for human and marine communities alike.

Larval forms of bivalves are preyed upon by many fish and marine invertebrates. As juveniles and adults, bivalves are major forage for all forms of fish, invertebrates (especially crabs, whelks, and starfish), shorebirds, seabirds, and even mammals.

Eastern Oyster *(Crassostrea virginica)*

Also known as the American oyster, this species is arguably the most historically dominant and commercially valuable shellfish species found throughout the region. Reefs occur in both subtidal and intertidal locations, with commercial activities focused on subtidal beds. Oysters are widely recognized as "ecosystem engineers" that create essential fish habitat, augment water quality, and provide services fundamental to the ecological health of estuaries and nearshore areas. The Eastern oyster occurs naturally from the Gulf of St. Lawrence (Canada) to the Gulf of Mexico. In the region, most remaining oysters are located from Delaware Bay south. Oysters form reefs in subtidal areas to depths of 10 m and intertidal areas (primarily south of Long Island), tolerating a wide range of temperatures and salinity levels. Spawning is temperature dependent, and larvae are planktonic. Larvae require hard substrate and prefer biogenic surfaces (e.g. shell bottom) for successful recruitment.

Hard Clam *(Mercenaria mercenaria)*

Hard clams, also known as quahogs or littlenecks, are widely-distributed in subtidal areas of the Northwest Atlantic. A commercially valued species, dense beds of hard clams create benthic habitat and contribute to improved water quality. The hard clam is found from the Gulf of St. Lawrence (Canada) to Texas, although they are most abundant from Massachusetts to Virginia. Hard clams aggregate in intertidal and subtidal areas to depths of 15 m, and typically occur in locations with salinity levels >19 ppt. Spawning is temperature dependent. Larvae are planktonic and settle in a variety of substrate types, including sand, sandy mud, and gravel.

Softshell Clam *(Mya arenaria)*

Softshell clams, also known as steamers, are a dominant filter-feeder in intertidal areas and mudflats of coastal embayments, from the Bay of Fundy to the mid-Atlantic coast, but are most abundant from New England to the Chesapeake Bay. An important commercial species, especially in New England, this species also stabilizes soft sediments and is capable of considerable water filtration. Softshell clams populate intertidal and subtidal areas to depths of 200 m, with preferred salinity levels > 20 ppt in northern areas and 4-15 ppt in southern areas. Spawning is temperature dependent. Larvae are planktonic and settle in a range of substrate types, including sand, sandy mud, mud, clay, and gravel, but not in cobble or rocky ledges.

Bay Scallops *(Argopecten irradians)*

Bay scallops, unlike deeper-water sea scallops, are primarily estuarine bivalves that congregate in subtidal low energy areas such as seagrass meadows. Bay scallops are historically an important commercial species, and existing populations help maintain water quality by filtering algae and phytoplankton. Distributed from New England to Texas, they are most abundant from Cape Cod (Massachusetts) to Virginia. The species occurs in low-energy, shallow subtidal areas to depths of 18 m. Bay scallops do not tolerate low annual salinity levels (< 10 ppt). Spawning is temperature dependent, and the planktonic larvae may attach to eelgrass shoots before settling to the bottom.

Blue Mussel *(Mytilus edulis)*

Blue mussels are found extensively in subtidal and intertidal areas throughout the Northwest Atlantic region, Europe, and other temperate waters. Beds are common from Labrador (Canada) to South Carolina, and typically found in littoral zones to depths of 100 m (maximum depth 500 m). Considered of lesser commercial value than other shellfish, mussels have become dominant shellfish species in northern regions, forming large reefs and filtering extensive reaches of coastal water bodies. Blue mussels are preyed upon by many aquatic species, especially waterfowl and macro-invertebrates. This species tolerates a wide range of salinity levels and temperatures. Spawning is temperature and food-dependent and may occur more than once a year. The planktonic larvae settle first on algae and seaweed before attaching to hard shell or rock substrates.

Ribbed Mussel *(Geukensia demissa)*

Ribbed mussels inhabit salt marshes throughout the region and oyster reefs in southern parts of the region. Where present, these mussels can form colonies as dense as 100 m^{-2} that provide sediment stabilization, water quality controls, and food sources for many crustacean and avian species. Ribbed mussels occur from the Gulf of St. Lawrence (Canada) to Texas. The species prefers intertidal areas of salt marsh and oyster reef habitat, and tolerates a wide range of salinity levels and temperatures. Spawning is temperature and food dependent. Larvae are planktonic and must attach to filamentous or reef-type structures.

Northwest Atlantic Distribution and Characterization

Methods

Overview

Previous terrestrially-focused ecoregional assessments by TNC delineated specific beach and dune systems and tidal wetlands of regional importance based on their size, natural condition, and presence of rare nesting birds, plants or exemplary terrestrial natural communities. Unlike these earlier efforts, this assessment is the first to focus on the coast from a marine perspective. To facilitate characterization of the entire coastline and potential values of various subsets of the coast for marine processes, the coast was divided into 62 discrete stretches of shoreline and nearshore habitat (Coastal Shoreline Units, hereafter CSUs). These were stratified by subregions (Gulf of Maine, Southern New England, and the Mid-Atlantic Bight), and by estuary type. Each unit in the United States portion fits into one of four Coastal Marine Ecological Classification Standard (CMECS) types (Madden et al. 2005) assigned by the Environmental Protection Agency (EPA) (Figure 2-7). The CMECS types of coastal areas are 1) river dominated, 2) lagoon, 3) coastal embayment, and 4) fjord. In addition, the relatively uniform Canadian coastline within this region was characterized as the Bay of Fundy type. The CSUs of the region sorted into the following categories:

- Lagoons (7 examples)
- Embayments (10 examples)
- River-dominated (20 examples)
- Fjords (18 examples)
- Bay of Fundy (7 examples)

Each discrete CSU delineates a segment of coast line typically encompassing a large estuary or a set of small interconnected estuaries or a barrier beach and lagoon system. Each was characterized by summarizing a variety of natural features that have presumed relevance to how the coastline contributes to marine productivity and biodiversity. These included:

- Amount of tidal marshes (both salt and brackish emergent marsh)
- Amount of eelgrass beds
- Types of shellfish beds
- Amount of beaches and dunes
- Amount of rocky shores and cliffs
- Number of salt ponds
- Diversity of natural shoreline habitats
- Importance to estuarine-dependent fish species
- Importance to diadromous fish species
- Importance to coastal breeding or wintering birds

In addition, the condition of each CSU was summarized with respect to the amount of development, man-made shoreline, and land use. It should be noted that the underlying data and methods for these characterizations could be applied to any geography, estuarine site classification, or state for purposes of comparison.

CMECS Classification

The CMECS classification focuses on the importance of estuary size, shape, and flushing in dictating processes within an estuary and the adjacent coastal area. The classification variables are considered to be "natural" characteristics of the estuary, in both material and energetic terms, meaning those which influence estuarine processing to varying degrees and are not generally controllable or influenced by either stressor or response variables. The types recognized in the CMECS classification are so distinct in geomorphology and hydrology that they not only look very different from each other, but also process nutrients in very different ways based on their exchange with the ocean, fresh water inflow, and residence time. Although other coastal and estuarine classifications exist in the region (Engle et al. 2007; Bricker et al. 2007), the CMECS classification brings together many local classifications via a standard format. The resultant classes provide useful descriptors for biological and response characteristics of the environment and are being used in the forthcoming EPA e-Estuary project which will provide a database and tools to support environmental decision-making for estuaries (Detenbeck 2008, personal communication).

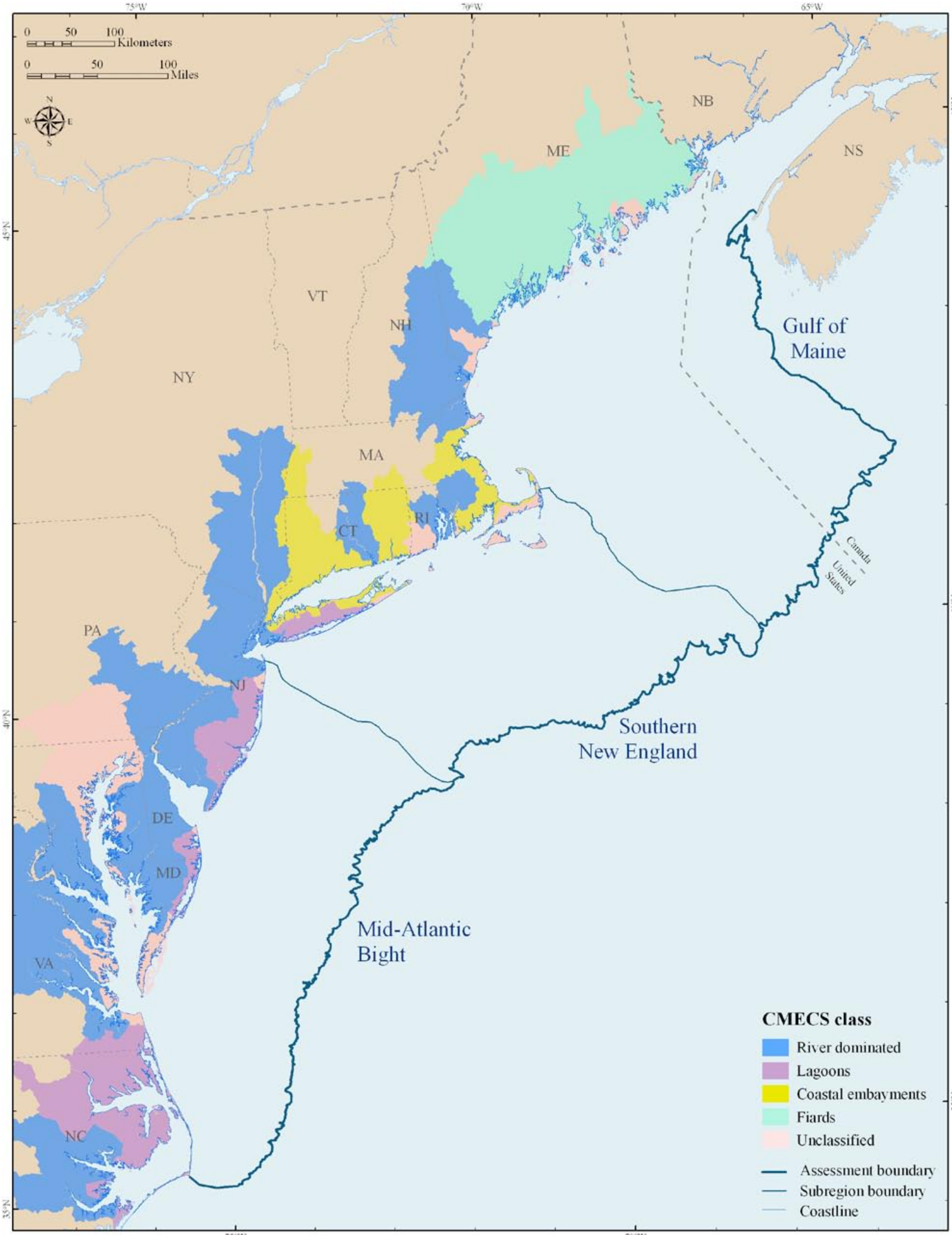


Figure 2-7. Coastal Marine Ecological Classification Standard (CMECS) types (Madden et al. 2005) as assigned by the EPA.

River Dominated areas include river channels, drowned river valleys, deltaic estuaries, salt wedge estuaries, and tidal fresh marshes. This class of estuary tends to be linear and seasonally turbid, especially in upper reaches, and can be subjected to high current speeds. These estuaries are sedimentary and depositional, and can be associated with a delta, bar, or barrier island and other depositional features. These estuaries also tend to be highly flushed, with a wide and variable salinity range, and seasonally stratified. They have moderate surface to volume ratios, high watershed to water area ratios, and can have very high wetland to water area ratios as well. These estuaries are often characterized by a V-shaped channel configuration and a salt wedge.

Coastal lagoon areas include lagoons, sloughs, barrier island estuaries, bar-built estuaries, and tidal inlets. This class of estuary tends to be shallow and highly enclosed, with reduced exchange with the ocean. They often experience high evaporation, and are quiescent in terms of wind, current, and wave energy. They tend to have a very high surface to volume ratio, low to moderate watershed to water area ratios, and can have a high wetland to water ratio. Note that the length of the outer barrier beaches that form the lagoons was included in the CSU characterizations below.

Coastal embayments include bays, sounds, and coastal bights. This class of estuary is loosely bounded by landforms, open to marine exchange, and has moderate to high salinities. They are well-flushed, often deep, and subject to potentially high energy input from tides, winds, waves and currents. These estuaries can range from very low to very high in terms of surface area to volume, watershed to water area, and wetland to water ratio.

Fjords, glacially carved embayments that are drowned by the sea, are deep, seasonally cold-water estuaries with low to moderate riverine inputs found at mid to high latitudes. This class of estuary has relatively complex, usually rocky shorelines and bottoms and is partially enclosed, sometimes by mountainous landforms. The waters of fjords are typically stratified, often due to a geologic sill formation at the seaward end formed by glacial action. However, the fjords of the Gulf of Maine (sometimes referred to as "fjards" – see Pettigrew et al. 1997) lack the topographic and benthic constrictions of true fjords and are generally well mixed.

Delineating CSU Boundaries

Four project sub-teams made CSU delineations based upon continuity of processes and natural breaks. The team collectively reviewed and approved a final set of 62 delineations, shown in Figure 2-8.

To the extent possible, areas were delineated at oceanographic discontinuities such as large-scale oceanic currents. Estuarine circulation models and tidal maps of discontinuities (i.e. where currents move in opposite directions) were consulted. These delineations were then compared with information on the biogeography of marine invertebrates (Wigley and Theroux 1981). The sub-teams attempted to avoid crossing over watersheds and consolidating areas with very different freshwater inputs. In Maine, focus area boundaries already delineated by Maine's Beginning with Habitat program were considered (BwH 2009). Generally, islands along the Maine coast were included in their most immediate nearby CSU. Riverine CSUs were separated for midsize to large tributaries by intuitive natural features. In general, strings of barrier island lagoons are presented as single CSUs. Unit boundaries were sometimes extended beyond a particular feature or estuarine unit so that the coast would be divided into a contiguous string of CSUs. (For some parts of the region where this delineation resulted in relatively large units, subunits were also delineated based on coastal ecology and locally accepted delineations for planning and management purposes.)

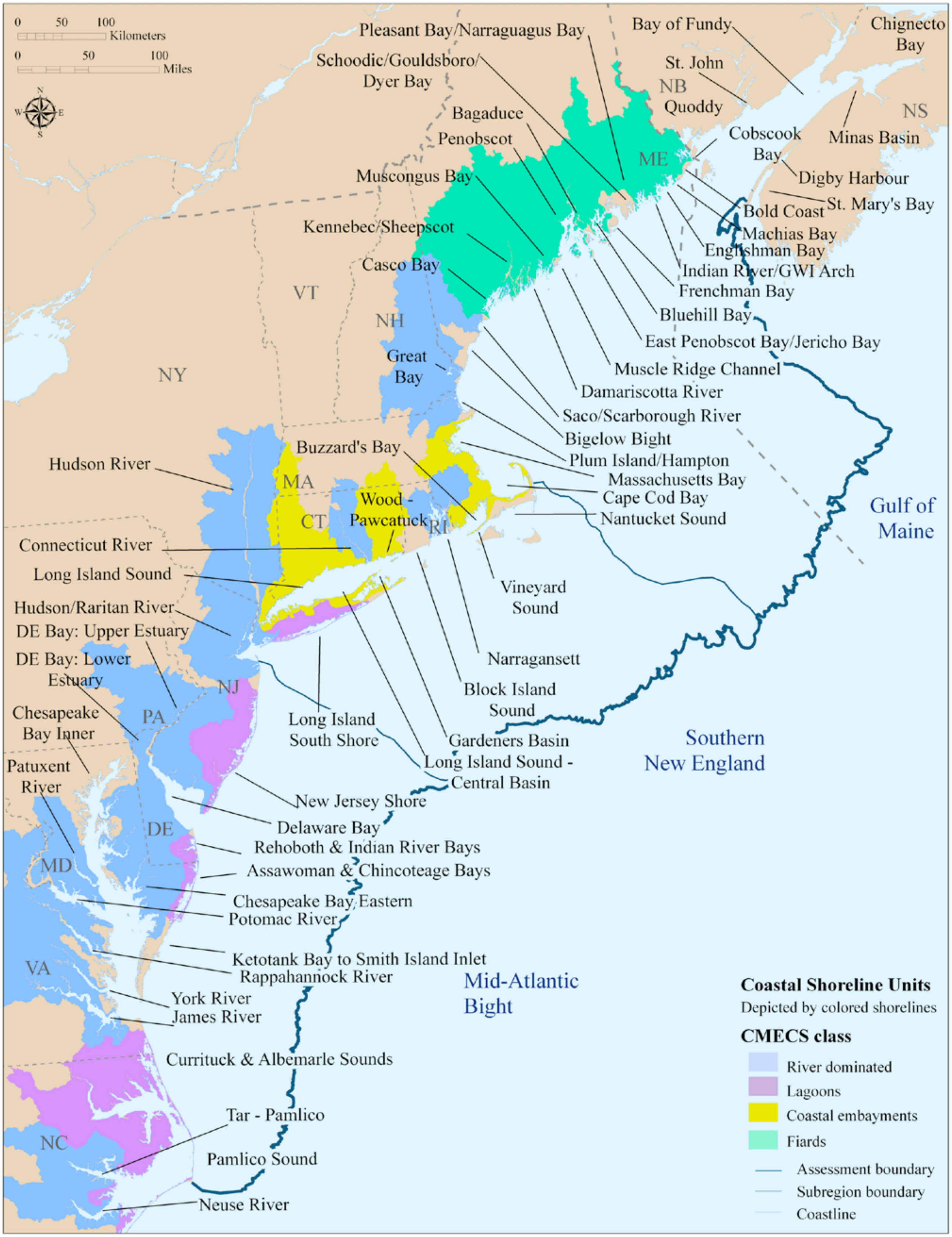


Figure 2-8. Coastal Shoreline Units (CSUs) delineations based upon continuity of processes and natural breaks.

Characterizing Coastal Shoreline Units

Each CSU was characterized with respect to size, habitat diversity, and condition in order to identify patterns by subregion and by CMECS type.

Size

Size is an important CSU parameter because many other variables are likely to correlate with it. Size of each CSU was characterized by shoreline length and hectares of intertidal habitat. In general, the lagoon and river types are much larger than the embayment or fjord CSU types, with an average shoreline length of 2,791 and 1,798 km respectively versus 690 and 483. Similarly, the average intertidal habitat area of lagoons is 10 times that of embayments. This is why subdivisions of many lagoons and rivers into tier 2 subunits were deemed helpful. However, there is a large range in size within all four classes. In particular, riverine CSUs range from 7,163 km for the eastern Chesapeake Bay CSU to only 237 km for the Saco River/Scarborough CSU in Maine. There is corresponding regional variation in size of CSUs. In general, the highly indented Gulf of Maine coast is characterized by fjords, on average the smallest of the four types, so the CSUs of the Gulf of Maine are on average one fifth the size of those of the Mid-Atlantic.

Habitat Diversity

Habitat diversity of CSUs was characterized in several ways. First, the length of each CSU shoreline was calculated by major habitat type, as per the ESI. The ESI classifies the coastline into 22 categories, which was consolidated into the following eight categories for simplification of interpretation: 1) beach, 2) flat, 3) marsh, 4) swamp, 5) rocky shore/cliff/platform, 6) non-rocky bluff/steep/platform, 7) manmade, and 8) undefined.

Second, the amount of six intertidal habitat classes was calculated (in hectares) for each CSU. Intertidal habitat types were mapped by extracting intertidal coded polygons from the NWI (US DOI FWS 2008) in the United States and by extracting coastal ecosystem polygons from the Northern Appalachian Ecoregional Planning coastal target polygon dataset (Anderson et al. 2006a) in Canada. The polygons were placed into the following six intertidal habitat categories 1) unconsolidated shore (sand, gravel, cobble), 2) unconsolidated shore (mud, organic, flat), 3) emergent marsh, 4) forested wetland, 5) rocky shore, and 6) scrub-shrub wetland.

The quantification of emergent marsh or vegetated tidal wetlands in the analyses presented here is different than the quantification of "tidal wetlands" in the North Atlantic Coast Ecoregional Assessment (Anderson et al. 2006b). Unlike the 2006 coastal assessment, which lumped unvegetated tidal wetlands and some submerged lands into tidal wetland complexes, this assessment separated out vegetated tidal wetlands (e.g., salt marsh, tidal marsh or emergent marsh) from unvegetated wetlands. The rationale for this difference in approach is the desire to distinguish "wetland loss" and "wetland conversion" as threats to these estuarine systems. With the exception of vegetated tidal wetlands that get filled and or armored, "wetland loss" attributable to other causes is often first evidenced by the loss of emergent vegetation and then submergence of land.

Third, the amount of seagrass was calculated and the number of coastal salt ponds was counted within each CSU. Unlike the NWI and ESI datasets, seagrass coverage was determined by combining many different datasets from federal, state and local data sources. These sources include Maine Department of Marine Resources, New Hampshire Department of Environmental Services, Massachusetts Department of Environmental Protection, Rhode Island Narragansett Bay Estuary Program, USFWS (for Connecticut), New York Sea Grant (for the Hudson River), Peconic Estuary Program, (for Peconic Bays, New York), NOAA Coastal Services (for Long Island's south shore estuaries), Rutgers Center for Remote Sensing and Spatial Analysis (for New Jersey), ESI (for Delaware), Virginia Institute of Marine Science (for Chesapeake Bay and the Eastern Shore of Virginia), and TNC's Carolinian Ecoregional Plan (for North Carolina). Data collection methods for seagrass coverage tend to vary by locality, as did year of data collection (1968 – 2008). For consistency at the regional scale, seagrass meadows are shown as presence or absence only, although in some geographies more fine scale delineations (such as continuous/discontinuous; thick, medium, or thin; or root or above ground biomass/unit area) are available and these attributes are preserved in the dataset. Some states have only one year of data, while others have several, collected in subsequent or consecutive years. Consequently, two different seagrass datasets were compiled: total historical seagrass coverage and the most recent available year of data. For this report, seagrass presence in the most recent year of data is presented, outlined by a 2-point line for graphical display. Coastal salt pond data was summarized from 2008 Natural Heritage Program Element Occurrences.

Finally, the diversity of benthic habitats was characterized, by depth, grain size, and seabed form, offshore to 1,000 m (see Chapter 3 for further information). Unfortunately, data were lacking for several of these parameters for the Canadian portion of the region, so the Fundy CSUs were not characterized for these attributes. The variables and the attribution method are briefly presented in a summary table (Table 2-2).

Assessment of CSU Condition

Indicators of both shoreline condition and water quality were examined within the estuaries for which there were consistent coast-wide data. For shoreline condition, the proportion of man-made vs. natural shoreline within each CSU was calculated, derived from the ESI. The number of man-made structures per unit of shoreline was determined to be another appropriate indicator, but found that the relevant NOAA dataset was inconsistent with respect to date and sometimes incomplete.

Nearshore land use is a relevant potential indicator of both shoreline condition and water quality. The amount of developed land in the nearshore zone was calculated for two areas: the area adjacent to the shoreline that was lower than 2 m elevation and for the area within 300 m horizontal distance of the shoreline. These two measures generally track each other but the former can be particularly helpful when considering potential impacts of sea level rise. Finally, the amount of developed and agricultural land and impervious surface was calculated within each CSU watershed. These watersheds do not exactly coincide with those used by NOAA in their Estuarine Eutrophication Assessments. Maps for the latter are provided for comparison and in many cases corroboration. The condition variables are briefly presented in Table 2-3.

Characterizing Nearshore Shellfish Assemblages

Despite the commercial importance of these target species (except ribbed mussel), reports of population distribution, abundance, and health status are not available consistently region-wide. To address questions of distribution and abundance, two metrics were examined for nearshore shellfish assemblages. Presence/absence of each species (where data were available) was documented for each bay to examine distribution. As a proxy for population status, NOAA's National Marine Fisheries monthly commercial landings statistics was analyzed.

Distribution

The primary source for distribution data was the 1995 National Shellfish Register of Classified Shellfish Growing Waters (NOAA 1997). The 1995 Register is the most recent, and only regional, dataset for shellfish distribution and abundance in the Northwest Atlantic. Other state and local shellfish datasets were identified, but a lack of consistent standards, spatial coverage, and availability rendered these sources unusable for this assessment. In developing the 1995 Register, NOAA worked with state shellfish resource managers to identify nearshore shellfish waterbody areas, resulting in a catalogue of about 2,900 discrete areas from Maine to North Carolina. State managers were asked to rank each waterbody, known as Classified Shellfish Areas (CSA), for the relative abundance of each shellfish species compared with all other state waterbodies.

The CSA database was found to contain many entries coded as "Not Reported," for non-managed shellfish species like blue mussel and ribbed mussel. Mussel abundance was reported for less than 1% of areas across the region.

Table 2-2. Attribute Variables for Coastal Shoreline Units (CSU).

Category	Data Source	Measure	Subtypes	Brief Method
Shoreline length by major habitat type	NOAA Environmental Sensitivity Index, 2001-2004. Scale 1:24,000 (US); Provincial Coastline Scale 1:24,000 (New Brunswick), 1:100,000 (Nova Scotia)	kilometers	beach	Each shoreline segment was assigned to a CSU to yield a total length for each CSU. For those CSUs in the US, the segment lengths were then summarized by the ESI subtype categories. For those CSUs in Canada, the only subtypes included were man-made and undefined.
Intertidal habitat area	USFWS National Wetlands Inventory, 1970-2008. Scale 1:100,000 (US) Provincial Wetland Datasets (New Brunswick and Nova Scotia), 2000. Scale 1:20,000-1:50,000.	hectares	unconsolidated shore (sand, gravel, cobble)	Each polygon was assigned to a given CSU based on nearest proximity. The total area of each of the habitat subtypes was then summed for each CSU.
			unconsolidated shore (mud, organic, flat)	
			emergent marsh (vegetated tidal wetlands)	
			forested	
			rocky shore	
			scrub-shrub	
Other Coastal Habitats	Various Seagrass Datasets, 1968 – 2008. Scale = < 1:24,000	hectares	seagrass	Each polygon was assigned to a given CSU based on nearest proximity. The total area of each in seagrass was then summed for each CSU.
	State Natural Heritage Program Element Occurrences 2008	number	coastal salt ponds	Each point was assigned to a given CSU based on nearest proximity. The total number of coastal salt ponds was then summed for each CSU.
Offshore 1000 m Buffer Benthic Habitat Diversity	TNC Ecological Marine Units (grain size, seabed form, depth) 2009	% of the 1000 m buffer zone	*Depth Zones*	Each CSU shoreline was buffered 1,000 m horizontally seaward. The Ecological Marine Units types and depth zones within the buffer were summarized for each CSU.
			0 to -1 m	
			-2 to -3 m	
			-4 to -10 m	
			-11 to -30 m	
			-31 to -100 m	
			-100 m and deeper	
			Grain Size	
			clay or silt	
			very fine sand	
			fine sand fine sand	
			% grain size medium sand	
			coarse sand	
			pebbles	
			Seabed Forms	
			Depression	
			Mid Flat	
			High Flat	
			Low Slope	
			High Slope	
			Steep/Sideslope	

Table 2-3. Condition variables for Coastal Shoreline Units (CSU).

Category	Data Source	Measure	Subtypes	Brief Method
Man-made shoreline	NNOAA Environmental Sensitivity Index, 2001-2004. Scale 1:24,000 (for US); Provincial Coastline Scale 1:24,000 (for New Brunswick), 1:100,000 (for Nova Scotia); US land cover: EPA National Land Cover Dataset, 2001; New Brunswick and Nova Scotia: DNRE. Generalized 1:10,000 forest stand data c. 1990s	% of total CSU length	beach	For the non-Maine part of the US coast, the length of "man-made" was summarized for each CSU based on source NOAA ESI line type coding. Special processing was done to assign a "man-made" class in Maine and Canada, where no man-made shoreline types had been assigned by NOAA or other sources. The processing method included overlapping the developed land cover cells with the shorelines to identify sections of the shoreline that were adjacent to developed lands, and thus likely "man-made" shorelines.
	United States land cover: EPA National Land Cover Dataset, 2001; EPA Impervious Surface Dataset, 2001	% of total land area in whole upstream watershed	% developed (residential, commercial, transportation, and quarries)	The full upstream watershed for each CSU was delineated using Basin Delineator Tool distributed with the USGS National Hydrography Plus dataset. Inputs to the tool for each CSU included all reaches with their outflow within 100 m of the CSU shoreline. The land cover types within the delineated full watershed were then summarized for each CSU.
			% agriculture (row crops and pasture)	
			% natural (including barren)	
			% impervious surface	
Eutrophication (for US only)	NOAA National Estuarine Eutrophication Assessment, 1999, 2004 update	Reporting of NOAA metrics in the primary and secondary Ecological Drainage Unit associated with each CSU	NOAA NEEA 1999 overall eutrophication	The NOAA NEEA dataset was provided at the Estuarine Drainage Area (EDA) watershed unit scale. These EDA units did not overlap one to one with our CSUs. To summarize the NEEA data by CSU, we joined each CSU component arc to the nearest EDA. The percent of the total CSU shoreline length occurring in each EDA was then calculated. The four eutrophication subtype metrics of interest were reported for the primary EDA with which each CSU was associated. For CSUs crossing more than one EDU, the four eutrophication subtype metrics of interest were also reported for the secondary EDA with which each CSU was associated.
			NOAA NEEA 1999 influencing factor on eutrophication (human influence)	
			NOAA NEEA 1999 projected changes in eutrophic conditions through 2020 based on projected population growth and susceptibility	
			NOAA NEEA 2004 update to overall eutrophication	

Lacking other spatial data sources for these species, mussels could therefore not be included in ecoregional abundance mapping.

For managed species, more than 50% of areas in the region included data for populations of Eastern oyster, hard clam, softshell clam, and bay scallop. For these species, most of the "Not Reported" areas appeared to be in states without substantial natural populations remaining. For example, oysters were under-reported in most of Maine and New Jersey; hard clams were under-reported in Maine and south of Virginia; and softshell clams and bay scallops were not reported south of New Jersey. In addition to species absence, some under-reporting was likely due to inconsistencies among states. NOAA noted that "data quality was directly related to the resources available to conduct shellfish management responsibilities." However, state managers did provide "final verification of the data content" (NOAA 1997). With a greater than 50% overall reporting rate, very good coverage of state-managed shellfish beds, and few other reporting options, the CSA database was determined to be a reasonable and adequate source for regional shellfish reporting.

In developing a map of target shellfish distribution and abundance, CSA entries with ranked abundances for the four target species under state management (oyster, hard clam, softshell clam, and bay scallop) were used. Abundance ranks could not be compared across states and further do not provide any historical context for shellfish distribution and abundance. Therefore, ranks of "High," "Medium," and "Low Abundance" for each shellfish species were converted to present and ranks of "None" or "Not Reported" to absent. In addition, each area was assigned a number from 0 to 4 depending on the number of reported target species present there in order to identify those areas of particular importance for protection of shellfish assemblages.

Population Status

As a proxy for population status, National Marine Fisheries Service (NMFS) monthly commercial landings data were analyzed for mollusk species (NOAA 2008). Eastern oyster, hard clam, softshell clam, and bay scallop landings data were queried for each state for the entire reporting period of the database (1950 to 2007). Data are from continuous records collected by joint state and federal agencies, and reported as metric tons (wet weight).

To understand the changes in historical landings for each state and species, time series of annual landings were analyzed for 1) maximum annual harvest in the series, 2) year of the maximum harvest, 3) total number of years reported (out of 58 possible reporting years from 1950 to 2007), 4) mean value for the last three years reported in the time series, and 5) last three-year average as a percentage of the maximum annual harvest. New Hampshire, as the only assessment state without commercial shellfish landings, was not included in the NMFS database. For New Hampshire, a time series of annual estimates of standing stock was analyzed for Eastern oyster and softshell clam, as surveyed by the New Hampshire Department of Fish and Game (NHEP 2006). Results are presented in Table 2-4.

Several important caveats apply to this use of commercial landings data as a proxy for abundance. First, data are not normalized for fishing effort. Peak harvest benchmarks may reflect levels of unsustainable pressure. Further, it is possible to have a sustainable fishery even if current harvest levels are very low compared to historic benchmarks. Natural variability in year-to-year recruitment can also produce wide swings in standing stock and harvest opportunity. Finally, NMFS mollusk datasets include aquaculture landings (totals not available separately) that contribute to recent landings totals and may mean that the results presented here overestimate natural bed conditions. For the four target species, maps were developed to show the last 3-yr average landings as a percent of maximum harvest by 0 - 10%, 11 - 50%, and 51 - 100% levels for each state (Figure 2-9, 2-10, 2-11, and 2-12).

Table 2-4. Monthly Commercial Landings Summary as reported by NOAA National Marine Fisheries Service (1950-2007). http://www.st.nmfs.noaa.gov/st1/commercial/landings/monthly_landings.html Note: New Hampshire values are estimated standing stock from field surveys (NHEP 2006) converted from bushels to metric tons (wet weight).

	ME	NH	MA	RI	CT	NY	NJ	DE	MD	VA	NC
Eastern Oyster											
Maximum harvest (metric tons)	158.7	2057.4*	134.1	418.3	3740.8	3985.7	3284.9	1968.6	9263.4	11568.4	735.2
Year of maximum	1990	1993	1980	1950	1993	1950	1950	1954	1973	1958	1952
Number years reported	35	12	49	46	57	58	55	48	58	57	58
Last 3 yr reported mean (metric tons)	19.8	99.9*	67.5	34.7	87	92.5	144.6	35.6	192.2	41	191.6
Last 3 yr mean (as % of maximum)	12%	5%	50%	8%	2%	2%	4%	2%	2%	0%	26%
Hard Clam											
Maximum harvest (metric tons)	258.1		985.7	2277	2330.3	3877.8	2306.4	366.6	360.4	1128.2	699.3
Year of maximum	1951		1951	1955	2004	1971	1950	1950	1969	1965	1980
Number years reported	51		49	57	56	57	46	56	39	47	58
Last 3 yr reported mean (metric tons)	1.8		197.1	361.3	1699	697.2	830.3	27.6	8.8	107.7	190.6
Last 3 yr mean (as % of maximum)	1%		20%	16%	73%	18%	36%	8%	2%	10%	27%
Softshell Clam											
Maximum harvest (metric tons)	3553.9	437.4*	932.3	227.1	1.7	178.3	204.1		3703.3	180.6	
Year of maximum	1977	1997	1982	1950	1950	2006	1950		1964	1966	
Number years reported	46	38	48	58	18	57	40		53	12	
Last 3 yr reported mean (metric tons)	840.5	57.4*	434.4	89.1	0.1	130.2	12.5		54.4	65.3	
Last 3 yr mean (as % of maximum)	24%	13%	47%	39%	6%	73%	6%		1%	36%	
Bay Scallop											
Maximum harvest (metric tons)			929.9	203.5	190.6	448.1	170.7				289.7
Year of maximum			1971	1978	1953	1962	1964				1968
Number years reported			41	29	17	58	15				54
Last 3 yr reported mean (metric tons)			53.3	1.3	5.5	3.5	11.7				5.4
Last 3 yr mean (as % of maximum)			6%	1%	3%	1%	7%				2%

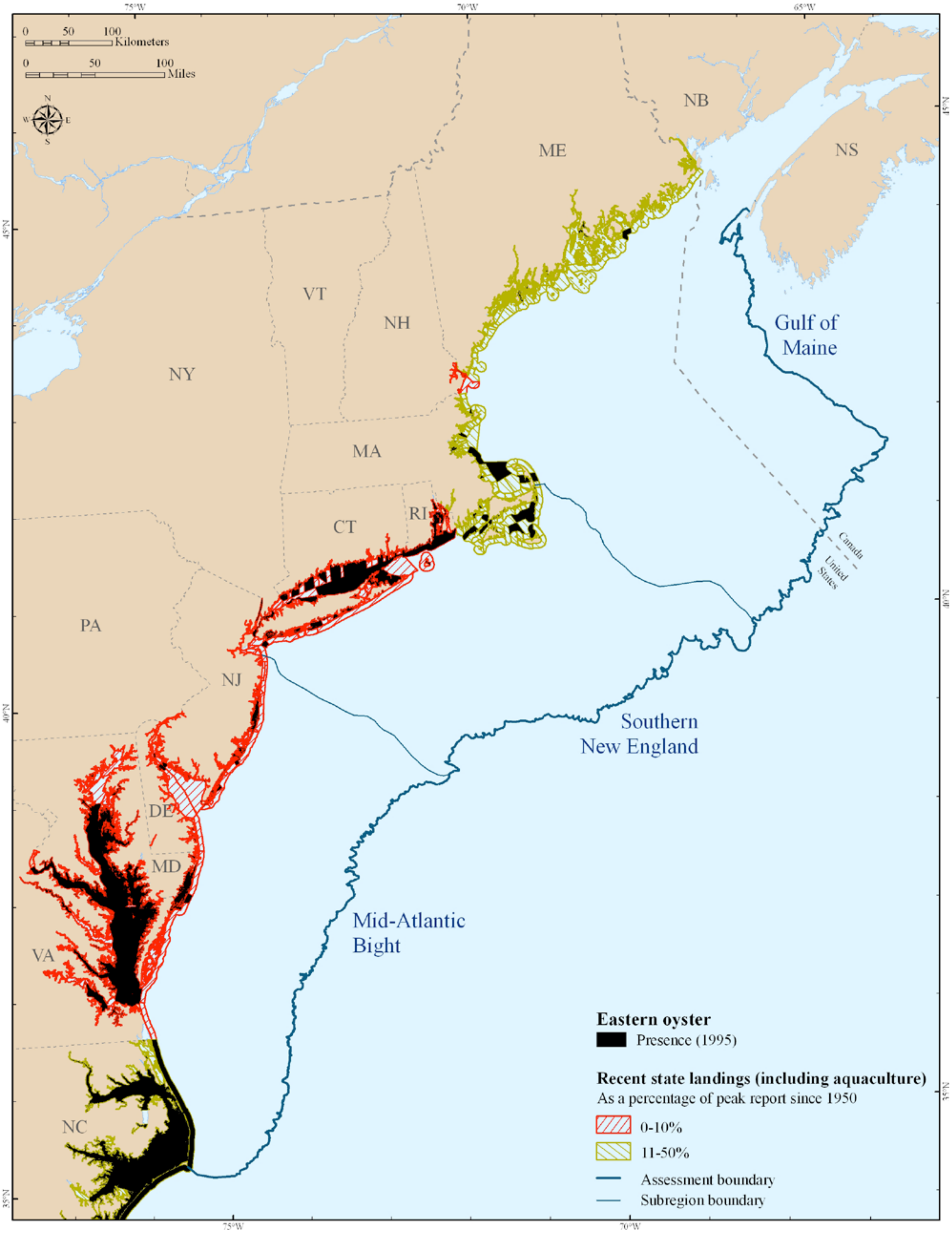


Figure 2-9. Most recent 3-yr average of Eastern oyster landings, represented as a percent of maximum harvest by 0-10%, 11-50%, and 51-100% levels for each state.

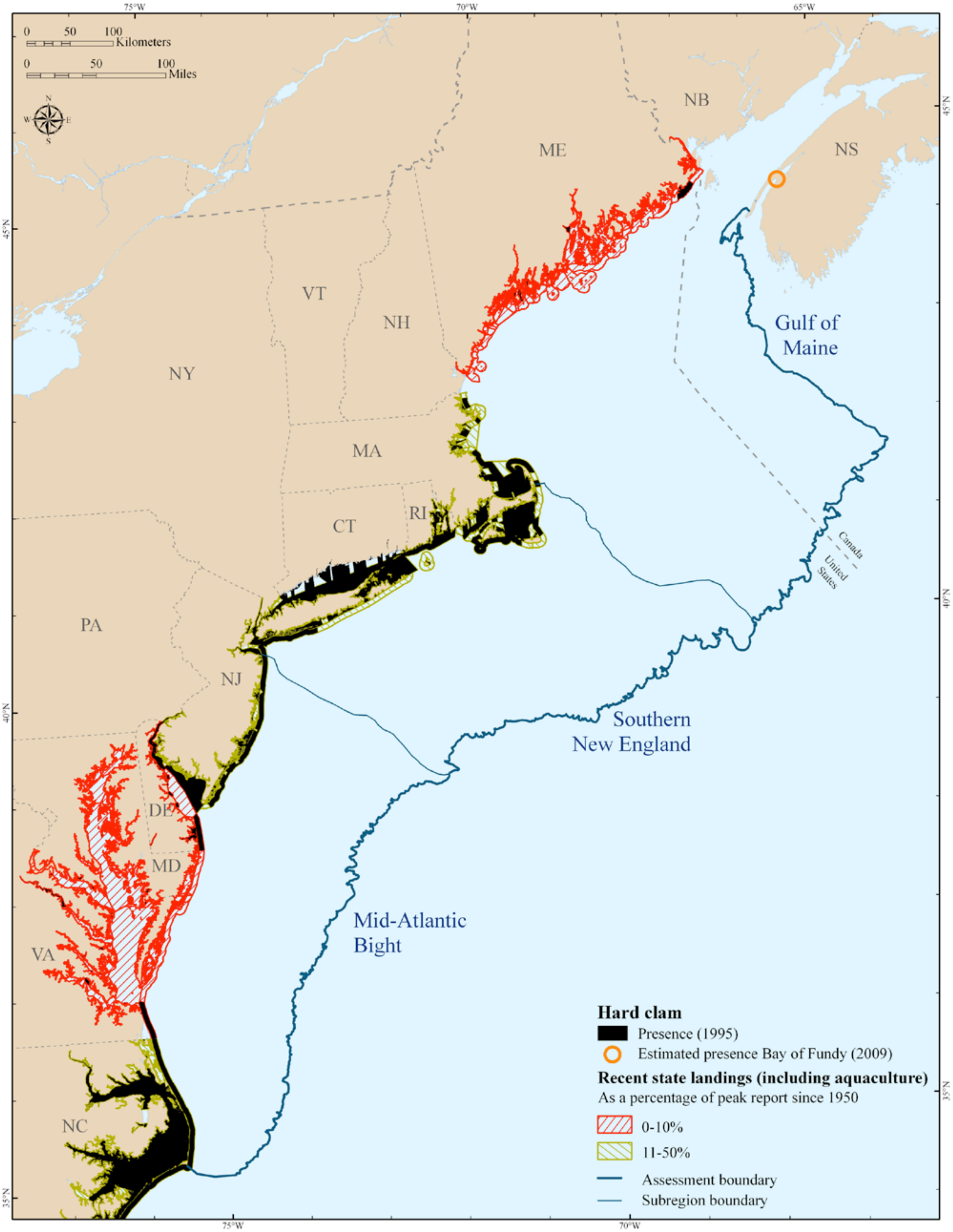


Figure 2-10. Most recent 3-yr average of hard clam landings, represented as a percent of maximum harvest by 0-10%, 11-50%, and 51-100% levels for each state.

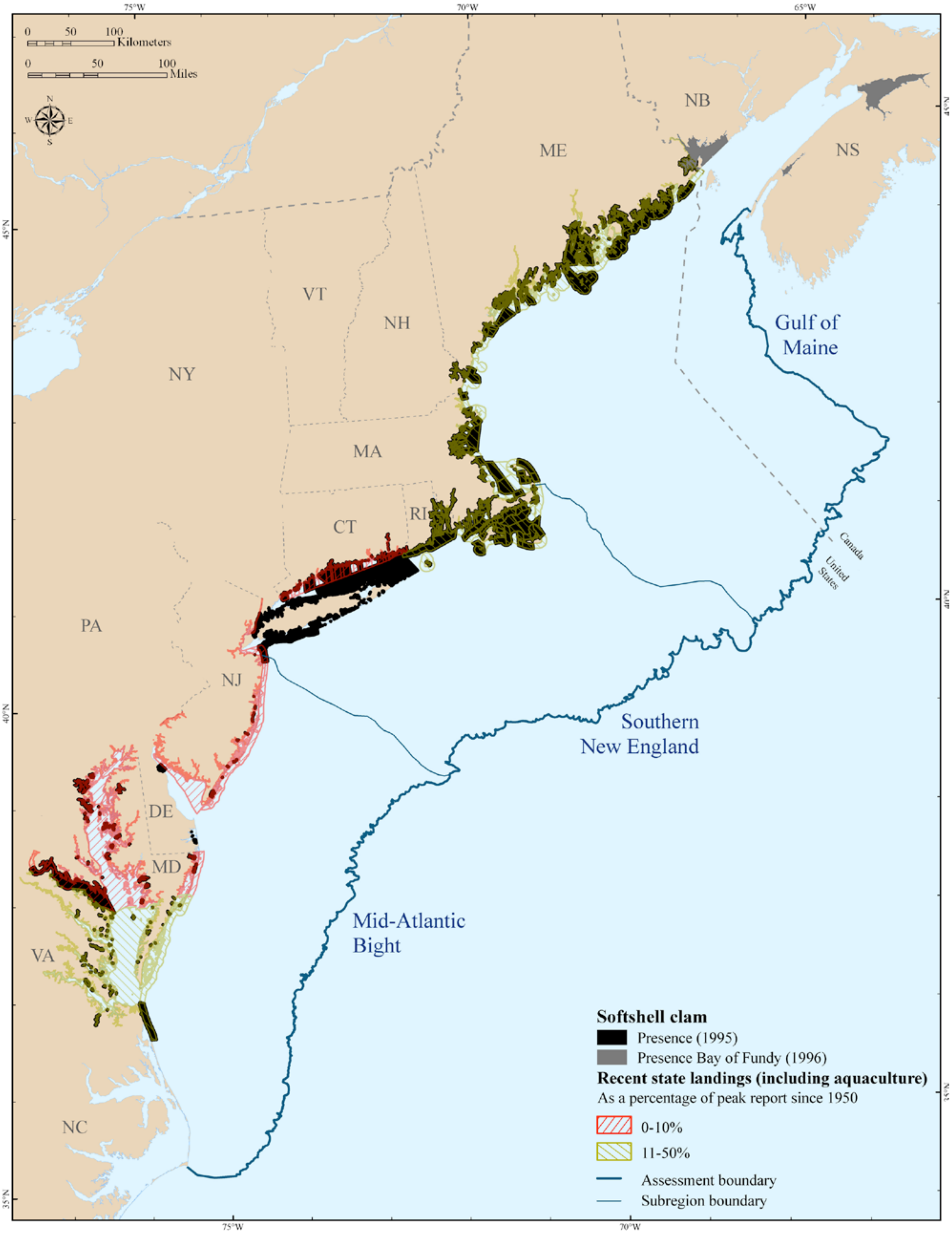


Figure 2-11. Most recent 3-yr average of soft shell clam landings, represented as a percent of maximum harvest by 0-10%, 11-50%, and 51-100% levels for each state.

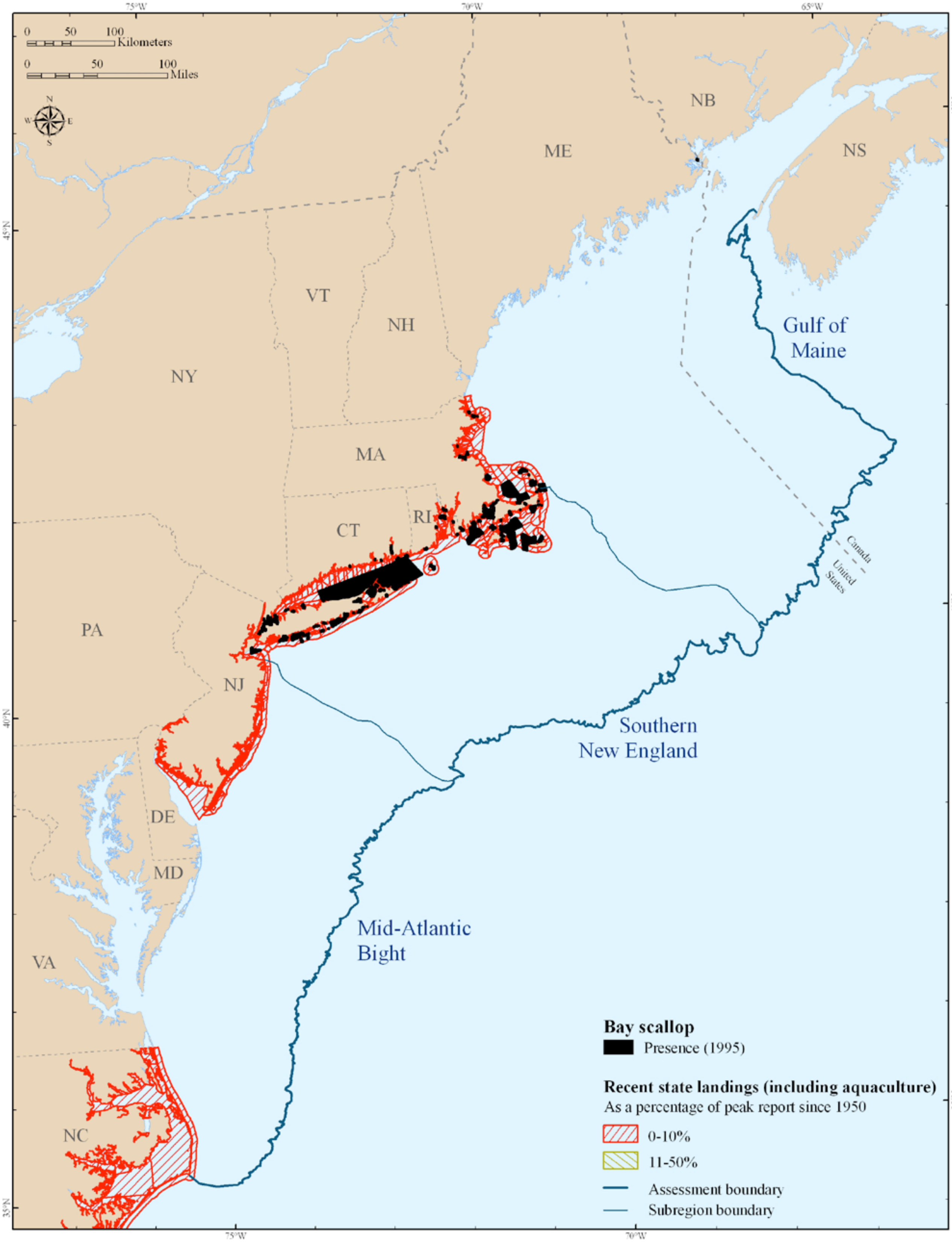


Figure 2-12. Most recent 3-yr average of bay scallop landings, represented as a percent of maximum harvest by 0-10%, 11-50%, and 51-100% levels for each state.

Data, Analysis, and Areas of Importance

Shoreline Habitat Diversity

The shoreline habitats and intertidal NWI type characterization corroborated stratification by CMECS class. For example, rocky shorelines are essentially non-existent in the lagoon and riverine types, but prominent in fjord types. Swamp shorelines are only a small percentage of any CSU shoreline, but do not occur at all in fjord or Fundy CSUs. Marshes make up the highest percentage of shoreline habitats in lagoons and riverine CSUs. Beach and flat shorelines are found in the highest percentages in embayments and fjord CSUs. However unconsolidated intertidal habitats of mud make up more than 50% of intertidal habitats in most fjords while unconsolidated shores of sand, gravel, and cobble make up over 50% of intertidal habitats in most embayments. Although these differences between CMECS classes were evident, significant differences among CSUs of the same CMECS class were also observed. For example, some embayment CSUs have > 50% beach shorelines, while others have only 10% - 15% beach shorelines. Differences were also observed among subregions (Gulf of Maine, Southern New England, and Mid-Atlantic Bight). Although the 8,000 km of beach shoreline in the region were surprisingly evenly distributed across the three subregions, beaches of fjords are most often small pocket or cove beaches whereas those of the lagoon and embayment areas are often very long, nearly continuous barrier beaches. Salt marshes are also found to occur in all subregions and CMECS estuarine types. As a percent of shoreline length, there are not such marked differences within CMECS types or subregions. However, in areal extent they make up over 70% of intertidal habitat in most lagoons and riverine types and < 35% in other groups. The total area of salt marshes in lagoon types of the Mid-Atlantic Bight is orders of magnitude greater than in the rest of the region, especially Gulf of Maine fjords (Figure 2-13, 2-14, and 2-15).

Seagrass beds occur along the entire Atlantic coast (Figure 2-16). Based on the most recent data available from each state, the largest seagrass bed coverage occurs in the Pamlico Sound CSU (36,429 hectares), although other CSUs have significant amounts of seagrass habitat (e.g., Casco Bay, 3,331 hectares; Nantucket Sound, 6,462 hectares; Long Island South Shore, 9,861 hectares; Chesapeake Bay Eastern, 24,838 hectares). By CMECS type, the vast majority of seagrass in the region occurs within CSUs of the lagoon (63,459 hectares) and riverine types (44,087 hectares). However, there is substantial variation within each CMECS class. For example, Chesapeake Bay Inner has 9,710 hectares of seagrass, whereas several other CSUs of the riverine type have only several hundred hectares. The regional seagrass dataset includes historical time series snapshots of eelgrass coverage and presents a new opportunity to evaluate loss and identify spatially explicit restoration priorities. Areas mapped as coastal salt ponds only occur in the embayment type. Among the 10 CSUs of this type, five had no coastal salt ponds and others had as many as six or eight.

Not surprisingly, these differences in characteristic habitat extend to the immediate offshore zone. At the scale of individual CSUs, calculating the percent of various benthic classes within the 1,000 m zone would not be accurate enough to fairly compare one CSU to another. However, when combined into CMECS classes, the average percentages do seem meaningful. The benthic zone just offshore from fjords includes significant areas deeper than 31 m and is characterized by steep canyon seabed forms, largely absent from the offshore zones of other CSUs. In contrast, benthic zones immediately offshore of lagoons and riverine CSUs have extensive areas within the seagrass growing depth zone of 1 to 3 m. The benthic zones offshore of lagoons are characterized by clays, silt, and fine sands and have zero mapped areas of pebble or cobble, which are abundant in the nearshore of the Gulf of Maine.

Abundance and variety of stream habitats feeding the CSUs, particularly relevant for diadromous fish, were not included because of the challenges of identifying comparable metrics across the region. Diadromous fish habitat use and distribution is addressed in a separate chapter.

Note: Further characterizations of spatial complexity, sinuosity, and functional connectivity among habitats could

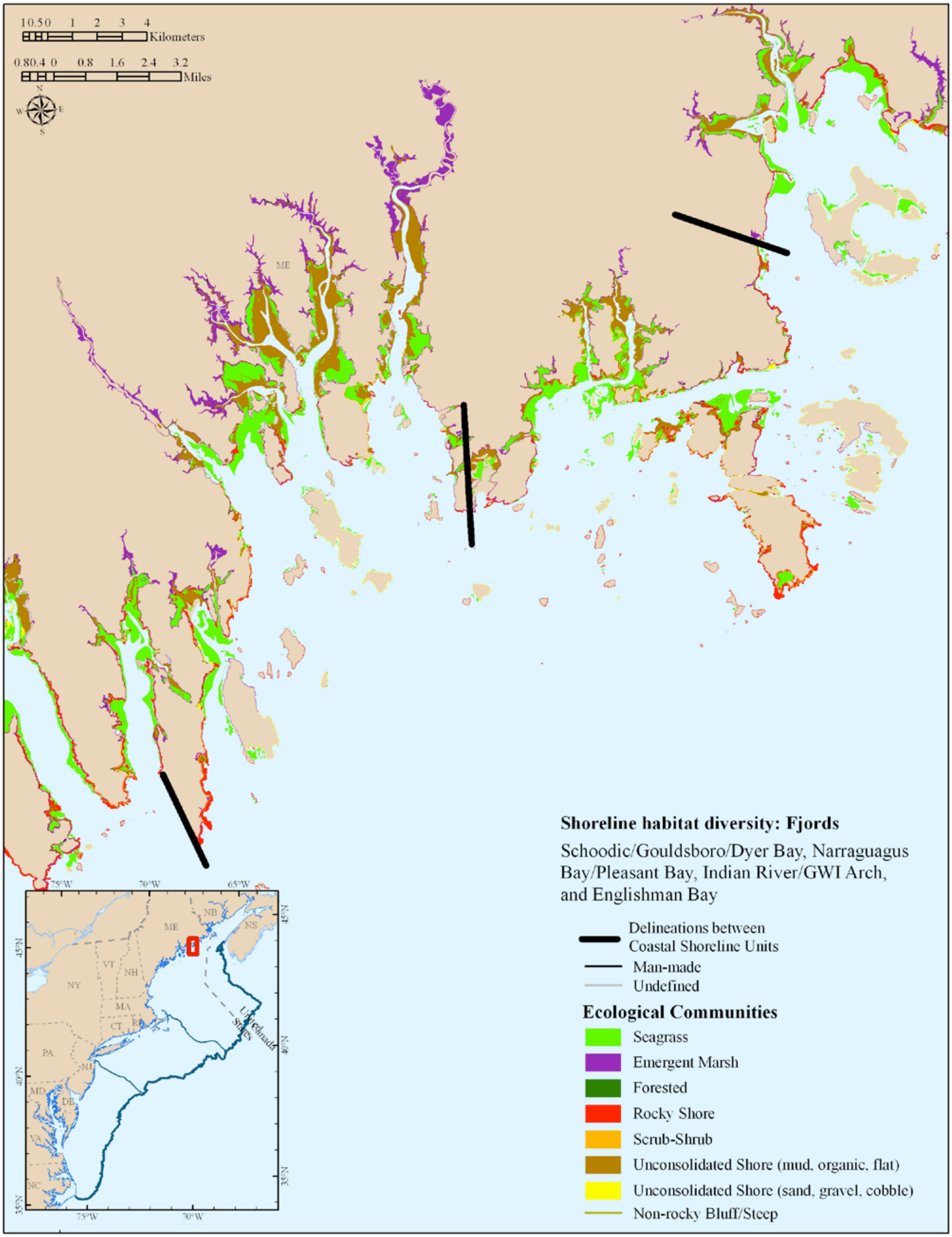


Figure 2-13. A fjord example of shoreline habitat diversity.

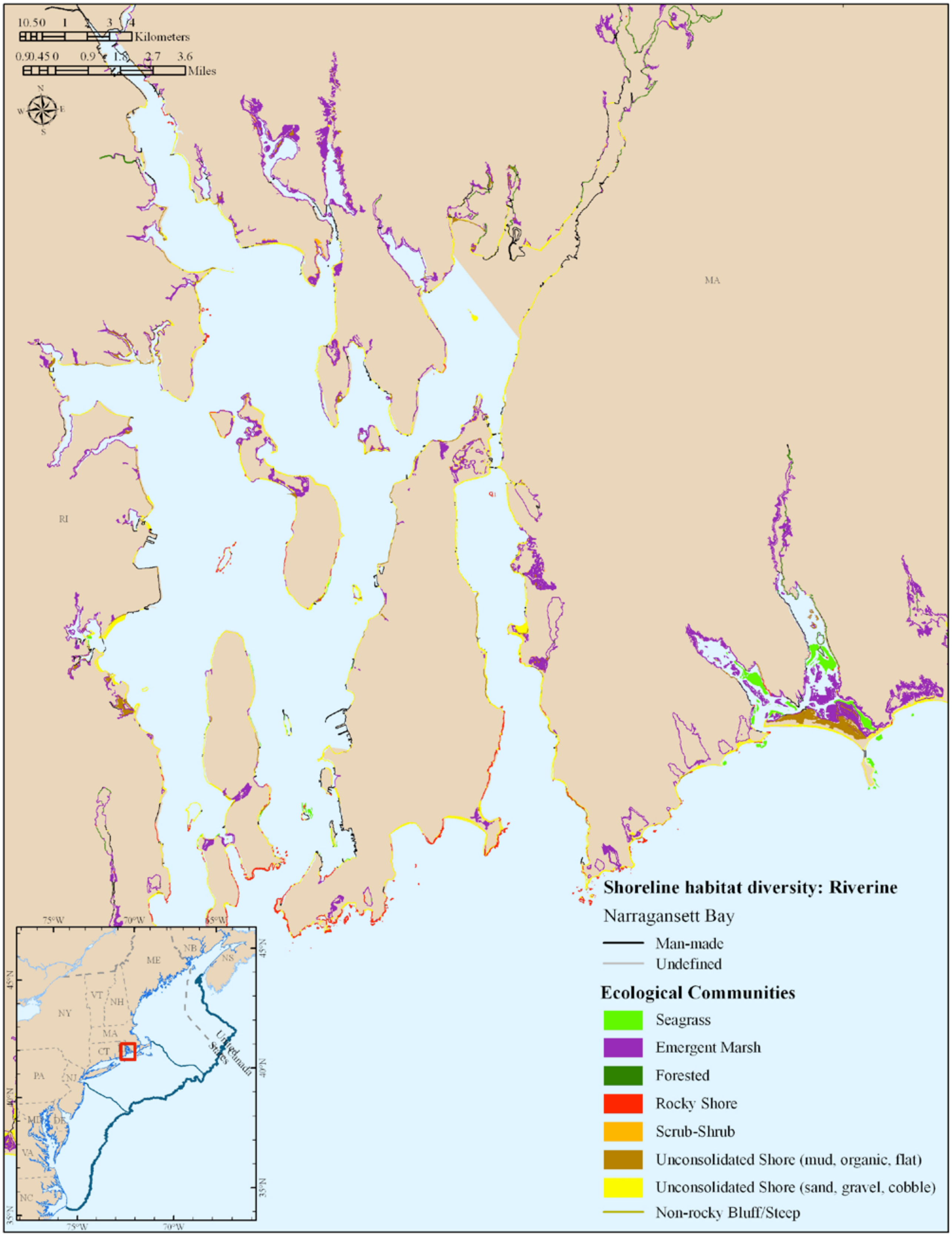


Figure 2-14. A riverine example of shoreline habitat diversity.

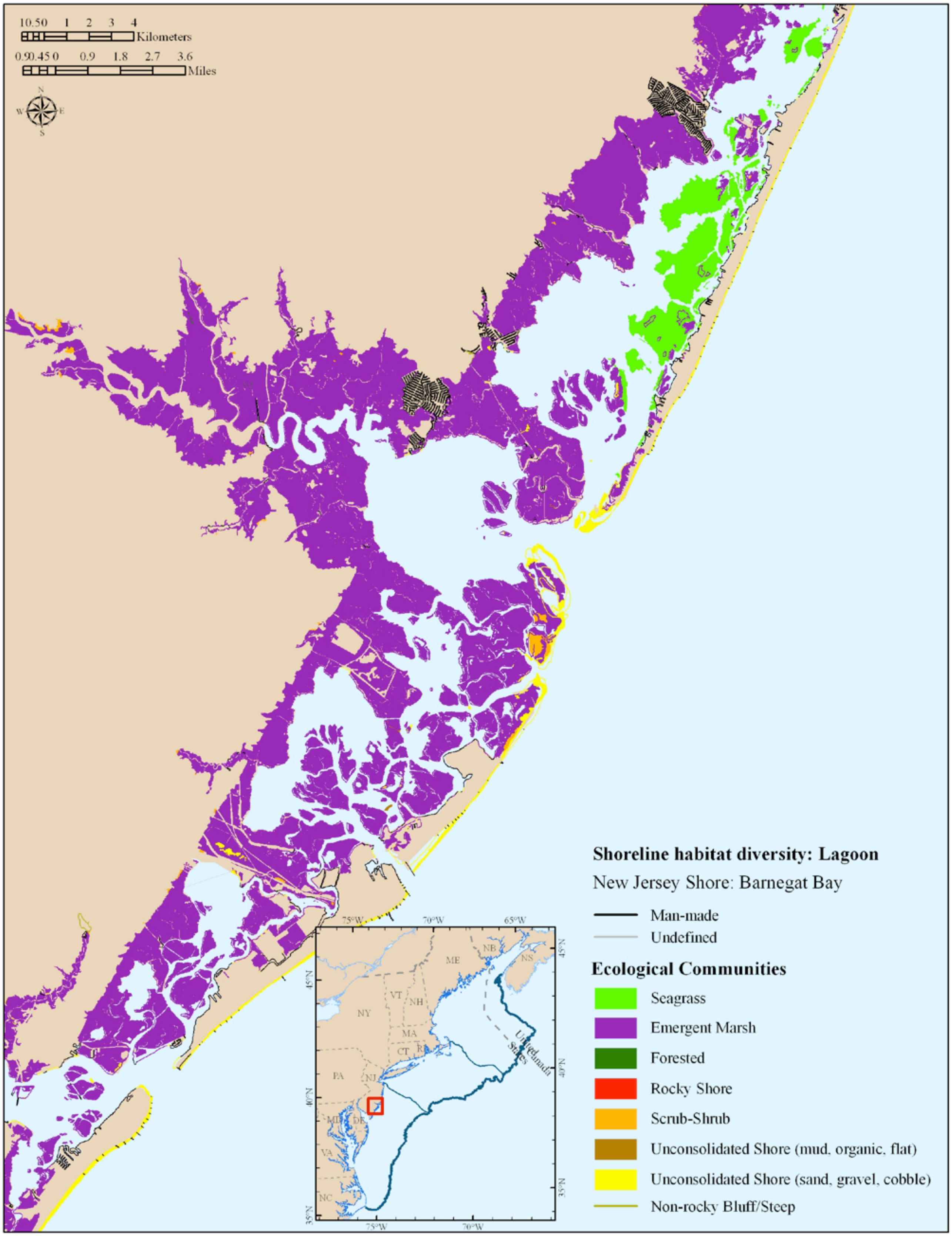


Figure 2-15. A lagoon example of shoreline habitat diversity.

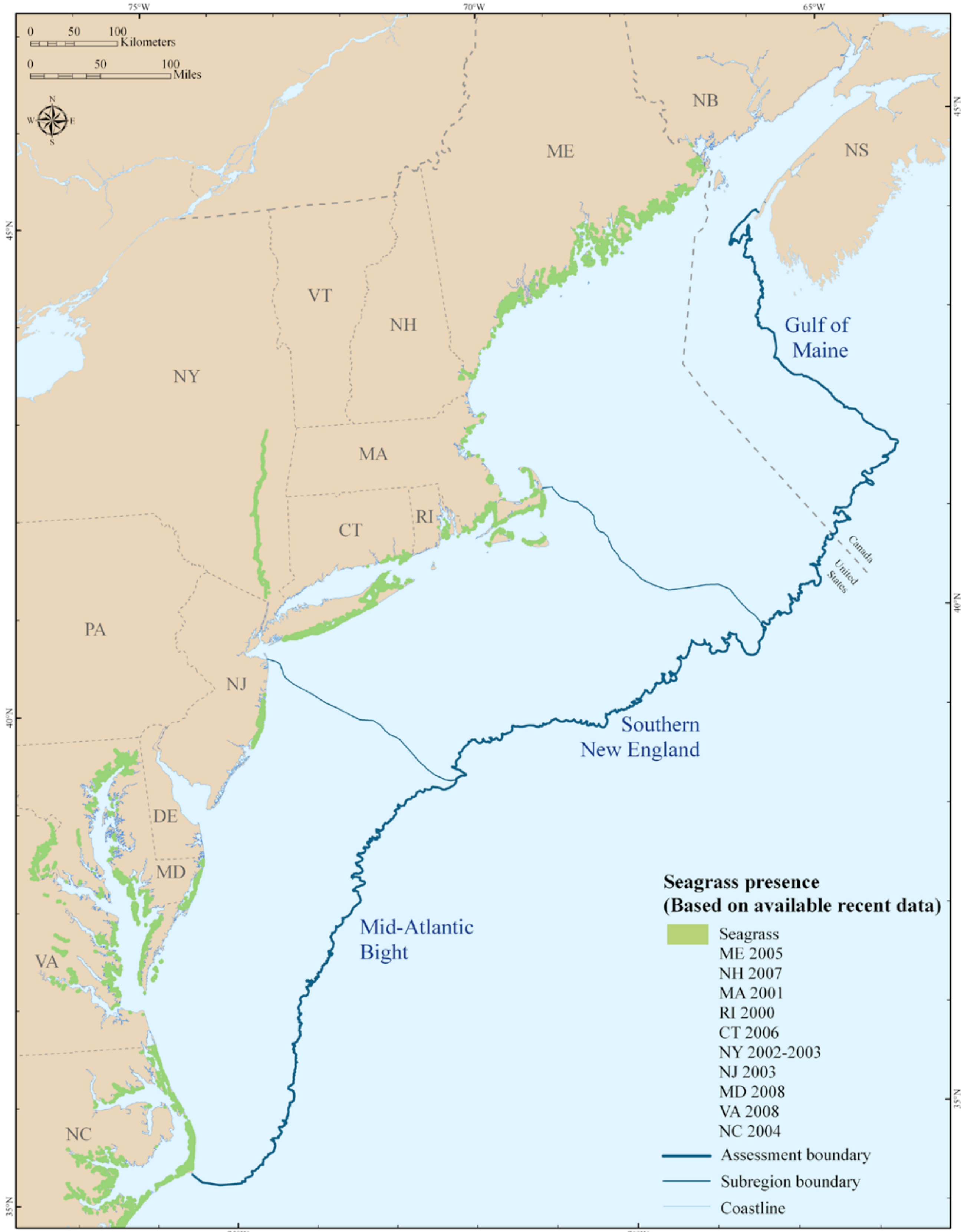


Figure 2-16. Seagrass presence (most recent year of data) in the Northwest Atlantic region.

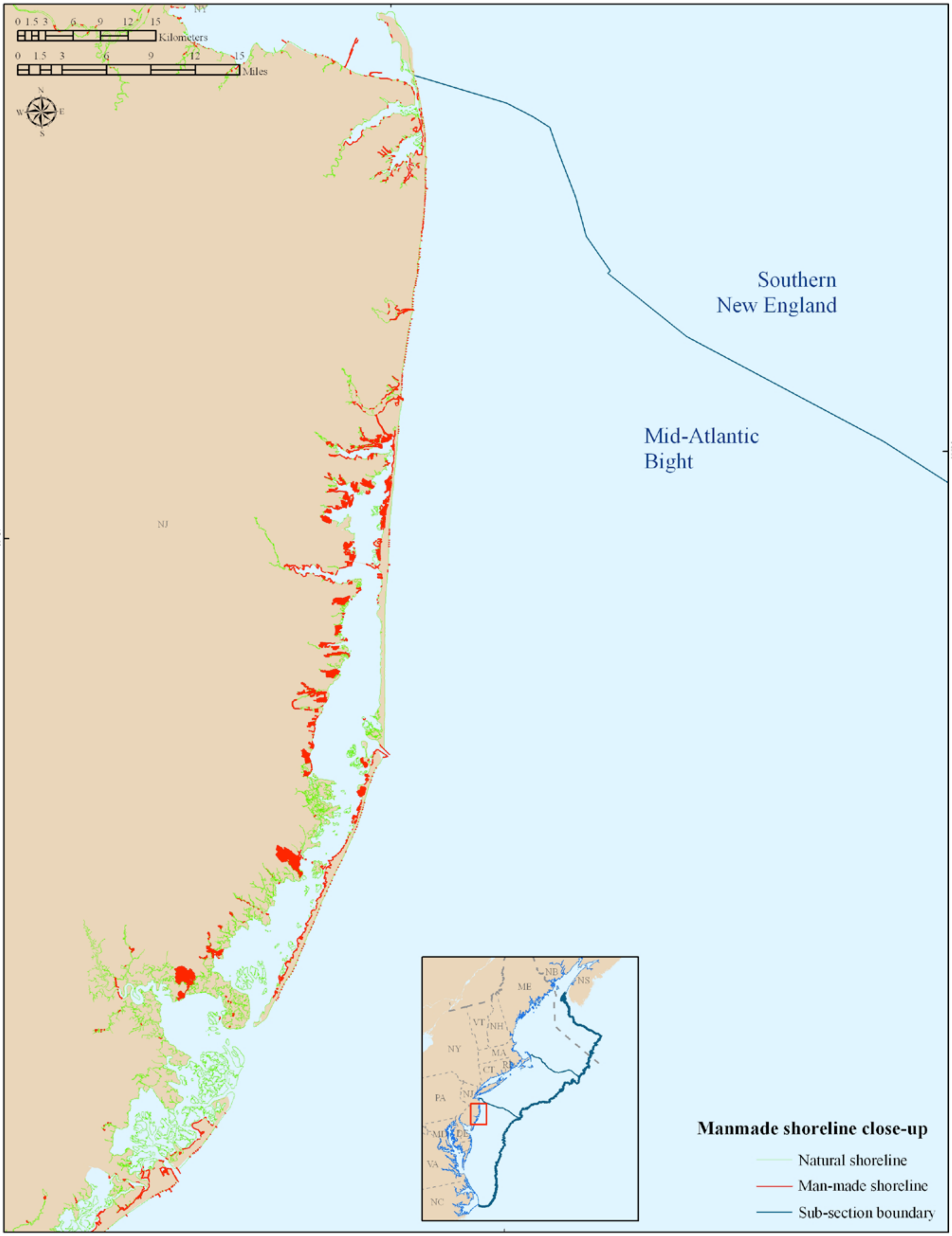


Figure 2-17. An example from Southern New England of the extent of man-made shoreline.

be very informative in assessing relative value of CSUs for coastal marine species. Sinuosity, basically the ratio of edge to area, reflects the amount of marsh/tidal creek edge per unit area. There is evidence from estuarine systems around the world that the value of estuarine habitats for marine species increases as spatial complexity (patch density), sinuosity, and functional connectivity among habitats increase. These are attributes one could theoretically calculate using GIS models. However, because of the need to further define indicators for these attributes that would be most relevant ecologically, as well as time constraints, and limitations of the relevant spatial data available region-wide, these analyses have not yet been attempted.

CSU Condition

A significant proportion of the shoreline of the Northwest Atlantic region is now man-made or heavily altered by human structures of various kinds. The average proportion of man-made shoreline per CSU across the region is 11%. Not surprisingly, in the more industrialized and populated coast of Southern New England, the average is 15%. However, there are marked differences in the proportion of man-made shoreline in different CSUs, ranging from over 30% to near zero (Figure 2-17).

To examine the condition of nearshore land, both the natural land within 2 m elevation and the natural land within a 300 m horizontal buffer were calculated. In the Gulf of Maine where the topography tends to be steeper, the area within 2 m elevation of the shore is only 15% of the area within the 300 m horizontal buffer. In Southern New England the area within 2 m elevation of shore is 25% of the area covered by the 300 m buffer, whereas in the flatter Mid-Atlantic Bight, the area covered by the 2 m elevation rise is 12% *larger* than the area within the 300 m horizontal buffer (Figure 2-18).

In the Gulf of Maine, there are fewer than 2,428 hectares within 2 m vertical elevation of the ocean shore in most CSUs. In contrast, in the Mid-Atlantic there are usually over 53,014 hectares per CSU within the same area. As such, across the entire region, a 2 m rise in sea level might inundate or significantly increase the tidal influence on almost 1 million hectares, (with a disproportionate effect to the south), of which 41%, or almost 415,000 hectares, is wetlands. The Mid-Atlantic Bight contributes over 800,000 hectares to the total projected inundated hectares and over 385,000 hectares of wetlands below 2 m elevation.

Within the 2 m vertical elevation zone, the proportion of that land with natural cover varies by subregion. The Gulf of Maine has the highest proportion of natural cover (average of 78% per CSU) followed by the Mid-Atlantic (69% natural cover) and Southern New England (56% natural cover). Yet within each subregion there are some CSUs with a very high proportion of natural cover within the 2 m elevation zone (the maximums for Gulf of Maine, Southern New England and the Mid-Atlantic are 96%, 95%, and 92%, respectively) and some with very little (the minimums for Gulf of Maine, Southern New England and the Mid-Atlantic Bight are 20%, 7%, and 47%, respectively). The horizontal buffer tells the same story: The average proportion of natural cover in this buffer per CSU in the Gulf of Maine, Southern New England, and the Mid-Atlantic Bight is 78%, 57%, and 70%, respectively.

The land cover/land use of the watershed, as with the proportion of man-made shoreline, shows marked differences geographically and among CSUs of the same estuarine type. Previous research suggests that watersheds with higher percentages of urban and agricultural land are associated with lower estuarine benthic indicators of condition and biodiversity (Hale et al. 2004) and reduced submerged aquatic vegetation (Li et al. 2007). Freshwater aquatic systems also become seriously impacted when impervious cover exceeds 10% (CWP 2003), and reductions in certain taxa sensitive to urban contaminants and habitat disturbance have been found where as little as 3% of the land cover of the watershed is urban (Coles et al. 2004). The average proportion of developed land within the watersheds of CSUs in Southern New England is 29%, and average impervious surface is 9%. A recent study by the Connecticut Department of Environmental Protection (CTDEP) using satellite-based land cover data combined with chemical and biological data from

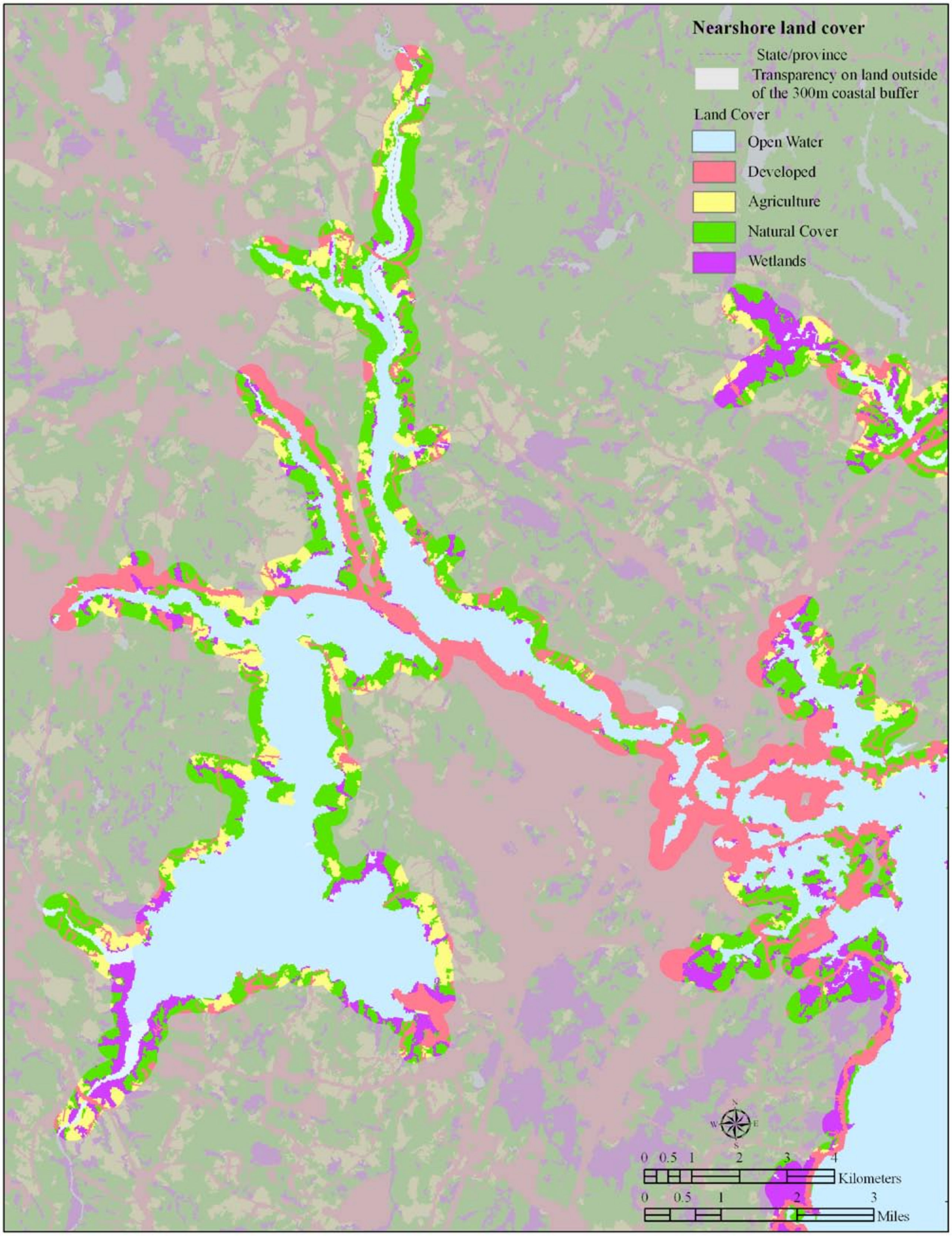


Figure 2-18. Condition of nearshore land within a 300 m buffer.

streams across the state found that "no segment of stream in Connecticut with > 12% Impervious Cover upstream of the sampling location was able to meet Connecticut Water Quality Standard for aquatic life" (CTDEP 2009). In contrast, the averages of proportion of developed land in Mid-Atlantic and Gulf of Maine watersheds are both 9% and their average impervious surface only 2 and 3% respectively. The Mid-Atlantic, however, has much more agriculture in most of its coastal watersheds. However, within each CMECS class and subregion there are some CSUs in very natural condition and others that are much more developed.

A comparison with the NOAA National Estuarine Eutrophication Assessment in some cases corroborates and parallels the watershed land cover characterization, but not in all cases. For example, Massachusetts Bay, classified by NOAA as moderate to high overall eutrophication, has one of the highest percentages of impervious surface, 23.7%. In contrast, the Neuse Riverine CSU in the Mid-Atlantic is classified as having high overall eutrophication although it is not among the highest in developed/agricultural land or impervious surface (Figure 2-19).

Nearshore Shellfish Distribution

Figure 2-9, 2-10, 2-11, and 2-12 show the reported 1995 regional distribution of oysters, hard clams, softshell clams, and bay scallops, respectively. Recent landings versus historic maxima are shown as shaded areas. Blue mussels and ribbed mussels are distributed throughout the region, but spatial data are not available.

With respect to shellfish species viability, we cautiously assert that regional patterns of weak recent harvests relative to benchmarks indicate low-density populations at risk of spawning failure in some areas. In particular, Eastern oyster landings are < 10% of historic highs in eight of 11 reporting states, and bay scallop landings are < 10% in all six reporting states. Hard clam landings are $\leq$ 10% in four states and < 25% in three other states, also suggesting spawning limitations. Softshell clam populations may be in slightly better condition, with only five of 10 states reporting recent landings < 25% of maxima.

Human Interactions

Natural Shoreline Communities

Most of the coastal areas in the northern half of the region were covered with ice less than 20,000 years ago. This reality speaks to the adaptability and resilience of many of the plants and animals now using these habitats. Today, however, a variety of pressures, including oil spills, climate change, invasive species introductions, eutrophication, and the impending squeeze between the rising sea and human development are rapidly threatening the biological and human communities which rely upon our coasts and estuaries.

Coastal Development

The squeeze of coastal habitats between human coastal development and sea level rise is and will continue to be a major threat, as long as there is a societal desire to engineer less stable shoreline types in an effort to protect vulnerable real estate from inundation and erosion. Coastal development also brings with it increased inputs of nutrients and toxins, alterations of tidal flow, and overland freshwater input, all of which can impact shoreline systems.

Shoreline Stabilization, Altered Sediment Regimes

Barrier islands and riverine deltas are the habitat types probably threatened most by storms and erosion, as they are the most geologically unstable and therefore likely to be impacted directly and indirectly by engineering that alters natural sediment supplies. Alteration of sediment dynamics by creation and maintenance of inlets to embayments, coastal salt ponds, and lagoons also impacts tidal amplitudes, residence times, temperature, and salinity, as well as the export and import of dissolved and particulate nutrients for entire systems. At a smaller scale, channel dredging can impact adjacent shores as sediments accumulate in the deeper channels rather than near the adjacent shores. Similarly, nearshore sand mining can starve some beaches of their natural sand supply in an attempt to nourish other beaches.

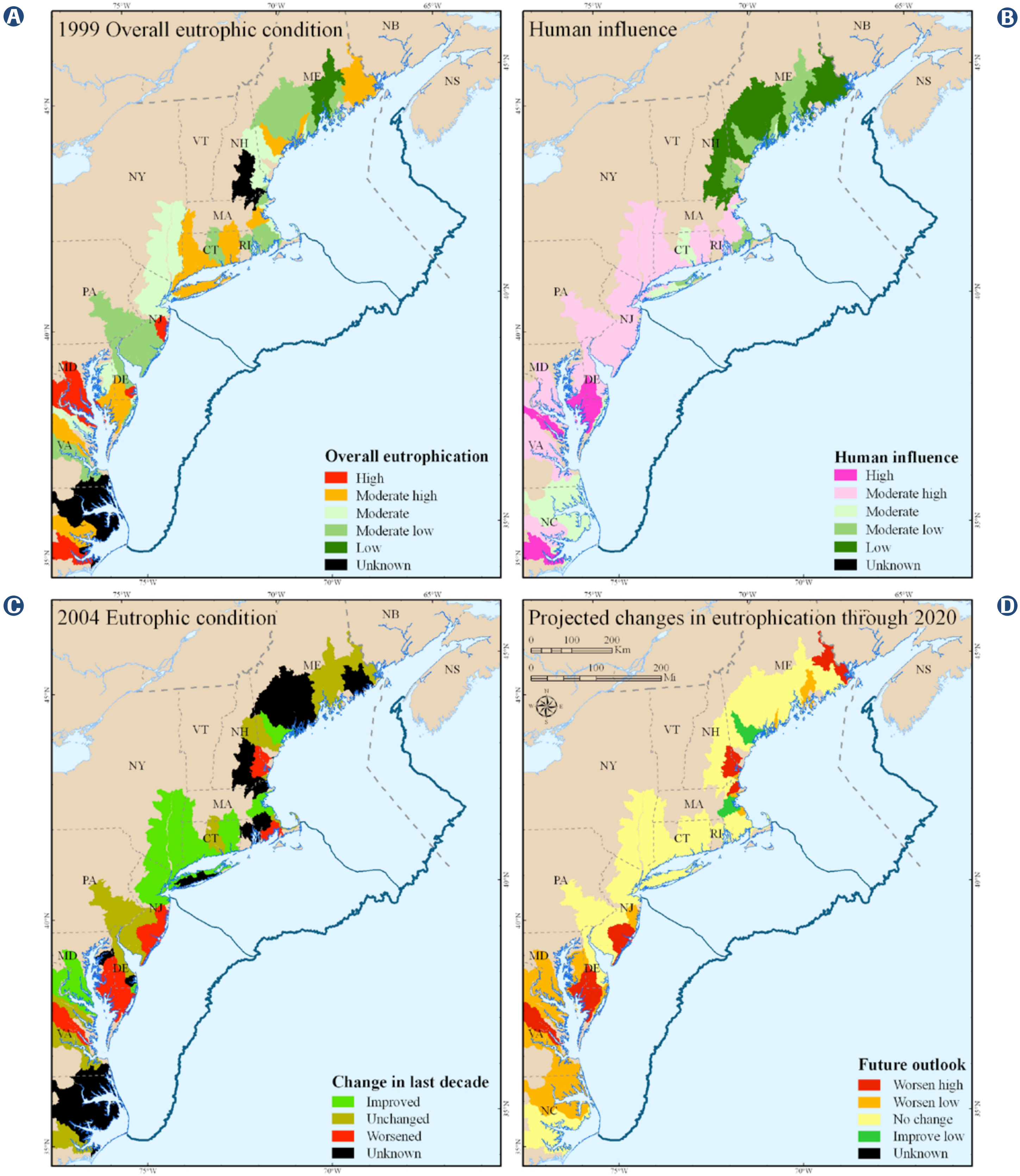


Figure 2-19. Eutrophic conditions in 1999 and 2004, human influence, and projected changes in eutrophication through 2020.

Shoreline armoring of all types (groins, bulkheading, rip rap, gambion, etc.) often causes direct loss of habitat, most often impacting adjacent properties (Nordstrom et al. 2003). There are legislative protections against dredging, filling, and bulkheading vegetated wetlands and/or sandy ocean beaches in some states. However, there is less protective legislation preventing the future armoring of shorelines in the sheltered coast. By their very nature, rocky shorelines are already hardened and more stable. With few exceptions, rocky coasts have been less subjected to anthropogenic shoreline armoring, and when present these structures have less of an ecological impact than they do when they are constructed on more geologically dynamic shoreline types.

Oil Spills

Oil spills are a significant threat to both marine and terrestrial wildlife along the shore. The potential threat of large-scale oil spills is related to the proximity of large shipping, storage, and/or oil and gas exploration operations. Appropriate regulations and precautions can be used to mitigate the potential for harmful spills in areas where the drilling and transport of oil occurs. ESI maps features sensitive to oil spills to facilitate rapid response.

Invasive Species

New exotic marine species can have major impacts on marine and coastal systems through competition with native species, predation (e.g. green crabs on clams), or actual habitat impacts. By the time they are detected, marine invasive species are virtually impossible to eradicate. The ecological consequences of recent marine invasions in this region are uncertain. Global shipping and aquaculture are the main vectors for introduction of exotic marine species and marine disease invasions. In salt marshes, the European genotype of common reed *(Phragmites australis)* is an aggressive competitor capable of forming dense monocultures that crowd out native salt-tolerant plant communities.

Sea Level Rise

Accelerated sea level rise due to global warming is a threat to all coastal targets. An in-depth look at this topic is addressed in the following section.

Seagrass Meadows

The mechanisms of seagrass loss can be characterized as direct or indirect. Examples of direct mechanisms include the uprooting of plants while harvesting shellfish, destruction of plants when motorized boats run aground, and a species-specific "wasting disease" which decimated many eelgrass beds in the last century. There is more uncertainty in the assessment of indirect threats to seagrass, some of which are correlated with each other and are likely to have cumulative and synergistic impacts, such as the direct physiological impacts of increased nutrient loading and the consequences of shading by chronic algal blooms and excessive siltation. Threats which characteristically impact the grasses' key ecological attributes include eutrophication, algal blooms, alterations to water temperature regime, benthic organism harvest methods, boating activities, shoreline armoring and impediments to natural sediment movements, barrier island and inlet stabilization approaches, invasive species (especially green crabs), toxins, excessive macroalgae, altered seed predation regime, dredging, decreased abundance of native shellfish, disease, and herbivory.

Nearshore Shellfish

Five critical threats to nearshore shellfish assemblages in the Northwest Atlantic region were identified:

Overharvest

Evidence of harvest of oysters, bay scallops, hard clams, and softshell clams, all valuable commercial species today, precedes written history. Despite management by state agencies, many historic populations have been exploited to levels too low for successful regeneration. For oysters, long-term harvest reports show that landings may have peaked for some regions as early as the 1880s (Stanley and Sellers 1986; Kirby 2004). Recent data show oyster landings on the United States East Coast at a mere 2% of historic highs (Eastern Oyster Biological Review Team

2007). A similar, albeit less drastic, pattern of regional resource exploitation is evident for hard clams (Stanley and DeWitt 1983), softshell clams (Abraham and Dillon 1986), and bay scallops (Fay et al. 1983). Overharvest is typically of most concern for repeat spawners like oysters and clams; scallops die after they spawn and therefore may be less susceptible to damaging impacts from late-season harvest.

Direct removal of shellfish brood stock has most certainly diminished populations, but indirect impacts from fishing activities, including dragging, dredging, and boat wakes, also threaten shellfish beds by damaging habitat. Fishing activities can scour benthic habitats, destroy hard substrates and seagrass beds critical for spawning, and suspend sediments that deposit silt on intertidal beds and cloud seagrasses. Destruction and removal of shell substrate during oyster harvesting eliminates the foundation on which future generations of oysters will settle.

Pollution

Pollution inputs from nutrient and sediment sources are a long-standing and accelerating problem for estuarine and coastal waters along the entire Atlantic coast. The most recent EPA National Coastal Condition report (2004) ranked the Maine-to-Virginia section of coast with its lowest national ratings for sediment quality and benthic indices, and its second-to-worst rating for water quality. In particular, nutrient pollution is extensive in the heavily populated region. High or moderate eutrophic conditions (i.e. elevated chlorophyll, low dissolved oxygen, extensive macroalgae, and diminished seagrasses) were detected in two thirds of the region's estuaries, with conditions in most expected to worsen by 2020 (Bricker et al. 1999).

Shellfish suffer from pollution from a number of sources, but direct and indirect effects of algae blooms are among the worst, as nutrient-mediated phytoplankton blooms (i.e., green, brown, and red tides) inhibit growth and cause recruitment failures (Summerson and Peterson 1990; Kraeuter and Castagna 2001). Dense beds of macroalgae, such as *Ulva,* disrupt filter feeding and eliminate suitable settling areas (Galtsoff 1964).

Sediment pollution is also major threat, as resuspended sediments and siltation events harm shellfish gills, interrupt feeding, and lower recruitment success (Kennedy et al. 1996). Marine shellfish ingest, retain, and bio-accumulate toxic metals and organic compounds from filtered seawater. Elevated levels of organic contaminants and metals found in shellfish tissue have been shown to inhibit growth and disrupt reproductive functions (Kennedy et al. 1996; Kraeuter and Castagna 2001).

Parasites, Diseases, and Invasive Species

Harmful parasites are prevalent in filter-feeding bivalves, especially oysters and hard clams. In particular, oyster populations in the region suffer from high infection rates by the protozoans Dermo *(Perkinsus marinus)* and MSX *(Haplosporidium nelsoni)* (Kennedy et al. 1996). These diseases may be limiting factors in the re-establishment of healthy oyster populations in many parts of the region, from Chesapeake Bay to New Hampshire. Likewise, hard clams suffer from a parasite known as Quahog Parasite Unknown (X) or QPX that causes wide-spread but less catastrophic mortality in beds from Canada to Virginia (Lyons et al. 2007).

The invasive European green crab *(Carcinus maenas)* is considered omnivorous and known to be an important predator of many shellfish species. In current areas of abundance from Gulf of Maine to Delaware Bay, this species can cause significant losses of shellfish populations, especially for clams and mussels (Kraeuter and Castagna 2001).

Altered Freshwater Regime

Human activities that result in freshwater diversions (e.g., dams, impoundments, freshwater withdrawals) can produce stressful conditions and higher mortality in estuarine shellfish populations. Lethal disease outbreaks in oysters are linked to higher salinity conditions (Kennedy et al. 1996), and several common shellfish predators such as the oyster drill *(Thais haemastoma),* starfish *(Asterias forbesi)*, and whelk *(Fasciolaria hunteria)* are limited in distribution to higher salinity areas (Kennedy et al. 1996).

Climate Change

Extreme precipitation events and warming sea surface temperatures due to global climate change are likely to disrupt shellfish recruitment strategies that rely on strong seasonal patterns of temperature, salinity, and circulation. As nearshore waters warm with climate change, range expansion of shellfish predators enhances the likelihood of locally heavy predation losses for shellfish beds in northern areas of the region. Warmer water is likely a factor in the spread of Dermo (Kennedy et al. 1996). In addition, lower ocean pH due to elevated global CO_2 concentrations (ocean acidification) may inhibit biochemical processes that bivalves rely on for shell development (Beesley et al. 2008). Below is an in-depth look at sea level rise, which discusses relative vulnerability, ecological resilience, and potential strategies for enhancing resilience of coastal systems.

Management and Conservation

Regulatory Authorities

Management of the coastal zone involves a myriad of state and federal agencies whose jurisdictions and authorities overlap in complex ways. Most states have further delegated authority for certain management activities to individual coastal towns, whether for zoning and permitting of development or shellfish management. One unifying federal program is the Coastal Zone Management Act which provides federal funding to each state to carry out research and outreach that may facilitate or enhance regulation but is not directly regulatory itself. Regulatory authority for specific activities within the coastal zone is still most often administered separately by different municipal, state, and federal agencies.

Given the wide variety of uses and activities in the coastal zone, it is not surprising that there is a complex mosaic of management authorities. Municipal, state, and federal authorities often overlap in the same geographic coastal areas and regulation of certain activities may require the involvement of multiple agencies at multiple levels of government. Current efforts being undertaken by the Obama Administration, such as the emerging National Ocean Policy and the framework for coastal and marine spatial planning, hold promise for additional coordination and improvement in coastal resource regulation and management.

All of the states in this region participate in the voluntary Coastal Zone Management Program, under the Coastal Zone Management Act of 1972, and have federally-approved management plans including regulatory authorities to protect and conserve coastal resources. Depending on the individual state, regulatory controls are exercised by a single state coastal agency or by a network of environmental, wildlife, and conservation agencies. The overall program objectives of the CZMA are to "preserve, protect, develop, and where possible, to restore or enhance the resources of the nation's coastal zone." The CZMA includes two national programs, the National Coastal Zone Management Program and the National Estuarine Research Reserve System. The state coastal programs aim to balance competing land and water issues in the coastal zone, while estuarine reserves serve as field laboratories to provide a greater understanding of estuaries and how humans impact them. In addition to regulatory approaches, most coastal programs have a local grants component and outreach and education programs and include emphases on such topics as nonpoint source pollution, habitat restoration and land conservation.

The extent and type of home rule authority granted to local governments varies considerably from state to state; in most states land use controls including zoning and land development permitting are exercised by local and/or county governments. Some states have delegated additional authorities to municipalities and other units of government for other management activities that concern coastal resources, such as, for example shellfish management, harbor management and wetland management.

The United States Exclusive Economic Zone (EEZ) extends from the outer boundary of state waters (3 miles) out to 200 miles from shore. However, the federal government's legal authority in navigation, commerce and security extends shoreward into state waters. The federal agencies that have a role in regulation or review of activities in state waters include NMFS, USFWS, EPA, United States Army Corps of Engineers (USACE), United States Coast Guard (USCG), and the Federal Energy Regulatory Commission (FERC).

Unlike groundfishing and mid-water trawling for forage fish or shrimp, nearshore shellfish harvest and aquaculture are regulated at the state level, with no overarching federal or regional management authorities, other than the Food and Drug Administration's oversight responsibilities for ensuring public health in relation to commercially harvested shellfish. Within Food and Drug Administration constraints, state, or in some areas, town shellfish managers set harvest limits and regulations, and shellfish sanitation commissions control the opening or closing of areas to harvest and consumption. Harvest of mussels is often unregulated.

Current Conservation Efforts

Conservation efforts on behalf of the many features and values of the coastal zone are as many and varied as the regulatory jurisdictions, with the addition of activities by a host of private organizations from global, such as TNC, to bay-specific. These are too numerous and varied to summarize here. Most have a specific geographic focus, and aim to link land-based activities with the health of the estuary and in turn the health of the estuary to the values to the human communities that border them. A notable feature of coastal zone conservation is the numerous examples of public-private partnerships and programs such as the National Estuary Program (EPA), the National Estuarine Research Reserve Program (NOAA), and the Chesapeake Bay Program, which are designed to engage stakeholders and foster broad partnerships and are often paralleled by complementary private organizations such as the Chesapeake Bay Foundation and Friends of Casco Bay.

Shellfish restoration activities provide one example of the varied players in these coastal estuarine programs. The NOAA Restoration Center is a primary provider of funding for shellfish restoration projects and activities, especially for oysters and hard clams. These programs are augmented by state-level programs for certain conservation activities, such as shell management for restoration in the Carolinas and private non-profit efforts such as those of TNC in Great South Bay, Long Island, New York. Restoration funding for shellfish often requires protection from harvesting, which is most often accomplished by siting projects in areas closed due to poor water quality. A combined focus on restoration and conservation has led to the concept of protected spawner sanctuaries in some areas. Oyster restoration projects in the Chesapeake Bay and Delaware Bay are particularly prominent in this region, although these large-scale projects also include harvest provisions.

The United States Department of Agriculture Natural Resources Conservation Service is another provider of funding for oyster restoration, especially in the context of expanded aquaculture operations that provide restoration benefits. This funding model has been successfully developed in Rhode Island, Virginia, and other Atlantic states.

In-depth Look: Sea Level Rise

Assessing Relative Vulnerability and Ecological Resilience to Sea Level Rise

Sea level rise is already impacting coastal communities and natural habitats along the East Coast of the United States. In the coming century, potentially accelerated rates of sea level rise could significantly impact coastal ecosystems and human communities. The assessment team recognized the challenge of including long term threats, such as climate change and sea level rise, in conservation planning efforts. For this reason, a subteam was established to review the state of the science and management of sea level rise within coastal systems. This is a departure from earlier terrestrial ecoregional assessments along the eastern seaboard completed by TNC in recent years. These included analyses of the status of coastal species and ecosystems, but climate change impacts were not considered, particularly the consequences of predicted sea level rise. The best available science indicates coastal species and ecosystems throughout the region are at risk of alteration and loss due to sea level rise (Titus 1990; Markham 1996; Feagin et al. 2005; Nicholls et al. 2007).

Of course, sea level rise and increasingly frequent intense storms will not be the only climatic impacts to Northwest Atlantic marine ecosystems. Other potential impacts such as increased water and air temperature and ocean acidification are addressed elsewhere in this report.

In order to inform prioritization of conservation locations and strategies in the face of climate change impacts to coastal ecosystems, the sea level rise team sought to:

1. Apply principles of vulnerability and resilience to sea level rise and storm impacts to the region's coastal ecosystems;
2. Compile existing information on sea level rise impact studies and on-going adaptation strategies for the Northwest Atlantic coast;
3. Assess additional information or analysis needs and appropriate data availability;
4. Determine potential next steps to further inform conservation action in the coastal zone.

How High and How Fast?

Twentieth century global sea level has been steadily rising at a rate of ~1.7 to 1.8 mm yr^{-1}, increasing to over 3 mm yr^{-1} within the last decade (IPCC 2007). Most of this increase comes from warming of the world's oceans (nearly 60%) and melting of mountain glaciers (~30%), which have receded dramatically in many places especially within the last few decades (IPCC 2007). However, the IPCC projections of an 18 to 59 cm sea level rise by 2100 may underestimate potential polar ice sheet contributions. Recent trends from Greenland and the West Antarctic ice sheet raise concern (Shepherd and Wingham 2007; Velicogna and Wahr 2006a; Thomas et al. 2006). Satellites detect a thinning of parts of the Greenland Ice Sheet at lower elevations, and glaciers are disgorging ice into the ocean more rapidly, adding 0.23 to 0.57 mm yr^{-1} to the sea within the last decade (Rignot and Kanagaratnam 2006). The West Antarctic Ice Sheet may also be thinning (~0.4 mm yr^{-1} from 2002- 2005). The combined ice sheet melting of Greenland and Antarctica from the 1990s to the present is adding some 0.35 mm yr^{-1} to sea level rise (Shepherd and Wingham 2007).

Global warming could cause further thinning of these ice sheets. Either ice sheet, if melted completely, contains enough ice to raise sea level by around 7 m. By contrast, mountain glaciers hold the equivalent of only ~0.5 m of potential sea level rise. A regional temperature rise of only 3°C (Gregory et al., 2004) or 3.2E- 6.2EC (IPCC 2007) may be enough to destabilize Greenland irreversibly. While such temperature increases fall within the range of several future climate projections by 2100, major breakdown of the ice sheet would probably lag warming by several centuries. If basal melting rates for buttressing Antarctic ice shelves exceed 5-10 m yr^{-1}, the West Antarctic Ice Sheet could break up within several centuries (Alley et al. 2005).

A recent study modeling ocean currents in response to sea level predicts that the Northwest Atlantic will experience even higher sea levels than the global average because of anticipated slowdowns of ocean currents in response to global warming (Yin et al. 2009). It is also important to point out that even with stabilization of global temperatures sea level is expected to continue to rise for centuries (Wigley 2005).

Several factors that contribute to relative sea level change vary geospatially. Locally-specific parameters include water surface elevation and land movement attributable to isostatic adjustment of the Earth's crust after the most recent ice age. The Columbia Center for Climate Systems Research and the Goddard Institute for Space Studies (CCCSR/GISS) recently produced projections of sea level rise for Long Island and Long Island Sound for TNC's Long Island coastal resilience project (http://coastalresilience.org) using seven of the IPCC Global Climate Models (GCMs) that are capable of producing projections for sea level rise, three emissions scenarios, and a parameter representing rapid ice sheet melting. These projections clustered around 1 m of rise by the end of the century in the absence of rapid ice sheet melting, and around 2 m by the end of the century with a rapid ice melt parameter included (GISS/CCCSR 2008). It should be noted that the local parameters in these projections are specific to the Long Island study area, and it is not clear how much of the assessment study area would be covered by the local adjustments made. Many stakeholders and scientists and planners associated with the project agree that these 1 and 2 m projections within this century are conservative.

While the Long Island project is a good example of downscaling climate data to generate locally relevant applications from GCMs, it is not possible to select the "true" model, as by their nature projections of SLR are uncertain. However, given the risks and potential costs of *in*action and under-prediction, it is essential to imagine potential impacts and develop plans and strategies that address these potential outcomes. Several state governments and other entities have confronted this uncertainty by selecting a value (in an informed, but necessarily arbitrary way) and requiring agencies to make plans that account for that amount of sea level change. For example, the State of Maine's Coastal Sand Dune Rules plans for two ft of sea level rise in 100 years; the state of Maryland's Department of Natural Resources uses a policy guidance document that plans for 2-3 ft of sea level rise in 100 years; and Rhode Island's Coastal Resources Management Council plans around an expected 3-5 ft of sea level rise in 100 years. Rhode Island's projection is consistent with TNC's recommendation of 1 and 2 m in 100 years as conservative projections for this region for the purposes of this review and proposed future analyses. However, it should be noted that the pace of sea level rise is as critical as the endpoint. If that change were to occur in 20 years rather than steadily over a century, it is much less likely that any natural systems would be able to adjust to keep up (Bricker-Urso 1989).

Multiple Climate Change Effects on Coastal Systems

In evaluating climate change's impact, one must consider the synergistic interactions of its effects. Combined impacts from sea level rise, increased precipitation, and intensity and frequency of storms and storm surges will include:

- both permanent inundation and increased flooding associated with episodic events
- increased salinities in tidal wetlands
- increased saline intrusion into coastal groundwater
- increased tidal velocities, and
- increased freshwater discharges and altered hydrology of tidal rivers

All of these impacts are likely, in turn, to cause increased erosion and wash-overs (French 2008), and 1) shrinking or disappearance of some islands, 2) landward migration of beaches and coastal wetlands where possible, 3) increased storm water run-off carrying pollutants, 4) increased eutrophication and contamination due to synergistic effects of impacts above in combination with rising water temperatures (EPA 2008), 5) alteration and conversion of high marsh to low marsh, and conversion of low marsh to unvegetated wetlands, and 6) loss of some wetlands, with associated loss of flood control, buffering, and nursery, foraging, and spawning areas for diverse marine fauna (http://www.fws.gov/chesapeakebay/slamm) and (http://www.slammview.org).

All of these first and second order impacts have significant implications for coastal habitat conservation and many are likely to lead to intense conflicts between flood defense and habitat restoration and protection objectives (French 2008). There are also likely to be significant implications for species whose populations are small or declining, especially species dependent on lower tidal elevation marsh habitats such as salt marsh sparrows, and beach-dependent species, such as piping plovers, horseshoe crabs and migratory shorebirds (Nicholls et al. 2007). There will also be significant costs for coastal communities beyond the most obvious impacts of flooded public and private infrastructure, including salt water intrusion into drinking water, overwhelmed storm water discharge systems, and the presence of hazardous waste at sites below projected flood levels (Cooper et al. 2008). Some human responses to protect life and property from sea level rise impacts will exacerbate negative impacts to natural systems (e.g., shoreline hardening) while others may facilitate ecosystem resilience and the persistence of critical habitats (e.g., living shorelines, coastal retreat).

Vulnerability and Resilience

For the purposes of this assessment, it is imperative to assess coastal system types in the context of both likely vulnerability and potential resilience to impacts from rising sea levels, storm surges, and flooding from increasingly frequent and intensified storms. *Vulnerability* is defined here as the relative impact sea level rise will have on a given system, and *resilience* as the ability of the system to adapt and persist in the face of these predicted effects. In particular, this assessment focused on 1) coastal beach and dune complexes and 2) salt marshes and other tidal wetlands, along with the species that depend on them, as the most vulnerable to sea level rise and associated impacts.

Coastal marshes and beaches of the Northwest Atlantic are naturally dynamic systems which characteristically vary both spatially and temporally. Specifically, they have been adapting to changes in relative sea level during all of the Holocene. However, it is the *rate* of change associated with contemporary sea level rise that is predicted to be a significant stressor. While all coastal systems are vulnerable to impacts from sea level rise to an extent, some are more vulnerable than others. Projecting *vulnerability* to sea level rise is, first and foremost, a matter of predicting extents and depths of storm surge and inundation and, in the case of tidal rivers, the distance of upstream salt wedge migration. These are driven by regional differences in geomorphology, coastal slope, relative sea-level change, shoreline erosion/accretion, mean tide range, and mean wave height (Coastal Vulnerability Index (CVI); Thieler and Hammer-Klose 1999). For instance, the CVI analysis by the United State Geological Service predicts that the rocky coast of the Gulf of Maine is much less vulnerable to sea level rise and erosion associated with storm surges than the relatively low-lying wetlands along Chesapeake Bay (Figure 2-20). However, the CVI is a relatively coarse scale analysis. Conservation investments, whether in land preservation or restoration activities, will be most effective when informed by finer scale spatial data regarding local variation in both vulnerability and resilience to sea level rise impacts. Local scale characterizations of predicted vulnerability and resilience require finer-scale datasets than are currently unavailable for most of the Northwest Atlantic coast.

Predicting relative *resilience* is in large part a matter of estimating the potential for natural systems to "migrate" (i.e. to move upslope and away from the sea) and adapt in the face of that inundation. However, the other existing stresses faced by a given site or ecosystem is essential information. Multiple additional stressors are likely to further reduce a site or ecosystem's resilience. It should be emphasized that human activity on the coast can potentially *increase* the vulnerability of an ecosystem and subsequently *decrease* its resilience (Leslie and Kinzig 2009). For example, permitting nearshore development adjacent to at-risk habitats inhibits their ability to migrate, and consequently increases their vulnerability and reduces their resilience. Similarly, shoreline armoring inhibits cross- and long-shore sediment movement and thereby increases the vulnerability of nearshore beaches and wetlands that rely on natural transport processes to maintain elevation. Accordingly, the human response to coastal risk is likely to be a major driver of both vulnerability and resilience to sea level rise and accompanying hazards.

A number of studies of the potential impacts of projected sea level rise have been conducted in and near the Northwest Atlantic region, including in Assateague Island National Seashore and the Virginia Coast Reserve (Pendleton et al. 2004), Chesapeake Bay, the New Jersey coast (Zhang et al. 2004), Long Island (New York) (Goddard Institute 2008), the Mid-Atlantic coast from New York to North Carolina (Titus and Wang 2008; Titus and Strange 2008; Titus et al. 2008; Reed et al. 2008; CCSP 2009), Quonochontaug Pond, Rhode Island (Vinhateiro 2008), Scarborough Marsh, Maine (Slovinsky and Dixon 2008), and Albermarle Sound, North Carolina (http://www.nature.org/initiatives/climatechange/work/art26197.html). See individual references for more information about each of these programs. Also, see TNC's coastal resilience project where notable subregional and site-specific examples of sea level rise impacts within the Northwest Atlantic region are being compiled (http://coastalresilience.org).

Predicting Ecological Resilience

While these studies offer information on the likely vulnerability of specific coastal areas and some provide predictions of potential beach and marsh migration, most do not provide comparative predictions of resilience for multiple sites. Are there attributes of particular coastal systems or classes of systems that would make them more or less ecologically resilient? Here the concept of *ecological resilience* is used as a predictor of persistence of the ecosystem type over time, with recognition that it may not persist in the same location with all of the same species. For instance, a fringing beach backed by a bedrock headland will likely disappear as sea levels rise; such a beach is not resilient to sea level rise once a certain threshold is reached. In contrast, a large and unconstrained barrier beach and dune system with a salt marsh behind it may be able to migrate and persist over time, as such beaches have done historically. Note that this use of resilience is distinct from the concept of *coastal hazards resilience* used by NOAA and others, which focuses primarily on attributes of human communities rather than natural systems. We believe assessing coastal systems' ecological resilience may be a useful additional method for prioritizing conservation investments and in choosing restoration and adaptation approaches.

Key attributes to consider in evaluating relative ecological resilience of coastal systems

Size

In general, there is a large body of conservation biology literature speaking to the greater resilience of larger systems versus smaller, e.g. the minimum dynamic area and minimum dynamic reserve concepts (Pickett and Thompson 1978; Leroux et al. 2007). Larger marshes are likely to have more microhabitats and more room to adjust. Larger beach and dune systems typically have more available sand and thus may be able to adjust up and away from the rising sea better than low narrow beaches.

Landward Topography and Barriers to marsh movement upslope

In order to keep pace with sea level rise, salt marshes must grow in two directions: horizontally and vertically. Horizontal growth occurs via migration into adjacent upland areas where the marshes are unimpeded by steep natural slopes or shoreline hardening and development; vertical growth occurs through the accumulation of mineral and biologic sedimentary materials that form the peat substrate. Likewise, tidal marshes with adjacent low-lying land normally can migrate into these lands unless the slopes are too steep or there are man-made or natural physical barriers (Titus et al. 1991). Along the Maine coast, there are a number of salt marshes with old tree stumps protruding or buried in the marsh peat attesting to such landward migration over the last several thousand years (Dickson, personal communication). However, in many places roads, railroads and buildings now crowd the marsh edge and various kinds of structures are in place to protect that infrastructure from infringing high water. Furthermore, there are many areas where additional barriers may likely to be constructed to protect current or planned human infrastructure. The presence of existing or potentially planned human infrastructure is an additional potential factor influencing the landward and upslope movement of both marshes and beaches.

Barriers to beach movement long-shore and landward
When subjected to rising sea levels, beaches may translate upward and landward. This concept applies when there is physical space in which to migrate horizontally unimpeded by obstructions and simultaneous sand accretion to build the beach vertically at a pace to keep up with sea level rise (Pilkey and Dixon 1996). Where there are subtidal supplies of sand, coastal storms can help replenish sediment by moving sand up the beach profile from offshore deposits (Cooper et al. 2008). However, if either of these conditions is absent, or if the pace of sea level rise is too rapid, a beach will subsequently erode and eventually become submerged.

In recognition of the importance of barrier beaches to the tidal wetlands and lagoons behind them, many states have taken action to protect their barrier beaches by preventing additional structures that might impede their natural accretion or migration (e.g. Massachusetts Barrier Beach Inventory and Executive Order restricting further building on barrier beaches).

Longitudinal upstream connectivity

As sea level rises the salt wedge will intrude farther upstream in coastal rivers (Najjar et al. 2000). Thus, where now there may be fringing salt marshes at the seaward end of estuaries and brackish and then freshwater tidal wetlands fringing farther upstream, in the future all these may become salt (if they remain elevated enough to be vegetated at all.) However, in some larger coastal rivers there is plenty of longitudinal space for these fringing tidal marshes to migrate upstream as the sea level rises and tidal influence and salt intrude farther. On the other hand, where coastal river continuity is truncated by natural falls, dams, or restricting culverts that would prevent a tidal wetland from moving upstream, it is likely that the freshwater and brackish tidal wetlands will disappear and/or become entirely saline. Note however, that modeling such changes specifically is complicated by the need to take into account changes in the river's hydrology due to potential changes in the rates and volumes of freshwater flow.

Rate of accretion/erosion

Tidal wetlands and other shorefront habitats can persist in the face of moderate rates of sea level rise through accretion, supported by sedimentation and organic matter accumulation (Chmura et al. 2003). However, if relative sea level change exceeds net elevation change (the net effect of accretion and compaction), wetlands and beaches will be inundated and ultimately lost (Peterson et al. 2008). In general, over the last century, salt marshes have accreted sediment at a rate to keep up with rising seas (Hartig et al. 2002; Najjar et al. 2000; Roman et al. 1997). Recently, however, several authors have predicted that salt marshes will not be able to accrete fast enough to keep up with predicted sea level rise and the result will be outright inundation in some cases or at the least major losses of *Spartina patens* dominated marsh and expansion of *Spartina alterniflora* dominated marsh (Gornitz et al. 2004; Morris et al. 2005).

Not all tidal wetlands accrete at the same rates. Some, such as freshwater tidal wetlands that may have sparse plant cover but harbor many rare plant species, are more dependent for accretion on sediment input from rivers than salt marshes (Neubauer 2008). Salt marshes are more dependent on vegetative accretion than sediment inputs and the vegetative production may be dependent on the stimulus of flooding (Nyman et al. 2006). In some areas warmer temperatures associated with climate change may increase marsh productivity and subsequently increase organic sediment accretion rates (Langley et al. 2009). However, this effect may be more pronounced in freshwater than saltwater systems and background accretion and erosion rates are a fairly site-specific phenomenon, depending on a variety of local factors not easily predicted without detailed studies. Titus (2008) has compiled maps that depict site-specific scenarios for wetland accretion along the Mid-Atlantic coast from New York to Virginia. Other authors have determined accretion rates in other states (e.g., CT: Orson et al. 1998; Warren and Niering 1993; RI: Bricker-Urso et al. 1989).

Potential Resilience Attributes to be Assessed at Regional Scales

Given data gaps and data resolution, comparative resilience is probably best addressed at an estuary or CSU level, rather than at a beach by beach or marsh by marsh level (EPA 2008). A logical start would be to build from some of the following system-specific attributes.

Beaches

Size

The area of all beach and dune systems in the Northwest Atlantic has been calculated using GIS data from TNC's Northern Appalachian and North Atlantic Coast ecoregional plans and generated for Chesapeake Bay based on the NWI, ESI, and National Land Cover Dataset (NLCD). It would be advisable to update these measurements using LiDAR data when available. Length can be reasonably measured from existing data sources. However, the width and height of beach/dune systems are key aspects of beach size related to resilience that are much more difficult to measure without extensive mapping efforts derived from orthophotography or localized geologic studies.

Appropriate adjacent habitat
Beaches could be assessed using shoreline (e.g. ESI), estuarine (e.g. NWI), and land cover classifications in addition to elevation to indicate whether they are backed by a headland, dunes, coastal wetlands, or forest types. Those backed by headland could be further characterized using geological data sources as to whether the headland is of unconsolidated material (sand, mud, gravel, which presumably could contribute to accretion of beach material) or bedrock.

Presence/Absence of artificial barriers to natural beach movement
Barriers could be assessed using NOAA structures data for piers, groins, and jetties, and NLCD or NOAA Coastal Change Analysis Program (CCAP) Land Use Land Cover data for roads and houses on the beach-dune. However, these are generally out of date and incomplete. Some states in the region have recently completed or are in the process of completing coast-wide coastal structures inventories. These datasets are likely to be the best approach to assessing this attribute on a regional basis. For the CSU analysis, the percent of total CSU length that was "man-made" was measured using ESI line type coding and, where this did not exist in Maine and Canada, by overlapping EPA and Canadian Department of Natural Resources and Energy data.

Shoreline Change Rates may be one of the most important factors in predicting beach resilience to sea level rise. Where local studies have been done or are underway these should be factored in.

Tidal Wetlands

Size
For the CSU characterization described above, the area of all tidal wetlands was calculated using GIS. Patches were grouped according to an algorithm based on adjacency and hydrological connections (e.g. marsh patches on either side of a tidal inlet or river) as above.

Landward topography
This parameter refers to the amount of adjacent land at less than 1 and 2 m elevation. For accuracy this would need to be calculated using LiDAR when available. Analysis of landward topography, that is, slope and amount of adjacent land under a particular elevation, is the primary approach of most of the studies of sea level rise impacts to coastal habitats cited above.

Presence/absence of artificial barriers to upslope movement
This parameter could be assessed using the NLCD or CCAP land cover data on natural versus developed cover types plus a transportation layer. On a site-specific scale these barriers can also be assessed in some areas by compiled maps of hardened shorelines or by analysis of digital orthophotos. These constraints to upslope migration are built into some, but not all, of the site-specific models of inundation (See U Arizona web-based model in addition to the SLAMM references).

Longitudinal Connectedness Upstream
There is no region-wide GIS dataset that would allow determination of natural or anthropogenic barriers to upstream migration of fringing tidal wetlands or salt wedges. However, this parameter could be determined on a site-specific basis by consulting local datasets and examination of aerial photos and contour and bathymetry maps.

Putting It All Together

Analyzing key ecological attributes from beach and tidal wetland ecosystems can support the growing understanding of resilience. Weighting, combining, and ranking these attributes to produce relative scales of resilience can further our ability to assess ecosystem structure and function in the face of climate change. Research and design of such methods are an important next steps in the Northwest Atlantic coastal system as we identify conservation priorities and strategies for taking action to protect specific places. For example, a relative scale of tidal salt marsh resilience could be evaluated in the context of current land use and conservation protection. This analysis may identify the protection of individual, relatively more resilient sites while also determining the need to secure or maintain protection of adjacent freshwater wetlands and uplands within 2 m of high water to give them space to migrate and persist in the future.

Much more research and modeling are needed regarding how coastal systems will react and adapt to sea level rise and what factors impede or facilitate resilience. Detailed scientific studies will necessarily focus on a relatively small scale, rather than the entire region, and should take place over multiple years (for instance, National Science Foundation funded research underway at TNC's Virginia Coast Reserve). For purposes of this assessment, the ultimate goal is to use site-specific assessments of sea level rise vulnerability and resilience in the prioritization of strategies and places for conservation and restoration. We hope that as federal and state coastal inundation analyses proceed they factor in some attributes relevant to resilience to add to collective knowledge.

We wish to reiterate that the vulnerability of human infrastructure and likely societal responses to protect infrastructure pose significant threats to the resilience of coastal systems which may compound and exacerbate natural impacts. It would be appropriate to take these into account in comparing vulnerability and resilience of various parts of the coast or one bay versus another (Titus and Wang 2008; Titus et al. 2009).

NOAA's Digital Coast Partnership

NOAA Coastal Services Center leads the Digital Coast effort, envisioned as an information delivery system that efficiently provides not only data, but also the training, tools, and examples needed to turn data into useful information for the management of coastal resources (http://csc.noaa.gov/digitalcoast/index.html). An important part of the Digital Coast is the partnership network, the guiding team that represents user groups and content providers. As a member of the partner network, TNC has been contributing to Digital Coast specifically by providing case studies. One study done in conjunction with this assessment was the development of a regional framework for assessing coastal vulnerability to sea level rise in southern New England (Cape Cod, Massachusetts to Long Island, New York).

The Southern New England Coastal Vulnerability study imposes an assessment of future coastal development and ecological resources on a regional framework based on coastal topography. This framework will help illustrate the current limitations of, and opportunities for, mapping SLR at regional scales, considering the relative vulnerability of human communities and deciphering whether the presence and contribution of coastal ecosystems presents a viable opportunity for adaptation solutions. With this study, TNC and its partners hope to add value to the growing field of coastal resilience and adaptation planning through the development of this initial regional framework (see http://webqa.csc.noaa.gov/digitalcoast/action/hazards/slr-newengland.html). In addition, the complete case study will be included in the Coastal Inundation Toolkit (http://csc.noaa.gov/digitalcoast/inundation/discover.html) by spring 2010.

TNC is working nationally with NOAA's Digital Coast program as well as in different geographies across the United States on issues of vulnerability and resilience as they pertain to sea level rise and coastal inundation. Please refer to TNC's climate change initiative (http://www.nature.org/initiatives/climatechange/work) for additional information.

Potential Strategies for Enhancing Resilience of Coastal Systems

The vulnerability of human infrastructure and likely societal responses to threats to that infrastructure will impact the resilience of coastal systems. While it will be important to maintain certain aspects of the built environment that protect and provide important services to human communities, this must be balanced with attempts to maintain natural diversity and natural infrastructure of coastal habitats, many of which provide vital services to those same communities.

It is imperative that government agencies and the public begin constructive discussions about appropriate responses to the new stresses climate change will place on already stressed coastal environments. Fortunately, many states are already engaged in such discussions and planning. A variety of strategies for increasing the long term resilience of coastal ecosystems should be considered, along with the appropriate means of mitigating the short term collateral impacts of such strategies on coastal landowners and municipalities:

- Acquiring low-lying natural land adjacent to beaches and marshes for conservation
- Inclusion of future habitats in land use planning
- Removing barriers to upstream connectivity, e.g., dams, roads, or dikes across marshes with narrow culverts
- Preventing armoring of beaches and building on dune systems
- Removing or preventing man-made barriers to upslope connectivity such as development adjacent to marshes
- Not rebuilding or removing armoring and seawalls; realigning and redesigning built "defenses" necessary to protect infrastructure to have less impact on natural systems
- Where stabilization is absolutely essential, supporting development of "soft solutions" and/or Living Shorelines instead of hardened shorelines for areas where complete retreat is not an option
- Reducing and mitigating impacts of other stresses, such as excessive nutrients (inadequate wastewater treatment, combined sewer overflows, etc.), incompatible development, and invasive species
- Avoiding beach replenishments which are often extremely expensive, temporary in impacts, and counter-productive, with impacts to beach fauna and subtidal shoal habitats; however in some cases beach nourishment can be beneficial by simulating a natural bypassing of sediment that would occur in the absence of an armoring structure.

In 2009, on Earth Day, the Heinz Center and Ceres released a "Resilience Coasts Blueprint" outlining proposed policy changes and local actions that could significantly reduce future United States coastal losses due to sea level rise and storm impacts. This report was endorsed by a diverse group including NOAA, representatives of major insurers, and The Nature Conservancy. In January of 2009, the EPA released an in depth document on coastal sensitivity to sea level rise with a focus on the Mid-Atlantic region which includes comprehensive overview of various response options and the federal and state policy implications for adaptation (CCSP 2009). These and other strategies should be assessed more completely in the future, and methods for prioritizing locations for deployment of site-specific strategies should be developed.

Literature Cited

Able, K.W. and S.M. Hagan. 2000. Effects of Common Reed (*Phragmites australis*) invasion on marsh surface macrofauna: Response of fishes and decapod crustaceans. Estuaries. 23(5): 633-646.

Able, K.W., D. M. Nemerson, P.R. Light, and R.O. Bush. 2000. Initial Responses of Fishes to Marsh Restoration at a former salt hay farm bordering Delaware Bay. In M. P. Weinstein and D. A. Kreeger (eds.), Concepts and Controversies in Tidal Marsh Ecology. Kluwer Academic Publishing, The Netherlands. 749-773

Abraham, B-J. and P.L. Dillon. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic)--Softshell Clam. U.S. Fish Wildlife Service Biological Report. 82(11.68). U.S. Army Corps of Engineers, TR EL-82-4. 1B PP

Alley, R.B., P. U. Clark, P. Huybrechts, and I. Joughin. 2005. Ice-sheet and sea-level changes. Science. 310: 456-460.

Anderson, M.G., Vickery, B., Gorman, M., Gratton, L., Morrison, M., Mailet, J., Olivero, A., Ferree, C., Morse, D., Kehm, G., Rosalska, K., Khanna, S., and S. Bernstein. 2006a. The Northern Appalachian / Acadian Ecoregion: Ecoregional Assessment, Conservation Status and Resource CD. The Nature Conservancy. Boston, MA.

Anderson, M. G., K. Lombard, J. Lundgren, B. Allen, S. Antenen, D. Bechtel, A. Bowden, M. Carabetta, C. Ferree, M. Jordan, S. Khanna, D. Morse, A. Olivero, N. Sferra, and A. Upmeyer. 2006b. The North Atlantic Coast: Ecoregional Assessment, Conservation Status Report and Resource CD. The Nature Conservancy. Boston, MA.

ASMFC. 2007. Public information document for Amendment 2 to the interstate fisheries management plan for shad and river herring. Atlantic States Marine Fisheries Commission. 21 pp.

Beck, M., R. Brumbaugh, L. Airoldi, A. Carranza, L. Coen, C. Crawford, O. Defeo, G. Edgar, B. Hancock., M. Kay, H. Lenihan, M. Luckenbach, C. Toropova , and G. Zhang, in review. Shellfish reefs at risk globally and recommendations for ecosystem revitalization. Submitted to Proceedings of the National Academy of Science.

Beesley, A., D.M. Lowe, C.K Pascoe, and S. Widdicombe. 2008. Effects of CO_2-induced seawater acidification on health of *Mytilus edulis*. Climate Research. 37:215-225.

BwH (Beginning with Habitat). 2009. Maine Department of Inland Fisheries & Wildlife. http://www.beginningwith-habitat.org/index.html.

Bertness, M. D. 2006. Atlantic Shorelines: Natural History and Ecology. Princeton University Press, Princeton, NJ.

Bowen, J. L. and I. Valiela. 2001. The ecological effects of urbanization of coastal watersheds: historical increases in nitrogen loads and eutrophication of Waquoit Bay estuaries. Canadian Journal of Fisheries and Aquatic Sciences. 58: 1489-1500.

Bricker, S., B. Longstaff, W. Dennison, A. Jones, K. Biocourt, C. Wicks, and J. Woerner. 2007. Effects of Nutrient Enrichment In the Nation's Estuaries: A Decade of Change. NOAA Coastal Ocean Program Decision Analysis Series No. 226. National Centers for Coastal Ocean Science, Silver Spring, MD. 328 pp.

Bricker, S.B., C.G. Clement, D.E. Pirhalla, S.P. Orlando, and D.G.G. Farrow. 1999. National Estuarine Eutrophication Assessment: Effects of nutrient enrichment in the Nation's estuaries. Silver Spring, MD: Special Projects Office and the National Centers for Coastal Ocean Science, National Ocean Service, National Oceanic and Atmospheric Administration.

Bricker-Urso, S., S. W. Nixon, J. K. Cochran, D. J. Hirschberg, and C. Hunt. 1989. Accretion rates and sediment accumulation in Rhode Island salt marshes. Estuaries. 12:300-317.

Bromberg Gedan, K. D. and M. D. Bertness. 2005. Reconstructing New England salt marsh losses using historical maps. Estuaries. 28(6): 823-832.

Bromberg Gedan, K. D., B. R. Silliman, and M. D. Bertness. 2009. Centuries of human-driven change in salt marsh ecosystems. Annual Review of Marine Science. 1:117-141.

Buchsbaum, R. J., J. Pederson, W. Robinson. 2005. The Decline of Fisheries Resources in New England: Evaluating the Impact of Overfishing, Contamination and Habitat Degradation. MIT Sea Grant Press. 167 pp. http://massbay.mit.edu/publications/NEFishResources/index.html

Carlton, J. T., J. B. Geller, M. L. Reaka-Kudla, and E. A. Norse. 1999. Historical extinctions in the sea. Annual Review of Ecology and Systematics. 30:525-538.

CCSP (Climate Change Science Program). 2009. Coastal Sensitivity to Sea-Level Rise: a Focus on the Mid-Atlantic Region. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [James G. Titus (Coordinating Lead Author), J. K. Eric Anderson, Donald R. Cahoon, Dean B. Gesch, Stephen K. Gill, Benjamin T. Gutierrez, E. Robert Thieler, and S. Jeffress Williams (Lead Authors)], U.S. Environmental Protection Agency, Washington, D.C. USA. http://www.epa.gov/climatechange/effects/coastal/SAP%204.1%20Final%20Report%2001.15.09.pdf

Center for Watershed Protection. 2003. Watershed Protection Research Monograph No. 1: Impacts of Impervious Cover on Aquatic Systems.

Chmura, G. L., S. C. Anisfeld, D. R. Cahoon, and J. C. Lynch. 2003. Global carbon sequestration in tidal, saline wetland soils. Global Biogeochemical Cycles. 17(4): 1111.

Cicchetti, G. and R. J. Diaz. 2000. Types of salt marsh edge and export of trophic energy from marshes to deeper habitats. In M. P. Weinstein and D. A. Kreeger (eds.), Concepts and Controversies in Tidal Marsh Ecology. Kluwer Academic Publishing, The Netherlands.

Coen, L.D., R.D. Brumbaugh, D. Bushek, R. Grizzle, M.W. Luckenbach, M.H. Posey, S.P. Powers, and S.G. Tolley. 2007. Ecosystem services related to oyster restoration. Marine Ecology Progress Series. 341: 303-307.

Coles, J. F., R. F. Cuffney, G. McMahon, and K. M. Beaulieu. 2004. The effect of urbanization on the biological, physical, and chemical characteristics of coastal New England streams. U.S. Geological Survey Professional Paper 1695.

CTDEP (Connecticut Department of Environmental Protection). 2009. Impervious Land Cover and Water Quality. Web. Accessed November, 2009. http://www.ct.gov/dep/cwp/view.asp?a=2719&q=433012&depNav_GID=1654

Cooper, M. J. P., M. D. Beevers, and M. Oppenheimer. 2008. The potential impacts of sea level rise on the coastal region of New Jersey, USA. Climate Change. 90: 475-492.

Costa, J.E., B.L. Howes, I. Valiela and A.E. Giblin. 1992. Monitoring nitrogen and indicators of nitrogen loading to support management action in Buzzards Bay. In: McKenzie et al. (eds.) Ecological Indicators, Chapter 6, pp. 497-529.
Cowan D. F. 1999. Methods for assessing relative abundance, size distribution, and growth of recently settled and early juvenile lobsters (*Homarus americanus*) in the lower intertidal zone. Journal of Crustacean Biology. 19(4):738-751.

Delaware Bay Oyster Restoration Partnership. 2009. Delaware Bay Oyster Restoration Partnership website. http://www.delawareestuary.org/ontheground activities/oysterrevitalization.asp. Accessed February 8, 2009.

Deegan, L. A., A. Wright, S. G. Ayvazian, J. T. Finn, H. Golden, R. R. Merson, and J. Harrison. 2002. Nitrogen loading alters seagrass ecosystem structure and support of higher trophic levels. Aquatic Conservation - Marine and Freshwater Ecosystems. 12: 193-212.

Den Hartog, C. 1989. Early records of wasting-disease-like damage patterns in eelgrass *Zostera marina*. Diseases of Aquatic Organisms. 7: 223.

Dionne, M., F. T. Short, and D. M. Burdick. 1999. Fish utilization of restored, created, and reference salt marsh habitat in the Gulf of Maine. American Fisheries Society Symposium 22:384-404.

Drake, S.A. 1875. Nooks and Corners of the New England Coast. Harper and Brothers, New York, NY. 459pp.

Eastern Oyster Biological Review Team. 2007. Status review of the Eastern Oyster (*Crassostrea virginica*). Report to the National Marine Fisheries Service, Northeast Regional Office. February 16, 2007. 105 pp.

Edinger, G.J., D.J. Evans, S. Gebauer, T.G. Howard, D.M. Hunt, and A.M. Olivero (editors). 2002. Ecological Communities of New York State. Second Edition. A revised and expanded edition of Carol Reschke's Ecological Communities of New York State. (Draft for review). New York Natural Heritage Program, New York State Department of Environmental Conservation, Albany, NY.

Engle, V. D., J. C. Kurtz, L. M. Smith, C. Chancy, and P. Bourgeois. 2007. A Classification of U.S. Estuaries Based on Physical and Hydrologic Attributes. Environmental Monitoring and Assessment. 129:397-412.

EPA (Environmental Protection Agency). 2004. National Coastal Condition Report II EPA-620/R-03/002

EPA (Environmental Protection Agency). 2008. Adaptation options for climate-sensitive ecosystems and resources. Federal Register: January 7, 2008. Volume 73, Number 4.

Epifanio, C.E. and R.W. Garvine. 2001. Larval Transport on the Atlantic Continental Shelf of North America: a Review. Estuarine, Coastal and Shelf Science 52: 51-77.

Fay, C.W., R.J. Neves, and G.B. Pardue. 1983. Species profiles : life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic) Bay Scallop. Fish & Wildlife Service Biological Report FWS/OBS-82/11.12. U.S. Army Corps of Engineers, TR EL-82-4. 17 pp.

Feagin, R. A., D. J. Sherman, and W. E. Grant. 2005. Coastal erosion, global sea-level rise, and the loss of sand dune plant habitats. Frontiers in Ecology and the Environment. 3:359-364.

French, J. R. 2008. Hydrodynamic modeling of estuarine flood defense realignment as an adaptive management response to sea-level rise. Journal of Coastal Research. 24(2B): 1-12.

Galtsoff, P.S. 1964. The American oyster *Crassostrea virginica* Gmelin. Fish. Bull. 64: 1-480.
Great Bay Estuarine Restoration Compendium. 2006. The Nature Conservancy, University of New Hampshire, New Hampshire Estuary Project, New Hampshire Coastal Program. http://conserveonline.org/library/GBERC%20report.pdf/view.html. 93 pp.

Geerat, J. V. 1993. Biogeography of recently extinct marine species: Implications for conservation. Conservation Biology 7(2): 391-397.

Goddard Institute for Space Studies and Columbia Center for Climate Systems Research. 2008. Draft projections developed for The Nature Conservancy on Long Island's Coastal Resilience Project (coastalresilience.org).

Gornitz, V., S. Hale, K. Larsen, N. Levine, C. Rosenzweig, and L. Sacks. 2004. Bracing for Climate Change in the Constitution State: What Connecticut Could Face. Environmental Defense. New York, NY.

Grabowski, J. H., and C. H. Peterson, editors. 2007. Restoring oyster reefs to recover ecosystem services. Ch. 15, pp. 281-298, in Ecosystem Engineers: Concepts, Theory and Applications, Eds., K. Cuddington, J.E. Byers, W.G. Wilson, and A. Hastings, Elsevier/Academic Press, Netherlands.

Gregory , J.M., P. Huybrechts, and S.C.B. Raper, 2004. Threatened loss of the Greenland ice-sheet. Nature. 428, 616.

Hale, S. S., J. F. Paul, and J. F. Heltshe. 2004. Watershed landscape indicators of estuarine benthic condition. Estuaries. 27(2): 283-295.

Hartig, E. K., V. Gornitz, A. Kolker, F. Mushacke, and D. Fallon. 2002. Anthropogenic and climate-change impacts on salt marshes of Jamaica Bay, New York City. Wetlands. 22(1): 71-89.

Heck, K. L., G. Hays, and R. J. Orth. 2003. Critical evaluation of the nursery role hypothesis for seagrass meadows. Marine Ecology Progress Series. 253: 123-136.

Huxley, T. 1884. Inaugural address. Fisheries Exhibition Literature. 4: 1-22.

Ingersoll, E. 1881. The history and present condition of the fishery industries. The oyster industry. Department of the Interior. Tenth Census of the United States. Government Printing Office. Washington. 252 pp.

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate change 2007: The physical science basis. Contribution of Working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)] Cambridge University Press, Cambridge, United Kingdom and New York, NY.

Jackson, C. F. 1944. A Biological Survey of Great Bay, New Hampshire. No. 1. Physical and Biological Features of Great Bay and the Present Status of its Marine Resources. New Hampshire Marine Fisheries Commission. Durham, NH.

Kennedy, V.S., R.I.E. Newell, and A.F. Able, editors. 1996. The Eastern Oyster *Crassostrea virginica*. Maryland Sea Grant College, College Park, MD, USA.

Kennish, M. J., S.B. Bricker, W.C. Dennison, P.M. Gilbert, R.J. Livingston, K.A. Moore, R.T. Noble, H.W. Paerl, J.M. Ramstack, S. Seitzinger, D.A. Tomasko, and I. Valiela. 2007. Barnegat Bay-Little Egg Harbor Estuary: Case study of a highly eutrophic coastal bay system. Ecological Applications. 17: S3-S16.

Kirby, M.X. 2004. Fishing down the coast: Historical expansion and collapse of oyster fisheries along continental margins. Proceedings of the National Academy of Sciences. 101(35): 13096-13099.

Kraeuter, J.N. and M. Castagna, editors. Biology of the Hard Clam. 2001. Elsevier Science, Amsterdam, Netherlands.

Langley, J. A., K. L. McKee, D. R. Cahoon, J. A. Cherry, and J. P. Megonigal. 2009. Elevated CO_2 stimulates marsh elevation gain, counterbalancing sea-level rise. Proceedings of the National Academy of Sciences. 106(15): 6182-6186.

Leroux, S. J., F. Schmiegelow, R. B. Lessard, and S. G. Cumming. 2007. Minimum Dynamic Reserves: A framework for determining reserve size in ecosystems structured by large disturbances. Biological Conservation. 138: 464-473.

Leslie, H. M. and A. P. Kinzig. 2009. Resilience Science. Pages 55-73 *in* K. L. McLeod and H. M. Leslie, editors. Ecosystem-Based Management for the Oceans. Island Press, Washington, DC.

Li, X., D. E. Weller, C. L. Gallegos, T. E. Jordan, and H. Kim. 2007. Effects of watershed and estuarine characteristics on the abundance of submerged aquatic vegetation in Chesapeake Bay subestuaries. Estuaries and Coasts. 30(5): 840-854.

LISHRI (Long Island Sound Habitat Restoration Initiative). 2003. Habitat Restoration Technical Manual, Section 3 Submerged Aquatic Vegetation.

Lotze, H. K., H.S. Lenihan, B.J. Bourque, R.H. Bradbury, R.G. Cooke, M.C. Kay, S.M. Kidwell, M.X. Kirby, C.H. Peterson, and J. B. C. Jackson. 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. Science. 312:1806-1809.

Lyons, M., R. Smolowitz, M. Gomez-Chiarri, and J.E. Ward. 2007. Epizootiology of Quahog Parasite Unknown disease in northern quahogs *Mercenaria mercenaria.* Journal of Shellfish Research. 11:130-148.

Mackenzie, C. L. 2007. Causes underlying the historical decline in eastern oyster *Crassostrea virginica* (Gmelin, 1791) landings. Journal of Shellfish Research. 26: 927-938.

Madden, C. J., D. H. Grossman, and K. L. Goodin. 2005. Coastal and Marine Systems of North America: Framework for an Ecological Classification Standard: Version II. NatureServe, Arlington, Virginia. 48pp.

Markham, A. 1996. Potential impacts of climate change on ecosystems: a review of implications for policymakers and conservation biologists. Climate Research. 6:179-191.

Maryland Department of Natural Resources. 2009. Oyster restoration program website. http://www.dnr.state.md.us/fisheries/recreational/articles/oysterrestoration.html Accessed February 8, 2009.

Menge, B. A. and G. M. Branch. 2001. Rocky Intertidal Communities. Pages 221-252 *in* M. D. Bertness, S. D. Gaines, and M. E. Hay, editors. Marine Community Ecology. Sinauer Associates, Inc., Sunderland, MA.

Meyer, D.L., E.C. Townsend, and G.W. Thayer. 1997. Stabilization and erosion control value of oyster cultch for intertidal marsh. Restoration Ecology 5:93-99. Morris, J. T., D. Porter, M. Neet, P. A. Noble, L. Schmidt, L. A. Lapine, and J. Jensen. 2005. Integrating LIDAR elevation data, multispectral imagery and neural network modeling for marsh classification. International Journal of Remote Sensing. 26:5221-5234.

Morris, J. T., D. Porter, M. Neet, P. A. Noble, L. Schmidt, L. A. Lapine, and J. Jensen. 2005. Integrating LIDAR elevation data, multispectral imagery and neural network modeling for marsh classification. International Journal of Remote Sensing. 26:5221-5234.

Muehlstein, L. K., D. Porter, and F. T. Short. 1991. *Labyrinthula zosterae* sp. nov., the causative agent of wasting disease of eelgrass, *Zostera marina*. Mycologia. 83:180.

Najjar, R. G., H.A. Walker, P.J. Anderson, E.J. Barron, R.J. Bord, J.R. Gibson, V.S. Kennedy, C.G. Knight, J.P. Megonigal, R.E. O'Connor, C.D. Polsky, N.P. Psuty, B.A. Richards, L.G. Sorenson, E.M. Steele, and R.S. Swanson. 2000. The potential impacts of climate change on the Mid-Atlantic coastal region. Climate Research. 14:219-233.

NOAA (National Oceanic and Atmospheric Administration). 1997. The 1995 National Shellfish Register of Classified Growing Waters. Silver Spring, MD: Office of Ocean Resources Conservation and Assessment, Strategic Environmental Assessments Division. 398 pp.

NOAA (National Oceanic and Atmospheric Administration). 2002. NOS OR&R 11 Environmental Sensitivity Index Guidelines. Version 3.0. Hazardous Materials Response Division. Office of Response and Restoration. NOAA Ocean Service. National Oceanic and Atmospheric Administration. Seattle, Washington.

NOAA (National Oceanic and Atmospheric Administration). 2003. Center for Sponsored Coastal Research. Ecological Effects of Sea Level Rise: A new research program sponsored by the NOAA's Center for Sponsored Coastal Ocean Research. http://www.cop.noaa.gov/stressors/climatechange/current/sea_level_rise.html

NMFS (National Marine Fisheries Service) 2008. Monthly Commercial Landing Statistics. Web. http://www.st.nmfs.noaa.gov/st1/commercial/landings/monthly_landings.html

Neubauer, S. C. 2008. Contributions of mineral and organic components to tidal freshwater marsh accretion. Estuarine Coastal and Shelf Science. 78(1): 78-88.

Newell, R.I.E. 2004. Ecosystem influences of natural and cultivated populations of suspension-feeding bivalve mollusks: A review. Journal of Shellfish Research. 23: 51-61.

Newell, R. E. and E. W. Koch. 2004. Modeling seagrass density and distribution in response to changes in turbidity stemming from bivalve filtration and seagrass sediment stabilization. Estuaries. 27(5): 793-806.

Nicholls, R. J., P. P. Wong, V. R. Burkett, J. O. Codignotto, J. E. Hay, R. F. McLean, S. Ragoonaden, and C. D. Woodroffe. 2007. Coastal systems and low-lying areas. Cambridge University Press, Cambridge, UK.

Niering, W. A and R. S. Warren. 1980. Vegetation patterns and processes in New England salt marshes. Bioscience. 30:301-307.

Nixon, S. W. 1980. Between coastal marshes and coastal waters: a review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry in Hamilton, P. and K.B. MacDonald (eds.) Estuarine and Wetland Processes. NY: Plenum Press. p. 437-525.

New Jersey Baykeeper. 2009. Oyster restoration program website. http://www.nynjbaykeeper.org/programs/42 Accessed February 8, 2009.

New Hampshire Estuaries Project. 2006. State of the Estuaries. University of New Hampshire, Durham, NH.

Nordstrom, K. F., N. L. Jackson, J. R. Allen, and D.J . Sherman. 2003. Longshore sediment transport rates on a microtidal estuarine beach. Journal of Waterway, Port, Coastal, and Ocean Engineering. 129: 1-4.

Nyman, J. A., R. J. Walters, R.D. Delaune, and W.H. Patrick, Jr. 2006. Marsh vertical accretion via vegetative growth. Estuarine Coastal and Shelf Science. 69(3-4): 370-380.

O'Connor, J. S. and O. W. Terry. 1972. The Marine Wetlands of Nassau and Suffolk Counties, New York. Marine Sciences Research Center. State University of New York at Stony Brook. Stony Brook, NY. 99pp.

Odum, E. P. 1970. Fundamentals of Ecology. Saunders, Philadelphia, PA. 546.

Orson, R. A., R. S. Warren, and W. A. Niering. 1998. Interpreting sea-level rise and rates of vertical marsh accretion in a southern New England tidal salt marsh. Estuarine and Coastal Shelf Science. 47:419-429.

Orth, R. J. and K. A. Moore. 1984. Distribution and abundance of submerged aquatic vegetation in Chesapeake Bay: An historical perspective. Estuaries. 7:531-540.

Orth, R. J., M. L. Luckenbach, S. R. Marion, K. A. Moore, and D. J. Wilcox. 2006. Seagrass recovery in the Delmarva Coastal Bays, USA. Aquatic Botany. 84: 26-36.

Orth, R. J. and K. A. Moore. 1983. Chesapeake Bay: An unprecedented decline in submerged aquatic vegetation. Science. 222: 51-53.

Pauly, D. 1995. Anecdotes and the shifting baseline syndrome of fisheries. Trends in Ecology and Evolution. 10(10): 430.

Pendleton, E. A., S. J. Williams, and E. R. Thieler. 2004. Coastal Vulnerability Assessment of Assateague Island National Seashore (ASIS) to Sea-Level Rise. U.S. Geological Survey Open-File Report 2004-1030.

Pernell, L. V. and D. S. Peters. 1984. Menhaden, a single step from vascular plant to fishery harvest. Journal of Experimental Marine Biology and Ecology. 84 (1): 95-100.

Perry, B. 1985. A Sierra Club Naturalist's Guide to the Middle Atlantic Coast - Cape Hatteras to Cape May. San Francisco, CA: Sierra Club Books. 470pp.

Peterson, B.J., K.L. Heck, 1999. The potential for suspension feeding bivalves to increase seagrass productivity. Journal of Experimental Marine Biology and Ecology. 240:37-52.

Peterson, C. H., J. H. Grabowski, and S. P. Powers. 2003. Estimated enhancement of fish production resulting from restoring oyster reef habitat: Quantitative valuation. Marine Ecology Progress Series. 264:249-264.

Peterson, C. H., R. T. Barber, K. L. Cottingham, H. K Lotze, C. A. Simenstad, R. R. Christian, M. F. Piehler, and J. Wilson. 2008. National Estuaries. In: Preliminary review of adaptation options for climate-sensitive ecosystems and resources. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [Julius, S.H., J.M. West (eds.), J.S. Baron, B. Griffith, L.A. Joyce, P. Kareiva, B.D. Keller, M.A. Palmer, C.H. Peterson, and J.M. Scott (Authors)]. U.S. Environmental Protection Agency, Washington D.C.

Peterson, M. S., B. H. Comyns, J. R. Hendon, P. J. Bond, and G. A. Duff. 2000. Habitat use by early life-history stages of fishes and crustaceans along a changing estuarine landscape: Differences between natural and altered shoreline sites. Wetlands Ecology and Management. 8(2-3): 209-219.

Pettigrew, N. R., D. A. Kistner, G. P. Barbin, A. K. Laursen, D. W. Townsend, and J. Christensen. 1997. Somes Sound: Fjord or well-mixed estuary? Northeastern Naturalist. 4(1): 35-44.

Piazza, B.P., P.D. Banks, and M.K. La Peyre. 2005. The potential for created oyster shell reefs as a sustainable shoreline protection strategy in Louisiana. Restoration Ecology. 13:499–506.

Pickett, S. T. A. and J. N. Thompson. 1978. Patch dynamics and the design of nature reserves. Biological Conservation. 13: 27-37.

Pilkey, O. H. and K. Dixon. 1996. The Corps and the Shore. Island Press. Washington, D.C. 286.

Powers, S. P., C. H. Peterson, J. H. Grabowski and H. S. Lenihan. In press. Evaluating the success of oyster reef restoration in the presence of multiple environmental stressors. Manuscript accepted for publication in Marine Ecology Progress Series. Published online: 15 March 2009 | DOI:10.1038/ngeo462.

Redfield, A. C. 1965. Ontogeny of a salt marsh estuary. Science. 147: 50-55.

Redfield, A. C. 1972. Development of a New England salt marsh. Ecological Monographs. 42: 201-237.

Reed, D. J., D. A. Bishara, D. R.Cahoon, J. Donnelly, M. Kearney, A. S. Kolker, L. L. Leonard, R. A.Orson, and J. C. Stevenson. 2008. Site-Specific Scenarios for Wetlands Accretion as Sea Level Rises in the Mid-Atlantic Region. Section 2.1 in Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1. J.G. Titus and E.M. Strange (eds.) EPA 430R07004.U.S. EPA, Washington, DC.

Reschke, C. 1990. Ecological Communities of New York State. New York Natural Heritage Program N.Y.S. Department of Environmental Conservation. Latham, NY.

Rignot, E. and Kanagaratnam, P., 2006. Changes in the velocity structure of the Greenland ice sheet. Science. 311, 986-990.

Roman, C. T., J. A. Peck, J. R. Allen, J. W. King, and P. G. Appleby. 1997. Accretion of a New England (U.S.A) salt marsh in response to inlet migration, storms, and sea level rise. Estuarine, Coastal and Shelf Science. 45(6):717-727.

Shepherd, A. and D. Wingham. 2007. Recent sea-level contributions of the Antarctic and Greenland ice sheets. Science. 315: 1529-1532.

Short, F., T. Carruthers, W. Dennison and M. Waycott. 2007. Global seagrass distribution and diversity: A bioregional model. Journal of Experimental Marine Biology and Ecology. 350 (1-2): 3-20.

Short, F. T., and D. M. Burdick. 2005. Interactive GIS-based, Site Selection Model for Eelgrass Restoration on CD-ROM. A Final Report Submitted to The NOAA/UNH Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET).

Slovinsky, P. A. and S. M. Dickson. 2006. Impacts of Future Sea Level Rise on the Coastal Floodplain. MGS Open-file 06-14. A report prepared by the Maine Geological Survey for the Maine Coastal Program/Maine State Planning Office pursuant to NOAA Award No. NA05NOS4191071.

Stanley, J. G., and R. DeWitt. 1983. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic) Hard Clam. U.S. Fish Wildl. Serv. FWS/OBS-82/11.18. U.S. Army Corps of Engineers, TR EL-82-4. 19 pp.

Stanley, J.G. and M.A. Sellers. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic) American oyster. U.S. Fish & Wildlife Service Biological Report 82(11.65). U.S. Army Corps of Engineers. TR EL-82-4. 25 pp.

Summerson, H.C. and C.H. Peterson. 1990. Recruitment failure of the Bay Scallop, *Argopecten irradians concentricus*, during the first red tide, *Ptychodiscus brevis*, outbreak recorded in North Carolina. Estuaries. 13: 322-331.

Teal, J. M. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology. 43:614-624.

Teal, J. M. and B. L. Howes. 2000. Salt Marsh Values: Retrospection from the end of the century. in Concepts and Controversies in Tidal Marsh Ecology (eds) M.P. Weinstein and D.A. Kreeger. Kluwer Academic Publishers. Dordrecht, The Netherlands. 9-19.

Thieler, E. R. and E. S. Hammer-Klose. 1999. Vulnerability to sea-level rise: preliminary results for the US Atlantic Coast. United States Geological Survey. Woods Hole, MA.

Thomas, R., E. Frederick, W. Krabill, S. Manizade, and C. Martin. 2006. Progressive increase in ice loss from Greenland. Geophysical Research Letters. 33, L10503, 4p.

Titus, J. G. and J. Wang. 2008. Maps of Lands close to Sea level along the Middle Atlantic Coast of the United States: an Elevation Data Set to use while waiting for LIDAR. Section1.1 in Background documents Supporting climate change Science Program Synthesis and Assessment product 4.1. J.G. Titus and E. M. Strange (eds.). EPA 430R07004.U.S. EPA, Washington, DC.

Titus, J.G., D.E. Hudgens, D.L. Trescott, M. Craghan, W.H. Nuckols, C. H. Herschner, J.M. Kassakian, C. J. Linn, P.G. Merritt, T.M. McCue, J.F. O'Connell, J. Tanski, and J. Wang. 2009. State and local governments plan for development of most land vulnerable to rising sea level along the US Atlantic coast. Environmental Research Letters. 4:1-7.

Titus, J. 1990. Greenhouse effect, sea level rise, and barrier islands: Case study of Long Beach Island, New Jersey. Coastal Management. 18:65-90.

Titus, J. G. and E. M. Strange, eds. 2008. Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1:Coastal Elevations and Sensitivity to Sea Level Rise. EPA 430R07004. U.S. EPA, Washington, DC.

Titus, J. G., R. Jones, and R. Streeter. 2008. Maps that depict site-specific scenarios for wetland accretion as sea level rises along the Mid-Atlantic coast. Section 2.2 in: Background documents supporting climate change science program synthesis and Assessment product 4.1, J.G. Titus and E.M. Strange (eds.). EPA 430R07004. USEPA, Washington, D.C.

Titus, J. G. R., A. Park, S. P. Leatherman, J. R. Weggel, M. S. Greene, P. W. Mausel, M. S. Trehan, S. Brown, C. Grant, and G. W. Yohe. 1991. Greenhouse effect and sea level rise: Loss of land and the cost of holding back the sea. Coastal Management. 19(2):171-204.

Tyrrell, M.C. 2005. Gulf of Maine Marine Habitat Primer. Gulf of. Maine Council on the Marine Environment, www.gulfofmaine.org.

UNEP. 2006. Marine and coastal ecosystems and human wellbeing: A synthesis report based on the findings of the Millennium Ecosystem Assessment. UNEP.

USFWS (United States Fish and Wildlife Service). 1977-2008. National Wetlands Inventory. Classification of Wetlands and Deepwater Habitats of the Coterminous United States. Washington, D.C. FWS/OBS-79/31 1:24,000. Vector digital data.

USCF (United States Commissioner of Fisheries). 1916. Annual report of the Commissioner of Fisheries to the Secretary of Commerce for the fiscal year ended June 30, 1916. Department of Commerce. Government Printing Office. Washington. 123 pp.

Valiela, I., J.M. Teal, and N.Y. Persson. 1976. Production and dynamics of experimentally enriched salt marsh vegetation: belowground biomass. Limnology and Oceanography. 21(2): 245-252.

Valiela, I., D. Rutecki, and S. Fox. 2004. Salt marshes: biological controls of food webs in a diminishing environment. Journal of Experimental Marine Biology and Ecology. 300(1-2): 131-159.

Velicogna, I. and J. Wahr. 2006a. Acceleration of Greenland ice mass loss in spring 2004. Nature. 443: 329-331.

Virginia Institute of Marine Science. 2009. Virginia oyster restoration atlas. http://web.vims.edu/mollusc/oyrestatlas/oraintro.htm. Accessed February 8, 2009.

Vinhateiro. 2008. Sea level Rise and Current Status of digital Terrain Data for the South Shore of Rhode Islands. A White Paper in Integrated Coastal Science prepared for the Coastal Resources Management Council. http://www.ci.uri.edu/ciip/WhitePaper/2008/Vinhateiro.pdf.

Wall, C. C., B. J. Peterson, and C. J. Gobler. 2008. The facilitation of seagrass *Zostera marina* productivity by suspension feeding bivalves. Marine Ecology Progress Series. 357:165-174.

Warren, R. S. and W. A. Niering. 1993. Vegetation change on a northeast tidal marsh: interaction of sea-level rise and marsh accretion. Ecology. 74 (1): 96-103.

Wazniak, C. E., M. R. Hall, T. J. B. Carruthers, B. Sturgis, W. C. Dennison, and R. J. Orth. 2007. Linking water quality to living resources in a Mid-Atlantic lagoon system, USA. Ecological Applications. 17: S64-S78.

Weisburg, S. B. and V. A. Lotrich. 1982. The importance of an infrequently flooded intertidal marsh surface as an energy source for the mummichog *Fundulus heteroclitus*: An experimental approach. Marine Biology. 66:307-310.

Wigley, T. M. L. 2005. The Climate Change Commitment. Science. 307: 1766-1769.

Wigley, R.L., and R.B. Theroux. 1981. Atlantic Continental Shelf and Slope of the United States- macrobenthic invertebrate fauna of the Middle Atlantic bight region- faunal composition and quantitative distribution. Department of the Interior. Geological Survey Professional Paper 529-N. United States Government Printing Office, Washington. 8

Wyda, J. C., L. A. Deegan, J. E. Hughes, and M. J. Weaver. 2002. The response of fishes to submerged aquatic vegetation complexity in two ecoregions of the mid-Atlantic bight: Buzzards Bay and Chesapeake Bay. Estuaries. 25: 86-100.

Yin, J., M. E. Schlesinger, and R. J. Stouffer. 2009. Model projections of rapid sea-level rise on the northeast coast of the United States. Nature Geoscience. 2: 262 – 266.

Young, A. 1846. Chronicles of the First Planters of the Colony of Massachusetts Bay, 1623-1636. C. C. Little and J. Brown (Original from Harvard University). 571 pp.

Zhang, K., B. C. Douglas, and S. P. Leatherman. 2004. Global Warming and Coastal Erosion. Climate Change. 64: 41-58.

CHAPTER

3

Benthic Habitats

Mark Anderson, Jennifer Greene, Dan Morse, Caroly Shumway, and Melissa Clark

Introduction

Benthic organisms are those that inhabit the ocean floor; from the Greek word benthos, meaning "depths of the sea." Living in soft substrates and feeding on plankton and organic debris, individual species are adapted to variations in light, depth, sediment size, temperature, and salinity. They are so well adapted to their environment that 15 entire phyla are exclusively marine (echinoderms, comb jellies, lampshells etc.) with no terrestrial counterparts (Norse 1993). Moreover, unlike the terrestrial world where three quarters of all diversity is contained in a single phylum (arthropods), the ocean contains almost the entire range of earth's body plans.

The seafloor habitats of the Northwest Atlantic reflect this immense diversity, containing over 2000 species in 13 phyla including:

- 662 species of arthropods (crabs, lobsters, shrimp, barnacles)
- 650 species of mollusks (clams, scallops, squid, limpets, sea slugs, snails)
- 547 species of annelids (sea worms)
- 195 species of echinoderms (sea stars, sea urchins, sea cucumbers, sand dollars)
- 141 species of bryozoans (crusts, bryozoans)
- 58 species of cnidarians (corals, anemones, jellyfish)
- 29 species of sipunculas (peanut worms)
- 21 species of chordates (sea squirts)
- 6 species of poriferans (sponges)
- 3 species of chaetognathans (arrow worms)
- 2 species of brachiopods (lamp shells)
- 1 species of nemerteans (ribbon worms)
- 1 species of ctenophores (comb jellies)

The distributions and life histories of benthic organisms are tied to their physical environment. Filter feeders, like sponges and mussels, strain suspended matter directly from the water column, and tend to dominate on shallow sandy bottoms. Deposit feeders, like terebellid worms, sift soil for detritus and may dominate in fine-grained mud. Mobile species such as sea stars, crabs, and snails scavenge in the habitats of their prey. It is these "habitats" that we aimed to identify, characterize, and map.

This chapter represents an initial effort to define and map marine benthic habitats using information on organism distributions combined with interpolated data on bathymetry, sediment grain size, and seafloor topography. The goal was to produce a regional map of broadly-defined, but distinct, seafloor habitats using a consistent and repeatable methodology. This work is ongoing and updated reports will be produced as the research matures. A team of scientists familiar with benthic classification served as a peer review team for this project and their comments have greatly improved this work. Comments on the methods and preliminary results were collected via meetings, individual and group phone calls, and in written edits. *Please note that critical steps of accuracy assessment, cross-validation using independent datasets, comparisons with demersal fish habitat, and final expert peer review are ongoing*

Technical Teams Members

Mark Anderson, Ph.D., The Nature Conservancy, Eastern Division
Matthew Arsenault, United States Geological Survey
Melissa Clark, The Nature Conservancy, Eastern Division
Zach Ferdana, The Nature Conservancy, Global Marine Initiative
Kathryn Ford, Ph.D., Massachusetts Division of Marine Fisheries
Jennifer Greene, The Nature Conservancy, Eastern Division
Ray Grizzle, Ph.D., University of New Hampshire
Les Kaufman, Ph.D., Boston University
Caroly Shumway, Ph.D., Boston University
Page Valentine, Ph.D., United States Geological Survey

Definition of Target Habitats

The goal of this work was to identify all of the benthic habitat types in the Northwest Atlantic and map their extent. We defined a benthic habitat as a group of organisms repeatedly found together within a specific environmental setting. For example, silt flats in shallow water typified by a specific suite of amphipods, clams, whelks and snails is one habitat, while steep canyons in deep water inhabited by hard corals is another. Conservation of these habitats is necessary to protect the full diversity of species that inhabit the seafloor, and to maintain the ecosystem functions of benthic communities.

Methods

To design a conservation plan for benthic diversity in the Northwest Atlantic, it is essential to have some understanding of the extent and location of various benthic habitats (e.g. a map). Fortunately, the challenge of mapping seafloor habitats has produced an extensive body of research (see Kostylev et al. 2001; Green et al. 2005; Auster 2006; World Wildlife Fund 2006; Todd and Greene 2008). In addition, comprehensive seafloor classification schemes have been proposed by many authors (see Dethier 1992; Brown 1993, European Environmental Agency 1999; Greene et al. 1999; Allee et al. 2000; Brown 2002; Conner et al 2004; Davies et al. 2004; Greene et al. 2005; Madden et al. 2009; Valentine et al. 2005; Kutcher 2006; and see reviews in National Estuarine Research Reserve System 2000 and Lund and Wilbur 2007).

Initially, we reviewed the literature on seafloor classification, and examined the variety of approaches already utilized in order to develop our methodology (Table 3-1). Many of the existing schemes base their classifications on physical factors such as bathymetry, sediment grain size, sediment texture, salinity, bottom temperature, and topographic features. This is logical as there is ample evidence that benthic distribution patterns are associated with many of these variables. For example, temperature is correlated with the community composition of benthic macroinvertebrates (Theroux and Wigley 1998); substrate type is correlated with community composition and abundance of both the invertebrates and demersal fish (Auster et al. 2001; Stevenson et al. 2004); habitat complexity is correlated with species composition, diversity, and richness (Etter and Grassle 1992; Kostylev et al. 2001; Serrano and Preciado 2007, reviews in Levin et al. 2001); and depth is correlated with abundance, richness, and community composition (Stevenson et al. 2004).

The approach presented here builds on existing schemes both explicitly and implicitly, and results can be readily compared to them. However, the goal of this assessment was to produce a map of broadly-defined benthic habitats in the Northwest Atlantic using readily available information. Therefore, a new classification system for benthic systems in general is not proposed here.

Table 3-1. A review of literature on seafloor classification and approaches utilized to develop our methodology.

Physical/Biological Variables	Ecological associations	Species	Data type/Comments	References
Temperature: annual temperature range	community composition	benthic macroinvertebrates		Theroux and Wigley 1998
Substrate type	species abundance	demersal fish and	benthic grabs; correlational analyses done separately for each group	Stevenson et al. 2004
	community composition	benthic macroinvertebrates		
	abundance	juvenile Atlantic cod	benthic grabs/submersible transects	Lough et al. 1989
	community composition	demersal fish	bottom trawls	Auster et al. 2001
		benthic macroinvertebrates	benthic grabs	Wigley and Theroux 1981
Habitat complexity	species abundance	demersal fish	video transects	Anderson and Yoklavich 2007
	community composition			
	species diversity	benthic macroinvertebrates	benthic grabs/photographs	Kostylev et al. 2001
			quadrat surveys; habitat complexity at fine scale – sediment heterogeneity	Serrano and Preciado 2007
			literature review	Levin et al. 2001
			benthic grabs	Etter and Grassle 1992
	juvenile survival rate	Atlantic cod	laboratory experiments	Lindholm et al. 1999
	species richness	demersal fish	visual surveys	Charton and Perez Ruzafa 1998
	total abundance			
Depth	organism density and community composition	benthic macroinvertebrates and demersal fish	benthic grabs; correlational analyses done separately for each group	Stevenson et al. 2004
Combination				
Depth + temperature	species assemblages	demersal fish	bottom trawl	Mahon et al. 1998
Depth + temperature + substrate (sediment) type	species abundance	Atlantic Cod; winter flounder; yellowtail flounder	bottom trawl; single species assessments	DeLong and Collie 2004
Depth (fixed) + substrate + bottom temperature + bottom salinity	benthic 'seascapes'	abiotic; no statistical correlational analyses performed with trawl data	abiotic; to 200 m only; Gulf of Maine, Georges Bank, Scotian shelf; depth was fixed at certain intervals	WWF/CLF 2006

Table 3-1 (continued). A review of literature on seafloor classification and approaches utilized to develop our methodology.

Physical/Biological Variables	Ecological associations	Species	Data type/Comments	References
Principal Component Analysis				
PC1: SST, thermal gradients, stratification, chlorophyll	species abundance and richness	pelagic (nekton) and benthic	bottom trawl; research survey trawls; bongo nets (for nekton); principal components combine physical and biological variables	Fogarty and Keith 2007
PC2: depth, primary production, chlorophyll, zooplankton, biomass, benthic biomass				
PC3: substrate type, nekton species richness				
PC4: nekton biomass				
PC5: benthic biomass				
PC6: nekton species richnes				

Biological Factors: Benthic Organisms

The map of benthic habitats presented here is based on the distribution and abundance of benthic organisms in the Northwest Atlantic. The knowledge of these species and their distributions comes largely from seafloor grab samples described below. In the analysis of this data, groups of species with shared distribution patterns were identified, then thresholds in the physical factors were identified that correlated with those patterns. Specifically, three basic steps were followed: 1) quantitative analysis of the grab samples to identify distinct and reoccurring assemblages of benthic organisms, 2) recursive partitioning to relate the species assemblages to physical factors (bathymetry, sediment types, and seabed topographic forms), and 3) mapping the habitats based on the statistical relationships between the organism groups and the distribution of the physical factors. Although organism distributions were used to identify meaningful thresholds and cutoffs in the physical variables, the final habitat maps are composed solely of combinations of enduring physical factors and are thus closely related to the maps and classification schemes proposed by others.

This study was made possible by access to over forty years of benthic sampling data by the National Marine Fisheries Service's (NMFS) Northeast Fisheries Science Center (NEFSC). The NEFSC conducted a quantitative survey of macrobenthic invertebrate fauna from the mid 1950s to the early 1990s across the region (Figure 3-1, Table 3-2). Each year, samples of the seafloor were systematically taken during 25+ individual cruises by five or more research vessels using benthic grab samplers designed to collect 0.1 to 0.6m^2 of benthic sediments. In total, over 22,000 samples were collected. Organisms collected in each sample were sorted and identified to species, genus, or family, and information on the sediment sizes, depth, and other associated features were recorded for each sample. A thorough discussion of the sampling methodology, gear types, history, and an analysis of the benthic dataset, including the distribution and ecology of the organisms, can be found in the publications of Wigley and Theroux (1981 and 1998). Recently, new video and remote sensing technologies have arisen to directly assess the seafloor and supplement the sample data (Kostylev et al. 2001). In future iterations of the assessment, we hope to integrate data collected using these new methods.

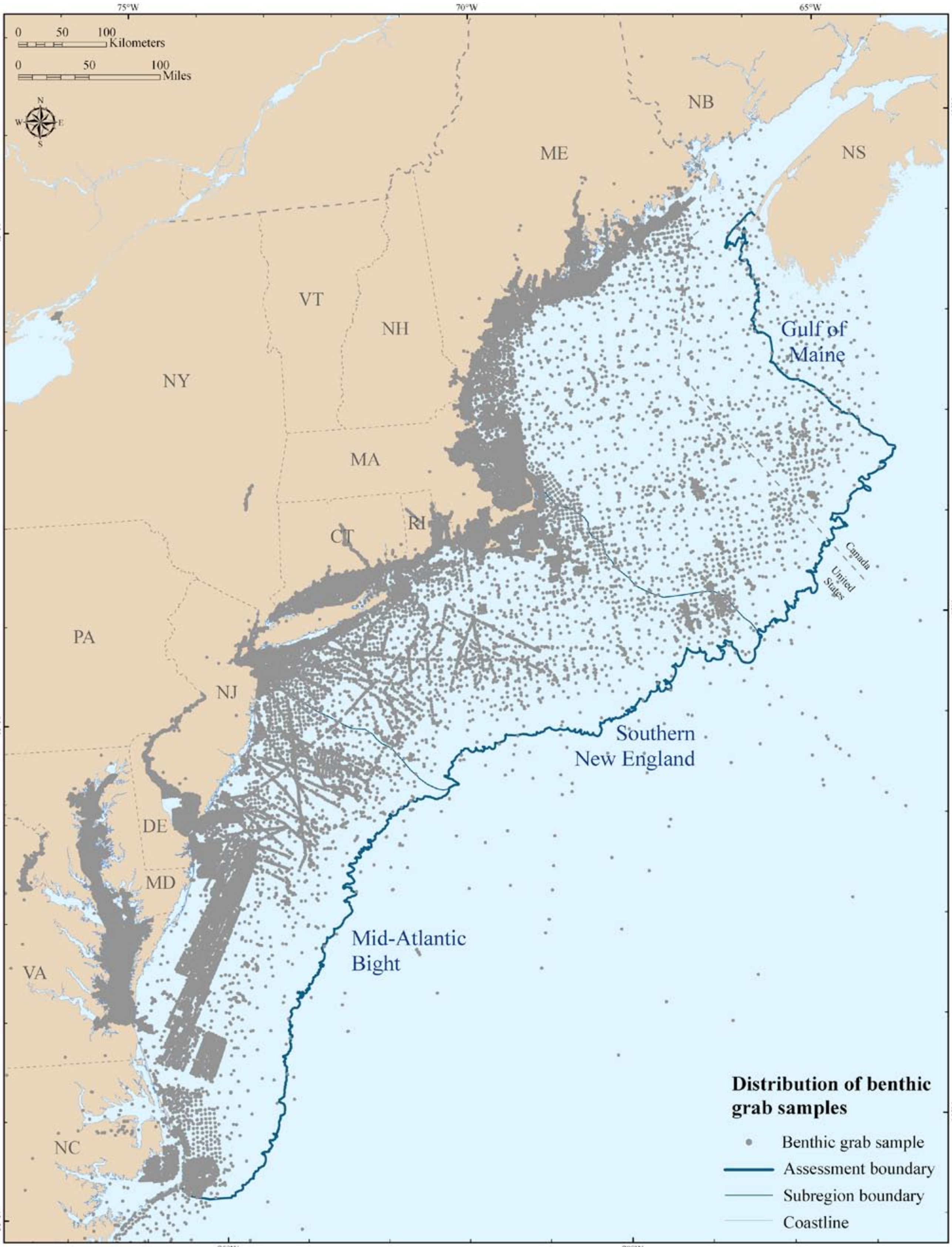


Figure 3-1. Distribution of the 11,132 benthic grab samples.

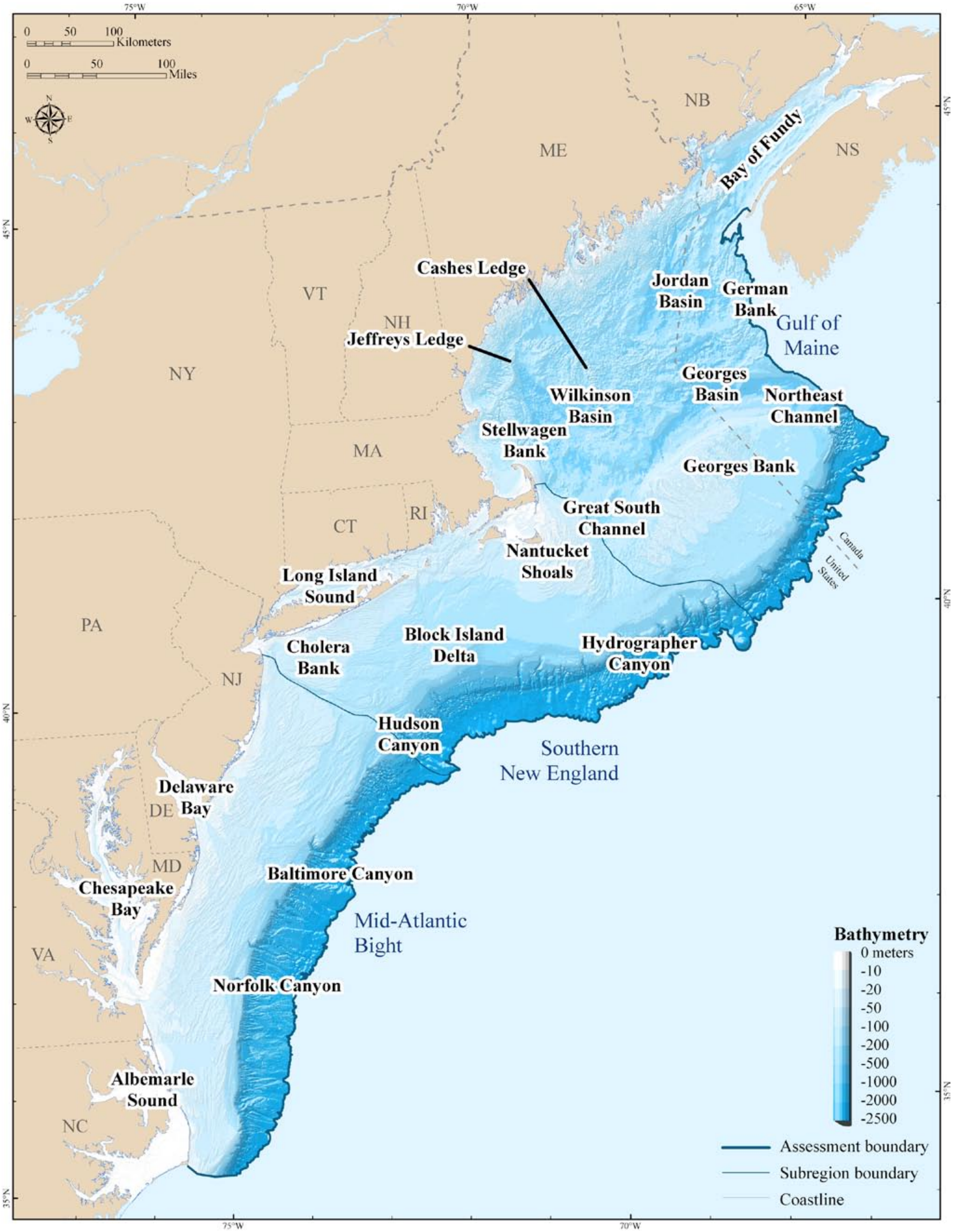


Figure 3-2. Geography of the region showing the three subregions.

Table 3-2. Distribution of the benthic grab samples by decade and subregion.

Decade	Gulf of Maine	Southern New England	Mid-Atlantic	Outside of region	Grand Total
Pre-1950	38	33	2	1	74
1950s	2,150	660	61	164	3,035
1960s	4,146	2,693	857	669	8,365
1970s	188	3,770	1,166	4	5,128
1980s	637	3,681	1,535	1	5,854
1990s			25		25
Total	7,159	10,837	3,646	839	22,481

Classification Methods

Classification analysis began with the entire 22,481 seafloor samples taken between 1881 and 1992. However, only about half of the samples contained information on the full composition or the sample identified to species, and it is that subset of 11,132 samples that is used in this analysis. Initially, two separate classifications were created - one based on genera and one based on species as a way of including more samples in the analysis. However, because the species level classification showed a stronger relationship with the physical factors, this level of taxonomy was used. Organisms in the samples that were identified only to family or order were omitted from the dataset, as were fish, plants, egg masses, and organic debris.

Separate classifications were created for each of the three subregions: the Gulf of Maine, Southern New England, and the Mid-Atlantic Bight (Figure 3-2). For each, samples with similar species composition and abundance were grouped together using hierarchical cluster analysis (PCORD, McCune and Grace 2002). This technique starts with pairwise contrasts of every sample combination then aggregates the pairs most similar in species composition into a cluster. Next, it repeats the pairwise contrasts, treating the clusters as if they were single samples, and joins the next most similar sample to the existing clusters. The process is repeated until all samples are assigned to one of the many clusters. For our analysis, the Sorenson similarity index and the flexible beta linkage technique with Beta set at 25 was used as the basis for measuring similarity (McCune and Grace 2002). After grouping the samples, indicator species analysis was used to identify those species that were faithful and exclusive to each organism group (Dufrene and Legrande 1997). Lastly, Monte Carlo tests of significance were run for each species relative to the organism groups to identify diagnostic species for each group using the criterion of a p-value less than or equal to 0.10 (90% probability). The number of sets of clusters (testing 10 to 40) was determined by seeing which amount gave the lowest average p-value. The test concluded that 20-22 organism groups for each subregion yielded the lowest p-value.

Physical Factors: Bathymetry, Substrate and Seabed Forms

To understand how the benthic invertebrate community distributions related to the distribution of physical factors, a spatially comprehensive data layer for each factor of interest was developed. Four aspects of seafloor structure were used: bathymetry, sediment grain size, topographic forms, and habitat complexity. These factors were chosen as they are both correlated with the distribution and abundance of benthic organisms (Table 3-1) and are relatively stable over time and space. Variables that fluctuate markedly over time were purposely avoided, such as temperature and salinity. Data on each physical factor were compiled from separate sources and the techniques used to create a comprehensive map are discussed below.

Bathymetry

A comprehensive bathymetry grid was created to characterize depths across the region, to uncover organisms' depth preferences, and to create seabed topographic forms (Figure 3). The primary dataset used for mapping bathymetry was National Geographic Data Center's Coastal Relief Model (CRM). The CRM is a "gridded" bathymetric surface (similar to an architect's site model) generated from soundings of the Continental Shelf and slope. The soundings are from hydrographic surveys completed between 1851 and 1965, from survey data acquired digitally on National Ocean Service (NOS) survey vessels since 1965, and are stored in the NOS Hydrographic Database. The CRM was prepared in a GIS format with the value for each 82m cell representing the depth of that cell. In some areas, however (particularly east of the Hudson Canyon), the dataset showed distinct artifacts of interpolation, with the resulting surface stretched into a taut plane marked with peaks and valleys at survey locations where actual depths were taken. In these places, data was augmented with insets from NOS Bathymetric and Fishing Maps (BFM). The BFM contours were drawn by hand, by cartographers interpreting topography from soundings, and provide a more credible topography in some of the problematic sections of the CRM. It should be noted that a considerable data gap exists off the coast of North Carolina and is reflected as an area of "no data" in subsequent analyses that rely on bathymetry (e.g., seabed forms, ecological marine units, benthic habitats).

The Canadian portion of the region, including the Bay of Fundy, was covered by United States Geological Survey's (USGS) Gulf of Maine 15' Bathymetry (Roworth and Signell 1998). Because the spatial resolution of this layer (~350 meter cell size) is coarser than the CRM (~82 m cell size), it was used only to fill in areas north of the Hague line and in a section of eastern Georges Bank. A fringe from the CRM was removed where data had been inferred up to 9 km beyond actual soundings.

Seafloor Substrates: Soft Sediments and Hard Bottoms
Substrate data for the entire United States portion of the region was obtained from usSEABED, an innovative system that brings assorted numeric and descriptive sediment data together in a unified database (Reid et al. 2005). The information includes textural, geophysical, and compositional characteristic of points collected from the seafloor, and is spatially explicit. The data coverage extends seaward across the Continental Shelf and slope, and combines more than 150 different data sources containing over 200,000 data points for the Atlantic seaboard. A unique feature of the database is its use of data mining and processing software to extend the coverage of information in areas where data coverage is more descriptive than quantitative (details in Reid et al. 2005).

Initially, two standard sediment classification schemes were experimented with - Shepard (1954) and Folk (1954) - that classify sediment types by their principal component (e.g. sand) and secondary components (e.g. muddy sand). Ultimately, the average grain size of each sample was used, which was recorded for almost every data point. To create a map of soft sediments for the region, points were removed from the dataset that were coded as hard bottoms ("0" in ave. grain size, and "solid" in the texture field). Then, interpolations were generated from the remaining sediment points that ranged from 0.001 mm clays to 9 mm gravels in average size (Table 3-3).

Interpolating this dataset - estimating the average grain size for areas between the sample points - was problematic because there was very little spatial autocorrelation in the average grain size of each point (Gearey's C = 0.034, $p<0.01$). In other words, nearby points were not necessarily more likely to have a similar grain size. Moreover, the density of data differed greatly across the region: sample points were considerably sparser in deep water areas. To account for this, a Voronoi map was generated to display spatial patterns and attribute benthic grab sample points with sediment information from the closest usSEABED point. A Voronoi analysis creates a cell around each data point such that all space within the cell is closer to the central point than to any other data point (Figure 3-4 and

Figure 3-3. Bathymetry map of the region derived from various sources.

Table 3-3. Grain size and sediment class names (Wentworth 1922).

Grain Size (mm)		Class	Grain Size (mm)		Class
0	0.001	Fine clay	0.25	0.5	Medium sand
0.001	0.002	Medium clay	0.5	1	Coarse sand
0.002	0.004	Coarse clay	1	2	Very coarse sand
0.004	0.008	Very fine silt	2	4	Very fine pebbles (granules)
0.008	0.016	Fine silt	4	8	Fine pebbles
0.016	0.031	Medium silt	8	16	Medium pebbles
0.031	0.063	Coarse silt	16	32	Coarse pebbles
0.063	0.125	Very fine sand	32	86	Very coarse pebbles to cobbles
0.125	0.25	Fine sand			

3-5). Next, the explanatory power of the closest sediment point in differentiating among the organism groups was tested using the partitioning methods described below. This allowed comparison of the various interpolation techniques by contrasting the results with the results of the closest point attributes and measuring the improvement, or lack of improvement, in explanatory power. In addition, the correlation between each interpolation method and the raw Voronoi output was determined, assuming that results that were highly uncorrelated with the Voronoi map were probably distorting the data.

After considerable experimentation, the following interpolation parameters were used: ordinary kriging, spherical semivariogram, variable search radius type using three points with no maximum distance, and output cell size of 500 meters. This method had the strongest correlation with the Voronoi map, and had the highest explanatory power for differentiating the organism groups. Moreover, kriging provides consistent results across areas that have been sparsely and densely sampled. Visually, the kriging interpolation resembled the Voronoi map, but with smoother surfaces and more realistic looking shapes (Figure 3-6).

A separate dataset of hard bottom locations was created from the points coded as "solid" in the usSeabed dataset. The dataset was supplemented by adding points coded as "solid" from the NMFS bottom trawl survey (see Chapter 5 for description of this database). Thus, the final sediment map consisted of the interpolated soft sediment points overlaid with the hard bottom locations (Figure 3-7).

Soft sediment diversity was mapped at a 10 km scale by superimposing a 10 km unit around each map cell and calculating the number of grain size classes within the unit's area. Each cell was scored with the results creating a visually seamless surface (Figure 3-8). Ideally, mapping sediment diversity helps identify *ecotonal benthic areas,* the transition area between two different habitats, where which demersal fish are known to favor (Kaufman, personal communication). However, these results were sensitive to the huge variations in data density across the region and were not used in the predictive models.

Seabed Topographic Forms

This region is characterized by a complexity of banks, basins, ledges, shoals, trenches, and channels in the north, shoals and deltas to the south, and deep canyons along the

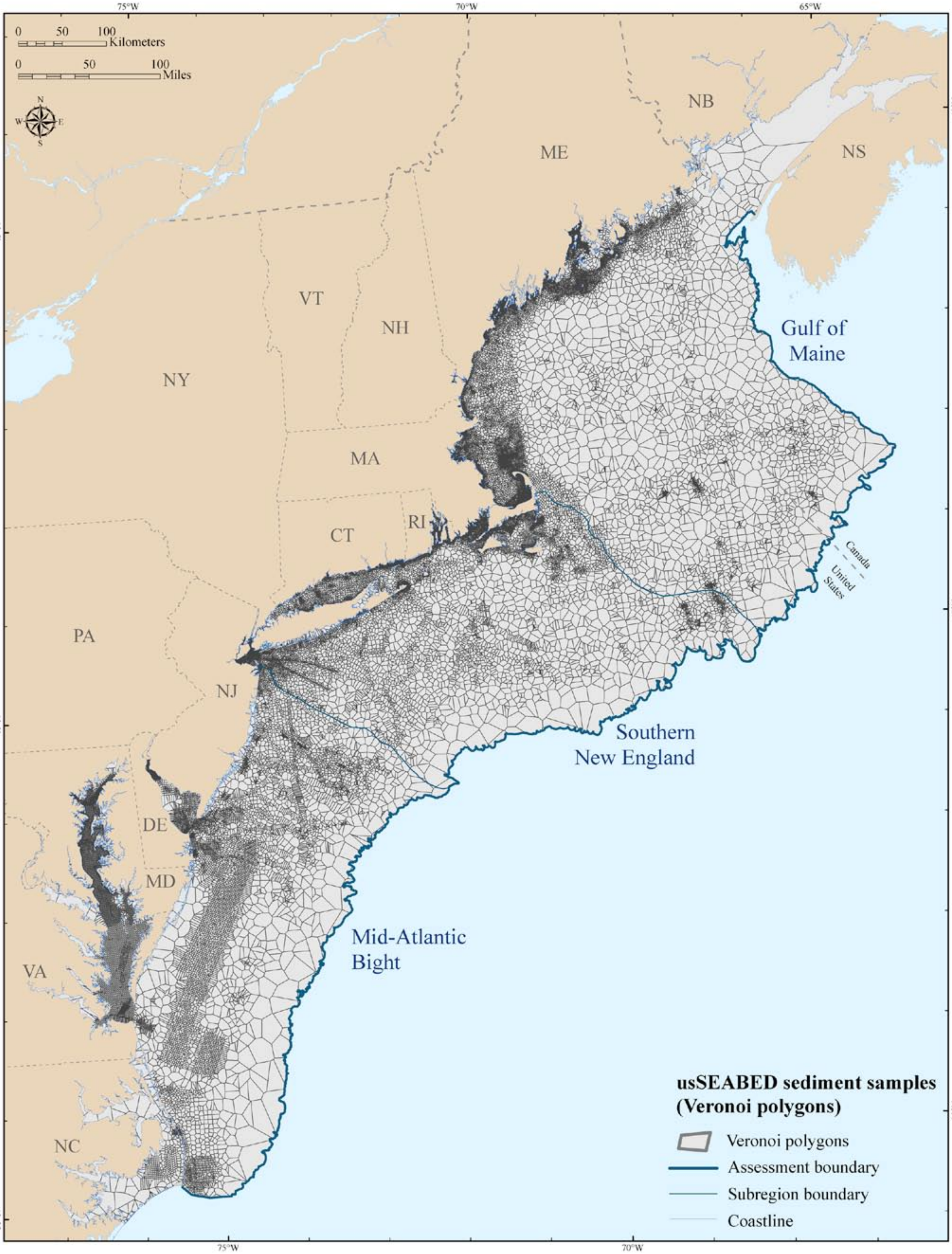


Figure 3-4. Voronoi map of the usSEABED database, showing the distance between samples.

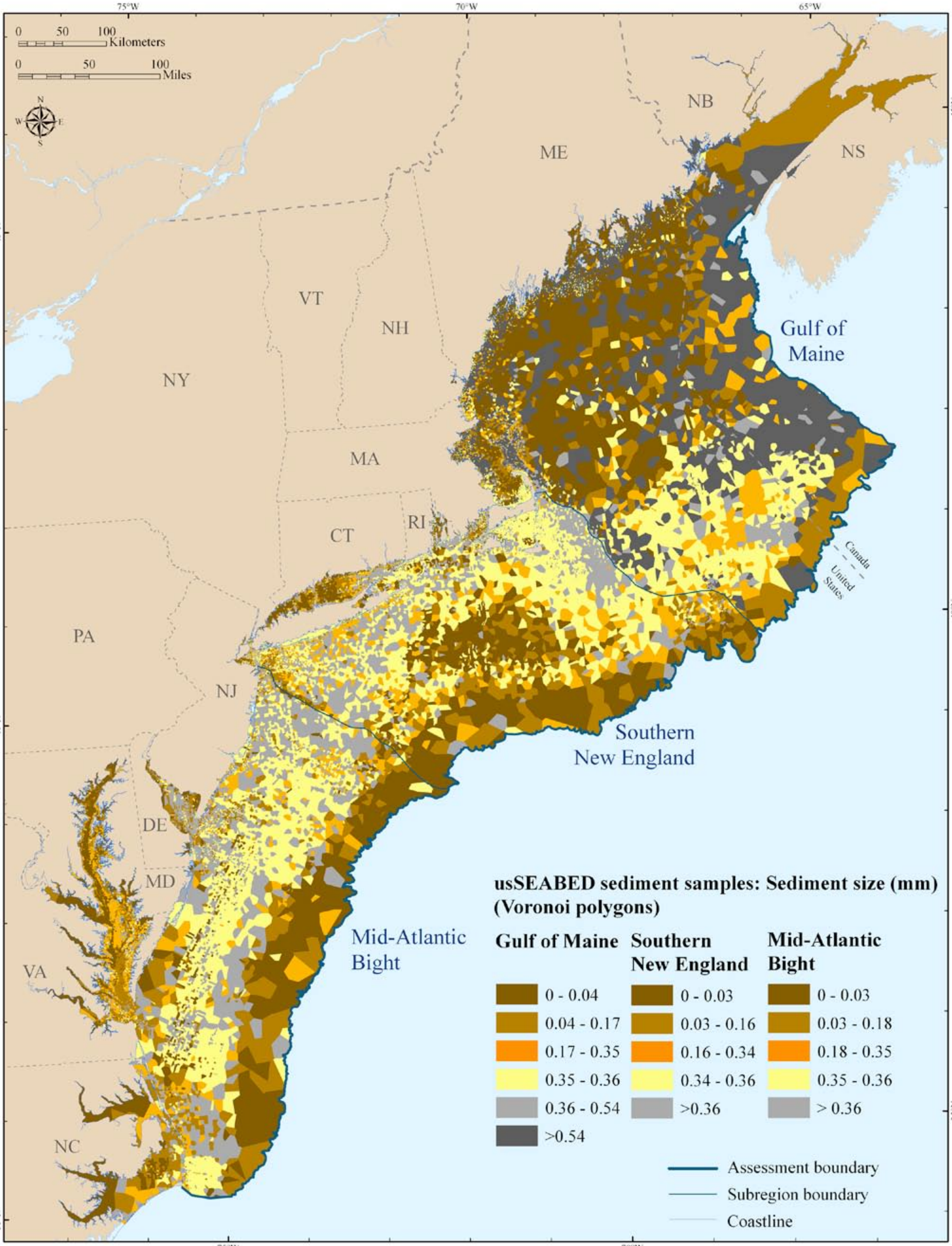


Figure 3-5. Voronoi map of the usSEABED database, showing sediment grain size.

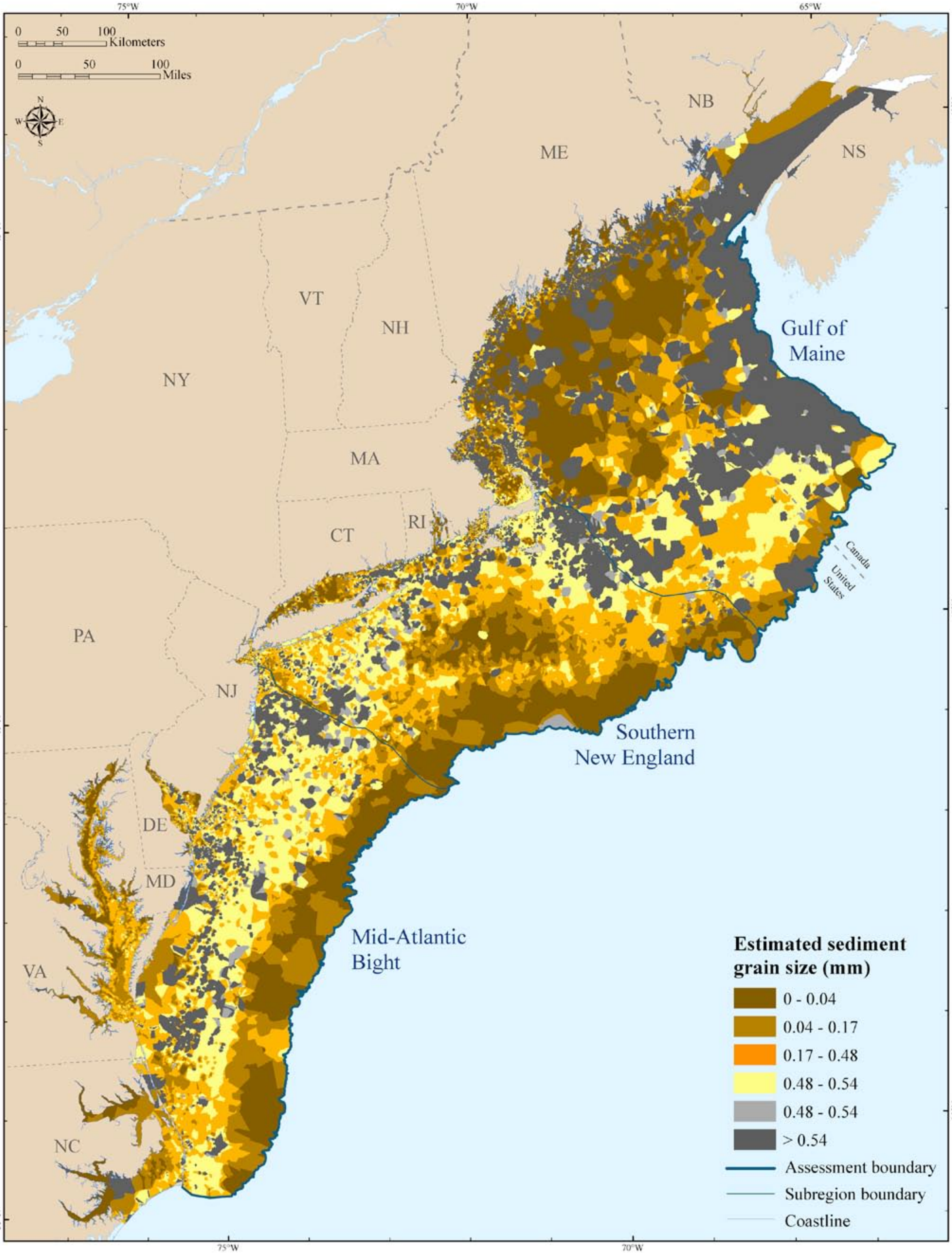


Figure 3-6. Interpolated map of soft sediments.

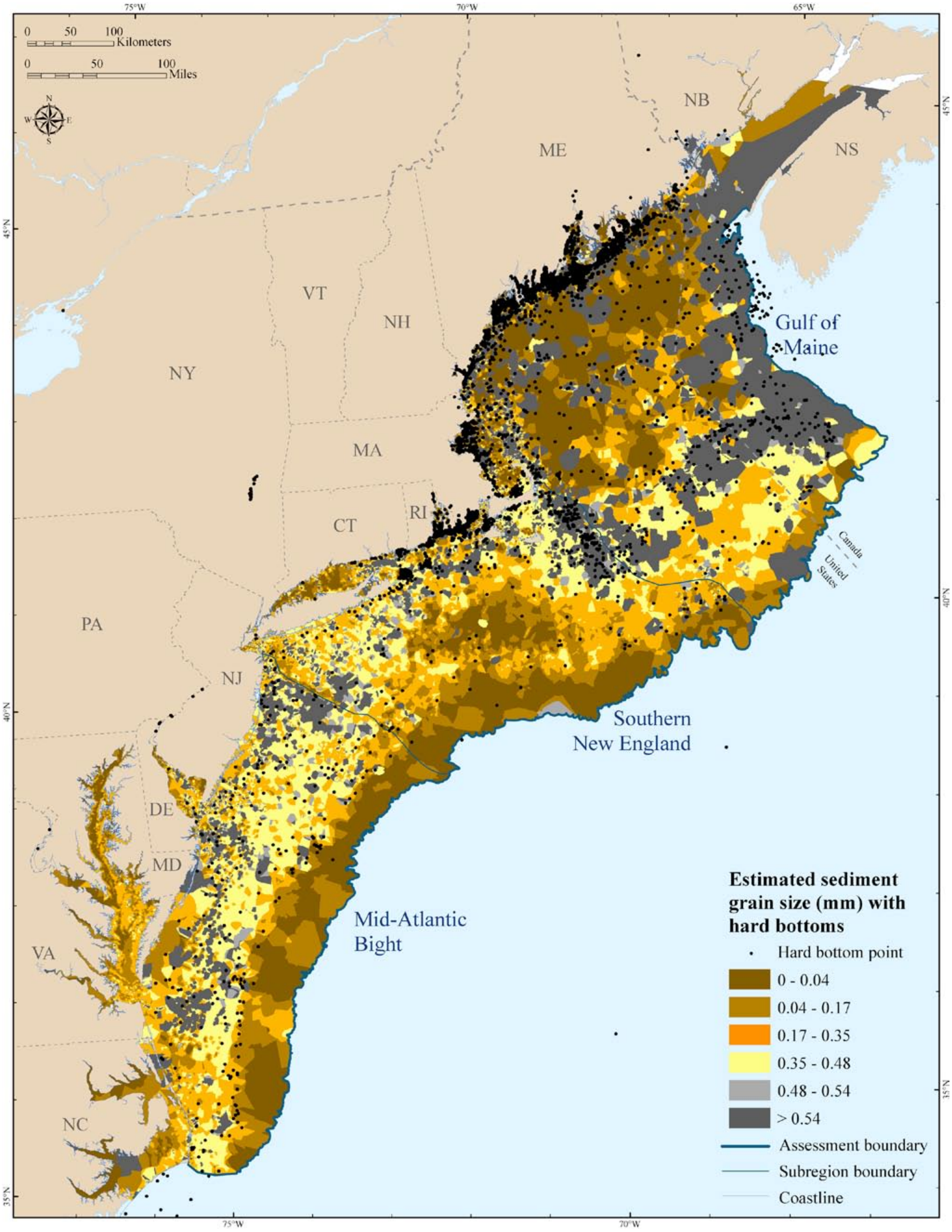


Figure 3-7. Hard bottom points overlaid on the soft sediment interpolation.

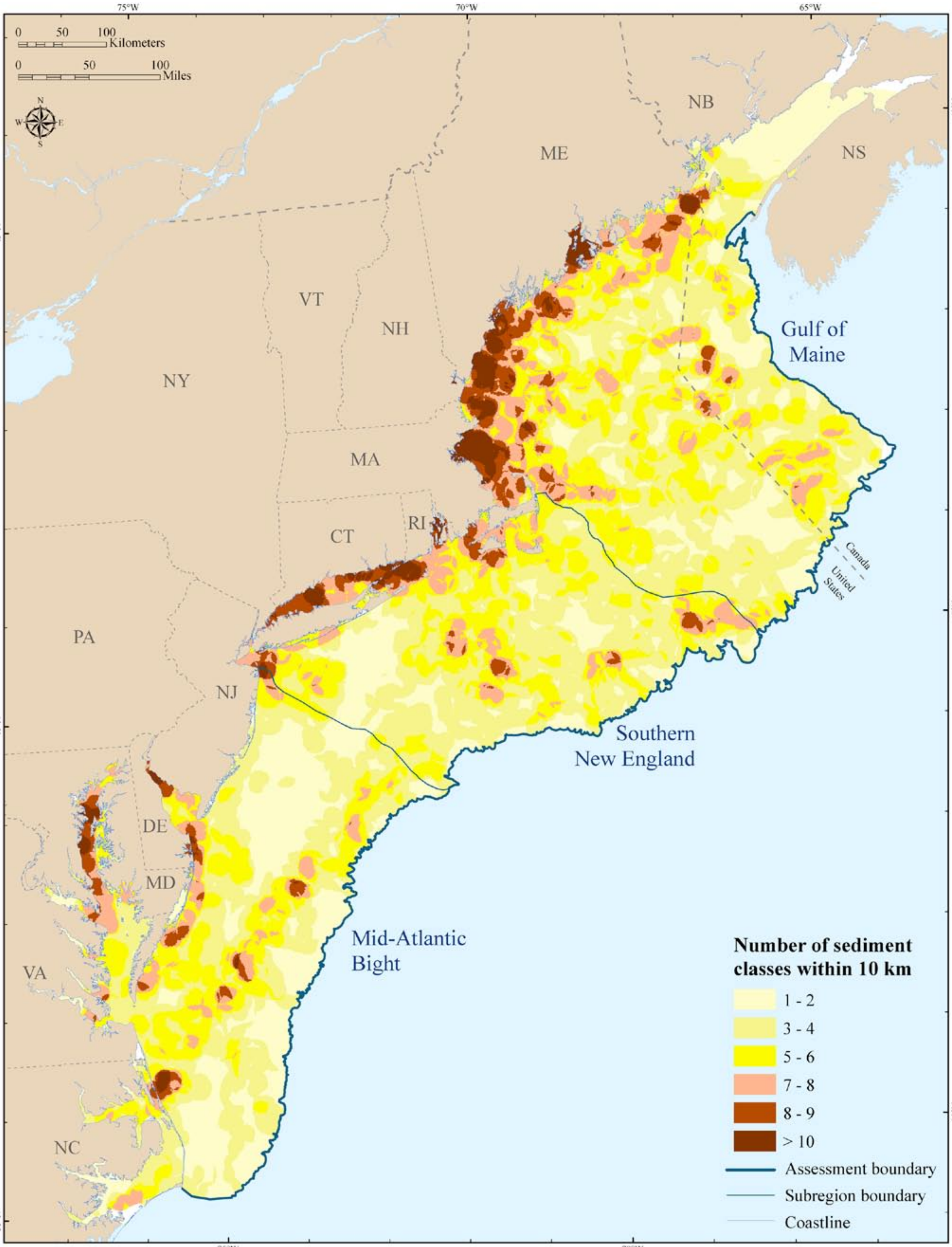


Figure 3-8. Map of sediment diversity using a 10 k focal window.

Continental Shelf (Figure 3-2). These features have a large influence on oceanic processes, and on the distribution of benthic habitats. With this in mind, the seabed form data layer was developed to characterize seafloor topography in a systematic and categorical way, relevant to the scale of benthic habitats. The units that emerge from this analysis, from high flats to depressions, represent depositional and erosional environments that typically differ in fluvial processes, sediments, and organism composition (Wigley and Theroux 1981).

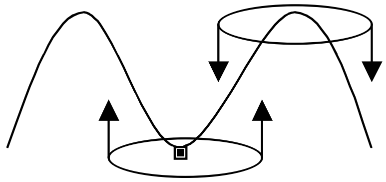
Seabed topographic forms were created from relative position and degree of slope of each seafloor cell. Seabed position (or topographic position) describes the topography of the area surrounding a particular 82 m cell. Calculations were based on the methods of Fels and Zobel (1995) that evaluate the elevation differences between any cell and the surrounding cells within a specified distance. For example, if the model cell is, on average, higher than the surrounding cells, then it is considered to be closer to the ridge top (a more positive seabed position value). Conversely, if the model cell is, on average, lower than the surrounding cells then it is considered closer to the slope bottom (a more negative seabed position value).

The relative position value is the mean of the distance-weighted elevation differences between a given point and all other model points within a specified search radius. The search radius was set at 100 cells after examining the effects of various radii. Position was grouped into six classes that were later simplified to three classes:

1) Very low	Low
2) Low	Low
3) Lower mid	Mid
4) Upper mid	Mid
5) High	High
6) Very high	High

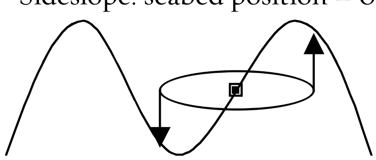
The following diagrams illustrate the seabed position index values along slopes:

Ridge: seabed position = positive value



Slope Bottom: seabed position = negative value

Sideslope: seabed position = 0



Flat: seabed position = 0

The second element of the seabed forms, degree of slope, was used to differentiate between steep canyons and flat depressions. Slope was calculated as the difference in elevation between two neighboring raster cells, expressed in degrees. After examining the distribution of slopes across the region, slopes were grouped according to the following thresholds:

1) 0° - 0.015°	Level flat
2) 0.015° - 0.05°	Flat
3) 0.05° - 0.8°	Gentle slope
4) 0.8° - 8.0°	Slope
6) >8.0°	Steep slope (includes canyons)

The cutoffs might be misleading if interpreted too literally, For example, there are very few locations on the Continental Shelf with slopes in the category >8° and most of these correspond to canyon walls reported as 35-45° slope by divers. The discrepancies are due to the cell size (82 m) of the analysis unit that averages slope over a larger area.

Table 3-4. Seabed forms showing position and slope combinations. For example, code 11 = Very low + Level flat = Low flat.

		Slope				
		Level flat	Flat	Gentle slope	Slope	Steep slope
Position	Very low	depression	depression	low slope	low slope	steep
	Low	depression	depression	low slope	low slope	steep
	Lower mid	mid flat	mid flat	sideslope	sideslope	steep
	Upper mid	mid flat	mid flat	sideslope	sideslope	steep
	High	high flat	high flat	high slope	high slope	steep
	Very high	high flat	high flat	high slope	high slope	steep

Slope and relative position were combined to create 30 possible seabed forms ranging from high flat banks to low level bottoms to steep canyons. Initially, all 30 types were used in the analysis of organism relationships, but results suggested that they could be simplified while maintaining, or improving, their explanatory power. Therefore, the analysis was simplified into the following six categories: 1) depression, 2) mid flat, 3) high flat, 4) low slope, 5) high slope,6) sideslope, and 7) steep (Table 3-4).

Small errors in the bathymetry grid were bypassed by identifying very small-scale variations in depth. Generalization tools were used to clean up small scale variations in the dataset. This eliminated thousands of "dimples" present in the CRM bathymetry without having to edit the original grid.

Each individual cell was assigned to a unique seabed form and often groups of forms cluster to define a larger scale topographic unit such as Jeffreys Ledge or Georges Bank (Figure 3-9). Depressions and mid position flats represent the broad plains common in Southern New England, steep areas identify the canyons of the continental slope, and highest position sideslopes occur on the cusp of the shelf-slope break.

Habitat Complexity: Standard Deviation of the Slope

In addition to the categorical analysis of topography for the seabed forms, habitat complexity was assessed using the standard deviation of slope. Using the bathymetry grid, "floating window" analyses of the standard deviation of the slope were conducted within a 500 m, 1 km, and 10 km search radii. To calculate the standard deviation of the slope, the slope for each cell was calculated using the GIS slope command (3 x 3 cell neighborhood). Next, the range was divided into ten equal interval classes and the mean and standard deviation of the cells within each search radius were calculated (Figure 3-10). The search radius matters because the importance of any given spatial feature depends on its size relative to the species of interest. The 1 km analysis had the greatest explanatory power for differentiating between the benthic organism groups.

Linking the Organisms to Physical Factors

Recursive partitioning (JMP software package) was used to uncover relationships between benthic communities and the physical environment. Recursive partitioning is a statistical method that creates decision trees to classify members of a common population (the classification types) based on a set of dependent variables (the physical

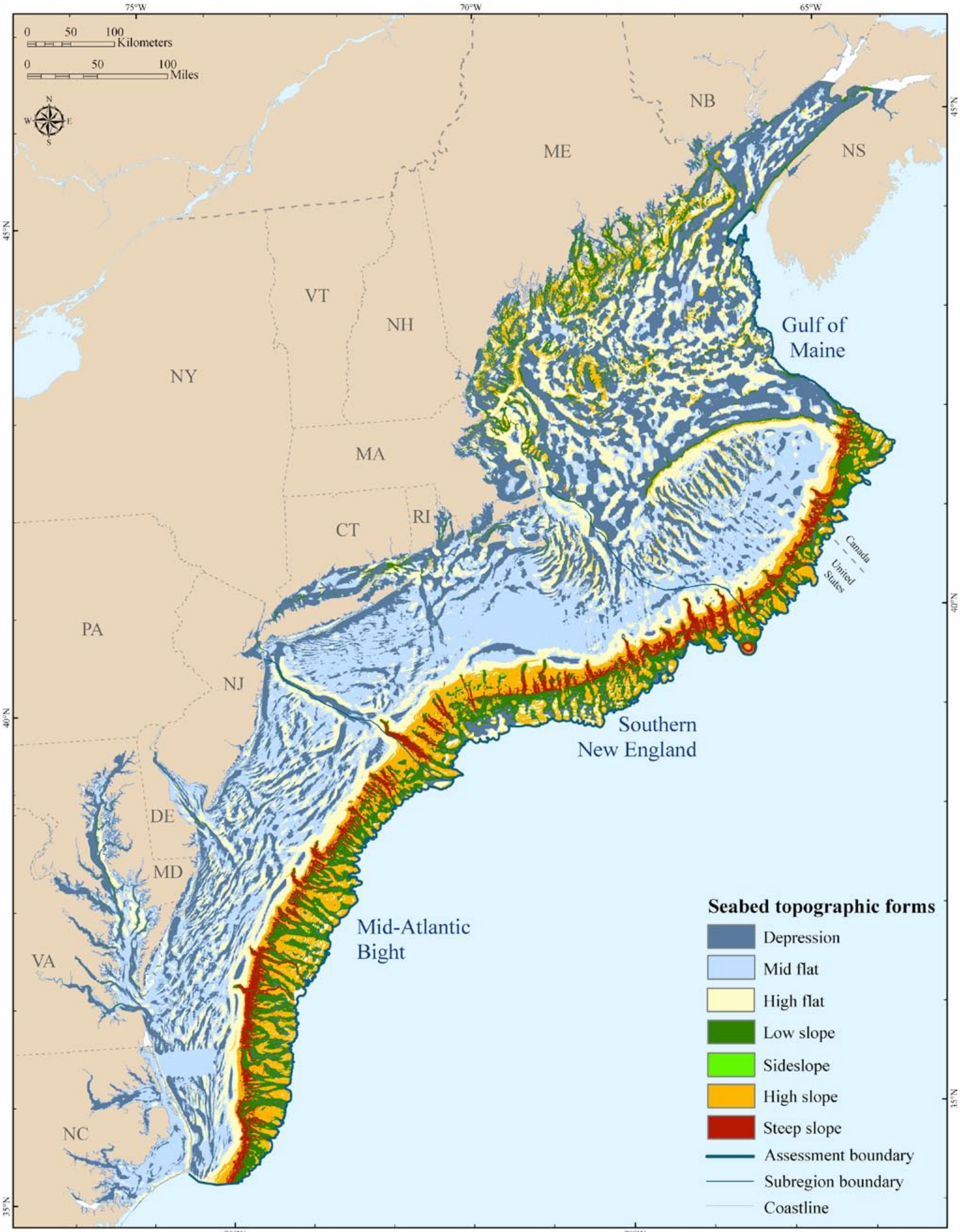


Figure 3-9. Map of the seabed topographic forms.

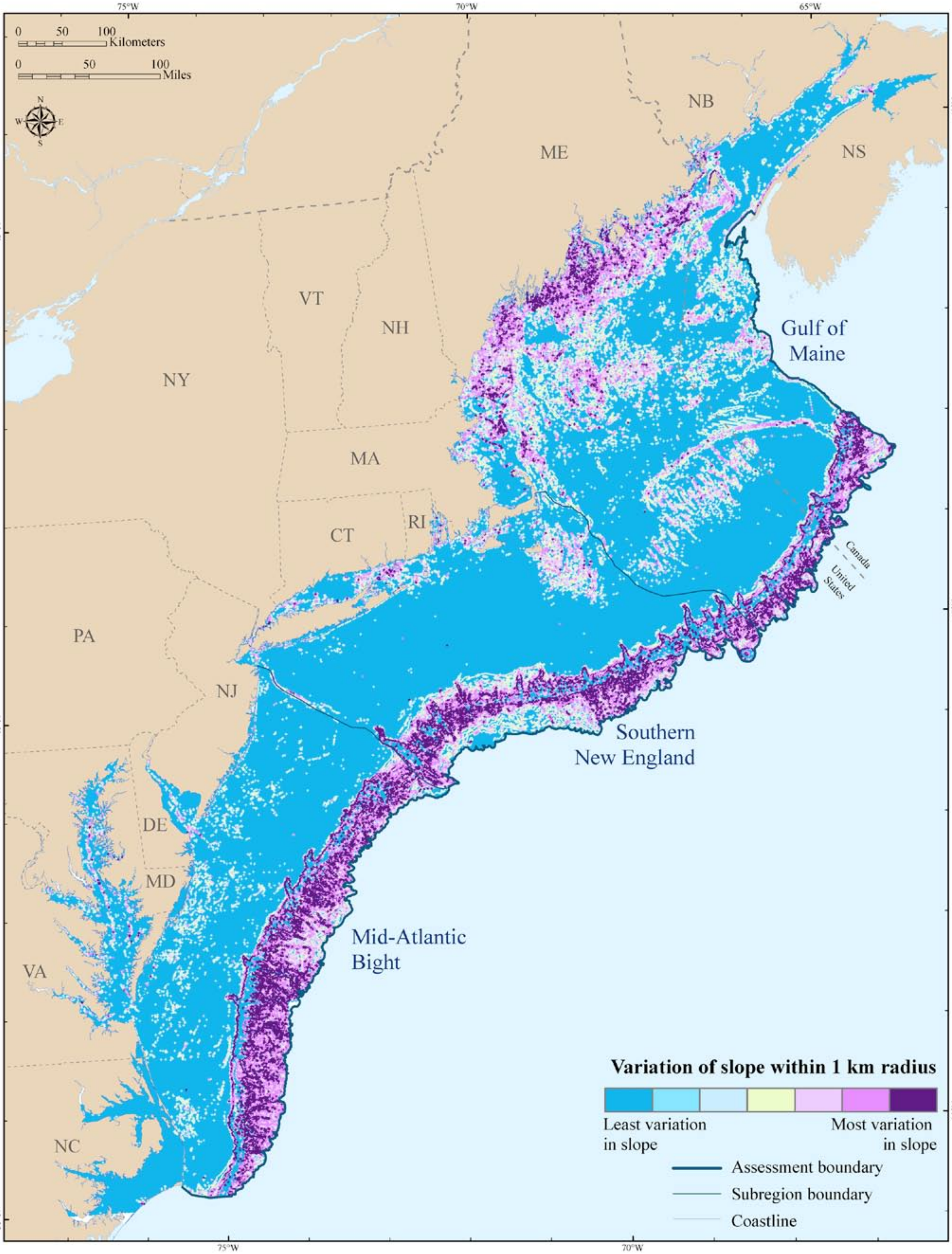


Figure 3-10. Map of standard deviation of slope using a 1 k focal window.

Table 3-5. Example of information for sample point #22254, a grab sample from the Mid-Atlantic Bight subregion classified in organism group 505. We calculated these metrics for each of the 11,132 grab sample points.

Sample ID	Organism Group	Subregion	Bathymetry (m)	Sediment Grain Size (mm)	Position	Slope	Seabed Form	STD_ Slope_1K
22254	505	Mid-Atlantic Bight	-996.62	0.143	Low	Steep	Canyon	0.8

variables). The analysis required each benthic grab sample to be attributed with the benthic community type that it belonged to, overlaid on the standardized base maps, and attributed with the information on depth, sediment grain size and seabed form appropriate to the point (Table 3-5).

Regression trees were first built using all variables collectively to identify the variables driving organism differences. Each analysis was run separately by subregion because initial data exploration revealed that the relationships between the species and the physical factors differed markedly among subregions.

After examining the variable contributions collectively, individual regression trees were built for depth, grain size, and seabed forms to identify critical thresholds that separated sets of organism groups from each other (see Appendix 3-1). In recursive partitioning, these cuts are identified by exhaustively searching all possible cuts and choosing the one that best separates the dataset into non-overlapping subsets. For example, the first run of the organism groups on the bathymetry data separated the deep water samples from the shallow water samples while identifying the exact depth that most cleanly separated the two sets.

Statistical significance was determined for each variable in each organism group using chi-squared tests. This method compares the observed distribution of each benthic organism group across each physical variable against the distribution expected from a random pattern. A variable and threshold was considered to be significant if it had a p-value less that 0.01 (less than a 99% probability that this pattern could have occurred by chance -Appendix 3-1).

Results

Based on the bathymetry dataset, the region varied in depth from 0 m at the coast to -2400 m along the shelf boundary, reaching a maximum of -2740 m at the deepest part. Critical depth thresholds for benthic organisms and habitats differed among the three subregions and are discussed under the organism classification. The three subregions also differed in physical structure, with the Gulf of Maine being made up of a moderately deep basin (-150 to -300 m), a distinctive shallower bank (-35 to -80 m), and a small portion of the deep slope. In contrast, the Mid-Atlantic Bight has extensive shallow water shoals (0 to -35 m), an extensive moderate depth plain (-35 to -80 m), and a large proportion of steeply sloping deep habitat along the Continental Shelf. The Southern New England region is similar in most ways to the Mid-Atlantic Bight.

The sediment maps show a seafloor dominated by coarse to fine sand with large pockets of silt in the Southern New England region, deep regions in the Gulf of Maine and along the Continental Slope. Large pockets of gravels are concentrated on the tip of Georges Bank, the eastern edge of Nantucket Shoals, around the Hudson Canyon, and in various other deep and shallow patches. Hard bottom points are concentrated near the Maine shoreline and offshore are loosely correlated with the gravel areas (Figure 3-7).

Organism Classification

For each subregion, we provide a summary of the characteristic species and their indicator values (Appendix 3-2). This table gives diagnostic species for each organism group and shows its distribution across all the organisms groups. The mean indicator value and the probability of this distribution being random chance is calculated for each species in the group that it is most closely associated with. Most species don't have a common name; Gosner (1979), Weiss (1995) and Pollock (1998) were used to add them where available. Often, these are common names for the family or genus, not the species.

Relationship of the organism groups to the physical factors

Across all subregions, depth was the most important explanatory variable, followed by grain size, and then seabed forms. Seabed forms were less important in the Mid-Atlantic Bight than the other regions. Standard deviation of depth was somewhat important in Southern New England, but not in the other regions. Basic relationships between each organism group and its characteristic physical setting are described below. Charts giving the distribution of the organism groups across each physical factor class, a chi-squared test for significance, and the class where this group is most likely to be found are given in Appendix 3-1. Tables of key physical factor values that correspond to ecological thresholds separating the distribution of one benthic habitat from another are provided in the subregion results (Table 3-6, 3-7, 3-8).

Benthic Habitat Types and Ecological Marine Units

The benthic habitat types identified for each subregion are presented in the following section of this document. Because the final results are a product of several steps, e.g. the macrofauna classification; the identification of relationships between the organism groups and the factors of depth, grain size and topography; and the mapping of benthic environments, the results and details on each step are provided separately in the appendices.

Two separate, but closely related final maps were created. The Ecological Marine Units (EMU) represent all three-way combinations of depth, sediment grain size, and seabed forms based on the ecological thresholds revealed by the benthic-organism relationships (Figure 3-11, 3-12, 3-13, 3-14). Benthic Habitats are EMUs clustered into groups that contain the same species assemblage (Figure 3-15). The two terms are not synonymous, but they are based on the same information, and thus, represent two perspectives on the seafloor. Essentially, the EMU maps show the full diversity of physical factor combinations, regardless of whether a specific habitat type was identified for the combination. The benthic habitat map shows only the combinations of factors, or groups of combinations, for which a benthic organism group was identified. It should be noted that the numbers of the EMUs and benthic habitats were derived from the statistical relationships and is completely arbitrary.

The Benthic Habitat map is simpler because a single organism group typically occurs across several EMUs, although in some instances a single EMU is synonymous with a single organism group. For example, in the Mid-Atlantic Bight, EMU 1101 (silty depression centers in water less than 15 m) is synonymous with organism group 768, a community identified by a specific set of amphipods, brittle stars, clams, whelks, and snails. More typical are organism groups that occur across several closely related EMUs such as Southern New England organism group 25. It ranges across both high position and mid position flats, very shallow to shallow water ranging in depth from 0-23 m, and medium to coarse sand. This community of shimmyworms, glass shrimp, hermit crabs, and surf clams is thus found across a small range of EMUs, and the habitat is mapped as the set of EMUs that define it.

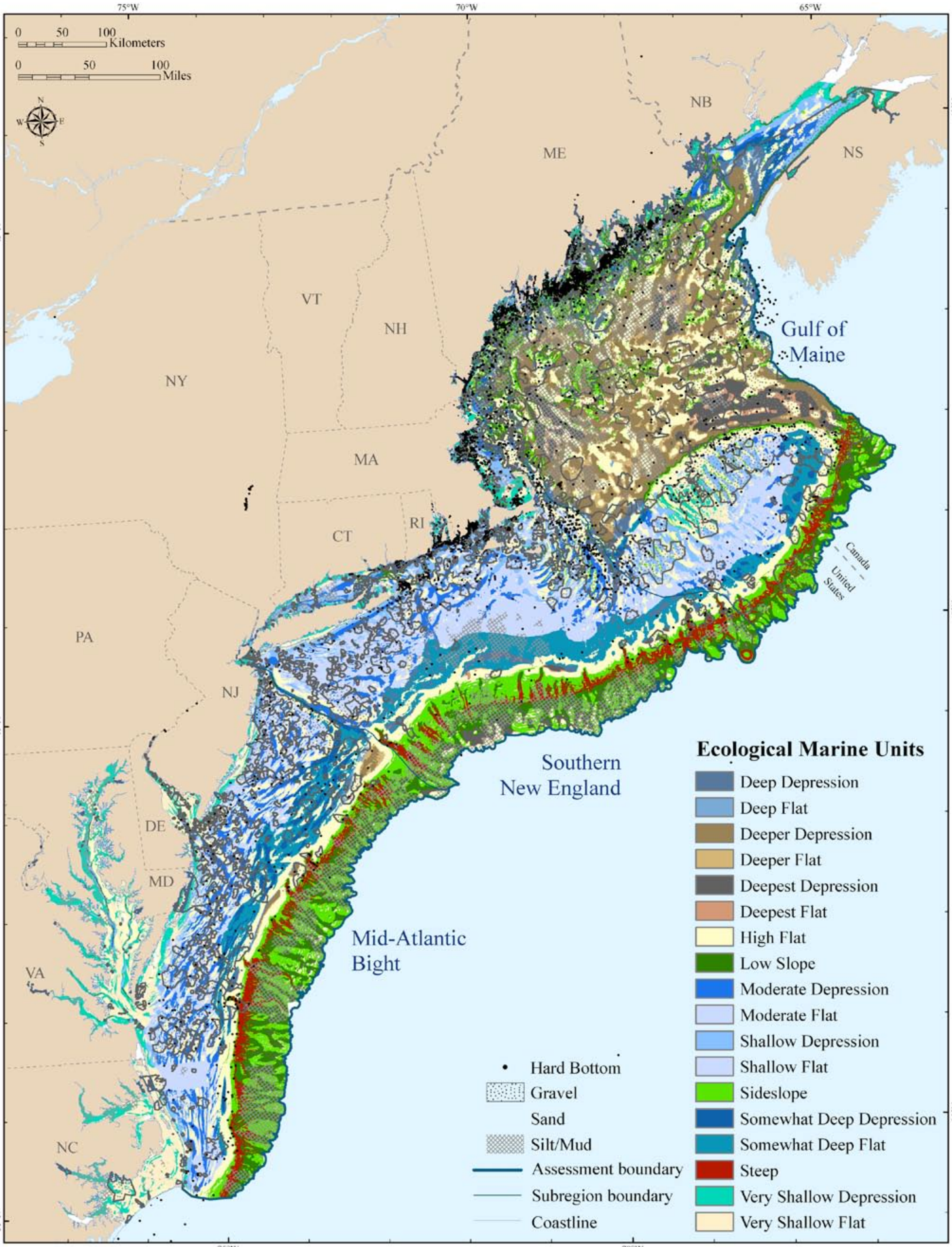


Figure 3-11. Ecological Marine Units of the Northwest Atlantic region. Scale 1:7,250.000

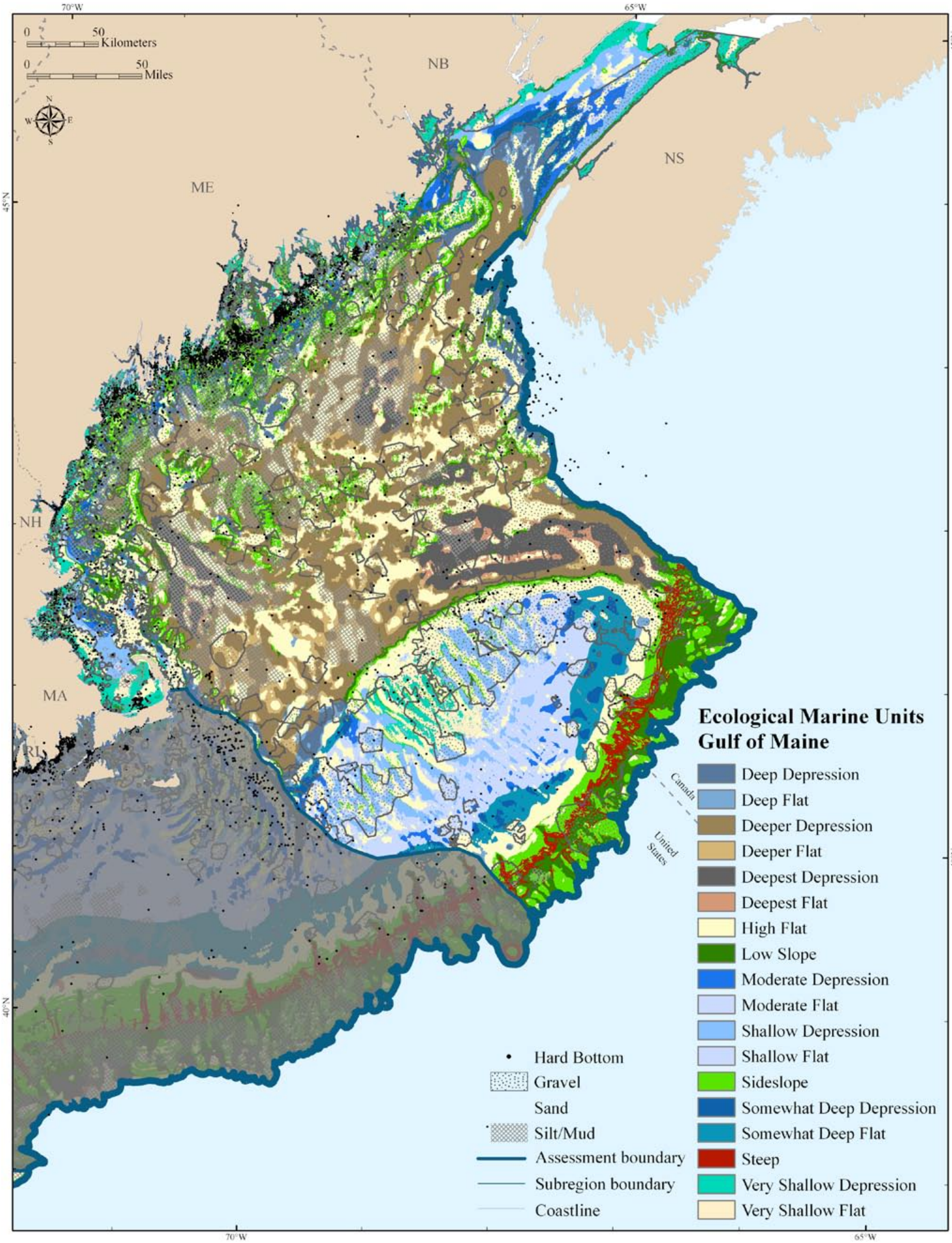


Figure 3-12. Gulf of Maine Ecological Marine Units. Scale 1:2,900,00

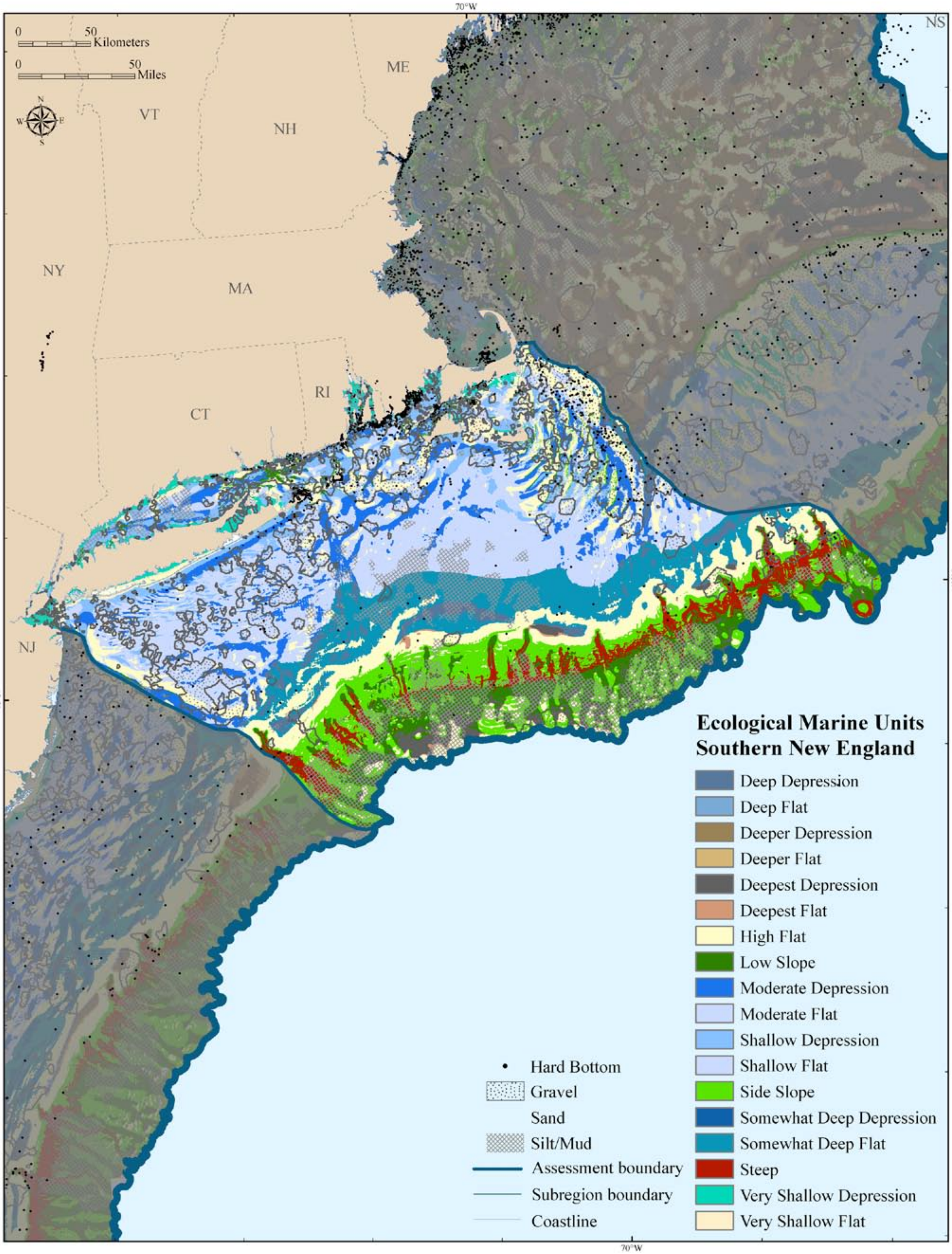


Figure 3-13. Southern New England Ecological Marine Units. Scale 1:2,600,000

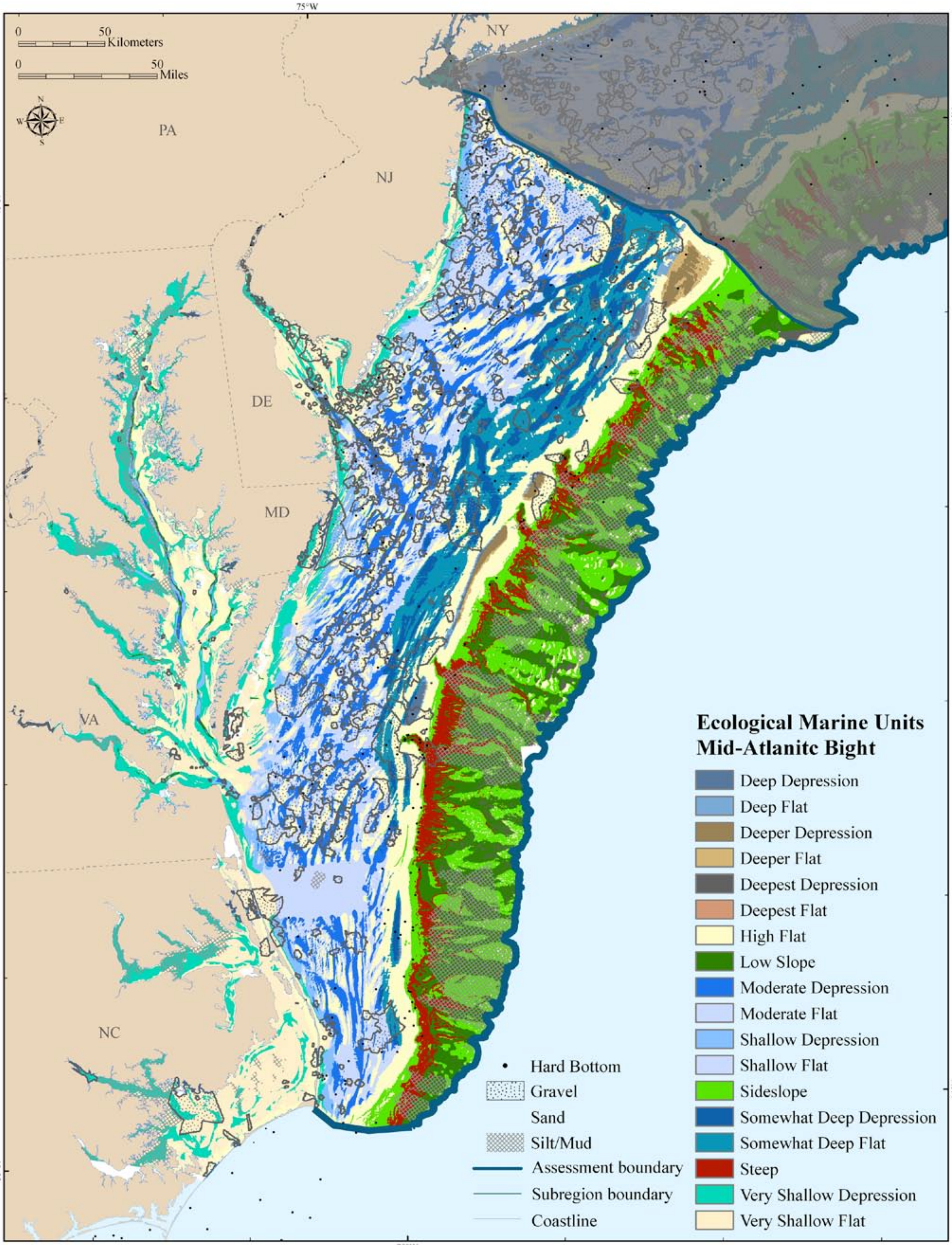


Figure 3-14. Mid-Atlantic Bight Ecological Marine Units. Scale 1:3,210,600

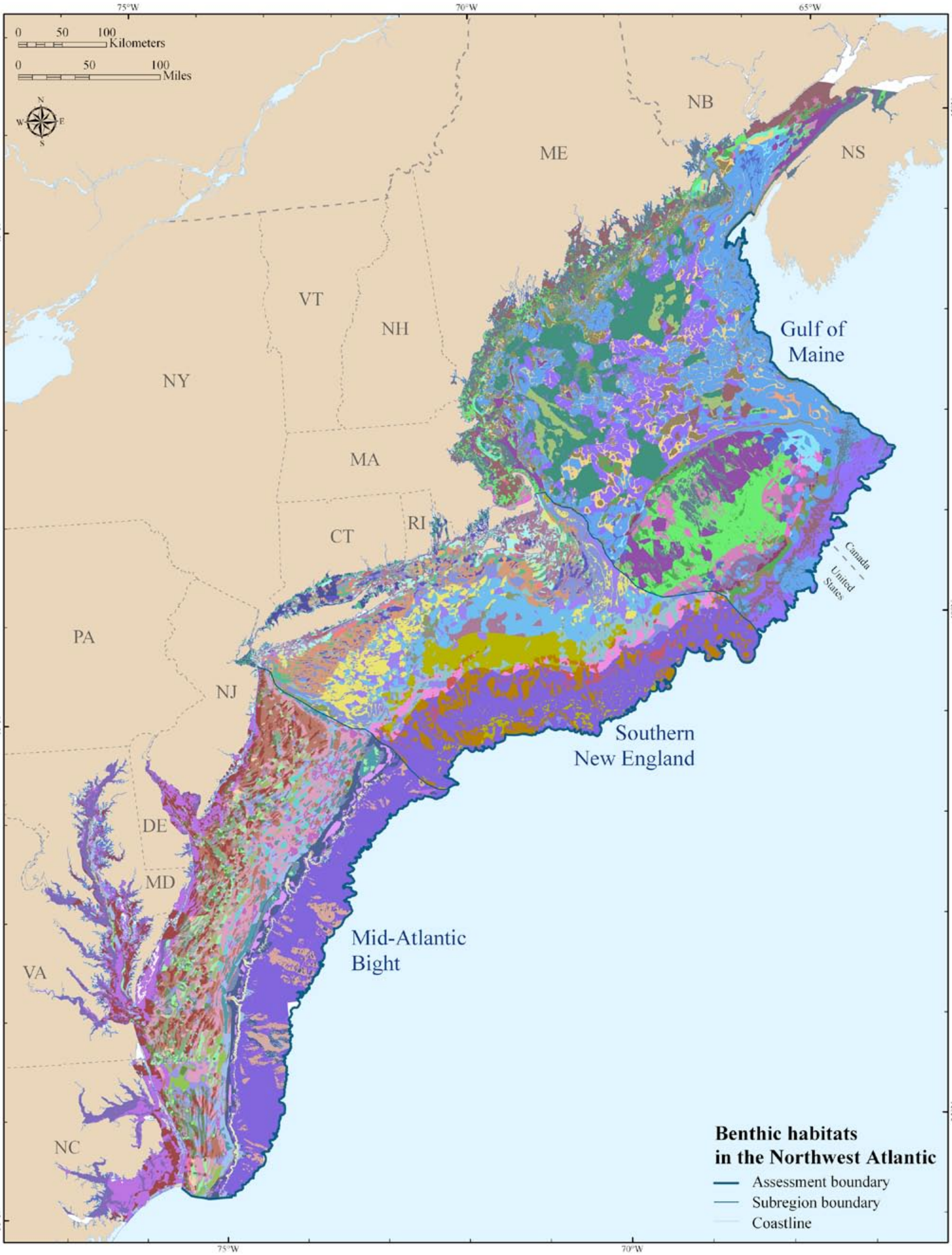
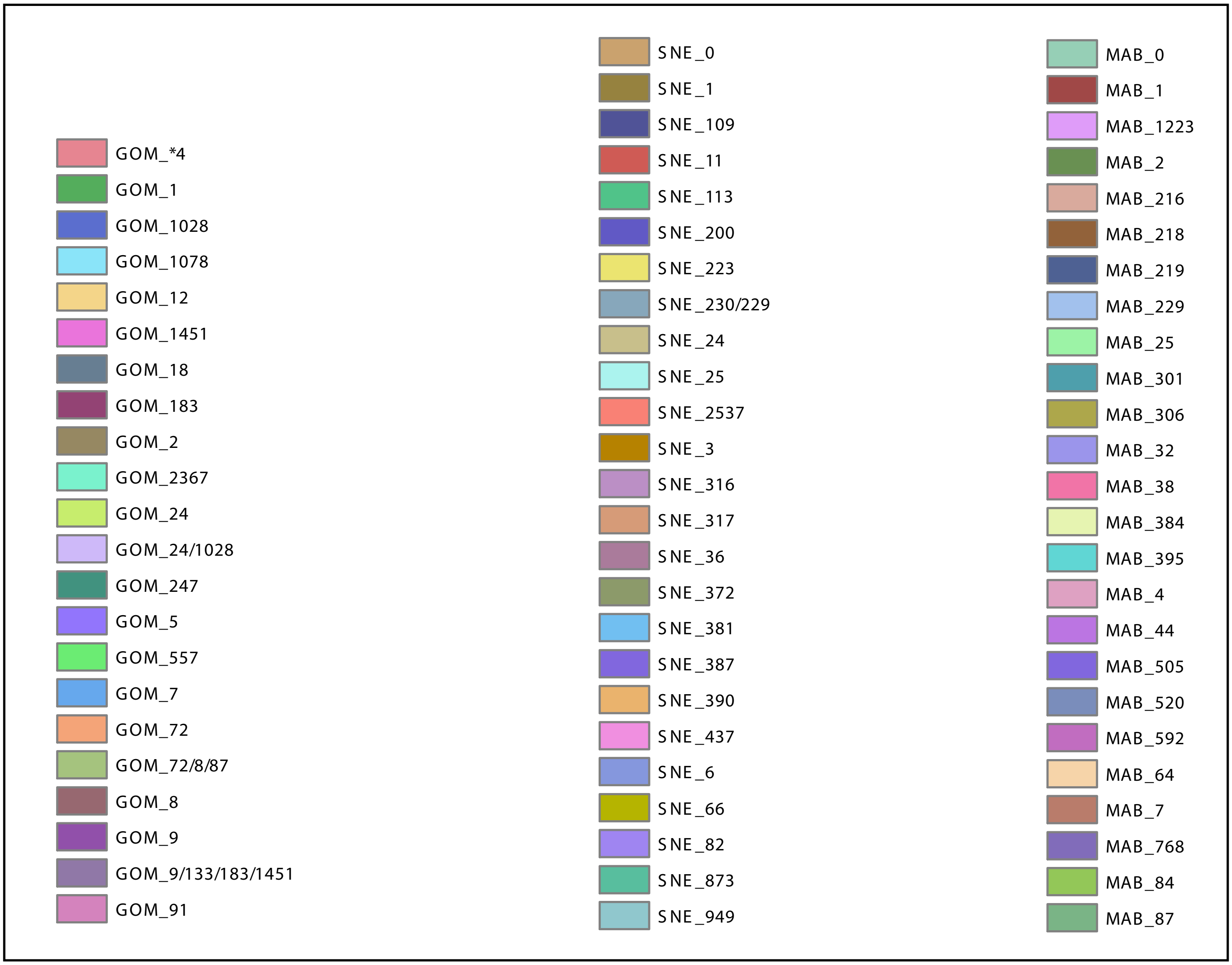


Figure 3-15. Benthic habitats of the Northwest Atlantic region.

Figure 3-15. Benthic Habitats Legend



Description of Benthic Habitats

Note: This section is arranged by subregion and benthic habitats are displayed from shallow to deep water habitats based on the average depth of each benthic habitat.

Gulf of Maine

Table 3-6. Physical factor values that correspond to ecological thresholds in the Gulf of Maine subregion.

Bathymetry (m)	Sediment Grain Size (mm)	Seabed Form
0-42	0-0.04 (mud and silt)	Depression
42-61	0.04-0.17 (very fine sand)	Mid Flat
61-70	0.17-0.36 (fine sand)	High Flat
70-84	0.36 -0.54 (sand)	Low Slope
84-101	>=0.54 (coarse sand and gravel)	Sideslope
101 - 143		Steep
143 -233		
>=233		

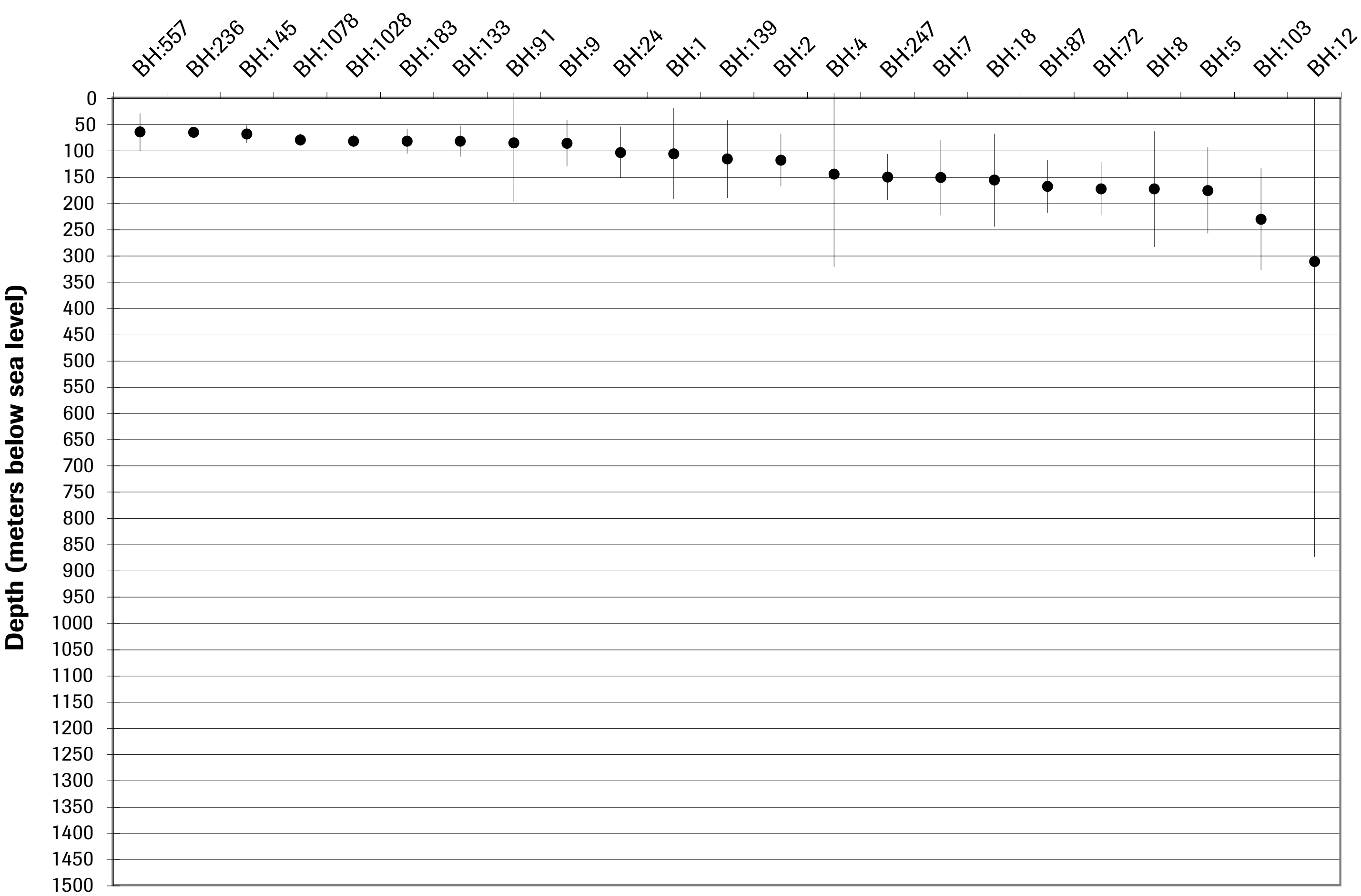


Figure 3-16. Average depth and range of each benthic habitat type in the Gulf of Maine subregion. Lines represent two standard deviations above and below the mean. Habitat types with the same depths often differ from each other by sediment grain size or topographic location. Habitats with very large depth ranges are widespread associations unrelated to, or weakly correlated with, depth.

Shallow to moderate (0 - 70 m)

Habitat 557 (125 Samples):
Mid position flats at shallow to moderate depth (42 - 79 m) on fine to medium sand.

Annelids
Bamboo worm *(Clymenella torquata)*
Bristle worm *(Spiophanes bombyx)*
Burrowing scale worm *(Sthenelais limicola)*
Paddle worm *(Anaitides mucosa)*
Paraonid worm *(Acmira catherinae)*
Scale worm *(Harmothoe extenuata)*
Shimmy worm *(Aglaophamus circinata)*
Spaghetti-mouth worm *(Ampharete arctica)*
Syllid worm *(Exogone hebes)*
Thread worm *(Lumbrineris acicularum)*

Arthropods
Cumacea *(Eudorellopsis deformis)*
Tanaidacea *(Tanaissus lilljeborgi)*
Other amphipods *(Byblis serrata, Corophium crassicorne, Ericthonius fasciatus, Orchomene minut, Leptocheirus pinguis, Monoculodes sp., Phoxocephalus holbolli, Pseudunciola obliquua, Parahaustorius longimerus , Protohaustorius sp., Rhepoxynius hudsoni, Unciola inermis, U. irrorata)*
Other isopods *(Chiridotea arenicola, Cirolana polita)*

Mollusks
False quahog *(Pitar morrhuana)*
Lea's spoon shell *(Periploma fragile)*
Paper clam *(Lyonsia arenos)*
Surf clam *(Spisula solidissima)*
Northern dwarf tellin *(Tellina agilis)*

Habitat 2367 (40 Samples):
Depressions at moderate depths (61 - 70 m) on very fine sand.

Annelids
Bamboo worm *(Maldane sarsi, Myriochelle oculata, Praxillella gracilis)*
Bristle worm *(Sternaspis fossor, Terebellides atlantis, Trochochaeta multisetosa)*
Chevron worm *(Goniada maculata)*
Clam worm *(Nereis grayi)*
Feather duster worm *(Euchone elegans, E. incolor)*
Fringe worm *(Chaetozone setosa, Tharyx acutus, Tharyx sp.)*

Spionid mud worm *(Laonice cirrata, Polydora socialis, Prionospio steenstrupi, Spio armata, S. filicornis)*
Sandbar worm *(Gattyana amondseni)*
Scale worm *(Antinoella sarsi, Hartmania moorei, Ophelina acuminate, Pholoe minuta)*
Shimmy worm *(Nephtys incisa)*
Spaghetti-mouth worm *(Asabellides oculata, Melinna cristata)*
Syllid worm *(Exogone verugera)*
Threadworm *(Cossura longocirrata, Heteromastus filiformis, Lumbrineris fragilis, Lumbrineris hebes, Ninoe nigripes)*
Other polychaetes *(Ancistrosyllis groenlandica, Anobothrus gracilis , Aricidea quadrilobata, Brada villosa, Diplocirrus hirsutus, Drilonereis longa, Haploscoloplos robustus, Leitoscoloplos mamosus, Mediomastus ambisetae, Paramphinome jeffreysii, Polycirrus sp., Tauberia gracilis)*

Arthropods
Skeleton shrimp *(Mayerella limicola)*
Cumacea *(Campylaspis rubicund, Diastylis cornuifer, Eudorella hispida, Eudorella pusilla, Leptostylis longimana, Leucon americanus)*
Other Amphipods *(Anonyx liljeborgi, Bathymedon obtusifrons, Byblis gaimardi, Haploops fundiensis, Harpinia propinqua, Metopa angustimana, Monoculodes sp., Stenopleustes sp.)*
Other isopods *(Edotea acuta, Pleurogonium rubicundum)*

Mollusks
Alvania *(Alvania carinata)*
Bean mussel *(Crenella decussata)*
Cone snail *(Oenopota concinnulus)*
Hatchet shell *(Thyasira flexuosa)*
Nutclam *(Nucula delphinodonta, N. tenuis)*
Short yoldia *(Yoldia sapotilla)*
Spoon shell *(Periploma papyratium)*
Stimpson's whelk *(Colus pubescens)*
Tusk shell *(Siphonodentalium occidentale)*
Yoldia *(Yoldiella iris, Y. sanesia)*
Other gastropods *(Cylichna alba, C. gouldi, C. occulta) Scaphander punctostriatus)*

Cnidarians
Burrowing anemone *(Edwardsia elegans)*
Twelve-tentacle burrowing anemone *(Halcampa duodecimcirrata)*

Echinoderms
Mud star *(Ctenodiscus crispatus)*
Sea cucumber *(Molpadia oolitica)*

Bryozoans
Hippodiplosia propinqua

Phoronids
Horseshoe worm *(Phoronis architecta)*

Sipunculids
Tube worm *(Phascolion strombi)*

Habitat 1451 (127 Samples):
Mid-position flats at shallow to moderate depths (42 - 101 m) on fine sand.

Arthropods
Atlantic rock crab *(Cancer irroratus)*
Hairy hermit crab *(Pagurus arcuatus)*
Lady crab *(Ovalipes ocellatus)*

Mollusks
Atlantic razor *(Siliqua costata)*
Dog whelk *(Nassarius trivittatus)*
Spotted northern moon-shell *(Lunatia triseriata)*
Common northern moon snail *(Euspira heros)*
Paper clam *(Lyonsia hyalina)*
Stimpson's whelk *(Colus stimpsoni)*

Cnidarians
Colonial anemone *(Epizoanthus americanus)*

Echinoderms
Common sand dollar *(Echinarachnius parma)*
Slender-armed star *(Leptasterias tenera)*

Habitat 1078 (305 Samples):
Mid-position flats on at moderate depths (61 - 101 m) on fine sand.

No diagnostic species, depauperate samples with occasional sea scallop *(Placopecten magellanicus)*

Habitat 1028 (67 Samples):
Mid-position flats at moderate depths (61 - 101 m) on fine sand.

Arthropods
American lobster *(Homarus americanus)*

Mollusks
Iceland scallop *(Chlamys islandica)*
Sea scallop *(Placopecten magellanicus)*
Other gastropods *(Stilifer stimpsoni)*

Habitat 183 (136 Samples):
Mid-position flats in shallow to moderate depths (42 - 101 m) on fine sand.

No diagnostic species, samples largely empty – some Northern shortfin squid *(Illex illecebrosus)*

Moderate Depths (70 - 233 m)

Habitat 133 (61 Samples):
Mid-position flats at moderate depths (70 - 101 m) on fine sand.

Annelids
Clam worm *(Nereis pelagica)*
Feather duster worm *(Chone infundibuliformis)*
Thread worm *(Lumbrinerides acuta)*
Spionid mud worm *(Scolelepis squamata)*
Paraonid worm *(Acmira cerruti)*
Shimmy worm *(Nephtys bucera)*
Syllid worm *(Streptosyllis arenae)*
Threadworm *(Notomastus latericeus)*

Arthropods
Fairy shrimp *(Erythrops erythrophthalma)*

Cumacea *(Pseudoleptocuma minor)*
Other amphipods (*Pontogeneia inermis)*

Mollusks
Sea butterfly *(Thecosomata spp.)*

Chaetognatha
Arrow worm *(Chaetognatha sp.)*

Habitat 91 (307 Samples):
Mid-position flats at moderate depths (42 to 83 m) on fine to medium sand.

Arthropods
Atlantic rock crab *(Cancer irroratus)*
Acadian hermit crab *(Pagurus acadianus)*
Cumacea *(Lamprops quadriplicata, Pseudoleptocuma minor)*
Krill *(Thysanoessa inermis, T. longicaudata)*
Mysid shrimp *(Mysidopsis bigelowi, Neomysis americana)*
Skeleton shrimp *(Caprella linearis)*
Sand shrimp *(Crangon septemspinosa)*
Sea spider *(Nymphon rubrum)*
Striped barnacle *(Balanus hameri)*
Other amphipods *(Ampelisca agassizi, A. macrocephala, Calliopius laeviusculus, Casco bigelowi , Ericthonius difformis, Haustorius arenarius, Hippomedon serratus, Melita sp., Monoculodes sp., Orchomene pinguis, Parahaustorius longimerus, Parathemisto bispinosa, P. compressa, Photis dentate, Podoceropsis nitida, Pontogeneia inermis, Protomedeia fasciata, Psammonyx terranovae, Rhepoxynius epistomus, Tmetonyx cicada, Unciola inermis)*
Other isopods *(Chiridotea arenicola, Chiridotea tuftsi, Cirolana concharum, Edotea triloba, Politolana polita)*

Mollusks
Atlantic razor *(Siliqua costata)*
Chestnut astarte *(Astarte castanea)*
Convex slipper shell *(Crepidula plana)*
Dog welk *(Nassarius trivittatus)*
Northern moon shell *(Lunatia triseriata)*
Pearly top snail *(Margarites groenlandicus)*

Cnidarians
Northern red anemone *(Urticina felina)*

Echinoderms
Dwarf brittlestar *(Amphipholis squamata)*

Bryozoans
Lacy crusts *(Electra pilosa)*

Chaetognatha
Arrow worm *(Chaetognatha sp.)*

Habitat 9 (219 Samples):
High and mid-postion flats at moderate depth (42 - 101 m) on fine to medium sand.

Annelids
Beard worm *(Pogonophora sp.)*
Mosaic worm *(Nothria conchylega)*

Arthropods
Acadian hermit crab *(Pagurus acadianus)*

Mollusks
Convex slipper shell *(Crepidula plana)*
Jingle shell *(Anomia simplex)*

Echinoderms
Green sea urchin *(Strongylocentrotus droebachiensis)*
Northern sea star *(Asterias vulgaris)*
Spiny sun star *(Crossaster papposus)*

Habitat 12 (56 Samples):
Steep slopes and flats at depths over 69 m, on fine to medium sand.

Arthropods
Sand shrimp *(Crangon septemspinosa)*
Other amphipods *(Diastylis quadrispinosa*, *D. sculpta)*

Mollusks
Bean mussel *(Crenella glandula)*
Black Clam *(Arctica islandica)*

Cone snail *(Oenopota harpularia)*
Hatchet shell *(Thyasira equalis, T. trisinuata)*
Northern moon snail *(Euspira immaculata)*
Paper bubble *(Philine quadrata)*
Rusty axinopsid *(Mendicula ferruginosa)*
Solitary glassy bubble *(Retusa obtusa)*
Top snail *(Solariella obscura)*

Bryozoans and Protozoans
Tessarodoma gracilis
Foraminiferida

Echinoderms
Dwarf brittle star *(Axiognathus squamatus)*
Sea cucumber *(Stereoderma unisemita)*

Habitat 24 (139 Samples):
Mid-position flats at moderate depths (70 - 101 m) on silt to fine sand.

Arthropods
Mysid shrimp *(Pseudomma affine)*
Cumacea *(Petalosarsia declivis, Lamprops quadriplicata)*

Habitat 1 (153 Samples):
High flats and slopes at any depth on silt, fine sand or sand.

Arthropods
Bristled longbeak shrimp *(Dichelopandalus leptocerus)*

Mollusks
Northern shorfin squid *(Illex illecebrosus)*

Echinoderms
Basket star *(Gorgonocephalus eucnemis)*

***Habitat 139** (90 Samples):
Various seabed postions in moderately shallow water (42 - 70 m) on fine to medium to coarse sand. Not a habitat type, but listed here for completeness.

No diagnostic species, samples largely empty – some squid *(Sepioidea)*

Habitat 2 (116 Samples):
Flats and slopes at moderate depth (70 - 233 m) on very coarse sand or pebbles.

Arthropods
Spiny lebbeid *(Lebbeus groenlandicus)*
Aesop shrimp *(Pandalus montagui)*
Sars shimp *(Sabinea sarsii)*

***Habitat 4** (791 Samples):
Any seabed form at any depth and any substrate. Not a habitat type, but included in this list for completeness.

Apparently poor samples, no diagnostic species, samples mostly krill *(Euphausia krohni)*

Habitat 247 (62 Samples):
Depressions and high flats in moderate to deep water (101 - 233 m) on silt and mud.

Arthropods
Pink glass shrimp *(Pasiphaea multidentata)*
Northern shrimp *(Pandalus borealis)*
Other decapods *(Geryon quinquedens)*

Habitat 7: (157 samples)
Depressions, and high flats and slopes, in deep water (143 - 233 m) mostly on silt and fine sand, but substrate is variable.

Annelids
Plumed worm *(Onuphis opalina)*
Sea mouse *(Laetmonice filicornis)*

Arthropods
Arctic eualid *(Eualus fabricii)*
Friendly blade shrimp *(Spirontocaris liljeborgii)*
Hermit crab *(Pagurus pubescens)*
Norwegian shrimp *(Pontophilus norvegicus)*
Parrot shrimp *(Spirontocaris spinus)*
Polar lebbeid *(Lebbeus polaris)*
Pycnogonum *(Pycnogonum littorale)*
Sea spider *(Nymphon grossipes, Nymphon longitarse, Nymphon*

macrum, Nymphon stroemi)
Other amphipods *(Epimeria loricata, Haploops tubicola, Stegocephalus inflatus)*
Other decopods *(Stereomastis sculpta)*

Mollusks
Arctic rock borer *(Hiatella arctica)*
Ark shell *(Bathyarca pectunculoides)*
Bean mussel *(Crenella pectinula)*
Broad yoldia *(Yoldia thraciaeformis)*
Chalky macoma *(Macoma calcarea)*
Astarte *(Astarte elliptica, A. subequilatera, A. undata)*
Chiton-like mullusk *(Amphineura sp.)*
Cone snail *(Pleurotomella packardi)*
Cup-and-saucer limpet *(Crucibulum striatum)*
Dipperclam *(Cuspidaria fraterna, C. glacialis)*
Dove shell *(Anachis haliaecti)*
Duckfoot snail *(Aporrhais occidentalis)*
Heart clam *(Cyclocardia borealis)*
Jingle shell *(Anomia aculeata)*
Keyhole limpet *(Puncturella noachina)*
Little cockle *(Cerastoderma pinnulatum)*
Moon snail *(Natica clausa)*
Mussel *(Musculus discors, M. niger)*
Northern moon shell *(Lunatia pallida)*
Nutclam *(Nuculana pernula)*
Nutmeg snail *(Admete couthouyi)*
Occidental tuskshell *(Antalis occidentale)*
Offshore octopus *(Bathypolypus arcticus)*
Pearly top snail *(Margarites costalis)*
Stimpson's whelk *(Colus pygmaeus)*
Ten-ridged whelk *(Neptunea decemcostata)*
Top shell *(Calliostoma occidentale)*
Turret snail *(Tachyrhynchus erosus)*
Velvet snail *(Velutina laevigata)*
Waved whelk *(Buccinum undatum)*
Wentletraps *(Epitonium greenlandicum)*
Yoldia *(Yoldiella lucida)*
Other bivalves *(Cyclopecten pustulosus)*

Brachipods and Bryozoans
Lamp shell *(Brachiopoda)*
Other bryozoan *(Bugula sp., Caberea ellisii, Idmonea atlantica)*

Chordates
Cactus sea squirt *(Boltenia ovifera)*

Cnidarians
Sea feather *(Pennatula aculeata)*
Soft coral *(Alcyonacea spp.)*

Echinoderms
Blood star *(Henricia sanguinoleata)*
Brittle star *(Ophiocten sericeum, Ophiura sarsi, Amphiura otteri, Ophiopholis amphiuridae)*
Cushion star *(Leptychaster arcticus)*
Hairy sea cucumber *(Havelockia scabra)*
Margined sea star *(Psilaster andromeda)*
Orange-footed cucumber *(Cucumaria planci)*
Psolus cucumber *(Psolus phantapus)*
Scarlet psolus cucumber *(Psolus fabricii)*
Sea urchin *(Brisaster fragilis)*
Sun star *(Lophaster furcifer)*
Other sea stars *(Diplopteraster multiples, Poraniomorpha hispida)*
Sea lilies *(Crinoidea sp.)*

Habitat 18 (204 Samples):
High flats at moderate to deep depths (over 101 m) on silt to fine sand.

Annelids
Bristle worm *(Trochochaeta carica)*
Clam worm *(Ceratocephale loveni)*
Thread worm *(Abyssoninoe winsnesae, Lumbrineris magalhaensis)*
Plumed worm *(Onuphis opalina)*
Others polychaetes *(Paramphinome pulchella)*

Arthropods
Horned krill shrimp *(Meganyctiphanes norvegica)*
Cumacea *(Eudorella truncatula)*
Other amphipods *(Tmetonyx cicada)*
Other decapods *(Calocaris templemanni, Stereomastis sculpta)*
Other isopods *(Politolana impressa)*

Mollusks
Alvania *(Alvania pelagica)*
Baltic macoma *(Macoma baltica)*
Broad yoldia *(Yoldia thraciaeformis)*
Cone snail *(Oenopota exarata)*
Conrad's thracia *(Thracia myopsis)*
Dipperclam *(Cuspidaria parva)*
Hatchet shell *(Thyasira equalis, T. gouldii, T. pygmaea, T. trisinuata)*
Mussel *(Dacrydium vitreum)*
Nutclam *(Nucula proxima)*
Softshell Clam *(Mya arenaria)*
Tusk shells *(Polyschides rushii)*
Yoldia *(Yoldia regularis)*

Echinoderms
Brittle star *(Ophiocten sericeum, Ophiura robusta)*

Habitat 87 (132 Samples):
Depressions and high flats at moderate depths (101 - 233 m) on silt and mud.

Arthropods
Sevenline shrimp *(Sabinea septemcarinata)*
Prawn *(Sergestes arcticus)*

Echinoderms
Mud star *(Ctenodiscus porcell)*

Deep 143 - 233 m

Habitat 72 (152 Samples):
Depressions and high flats at deep depths (143 - 233 m) on silt and mud.

Arthropods
Shrimp *(Pandalus propinquus)*
Others amphipods *(Epimeria loricata)*

Habitat 8 (266 Samples):
Depressions and side slopes in deep water (143 - 233 m) on silt and mud.

Annelids
Bristle worm *(Trochochaeta carica)*
Clam worm *(Ceratocephale loveni)*
Thread worm *(Abyssoninoe winsnesae, Lumbrineris magalhaensis)*
Plumed worm *(Onuphis opalina)*
Other polychaetes *(Paramphinome pulchella)*

Arthropods
Horned krill shrimp *(Meganyctiphanes norvegica)*
Other decopods *(Stereomastis sculpta)*

Mollusks
Alvania *(Alvania pelagica)*
Broad yoldia *(Yoldia thraciaeformis)*
Conrad's thracia *(Thracia myopsis)*
Dipper clam *(Cuspidaria parva)*
Hatchet shell *(Thyasira equalism, T. gouldii, T. pygmaea, T. trisinuata)*
Mussel *(Dacrydium vitreum)*
Nutclam *(Nucula proxima)*
Softshell Clam *(Mya arenaria)*
Tusk shells *(Polyschides rushii)*
Yoldia *(Yoldia regularis)*

Echinoderms
Brittle star *(Ophiocten sericeum)*

Habitat 5 (130 Samples):
Depressions, high flats and slopes in deep water (101 - 233 m) on silt, fine sand and sand.

Annelids
Sea mouse *(Aphrodita hastata)*

Arthropods
Shrimp *(Pandalus propinquus)*

Habitat 103 (42 Samples):
High slopes, steep slopes and depressions in deep water (over 233 m) on silt and fine sand.

Arthropods
Prawn *(Sergestes arcticus)*
Pink glass shrimp *(Pasiphaea multidentata)*

Southern New England

Table 3-7. Physical factor values that correspond to ecological thresholds in the Southern New England subregion.

Bathymetry (m)	Sediment Grain Size (mm)	Seabed Form
0-9	0-0.03 (mud and silt)	Depression
9-23	0.03- 0.16 (very fine sand)	Mid Flat
23-31	0.16-0.34 (fine sand)	High Flat
31-44	0.34 -0.36 (sand)	Low Slope
44-76	>=0.36 (medium and coarse sand)	Sideslope
76-139		Steep
>=139		

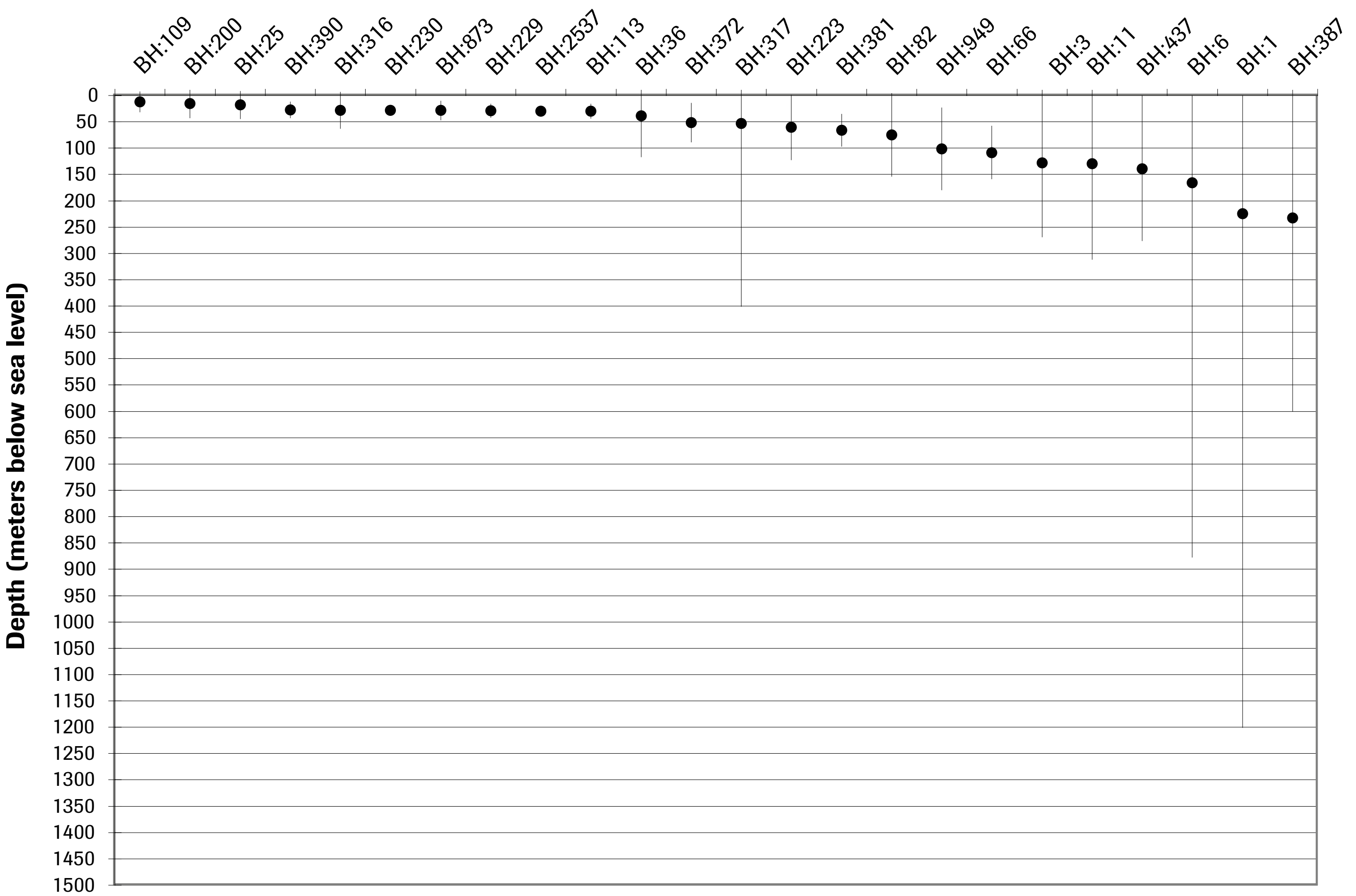


Figure 3-17. Average depth and range of each benthic habitat type in the Southern New England subregion. Lines represent two standard deviations above and below the mean. Habitat types with the same depths often differ from each other by sediment grain size or topographic location. Habitats with very large depth ranges are widespread associations unrelated to, or weakly correlated with, depth.

Shallow (0 - 31 m)

Habitat 109 (134 Samples):
Depressions in very shallow water (0 - 23 m) mostly on medium to coarse sand but occasionally on silt.

Annelids
Others polychaetes *(Maldanopsis elongate, Sigambra tentaculata)*
Bamboo worm *(Euclymene collaris, Owenia fusiformis)*
Blood worm *(Glycera americana)*
Burrowing scale worm *(Sthenelais boa)*
Clam worm *(Neathes succinea)*
Spionid mud worm *(Polydora ligni, Spio filicornis, Streblospio benedicti)*
Orbiniid worm *(Scoloplos acutus)*
Paddle worm *(Eteone heteropoda, Eumida sanguinea)*
Spaghetti-mouth worm *(Ampharete arctica, Melinna cristata)*
Syllid worm *(Exogone dispar)*
Terebellid worm *(Polycirrus medusa)*
Thread worm *(Heteromastus filiformis)*

Arthropods
Bay barnicle *(Balanus improvisus)*
Longwrist hermit crab *(Pagurus longicarpus)*
Other amphipods *(Ampelisca abdita, Corophium bonelli, Corophium insidiosum, Microdeutopus gryllotalpa, Unciola serrata)*

Mollusks
Channeled barrel-bubble *(Acteocina canaliculata)*
Common razor clam *(Ensis directus)*
Slipper shell *(Crepidula convex, C. fornicata)*
Dog welk *(Nassarius trivittatus)*
False anglewing *(Petricola pholadiformis)*
File yoldia *(Yoldia limatula)*
Gould's pandora *(Pandora gouldiana)*
Hard-shelled clam *(Venus gallina)*
Little surf clam *(Mulinia lateralis)*
Northern quahog *(Mercenaria mercenaria)*
Paper clam *(Lyonsia hyalina)*
Pyramid snail *(Turbonilla elegantula)*
Softshell clam *(Mya arenaria)*
White baby ear *(Sinum perspectivum)*
Other bivalves *(Mysella planulata)*

Habitat 200 (163 Samples):
Depressions at very shallow to moderate depths (0 – 44 m) on very fine to medium sand.
Annelids
Sludge worm *(Peloscolex gabriellae)*

Mollusks
Pitted baby-bubble *(Acteon punctostriatus)*

Habitat 25 (492 Samples):
Flats and side slopes in very shallow to shallow water (0 - 23 m) on fine to coarse sand.

Annelids
Blood worm *(Hemipodus roseus)*
Mageloni worm *(Magelona rosea)*
Spionid mud worm *(Scolelepis squamata)*
Shimmy worm *(Nephtys bucera)*
Other polychaetes *(Pisione remota)*

Arthropods
Glass shrimp *(Leptochelia savignyi)*
Hermit crab *(Pagurus politus)*
Cumacea *(Leptocuma minor)*
Tanaidacea *(Leptognathia caeca)*
Other isopods *(Chiridotea arenicola)*
Other amphipods *(Acanthohaustorius millsi, A. similis, Ampelisca verrilli, Parahaustorius attenuatus, P. longimerus, Protohaustorius sp.)*

Mollusks
Surf clam *(Spisula solidissima)*

Habitat 36 (61 Samples):
Depressions and high flats in very shallow to moderate depths (0 – 75 m) on medium to coarse sand.

Arthropods
Green crab *(Carcinus maenas)*
Portly spider crab *(Libinia emarginata)*

Mollusks
Bittium snail *(Bittium alternatum)*
Egg cockle *(Laevicardium mortoni)*

Habitat 390 (117 Samples):
Depressions in shallow water (23 - 44 m) in very fine to fine sand.

Annelids
Feather duster worm *(Euchone rubrocincta)*
Fringeworm *(Tharyx acutus, T. annulosus)*
Paraonid worm *(Aricidea jeffreysii, Paraonides lyra)*
Other polychaetes *(Protodrilus sp., Schixtomeringos caecus)*

Arthropods
Other amphipods *(Elasmopus laevis)*

Mollusks
Oval yoldia *(Yoldia myalis)*
Pyramid snail *(Odostomia sp.)*
Swamp snail *(Hydrobia minuta)*
Northern dwarf tellin *(Tellina agilis)*

Habitat 316 (301 Samples):
Flats in shallow water (8-44 m) on very fine to medium sand.

Annelids
Other polychaetes *(Polygordius triestinus, Protodrilus symbioticus)*
Bamboo worm *(Clymennella zonalis)*
Mageloni worm *(Magelona riojai)*

Arthropods
Other amphipods *(Protohaustorius sp.)*
Other isopods *(Chiridotea tuftsi)*

Habitat 230 (227 Samples):
Depressions in shallow depths (23 - 44 m) on very fine sand.

Annelids
Burrowing scale worm *(Sthenelais limicola)*
Fan worm *(Potamilla reniformis)*
Spionid mud worm *(Polydora quadrilobata)*
Other polychaetes *(Autolytus cornutus, Pherusa affinis)*

Arthropods
Other amphipods *(Ischyrocerus sp., Photis pollex)*

Mollusks
Pyramid snail *(Fargoa gibbosa)*

Habitat 873 (113 Samples):
Flats and side slopes in shallow water (8 - 31 m) on very fine to medium sand.

Annelids
Blood worm *(Glycera dibranchiata)*
Bristle worm *(Spiophanes bombyx)*
Thread worm *(Lumbrineris fragilis)*
Spionid mud worm *(Prionospio malmgreni)*
Shimmy worm *(Nephtys picta, N. schmitti)*
Other polychaetes *(Haploscoloplos fragilis, Phyllodoce arenae, Scoloplos armiger)*

Mollusks
Atlantic razor *(Siliqua costata)*

Habitat 229 (225 Samples):
Depressions in shallow depths (8.4 to 44 meter) on very fine sand.

Annelids
Bamboo worm *(Asychis elongata)*
Blood worm *(Glycera robusta)*
Clam worm *(Neanthes virens)*
Spionid mud worm *(Scolelepis bousfieldi, Spio setosa)*
Other polychaetes *(Haploscoloplos robustus)*

Arthropods
Cephalocarid *(Hutchinsonella macracantha)*
Other isopods *(Politolana polita)*

Mollusks
Black Clam *(Arctica islandica)*
Conrad's thracia *(Thracia sp.)*
False Quahog *(Pitar morrhuana)*
Little Cockle *(Cerastoderma pinnulatum)*
Nutclam *(Nucula proxima)*
Pyramid snail *(Turbonilla sp.)*
Other gastropods *(Acteocina oryza)*

Cnidarians
Lined anemone *(Edwardsia sipunculoides)*

Echinoderms
Rat tailed cucumber *(Caudina arenata)*

Habitat 2537 (37 Samples):
Depressions and high flats in shallow water (23 - 31 m) on very fine to fine sand.

Annelids
Clam worm *(Nereis zonata)*
Hesion worm *(Microphthalmus sczelkowii)*
Paddle worm *(Eteone flava)*
Plumed worm *(Diopatra cuprea)*
Thread worm *(Capitella capitata)*

Arthropods
Atlantic rock crab *(Cancer irroratus)*
Lady Crab *(Ovalipes ocellatus)*
Other amphipods *(Melita nitida)*

Habitat 36 (61 Samples):
Depressions and high flats in very shallow to moderate depths (0 – 75 m) on medium to coarse sand.

Arthropods
Green crab *(Carcinus maenas)*
Portly spider crab *(Libinia emarginata)*

Mollusks
Bittium snail *(Bittium alternatum)*
Egg cockle *(Laevicardium mortoni)*

Moderate Depths (31 - 76 m)

Habitat 113 (314 Samples):
Depressions and mid-position flats at moderate depths (23 - 44 m) on very fine sand.

Annelids
Paddle worm *(Parougia caeca)*
Paraonid worm *(Paraonis fulgens)*
Spaghetti-mouth worm *(Asabellides oculata)*
Other polychaetes *(Paranaitis speciosa)*

Arthropods
Other amphipods *(Dulichia monocantha)*

Habitat 372 (125 Samples):
Depressions and los slopes at moderate depths (44 – 75 m) on very fine sand.

Annelids
Feather duster worm *(Euchone incolor)*
Fringe worm *(Tharyx dorsobranchialis, T. marioni)*
Thread worm *(Cossura longocirrata, Lumbrineris hebes, Ninoe nigripes)*
Spionid mud worm *(Polydora socialis, Prionospio steenstrupi)*
Paddle worm *(Eteone lacteal, E. longa)*
Paraonid worm *(Acmira catherinae, Aricidea quadrilobata, Tauberia gracilis)*
Scale worm *(Hartmania moorei, Pholoe minuta)*
Shimmy worm *(Nephtys incisa)*
Other polychaetes *(Apistobranchus typicus, Drilonereis longa, Mediomastus ambiesetae, Polycirrus sp.)*

Arthropods
Cumacea *(Campylaspis affinis, Campylaspis rubicund, Diastylis abbreviate, D. cornuifer, Jassa falcata, Leptostylis longimana)*
Other amphipods *(Argissa hamatipes, Metopa angustimana, Photis macrocoxa, Stenopleustes)*
Other isopods *(Edotea acuta)*

Mollusks
Alvania *(Alvania carinata)*
Nutclam *(Nucula delphinodonta)*
Short yoldia *(Yoldia sapotilla)*

Echinoderms
Burrowing anemone *(Edwardsia elegans)*
Twelve-tentacle burrowing anemone *(Halcampa duodecimcirrata)*

Phoronids
Horseshoe worm *(Phoronis architecta)*

Habitat 317 (190 Samples):
Mid-position flats at moderate depths (31 - 75 m) on fine to medium sand.

Annelids
Bamboo worm *(Clymenura dispar, Euclymene zonalis)*
Burrowing scale worm *(Sigalion areicola)*
Chevron worm *(Goniadella gracilis)*
Feather duster worm *(Euchone elegans)*
Fringe worm *(Caulleriella killariensis, Chaetozone setosa)*
Thread worm *(Lumbrinerides acuta, Lumbrineris acicularum)*
Orbiniid worm *(Orbinia swani, Scoloplos acmeceps)*
Paraonid worm *(Aricidea wassi, Cirrophoris brevicirratus, C. furcatus, Paraonis pygoenigmatica)*
Sandbar worm *(Ophelia denticulata)*
Scale worm *(Harmothoe extenuata)*
Shimmy worm *(Aglaophamus circinata)*
Spionid mud worm *(Polydora caulleryi)*
Syllid worm *(Exogone hebes, Sphaeroyllis erinaceus, Streptosyllis arenae, Syllides sp.)*
Other polychaetes *(Drilonereis magna)*

Arthropods
Acadian hermit crab *(Pagurus acadianus)*
Lysianisid shrimp *(Hippomedon serratus)*
Sand shrimp *(Crangon septemspinosa)*
Cumacea *(Petalosarsia declivis)*
Tanaidacea *(Tanaissus lilljeborgi)*
Other amphipods *(Acanthohaustorius spinosus , Byblis serrata, Corophium crassicorne, Pseudunciola obliquua, Phoxocephalus holbolli, Protomedeia fasciata, Monoculodes sp., Rhepoxynius hudsoni, Siphonoecetes sp., Unciola inermis)*
Other isopods *(Cirolana polita)*

Mollusks
Chestnut astarte *(Astarte castanea)*
Northern moon shell *(Lunatia triseriata)*
Northern moonsnail *(Euspira immaculata)*
Paper clam *(Lyonsia arenos)*
Pearly top snail *(Margarites groenlandicus)*
Stimpson's whelk *(Colus pygmaeus)*
Top snail *(Solariella obscura)*

Echinoderms
Common sand dollar *(Echinarachnius parma)*

Habitat 223 (98 Samples):
Mid-position flats and depressions at moderate depths (44 - 75 m) on fine to medium sand.

Annelids
Bristle worm *(Spiophanes kroeyeri)*
Terebellid worm *(Polycirrus eximius)*

Arthropods
Cumacea *(Eudorella emarginata, E. truncatula, Eudorellopsis deformis)*
Other amphipods *(Ampelisca macrocephala, A. vadorum, Dyopedos porrectus, Ericthonius rubricornis, Leptocheirus pinguis, Orchomella pinguis, Rhepoxynius epistomus, Unciola irrorata)*
Other decapods *(Stereomastis sculpta)*
Other isopods *(Idotea balthica)*

Mollusks
Bean mussel *(Crenella pectinula)*
Hatchet shell *(Thyasira gouldii)*
Mussel *(Musculus niger)*
Pyramid snail *(Turbonilla interrupta)*
Other gastropods *(Cylichma gouldi, C. alba)*

Nemerteans
Ribbon worm *(Nermertea spp.)*

Sipunculids
Tube worm *(Phascolion strombi)*

Habitat 381 (99 Samples):
Mid and high position flats in moderate depths (44 - 79 m) on fine to very fine sand.

Annelids
Bristle worm *(Spiophanes wigleyi, Sternaspis fossor, Terebellides atlantis)*
Chevron worm *(Goniada maculata)*
Clam worm *(Nereis grayi)*
Fan worm *(Myxicola infundiliulum)*
Feather duster worm *(Chone infundibuliformis)*
Thread worm *(Lumbrineris magalhaensis)*
Spionid mud worm *(Laonice cirrata)*
Paraonid worm *(Acmira cerruti)*
Sandbar worm *(Ophelina acuminata)*
Scale worm *(Gattyana amondseni, Harmothoe imbricata)*
Sea mouse *(Aphrodita hastata)*
Spaghetti-mouth worm *(Melinna elisabethae)*
Sphaerod worm *(Sphaerodoropsis minuta)*
Syllid worm *(Exogone verugera)*
Terebllid worm *(Nicolea venustula, Polycirrus phosphoreus, Streblosoma spiralis)*
Thread-like worm *(Notomastus latericeus, Notomastus luridus)*
Other polychaetes *(Anobothrus gracilis, Asychis biceps, Brada villosa, Clymenella torquata, Leitoscoloplos mamosus, Myriochelle oculata, Praxillura ornate, Protodorvillea gaspiensis, Rhodine gracilior, Scalibregma inflatum)*

Arthropods
Cumacea *(Eudorella pusilla)*
Long-horned skeleton shrimp *(Aeginina longicornis)*
Other amphipods *(Ampelisca agassizi, Anonyx liljeborgi, A. sarsi, Casco bigelowi, Diastylis quadrispinosa, D. sculpta, Eriopisa elongate, Ericthonius brasiliensis, Ericthonius fasciatus, Harpinia propinqua, Melita sp., Orchomene minuta, Photis dentata)*
Other decapod *(Axius serratus)*
Other isopods *(Pleurogonium inerme, P. runicundum, P. spinossimum, Ptilanthura tenuis, P. tricarina)*

Mollusks
Alvania *(Alvania exarata)*
Arctic paper-bubble *(Diaphana minuta)*
Astarte *(Astarte undata)*
Bean mussel *(Crenella decussate, C. glandula)*
Hatchet shell *(Thyasira flexuosa, T. trisinuata)*
Spoon shell *(Periploma fragile, P. papyratium)*
Stimpson's whelk *(Colus pubescens)*

Echinoderms
Sea cucumber *(Pentamera calcigera)*
Slender-armed star *(Leptasterias tenera)*

Bryozoans
A bryozoan *(Hippodiplosia propinqua)*

Hemichordates
Acorn worm *(Stereobalanus canadensis)*

Moderate to Deep Depths (76 - 139 m)

Habitat 82 (92 Samples):
All types of flats in moderately deep water (44 – 139 m) on medium to coarse sand.

Mollusks
Sea scallop *(Placopecten magellanicus)*
Cup-and-saucer limpet *(Crucibulum striatum)*
Limpet *(Acmaea testudinalis)*

Echinoderms
Green sea urchin *(Strongylocentrotus droebachiensis)*

Habitat 949 (31 Samples):
Mid and low flats in deep water (75-139 m) on medium to fine sand.

Mollusks
Longfin squid *(Loligo pealeii)*

Habitat 66 (121 Samples):
Hihg flats and slopes in moderately deep water (75 - 139 m) on very fine to fine sand.

Annelids
Bamboo worm *(Paralacydonia paradoxa)*
Fringe worm *(Tharyx tesselata)*
Hesion worm *(Gyptis vittata)*
Thread worm *(Lumbrineris brevipes)*
Shimmy worm *(Aglaophamus minusculus)*

Echinoderms
Dwarf brittlestar *(Amphipholis squamata)*

Cnidarians
Slender sea pen *(Stylatula elegans)*

***Habitat 3** (78 Samples):
Flats and slopes at moderate to very deep depths (average 128 m, min 44 m) on fine to very fine sand.

No diagnostic species, samples largely empty except for deep sea *Spirula* squid (*Sepioidea)*. Not a benthic habitat type, but listed here for completeness.

Habitat 11 (78 Samples):
High slopes, canyons, flats in deep water (60 – 485 m) on medium to fine sand.

Arthropods
Shrimp *(Pontophilus brevirostris)*
Arthropods *(Pycnogonum littorale)*
Bristled longbeak shrimp *(Dichelopandalus leptocerus)*
Deepwater humpback shrimp *(Solenocera necopina)*
Friendly blade shrimp *(Spirontocaris liljeborgii)*
Hermit crab *(Catapagurus sharreri)*
Krill *(Thysanoessa longicaudata)*
Parrot shrimp *(Spirontocaris spinus)*
Rose shrimp *(Parapenaeus politus)*
Sand shrimp *(Crangon septemspinosa)*
Shrimp *(Palicus gracilis)*
Slender tube makers *(Ericthonius difformis)*
Squat lobsters *(Munida valida)*
Striped barnacle *(Balanus hameri)*
Other amphipods (*Monoculodes spp.*, *Tiron acanthurus*)

Mollusks
Bobtail squid *(Rossia tenera)*
Iceland cockle *(Clinocardium ciliatum)*
Iceland scallop *(Chlamys islandica)*
Offshore octopus *(Bathypolypus arcticus)*
Rock borer clam *(Panomya arctica)*

Cnidarians
Badge sea star *(Porania insignis)*
Blood star *(Henricia sanguinoleata)*
Margined sea star *(Astropecten americana)*
Northern sea star *(Asterias vulgaris)*

Habitat 437 (34 Samples):
High flats and slopes in deep to very deep water (75 - 200 m) on fine sand.

Arthropods
American Lobster *(Homarus americanus)*
Jonah Crab *(Cancer borealis)*
Swimming crab *(Bathynectes superba)*
Other decapods *(Geryon quinquedens)*

Mollusks
Northern shortfin squid *(Illex illecebrosus)*
Longfin squid *(Loligo pealeii)*

Echinoderms
Margined sea stars *(Astropecten cingulatus)*

Habitat 6 (105 Samples):
High slopes and flats at moderate to deep depths (44 - 139 m) on coarse to fine sand.

Arthropdoda
Aesop shrimp (*Pandalus montagui*)
Arctic lyre crab (*Hyas coarctatus*)
Hermit crab (*Pagurus pubescens*)

Mollusks
Chiton-like mullusk (*Amphineura spp.*)
Arctic rock borer (*Hiatella arctica*)
Jingle shell (*Anomia simplex*)
Mussel (*Musculus discors*)

Echinoderms
Daisy brittle star
(*Ophiopholis amphiuridae*)
Green sea urchin
(*Strongylocentrotus droebachiensis*)

***Habitat 1** (627 Samples):
Variable settings in a wide range of depths on fine to coarse sand. A very mixed set of samples with many unidentified species and few commonalities. Not a benthic habitat type, but listed here for completeness.

Deep to Very Deep (> 139 m)

Habitat 387 (29 Samples):
High slopes and flats in very deep water (>139 m) on fine sand.

Annelids
Beard worm *(Siboglinum ekmani)*
Plumed worm *(Onuphis opalina)*
Fairy shrimp *(Erythrops erythrophthalma)*
Cumacea *(Eudorella hispida)*

Molluks
Ark shell *(Bathyarca pectunculoides)*
Chestnut Astarte *(Astarte subequilatera)*
Nutclam *(Nuculana acuta)*
Occidental Tuskshell *(Antalis occidentale)*
Rusty Axinopsid *(Mendicula ferruginosa)*
Other bivalves *(Lucina filosa)*

Echinoderms
Sea butterfly *(Thecosomata)*
Burrowing brittle star *(Amphioplus macilentus, Amphilimna olivacea)*

Hemichordates
Acorn worm (*Enteropneusta)*

Nemotoda
Round worm (*Nematoda)*

Protozoans
Foraminiferida

Sipunculids
Peanut worm (*Golfingia catharinae, Onchnesoma steenstrupi*

Mid-Atlantic Bight

Table 3-8. Physical factor values that correspond to ecological thresholds in the Mid-Atlantic Bight subregion.

Bathymetry (m)	Sediment Grain Size (mm)	Seabed Form
0-15	0-0.18 (silt and very fine sand	Depression
15-22	0.18-0.35 (fine sand)	Mid Flat
22-45	0.35-0.36 (sand)	High Flat
45-48	0.36 -0.48 (sand)	Low Slope
48-82	>=0.48 (coarse sand)	Sideslope
82-95		Steep
95-592		
>592		

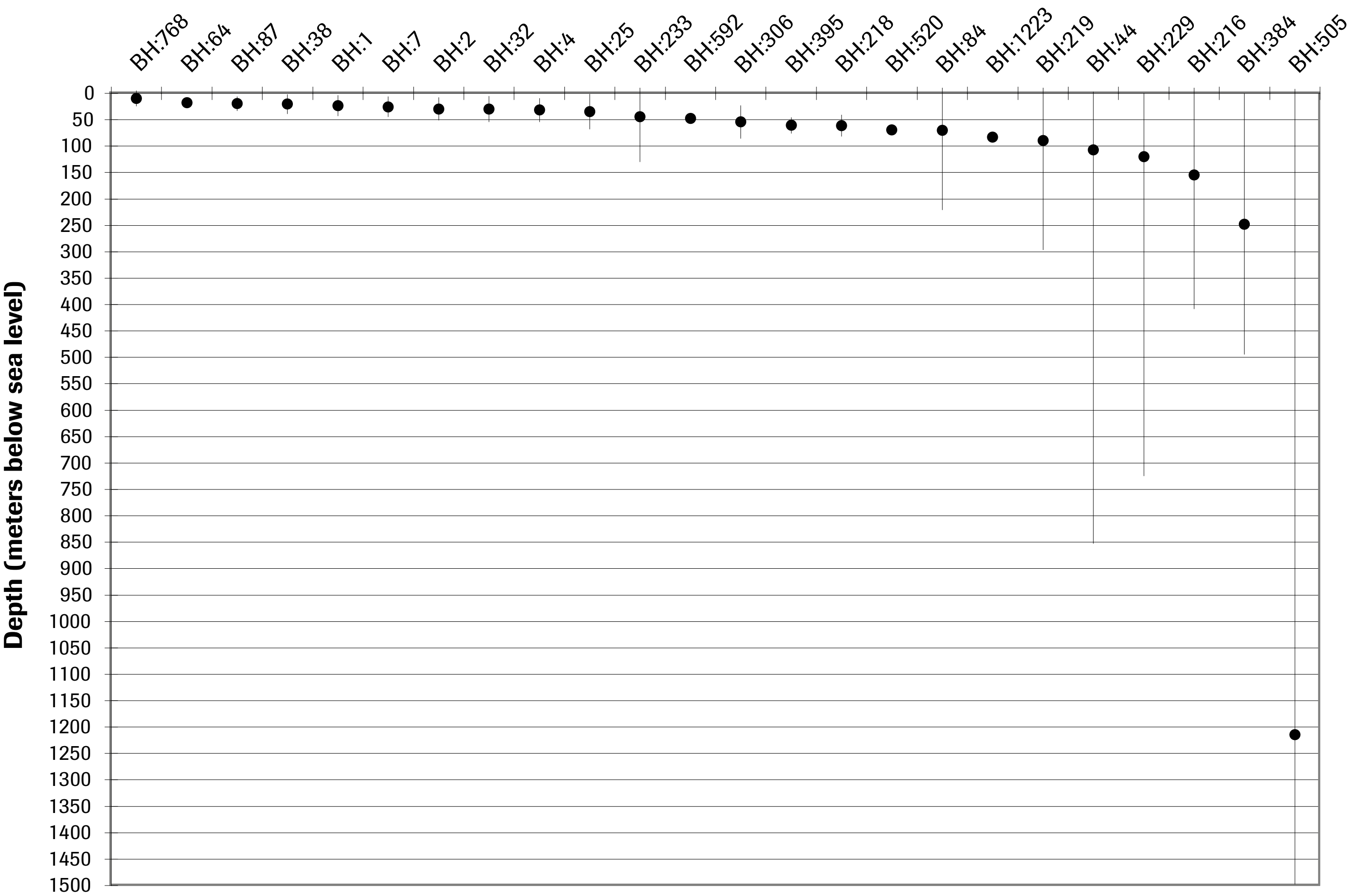


Figure 3-18. Average depth and range of each benthic habitat type in the Mid-Atlantic Bight subregion. Lines represent two standard deviations above and below the mean. Habitat types with the same depths often differ from each other by sediment grain size or topographic location. Habitats with very large depth ranges are widespread associations often unrelated to, or only weakly correlated with, depth.

Very Shallow (0 – 22 m)

Habitat 768 (22 Samples):
Depressions in very shallow water (0 - 15 m) on silt to fine sand.

Arthropods
Mysid shrimp *(Neomysis americana)*
Other amphipods *(Ampelisca abdita)*

Mollusks
Elongated macoma *(Macoma tenta)*
Tellin clam *(Tellina sybaritica)*
Channeled whelk *(Busycon canaliculatum)*
Cone snail *(Kurtziella cerina)*
Dove shell *(Mitrella lunata)*
Pyramid snail *(Odostomia winkleyi)*
Solitary glassy bubble *(Retusa canaliculata)*
Wentletraps *(Epitonium rupicola)*

Echinoderms
Burrowing brittle star *(Micropholis atra)*

Habitat 64 (62 Samples):
Depressions and mid-position flats in shallow water (15 and 22 m) on medium sand.

Annelids
Blood worm (*Hemipodus roseus*)
Fringe worm (*Tharyx* sp.)
Hesion worm (*Microphthalmus sczelkowii*)
Thread worm (*Lumbrineris acicularum*)
Paddle worm (*Hesionura augeneri*)
Paraonid worm (*Acmira catherinae, A. cerruti*)
Sandbar worm (*Ophelia denticulata*)
Spaghetti-mouth worm (*Ampharete arctica*)
Syllid worm (*Brania wellfleetensis, Streptosyllis pettiboneae, S. websteri, Syllides longicirrata*)
Other polychaetes (*Pisione remota*)

Arthropods
Sharp-tailed cumacean (*Oxyurostylis smithi*)
Other isopods (*Chiridotea arenicola*)

Mollusks
Blue mussel (*Mytilus edulis*)
Dove shell (*Anachis lafresnayi*)
Eastern aligena (*Aligena elevata*)

Habitat 87 (20 Samples):
Depressions and high flats in shallow water (15 - 22 m) on medium sand.

Annelids
Burrowing scale worm *(Sigalion areicola)*
Fringe worm *(Caulleriella killariensis)*
Mageloni worm *(Magelona riojai)*
Spionid mud worm *(Scolelepis squamata, Dispio uncinata, Polydora caulleryi)*
Sphaerod worm *(Sphaerodoropsis corrugata)*
Syllid worm *(Streptosyllis varians)*

Arthropods
Glass shrimp *(Leptochelia savignyi)*
Gammarid amphipods *(Acanthohaustorius bousfieli, A.intermedius, A. Similis)*
Other amphipods *(Bathyporeia quoddyensis, B. parkeri, B. quoddyensis, Parahaustorius attenuates, Synchelidium americanum)*
Tanaidacea *(Tanaissus lilljeborgi)*
Other isopods *(Chiridotea tuftsi)*

Echinoderms
Sand dollar *(Encope emarginata)*

Mollusks
Atlantic razor *(Siliqua costata)*
Gould's pandora *(Pandora trilineata)*
Lea's spoon shell *(Periploma leanum)*
Pandora *(Pandora trilineata)*
Surf clam *(Spisula solidissima)*
Margin shells *(Dentimargo eburneolus)*

Habitat 38 (95 Samples):
Depressions in water shallow (15 - 22 m) on medium to coarse sand.

Annelids
Bamboo worm (*Owenia fusiformis*)
Chevron worm (*Glycinde solitaria*)
Orbiniid worm (*Scoloplos rubra*)
Paddle worm (*Eteone heteropoda, Eteone lactea*)
Plumed worm (*Diopatra cuprea*)
Shimmy worm (*Nephtys picta*)
Spionid mud worm (*Paraprionospio pinnata, Polydora ligni, Prionospio pygmaea, Scolelepis bousfieldi, Spio pettiboneae, S. setosa*)
Thread worm (*Notomastus hemipodus, N. luridus*)

Arthropods
Olivepit porcelain crab (*Euceramus praelongus*)
Pea crab (*Pinnixa sayana*)
Other amphipods (*Corophium tuberculatum, Parametopella cypris*)

Mollusks
Arctic paper-bubble (*Diaphana minuta*)
Common razor clam (*Ensis directus*)
Pandora (*Pandora bushiana*)
Margin shells (*Marginella virginiana*)
Miniature moonsnail (*Tectonatica pusilla*)
Pitted baby-bubble (*Acteon punctostriatus*)
Pyramid snail (*Odostomia* sp., *Turbonilla interrupta*)
Solitary glassy-bubble (*Haminoea solitaria*)
Northern dwarf tellin (*Tellina agilis*)
Other gastropods (*Acteocina oryza*)

Hemichordates
Acorn worm (*Stereobalanus canadensis*)

Shallow (22 - 45 m)

Habitat 1(109 Samples):
Depressions and mid-position flats, shallow to moderate depth (0 - 45 m) on coarse to fine sand.

Annelids
Shimmy worm (*Nephtys bucera*)

Arthropods
Other amphipods (*Protohaustorius deichmannae, Acanthohaustorius spinosus, A. shoemakeri*)

Mollusks
Astarte (*Astarte borealis*)
Lunate crassinella (*Crassinella lunulata*)

Chordates
Lancelet (*Branchiostoma virginiae*)

Habitat 7 (83 Samples):
Mid-position flats and depressions in shallow water (25 - 45 m) on medium to coarse substrate.

Annelids
Blood worm (*Hemipodus armatus*)
Fringe worm (*Tharyx acutus, T. Annulosus*)
Hesion worm (*Microphthalmus aberrans*)
Thread worm (*Lumbrineris coccinea, L.fragilis*)
Spionid mud worm (*Prionospio malmgreni, Spio filicornis*)
Paraonid worm (*Aricidea jeffreysii, Paraonides lyra*)
Syllid worm (*Eusyllis blomstrandi, Syllis cornuta*)
Other polychaetes (*Protodrilus symbioticus*)

Arthropods
Tanaidacea (*Leptognathia caeca*)

Cnidarians
Frilled anemone (*Metridium senile*)

Echinoderms
Common sea star (*Asterias forbesi*)

Habitat 2 (58 Samples):
Flat depressions at shallow to moderate depth (0 - 45 m) in medium sand.

Annelids
Bamboo worm (*Asychis elongata*)
Burrowing scale worm (*Sthenelais boa*)
Chevron worm (*Goniada norvegica, G. carolinae*)

Flabelliger worm (*Pherusa affinis*)
Fringe worm (*Tharyx dorsobranchialis, T. marioni*)
Spionid mud worm (*Polydora quadrilobata, Streblospio benedicti*)
Paddle worm (*Eteone longa, Paranaitis speciosa*)
Paraonid worm (*Tauberia gracilis*)
Shimmy worm (*Nephtys incisa*)
Spaghetti-mouth worm (*Asabellides oculata*)
Thread-like worm (*Cossura longocirrata*)
Threadworm (*Capitella capitata*)

Arthropods
Amphipod (*Dulichia monocantha, Photis macrocoxa*)

Cnidarians
Burrowing anemone (*Edwardsia elegans*)
Sea cucumber (*Pentamera calcigera*)

Mollusks
Dog welk (*Nassarius trivittatus*)
False quahog (*Pitar morrhuana*)
File yoldia (*Yoldia limatula*)
Hard-shelled clam (*Venus gallina*)
Nutclam (*Nucula annulata, N. proxima*)
Short yoldia (*Yoldia sapotilla*)

Phoronids
Horeshoe worm (*Phoronis architecta*)

Habitat 32 (52 Samples):
Mid-position flats at shallow to moderate depths (22 - 45 m) on medium sand.

Arthropods
Atlantic rock crab *(Cancer irroratus)*
Longnose spider crab *(Libinia dubia)*

Mollusks
Common northern moon snail *(Euspira heros)*
Northern moon shell *(Lunatia triseriata)*
Astarte *(Astarte quadrans)*
Blood ark *(Anadara ovalis)*

Echinoderms
Common sand dollar *(Echinarachnius parma)*

Habitat 4 (128 Samples):
Mid-position flats in shallow water (25 - 45 m) on coarse to medium sand.

Annelids
Bamboo worm (*Clymennella zonalis*)
Chevron worm (*Goniadella gracilis*)
Thread worm (*Lumbrinerides acuta*)
Syllid worm (*Streptosyllis arenae*)
Other polychaetes (*Polygordius triestinus*)

Arthropods
Other amphipods (*Parahaustorius longimerus*)
Other isopods (*Cirolana polita, Chiridotea coeca*)

Mollusks
Chestnut astarte (*Astarte castanea*)

Moderate depth (45 - 82 m)

Habitat 25 (46 Samples):
Depressions at moderate depths (15 - 82 m) on fine to coarse sand.

Annelids
Bamboo worm (*Myriochelle heeri*)
Bristle worm (*Spiophanes bombyx, S. missionensis*)
Mageloni worm (*Magelona rosea*)
Spionid mud worm (*Scolelepis sp.*)
Orbiniid worm (*Orbinia swani*)
Shimmy worm (*Nephtys schmitti*)
Other polychaetes (*Novaquesta trifurcata*)

Arthropods
Mysid shrimp (*Neomysis Americana*)

Mollusks
Moon snail (*Natica clausa*)

Cnidarians
Lined anemone (*Edwardsia sipunculoides*)

Habitat 592 (50 Samples):
Mid-position flats at moderate depth (45 - 82 m) on medium sand.

Annelids
Bamboo worm (*Clymenella torquata, Myriochelle oculata*)
Blood worm (*Glycera dibranchiata*)
Burrowing scale worm (*Sthenelais limicola*)
Fan worm (*Potamilla reniformis*)
Fringe worm (*Cirratulus cirratus*)
Paddle worm (*Anaitides maculata*)
Paraonid worm (*Paraonis fulgens*)
Shimmy worm (*Aglaophamus circinata*)
Other polychaetes (*Leitoscoloplos mamosus*)

Arthropods
Cumacea (*Eudorellopsis deformis*)
Other amphipods (*Argissa hamatipes, Corophium crassicorne, Diastylis sculpta, Hippomedon serratus, Parahaustorius holmesi, P. borealis, P. caroliniensis, Melita dentate, Monoculodes edwardsi , Photis pollex, Pontogeneia inermis, Rhepoxynius hudsoni, Stenopleustes gracilis*)
Other isopods (*Edotea acuta, Idotea metallica*)

Mollusks
Arctic rock borer (*Hiatella arctica*)
Black clam (*Arctica islandica*)
Little cockle (*Cerastoderma pinnulatum*)
Pearly top snail (*Margarites groenlandicus*)
Sea slug (*Acanthodoris pilosa*)
Other gastropods (*Scaphander punctostriatus*)

Habitat 306 (29 Samples):
All types of flats at medium depth (45 - 82 m) on medium sand.

Arthropods
Acadian hermit crab *(Pagurus acadianus)*

Echicoderms
Daisy brittle star *(Ophiopholis amphiuridae)*

Habitat 395 (78 Samples):
Depressions and high flats at moderate depths (45 - 82 m) on fine to medium sand.

Annelids
Bamboo worm *(Clymenura dispar, Macroclymene zonalis)*
Bristle worm *(Terebellides stroemi)*
Fringe worm *(Chaetozone setosa)*
Spionid mud worm *(Polydora socialis)*
Orbiniid worm *(Scoloplos acutus)*
Sandbar worm *(Ophelina cylindricaudata)*
Scale worm *(Antinoella sarsi)*
Spaghetti-mouth worm *(Ampharete acutifrons)*
Syllid worm *(Exogone gemmifera)*
Thread worm *(Lumbrineris tenuis)*
Other polychaetes *(Drilonereis magna, Schistomeringos caecus)*

Arthropods
Other amphipods *(Ampelisca macrocephala, Siphonoecetes smithianus)*
Cumacea *(Eudorella emarginata)*

Mollusks
Moon snails *(Euspira triseriata, E. immaculata)*
Paper clam *(Lyonsia hyalina)*
Paper bubble *(Philine finmarchia)*
Pearly top snails *(Margarites helicinus, M. umbilicatus)*

Echinoderms
Sea star *(Asterias tanneri)*
Purple-spined sea urchin *(Arbacia punctulata)*

Cnidarians
Burrowing anemone *(Ceriantheopsis americana)*

Sipunculids
Tube worm *(Phascolion strombi)*

Habitat 218 (96 Samples):
Depressions at moderate depths (45 - 82 m) on medium to coarse sand.

Annelids
Bamboo worm *(Praxillura ornata)*
Clam worm *(Nereis grayi)*
Feather duster worm *(Euchone incolor)*
Flabelliger worm *(Brada villosa, Diplocirrus hirsutus, Pherusa aspera)*
Thread worm *(Lumbrineris hebes, Ninoe nigripes, Lumbrineris hebes)*
Paddle worm *(Eulalia bilineata)*
Paraonid worm *(Cirrophorus lyriformis)*
Scale worm *(Harmothoe extenuata)*
Sea mouse *(Aphrodita hastata)*
Sphaerod worm *(Sphaerodoridium claparedi, S. minuta)*
Syllid worm *(Typosyllis alternata)*
Terebellid worm *(Nicolea venustula,Polycirrus sp.)*
Other polychaetes *(Drilonereis longa, Meiodorvillea minuta, Scalibregma inflatum)*

Arthropods
Cumacea *(Petalosarsia declivis, Campylaspis affinis)*
Other amphipods *(Ampelisca vadorum, Anonyx sarsi, Casco bigelowi, Leptocheirus pinguis, Orchomella minuta, O. pinguis)*
Other isopods *(Janira alta, Pleurogonium inerme)*

Mollusks
Bean mussel *(Crenella decussata)*
Conrad's thracia *(Thracia morrisoni)*
Mussel *(Musculus discors)*
Nutclam *(Nucula delphinodonta)*
Alvania *(Alvania carinata)*
Stimpson's whelk *(Colus pubescens)*
Striate aclis *(Aclis striata)*

Cnidarians
Twelve-tentacle burrowing anemone *(Halcampa duodecimcirrata)*

520 (31 Samples):
Mid position flats and depressions at moderate depths (45 - 82) on mostly coarse to occsasionaly fine sand.

Annelids
Bamboo worm (*Rhodine gracilior, R. Loveni*)
Bristleworm (*Spiophanes wigleyi, Terebellides atlantis*)
Chevron worm (*Goniada brunnea, G.maculata, Ophioglycera gigantea*)
Clam worm (*Nereis zonata*)
Fan worm (*Myxicola infundiliulum*)
Feather duster worm (*Euchone elegans*)
Fringe worm (*Dodecaceria corallii*)
Thread worm (*Lumbrineris brevipes*)
Spionid mud worm (*Laonice cirrata, Minuspio cirrifera, Polydora giardi, Prionospio steenstrupi*)
Orbiniid worm (*Scoloplos armiger*)
Paddle worm (*Anaitides mucosa, Eumida sanguinea, Mystides boreali, Notophyllum foliosum*)
Paraonid worm (*Aricidea belgicae, Cirrophorus furcatus*)
Parchment worm (*Spiochaetopterus oculatus*)
Sandbar worm (*Ophelina acuminata*)
Scale worm (*Arcteobia anticostiensis, Gattyana nutti, Gattyana sp. Harmothoe imbricate, Pholoe minuta*)
Spaghetti-mouth worm (*Amphicteis gunneri, Melinna cristata, M.elisabethae*)
Syllid worm (*Exogone verugera, Sphaerosyllis erinaceus, Typosyllis tegulum*)
Terebellid worm (*Eupolymnia nebulosa, Polycirrus eximius, P. Medusa, Streblosoma spiralis*)
Threadworm (*Notomastus latericeus*)
Other polychaetes (*Aberranta enigmatica*)

Arthropod
Long-horned skeleton shrimp (*Aeginina longicornis*)
Cumacea (*Eudorella pusilla*)
Other amphipods (*Eriopisa elongate, Anonyx liljeborgi, Ampelisca agassizi, Diastylis quadrispinosa, Ericthonius fasciatus, Harpinia propinqua, Photis dentata, Phoxocephalus holbolli, Unciola irrorata*)
Other decapods (*Axius serratus*)

Mollusks
Astarte (*Astarte undata*)
Hatchet shell (*Thyasira flexuosa*)
Heart clam (*Cyclocardia borealis*)

Spoon shell (*Periploma fragile, P. Papyratium*)
Mussel (*Dacrydium vitreum*)
Pyramid snail (*Odistomia sulcosa*)
Risso (*Boreocingula castanea*)
Other bivalves (*Lucina filosa, Mysella planulata*)

Echinoderms
Sea star (*Asterias rathbuni*)
Dwarf brittlestar (*Amphipholis squamata*)
Margined sea star (*Astropecten irregularis*)

Bryozoans
A bryozoan (*Hippodiplosia propinqua*)

Sipunculids
Peanut worm (*Themiste alutacea*)

Habitat 84 (104 Samples):
All types of flats at moderate depth (22 - 82 m) on fine to medium sand.

Annelids
Beardworm (*Siboglinum bayer, Diplobrachia ii, Oligobrachia floridana*)
Marphysa worm (*Marphysa belli*)
Paddle worm (*Anaitides arenae*)
Sandbar worm (*Ophelina aulogaster*)

Arthropods
Cumacea (*Eudorella truncatula, Pseudoleptocuma minor*)
Other decapods (*Calocaris macandreae*)
Other amphipods (*Ampelisca verrilli, Byblis serrata, Lembos Webster, Rhepoxynius epistomus*)

Echinoderms
Heart sea urchin (*Echinocardium cordatum*)
Sea urchin (*Brisaster fragilis*)
Burrowing brittle star (*Amphioplus macilentus*)

Mollusks
Cross-hatched lucine (*Divaricella quadrisulcata*)
Bean mussel (*Crenella pectinula*)
Astarte (*Astarte elliptica*)
Gould's pandora (*Pandora gouldiana*)
Hard-shelled clam (*Chione latilirata*)
Hatchet shell (*Thyasira trisinuata*)
Lucine clam (*Lucinoma blakeanum*)
Nutclam (*Nuculana acuta*)
Dove shell (*Mitrella dissimilis*)
Margin shells (*Marginella roscida*)
Pyramid snail (*Turbonilla areolata*)
Pyramid snail (*Turbonilla rathbuni*)
Ribbed moelleria (*Moelleria costulata*)
Wentletraps (*Epitonium dallianum*)
Other bivalves (*Cyclopecten nanus*)
Other gastropods (*Granulina ovuformis*)

Deep (82 - 592 m)

Habitat 1223 (35 Samples):
High flats in moderately deep water (82 - 95 m) on medium sand.

Annelids
Bamboo worm (*Clymenura borealis, Euclymene zonalis*)
Blood worm (*Glycera robusta*)
Eunice worm (*Eunice norvegica*)
Fan worm (*Manayunkia aestuarina*)
Feather duster worm (*Chone infundibuliformis, Fabricia sabella*)
Thread worm (*Lumbrineris magalhaensis*)
Spionid mud worm (*Malacoceros indicus, Polydora barbilla, P. concharum*)
Opal worm (*Arabella iricolor, Arabella mutans*)
Orbiniid worm (*Scoloplos acmeceps*)
Paraonid worm (*Acmira lopezi, Aricidea wassi, Paraonis pygoenigmatica*)
Plumed worm (*Onuphis opalina, O. pallidula*)
Sandbar worm (*Travisia parva*)
Shimmy worm (*Aglaophamus igalis, Nephtys squamosa*)
Syllid worm (*Exogone dispar, E.hebes, E.naidina*)
Tube worm (*Hydroides dianthus*)
Other polychaetes (*Drilonereis caulleryi, Protodorvillea gaspiensis*)

Arthropods
Other amphipods (*Idunella bowenae, Jerbarnia Americana, Rhachotropis inflate, Unciola serrata*)
Other isopods (*Apanthura magnifica, Ptilanthura tricarina*)

Mollusks
Bean mussel (*Crenella glandula*)
Eastern beaded chiton (*Chaetopleura apiculata*)
Heart clam (*Pleuromeris tridentata*)
Striate scallop (*Palliolum striatum*)
Other bivalves (*Cumingia tellinoides, Diplodonta punctata, Mysella grippi*)
Other gastropods (*Cocculina beani*)

Cnidarians
Burrowing anemone (*Haloclava producta*)
Twelve-tentacle parasitic anemone (*Peachia parasitica*)

Echinoderms
Margined sea stars (*Astropecten articulatus*)

Habitat 219 (44 Samples):
High flats at moderate depths (45 - 82 m) on coarse to fine sand.

Arthropods
Prawn *(Sergestes robustus)*

Mollusks
Broad yoldia *(Yoldia thraciaeformis)*
Sea scallop *(Placopecten magellanicus)*
Jingle shell *(Anomia simplex)*
Longfin squid *(Loligo pealeii)*
Duckfoot snail *(Aporrhais occidentalis)*

Echidoderms
Mud star *(Ctenodiscus porcell)*

Habitat 44 (82 Samples):
Depressions and mid-position flats mostly very shallow (0 - 22m), but occasionally very deep on fine to coarse sand.

Arthropods
Prawn (*Sergestes arcticus*)
Jonah crab (*Cancer borealis*)
Other isopods (*Chiridotea nigrescens*)

Mollusks
Amethyst gemclam (*Gemma gemma*)
Baltic macoma (*Macoma baltica*)
Little surf clam (*Mulinia lateralis*)

Echinoderms
Northern sea star (*Asterias vulgaris*)

Habitat 229 (57 Samples):
High flats and depressions at shallow to deep depths (22 - 592 m) on a fine to medium sand.

Arthropods
Jonah crab *(Cancer borealis)*

Echinoderms
Common sea star *(Asterias forbesi)*
Northern sea star *(Asterias vulgaris)*
Green sea urchin *(Strongylocentrotus droebachiensis)*

Cnidarians
Anemone *(Actiniaria spp.)*

Habitat 216 (41 Samples):
High slopes in deep water (95 - 592 m) on medium to fine sand.

Arthropods
American lobster *(Homarus americanus)*
Bristled longbeak shrimp *(Dichelopandalus leptocerus)*
Fairy shrimp *(Bathymysis renocullata)*
Friendly blade shrimp *(Spirontocaris liljeborgii)*
Hermit crab *(Pagurus politus)*
Norwegian shrimp *(Pontophilus norvegicus)*
Rose shrimp *(Parapenaeus politus)*
Shrimp *(Palicus gracilis)*
Squat lobsters *(Munida iris, M. valida)*
Other decapods *(Nematocarcinus ensifer, Scyllarus depressus)*

Echinoderms
Margined sea stars *(Astropecten americana)*
Sea urchin *(Genocidaris maculata)*

Cnidarians
Sea feather *(Pennatula aculeata)*

Cephalopods
Bobtail squid *(Rossia glaucopis)*
Offshore octopus *(Bathypolypus arcticus)*
Squid *(Sepioidea)*

Habitat 384 (14 Samples):
High slopes and canyons in deep water (95 - 592 m) on any substrate.

Annelids
Scale worm (*Alentiana aurantiaca*)

Arthropods
Florida lobsterette (*Nephropsis aculeata*)
Royal red shrimp (*Pleoticus robustus*)
Prawn (*Sergestes arcticus*)
Swimming crab (*Bathynectes superba*)

Very Deep (> 592 m)

Habitat 505 (51 Samples):
Slopes and canyons in very deep water (>592 m) on silt and mud.

Annelids
Beardworms *(Pogonophora sp., Siboglinum angustum, S.ekmani, S. holmei, S. pholidotum, Diplobrachia similis)*

Mollusks
Dipperclams *(Cuspidaria glacialis, Cuspidaria parva)*
Hatchet shells *(Thyasira elliptica, T. equalis, T. gouldii)*
Limops *(Limopsis affinis, L. minuta)*
Nutclams *(Nucula tenuis, Nuculana carpenteri)*
Rusty axinopsid *(Mendicula ferruginosa)*
Small-ear fileclam *(Limatula subauriculata)*
Alvania *(Alvania brychia)*
Cone snails *(Mangelia bandella, Oenopota bicarinata, O. ovalis)*
Dove shell *(Anachis haliaecti, Mitrella pura)*
Sea snail *(Cylichna alba)*
Small sea snail *(Balcis stenostoma)*
Whelks *(Colus pygmaeus, C. obesus, C. pygmaeus)*
Wentletraps *(Epitonium pandion)*
Chiton-like mullusk *(Amphineura sp.)*
Occidental tuskshell *(Antalis occidentale)*
Tusk shell *(Dentalium meridionale)*
Other bivalves *(Malletia obtuse, Saturnia subovata)*

Echinoderms
Hairy sea cucmber *(Havelockia scabra)*
Rat-tailed cucumber *(Caudina arenata)*
Brittle star *(Ophiomusium lymani)*
Burrowing brittle star *(Amphiura otteri)*

Cnidarians
Soft coral *(Alcyonacea)*
Stony corals *(Zoantharia)*

Sipunculids
A sipuculid worm *(Golfingia catharinae, G. minuta)*
A tube worm *(Sipunculus norvegicus)*

Habitat 301 (34 Samples):
Any seabed form at moderate to deep depths (45 -592) on any substrate.

Mollusks
Gould's pandora *(Pandora gouldiana)*
Other bivalves *(Lucina filosa)*

Cnidarians
Calcareous coral *(Madreporaria spp.)*

Protozoans
Foraminiferida

Discussion

In the Gulf of Maine/Georges Bank/Scotian Shelf region, World Wildlife Fund and the Conservation Law Foundation conducted an earlier analysis of the seafloor, resulting in "seascapes," a concept similar to EMUs (World Wildlife Fund and Conservation Law Foundation 2006). In their approach, they used fixed depth, bottom temperature and salinity, and sediment type to define a seascape. Our approach was influenced by their work, with some differences. This analysis extends to the entire Northwest Atlantic region and depth and sediment classes were not pre-assigned, but as described above, the cluster analysis of grab samples was used to determine the ecologically relevant splits. Seabed forms were also correlated with the benthic invertebrate assemblages. In addition, temperature and salinity were explored as variables, but not used in this analysis. The assumption was that these two factors may not be geographically stable over long time periods, especially in light of climate change, and the goal was to understand the importance of enduring physical places on benthic habitats.

© SBNMS

The thresholds used to define depth, grain size, and seabed forms for the EMUs were extracted directly from the organism data. This step was important in ensuring that the EMUs represent truly different environments as perceived by the benthic macrofauna. Moreover, this approach allowed us to sidestep the problem of determining which of the many proposed physical factor classifications is best for a given region. Finding the most important physical thresholds for each organism group in order to determine a meaningful number of EMUs to which we could link a clear organism group or set of groups was an important part of this process. The results presented here range from 108 to 168 EMUs per subregion with correspondingly different thresholds for each subregion. Because this approach used the actual types and amounts of seafloor structures, the results are not generalizable to other regions. In other words, the patterns uncovered are ecological, not physiological, and presumably somewhat different relationships between depth and grain-size and benthic assemblages would be observed in other regions.

The use of habitat complexity as a metric for separating *among* examples of the same habitat type is still being explored. The complexity of a habitat can affect whether an animal survives predation. It also affects the number of available niches. To date, habitat complexity has been shown to be correlated with a number of biological variables, including species richness, diversity, abundance, and community composition. Other variables under consideration for distinguishing and prioritizing among examples of the same habitat type include: confirmed rare species such as corals, diversity (phyla to species), size of the feature, intactness relative to human uses, and confirmed importance from other sources. As it will not be possible to conserve all examples of every benthic habitat type, these metrics are intended to help focus conservation on the most critical examples of each type.

Future Research: Demersal Fish Habitats

We will apply this methodology to demersal fish data collected over 40 years in the NMFS bottom trawl surveys. At this point, the proof-of concept analysis has been initiated for demersal fish using data from one year (2005), but the statistical analysis necessary to solidly connect the organism groups with the physical factors have not been performed. However, initial results look promising and a draft of the fish-based habitats will be completed in 2010.

Human Interactions

Benthic habitats are vulnerable to a wide variety of human activities that disturb the physical structure of seafloor sediments or alter the composition of the community. In shallow environments, soft sediment habitats are susceptible to the effects of shoreline hardening and dredging for marinas and navigation. In deeper subtidal habitats, biological resource harvest, particularly trawling in mud and sand, and overfishing affect habitat structure (Gulf of Maine Council 2005).

Commercial fishing is one of the most studied human impacts on the marine benthic environment. Bottom contact nets and dredge fisheries disturb benthic habitats as gear is dragged across the seafloor. Experimental studies suggest that up to 20% of the variability in the macrofauna composition of some benthic communities might be attributed to fishing effects. Overall effects include a decrease in the total number of species and individuals, as well as decreases in the density of several functional groups including deposit feeders, echinoderms, long-lived surface dwellers, and large epifauna (Thrush et al. 1998; Gaspar 2009). Moreover, diversity of the very small "meiofauna," the major contributor to benthic production, also decreases after trawling because of direct mortality or displacement, changes in sediment structure and geochemistry, and alterations in the abundance of predators or competitors. (Schratzberger and Jennings 2002). As these changes are identifiable over broad spatial scales, they are likely to have important ramifications for the development of sustainable fisheries that depend on productive benthic communities.

There is a need to document commercial and recreational fishing efforts on the communities mapped in this chapter, as well as the sensitivities and recovery rates of each habitat type. It may be important to address regulatory efforts pertaining to specific habitat types. For example, vulnerable habitats, such as eelgrass and cold water corals, might be protected through regulations that designate some of these areas as off-limits to bottom tending gear. Other areas, like mud, gravel and cobble, which are much more widespread, could be subjected to rotational closures (Gulf of Maine Council 2005).

LITERATURE CITED

Allee, R. J., M. Detheir, D. Brown, L. Deegan, R. G. Ford, T. F. Hourigan, J. Maragos, C. Schoch, K. Sealey, R. Twilley, M. P. Weinstein and M. Yoklavich. 2000. Marine and estuarine ecosystem and habitat classification. NOAA Technical Memorandum. NMFS-F/SPO-43.

Anderson, T. J. and M. M. Yoklavich. 2007. Multiscale habitat associations of deepwater demersal fishes off central California. Fishery Bulletin. 105:168-179.

Auster, P. J. 2006. Linking Seafloor Habitat Mapping Protocols to Management and Policy Needs. Funding application to US Environmental Protection Agency.

Auster, P. J., K. Joy and P. C. Valentine. 2001. Fish species and community distributions as proxies for seafloor habitat distributions: the Stellwagen Bank National Marine Sanctuary example (Northwest Atlantic, Gulf of Maine). Environmental Biology of Fishes 60:331-346.

Brown, B. 1993. A Classification System of Marine and Estuarine Habitats in Maine: An Ecosystem Approach to Habitats. Maine Natural Areas Program. Department of Economic and Community Development. 51 pp. Augusta, ME.

Brown, S.K. 2002. Our living Oceans Benthic Habitat Classification System. NOAA NMFS Office of Science and Technology.

Charton, J. A. and A. Perez Ruzafa. 1998. Correlation between habitat structure and a rocky reef fish assemblage in the southwest Mediterranean. Marine Ecology. 19:111-128.

Connor, D. W., J. Allen, N. Golding, K. Howell, L. Lieberknecht, K. Northen, and J. Reker. 2004. The national marine habitat classification for Britain and Ireland, version 04.05. Joint Nature Conservation Committee. http://www.jncc.gov.uk/pdf/04_05_introduction.pdf .

Danovaro, R., C. Gambi, A. Dell'Anno, C. Corinaldesi, S. Fraschetti, A. Vanreusel, M. Vincx, and A. J. Gooday. 2008. Exponetial decline of deep-sea ecosystem functioning linked to benthic biodiversity loss. Current Biology. 18(1): 1-8.

Davies, C., D. Moss, and M. O. Hill. 2004. EUNIS Habitat Classification. European Environment Agency.

DeLong, A. K. and J. S. Collie. 2004. Defining Essential Fish Habitat: A Model-Based Approach. Rhode Island Sea Grant, Narragansett, R.I.

Dethier, M. N. 1992. Classifying marine and estuarine natural communities: an alternative to the Cowardin system. Natural Areas Journal. 12(2): 90-100.

Divins, D. L., and D. Metzger. NGDC Coastal Relief Model. Accessed 2008. http://www.ngdc.noaa.gov/mgg/coastal/coastal.html.

Dufrene, M. and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecolological Monographs. 67(3): 345-366.

Etter, R. J., and J. F. Grassle. 1992. Patterns of species diversity in the deep sea as a function of sediment particle size diversity. Nature. 360: 576-578.

European Environment Agency. 1999. European Topic Centre on Nature Conservation. Work Programme: Task 4.3 EUNIS Habitat Classification, Draft Final Report. 209 pp. http://www.searchmesh.net/.

Fels, J. and R. Zobel. 1995. Landscape position and classifying landtype mapping for statewide DRASTIC mapping Project. North Carolina State University. Technical Report. VEL.95.1 to the North Carolina Department of Environment, Health, and Natural Resources, Division of Environmental Management.

Fogarty, M. J. and C. Keith. 2007. Delineation of Regional Ecosystem Units on the U.S. Northeast Continental Shelf. Northeast Fisheries Science Center, National Marine Fisheries Service, Woods Hole, MA.

Folk, R. L., 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. Journal of Geology. 62 (4): 344-359.

Gaspar, M. B., Carvalho, S., Constantino, R., Tata-Regala, J., Cúrdia, J., and Monteiro, C. C. 2009. Can we infer dredge fishing effort from macrobenthic community structure? ICES Journal of Marine Science 66: 2121–2132.

Gosner, K. L. 1979. A field guide to the Atlantic seashore. Houghton Mifflin, Boston, MA. 329 pp.

Greene, H. G., J. J. Bizzarro, J. E. Tilden, H. L. Lopez, and M. D. Erdey. 2005. The benefits and pitfalls of geographic information systems in marine benthic habitat mapping. Pages 34-46, in Wright, D. J. and Scholz, A. J., eds. Place Matters. Oregon State University Press, Portland, OR.

Greene, H. G., M. M. Yoklavich, R. M. Starr, V. M. O'Connell, W. W. Wakefield, D. E. Sullivan, J. E. McRea Jr., and G. M. Caillet. 1999. A classification scheme for deep seafloor habitats. Oceanologica Acta. 22: 663-678.

Gulf of Maine Council on the Environment. 2005. Workshop Proceedings: Marine Habitats in the Gulf of Maine. Online publication. http://www.gulfofmaine.org/council/publications/marine-habitat-workshop-proceedings.pdf.

Kostylev, V. E, B. J. Todd, G. B. Fader, R. C. Courtney, G. D. M. Cameron, and R.A. Pickrill. 2001. Benthic habitat mapping on the Scotian Shelf based on multibeam bathymetry, surficial geology and sea floor photographs. Marine Ecology Progress Series. 219: 121-137.

Kutcher, T. E. 2006. A comparison of functionality between two coastal classification schemes developed within the National Oceanic and Atmospheric Administration. Report to NOAA/NOS/OCRM. Silver Spring, MD. 5 pp.

Levin, L. A., R. J. Etter, M. A. Rex, A. J. Gooday, C. R. Smith, J. Pineda, C. T. Stuart, R. R. Hessler, and D. Pawson. 2001. Environmental influences on regional deep-sea species diversity. Annual Review of Ecology, Evolution, and Systematics. 32: 51-93.

Lindholm, J. B., P. J. Auster, and L. S. Kaufman. 1999. Habitat-mediated survivorship of juvenile (0-year) Atlantic cod *Gadus morhua*. Marine Ecology Progress Series. 180: 247-255.

Lough, R. G., P. C. Valentine, D. C. Potter, P. J. Auditore, G. R. Bolz, J. D. Neilson, and R. I. Perry. 1989. Ecology and distribution of juvenile cod and haddock in relation to sediment type and bottom currents on eastern Georges Bank. Marine Ecology Progress Series. 56: 1-12.

Lund, K. and A. R. Wilbur. 2007. Habitat Feasibility study of coastal and marine environments in Massachusetts. Massachusetts Office of Coastal Zone Management. Boston, MA. 31 pp.

Madden, C. J., K. Goodin, R. J. Allee, G. Cicchetti, C. Moses, M. Finkbeiner, and D. Bamford. 2009. Coastal and Marine Ecological Classification Standard. NOAA and NatureServe. 107 pp.

Mahon, R., S. K. Brown, K. C. T. Zwanenburg, D. B. Atkinson, K. R. Buja, L. Clafin, G. D. Howell, M. E. Monaco, R. N. O'Boyle, and M. Sinclair. 1998. Assemblages and biogeography of demersal fishes of the east coast of North America. Canadian Journal of Fisheries and Aquatic Sciences. 55: 1704-1738.

McCune, B. and J. B Grace. 2002. Analysis of Ecological Communities. MjM software design. Oregon USA. 300 pp. www.pcord.com.

NERRS (National Estuarine Research Reserve System). 2000. Evaluations of marine and estuarine ecosystem and habitat classification. NOAA Technical Memorandum. NMFS-F/SPO-43.

National Ocean Service, Office of Coast Survey, US Bathymetric & Fishing Maps. Accessed 2008. http://www.ngdc.noaa.gov/mgg/bathymetry/.

Norse, E. A. 1993. Global marine biological diversity. Center for Marine Conservation. Island Press, Washington, D.C. 383 pp.

Pollock, L. W. 1998. A Practical Guide to the Marine Annimals of Northeast North America. Rutgers University Press. New Brunswick, NJ.

Reid, J. M., J. A. Reid, C. J. Jenkins, M. E. Hastings, S. J. Williams, and L. J. Poppe. 2005. usSEABED: Atlantic coast offshore surficial sediment data release: U.S. Geological Survey Data Series 118, version 1.0. http://pubs.usgs.gov/ds/2005/118/.

Roworth, E. and R. Signell. 1998. Construction of a Digital Bathymetry for the Gulf of Maine. U.S.Geological Survey Publications. of98-901. http://pubs.usgs.gov/of/1998/of98-801/bathy/.

Schratzberger, M., and S. Jennings. 2002. Impacts of chronic trawling disturbance on meiofaunal communities. Marine Biology. 141: 991-1000.

Serrano, A., and I. Preciado. 2007. Environmental factors structuring polychaete communities in shallow rocky habitats: role of physical stress versus habitat complexity. Helgoland Marine Research. 61: 17-29.

Shepard, F. P. 1954. Nomenclature based on sand-silt-clay ratios. Journal of Sedimentary Petrology. 24: 151-158.

Stevenson D., L. Chiarella, D. Stephan, R. Reid, K. Wilhelm, J. McCarthy and M. Pentony. 2004. Characterization of the fishing practices and marine benthic ecosystems of the northeast US shelf, and an evaluation of the potential effects of fishing on essential habitat. NOAA Technical Memorandum. NMFS NE 181. 179 pp.

Theroux, R. B. and R. L. Wigley. 1998. Quantitative composition and distribution of the macrobenthic invertebrate fauna of the continental shelf ecosystems of the northeastern United States. NOAA Technical Report. NMFS 140. 240 pp.

Thrush, S. F., J. E. Hewitt, V. J. Cummings, P. K. Dayton, M. Cryer, S. J. Turner, G. A. Funnell, R. G. Budd, C. J Milburn, and M. R. Wilkinson. 1998. Disturbance of the marine benthic habitat by commercial fishing: Impacts at the scale of the fishery. Ecological Applications. (8)3: 866-879.

Todd, B. J. and H. G. Greene. 2008. Mapping the Seafloor for Habitat Characterization. Geological Association of Canada. 327 pp.

Valentine, P. C., B. J. Todd, and V. E. Kostylev. 2005. Classification of marine sublittoral habitats, with application to the northeastern North America region. American Fisheries Society Symposium 41:183-200. Available at: http://woodshole.er.usgs.gov/project-pages/stellwagen/index.html. 31.

Weiss, H. M. 1995. Marine animals of Southern New England and New York. State geological and natural history survey of Connecticut. Connecticut Department of Environmental Protection. Bulletin 115.

Wentworth, C. K. 1922. A scale of grade and class terms for clastic sediments. Journal of Geology. 30: 377–392.

Wigley, R. L. and R. B. Theroux. 1981. Atlantic continental shelf and slope of the United States-Macrobenthic invertebrate fauna of the Middle Atlantic Bight region-Faunal composition and quantitative distribution. Dept. of Interior, Geological Survey. Prof. Paper 529-N.

World Wildlife Fund and Conservation Law Foundation. 2006. Marine Ecosystem Conservation for New England and Maritime Canada: a Science-Based Approach to Identifying Priority Areas for Conservation. Conservation Law Foundation, Boston, MA and WWF-Canada, Halifax, Nova Scotia.

APPENDIX 1

Distribution of benthic habitats in each subregion across each physical factor (depth, sediment grain size, and seabed forms). A p-value of <0.01 for the chi-square test indicates that the observed distribution is significantly different than expected if the habitat was randomly distributed.

Gulf of Maine Benthic Habitat (Code)	Depth (m)									Sediment Grain Size (mm)						Seabed Forms						
	0-42	42-61	61-70	70-84	84-101	101-143	143-233	>=233	p-value	0-0.04 (mud and silt)	0.04-0.17 (very fine sand)	0.17-0.36 (fine sand)	0.36-0.54 (sand)	>=0.54 (coarse sand and gravel)	p-value	Depression	Mid Flat	High Flat	Low Slope	High Slope	Sideslope/Steep**	p-value
1		32%	16%	2%	46%	5%			0.00	16%		69%	15%		0.00			63%		37%		0.05
2			8%	18%	47%	28%			0.00	41%		38%	21%		0.00			90%	5%	5%		0.03
*4		1%	11%	23%	51%	14%			0.00	19%		68%	13%		0.00		53%	47%				0.00
5						37%	63%	0%	0.00	15%		67%	18%		0.00	35%		30%	22%	13%		0.24
7				12%	15%	8%	66%		0.00	39%		33%	14%	15%	0.00	55%		32%		12%		0.04
8							100%		0.00	89%		8%	3%		0.00	93%			3%		4%	0.00
9		19%	19%	42%	21%				0.00			89%	11%		0.00		88%	12%				0.00
12			22%	44%	11%	4%		20%	0.00			85%	16%		0.00		56%			9%	35%	0.00
18						14%	56%	30%	0.01	34%		55%	11%		0.00			100%				0.00
24			3%	35%	62%				0.00	7%		87%	7%		0.00		100%	0%				0.00
72						1%	99%		0.00	96%		4%			0.00	78%		22%				0.03
87						12%	88%		0.00	95%		5%			0.00	80%		20%				0.00
91		34%	41%	21%	4%				0.00			89%	11%		0.00		100%					0.00
103								100%	0.00	50%		49%	2%		0.00	47%				49%	4%	0.04
133			3%	75%	22%				0.00			97%	3%		0.00		100%					0.00
*139		44%	11%	39%		5%			0.00			86%	14%		0.00		48%	12%		32%	8%	0.00
183		12%	17%	41%	30%				0.00			92%	8%		0.00		88%	12%				0.00
247				9%		32%	59%		0.00	92%		9%			0.00	45%		49%	6%			0.15
557	3%	57%	39%	2%					0.00			72%	29%		0.00		100%					0.00
1028			15%	27%	59%				0.00			87%	13%		0.00		95%	6%				0.00
*1078			16%	50%	35%				0.00			97%	3%		0.00		100%					0.00
1451		24%	18%	48%	10%				0.00			90%	10%		0.00		100%					0.00
2367			100%						0.00	5%	95%				0.00	100%						0.00

*Apparently poor samples, few species, no diagnostics. Not a habitat type, but included here for completeness.

**Groups were combined due to few sampling points.

Southern New England Benthic Habitat (Code)	Depth (m)								Sediment Grain Size (mm)						Seabed Forms						
	0-9	9-23	23-31	31-44	44-76	76-139	>=139	p-value	0-0.03 (mud and silt)	0.03-0.16 (very fine sand)	0.16-0.34 (fine sand)	0.34-0.36 (sand)	>=0.36 (medium and coarse sand)	p-value	Depression	Mid Flat	High Flat	Low Slope	High Slope	Sideslope/Steep**	p-value
*1	78%	22%						0.00		18%	34%		48%	0.00	42%		27%		30%	1%	0.00
3						78%	22%	0.00		58%	42%			0.00		12%	42%		47%		0.00
6				24%	63%	13%		0.00			14%	16%	71%	0.00	18%	30%	52%				0.01
11					24%	62%	15%	0.00			21%	79%		0.00		28%	29%		40%	3%	0.00
25	27%	60%	14%					0.00		3%	25%		72%	0.00	60%		17%			24%	0.00
36	65%	17%	6%		12%			0.00				27%	73%	0.00	50%		41%	9%			0.00
66						100%		0.00	70%	30%				0.00	51%	31%	18%				0.00
82					81%	19%		0.00			7%	48%	45%	0.00	21%	54%	25%				0.00
109	63%	24%	14%					0.00	29%				71%	0.00	100%						0.00
113			98%	2%				0.00		100%				0.00	67%	33%				1%	0.00
200	71%	7%	11%	11%				0.00		47%	16%		38%	0.00	100%						0.00
223		4%		4%	92%	0%		0.00			42%		58%	0.00	13%	87%					0.00
229		12%	79%	9%				0.00		100%				0.00	100%						0.00
230			92%	8%				0.00		100%				0.00	99%					1%	0.00
316		41%	59%					0.00		34%	48%		18%	0.00	69%	11%	20%				0.00
317			9%	66%	26%			0.00			68%		33%	0.00		100%					0.00
372			32%	10%	58%			0.00		100%				0.00	88%			12%			0.00
381					99%	1%		0.00		18%	83%			0.00		79%	21%				0.00
387						14%	86%	0.00		1%	99%			0.00			42%		58%		0.00
390		8%	80%	12%				0.00		85%	15%			0.00	94%					7%	0.00
437						77%	23%	0.00		5%	95%			0.00			41%		59%		0.00
873		9%	90%	0%				0.00		49%	29%		22%	0.00	52%	4%	33%			11%	0.00
949						100%		0.00			25%	75%		0.00		89%	11%				0.00
2537			90%	10%				0.00		55%	45%			0.00	81%		19%				0.00

*Apparently poor samples, few species, no diagnostics. Not a habitat type, but included here for completeness.

**Groups were combined due to few sampling points.

Mid-Atlantic Bight Benthic Habitat (Code)	Depth (m)									Sediment Grain Size (mm)						Seabed Forms						
	0-15	15-22	22-45	45-48	48-82	82-95	95-592	>592	p-value	0-0.18 (silt and very fine sand)	0.18-0.35 (fine sand)	0.35-0.36 (sand)	0.36-0.48 (sand)	>=0.48 (coarse sand)	p-value	Depression	Mid Flat	High Flat	Low Slope	High Slope	Sideslope/Steep**	p-value
1		66%	34%						0.00		19%	30%		51%	0.00	95%	5%					0.00
2		28%	73%						0.00			100%			0.02	100%						0.00
4		29%	64%	7%					0.00			19%	30%	51%	0.00		100%					0.00
7		45%	54%	1%					0.00				16%	84%	0.00	17%	83%					0.00
25		53%	23%		24%	1%			0.00		51%		30%	19%	0.00	100%						0.00
32		4%	96%						0.00		3%	97%			0.00		100%					0.00
38		100%	0%						0.00				82%	18%	0.00	100%						0.00
44	57%	27%					16%		0.00		45%		32%	23%	0.00	88%	12%					0.01
64		100%							0.00			9%	91%		0.00	53%	47%					0.00
84			69%		31%				0.00		64%		36%		0.00	15%	39%	46%				0.00
87		100%							0.00			11%	89%		0.00	85%		15%				0.00
216					20%		80%		0.00		21%	79%			0.00			4%		96%		0.00
218					100%				0.00			78%		22%	0.00	100%						0.00
219					53%	31%	16%		0.00		24%	30%	21%	25%	0.00			100%				0.00
229			25%	0%	28%		47%		0.00		12%	67%	22%		0.00	28%		72%				0.07
301					38%	5%	57%		0.00		NS		NS	NS	0.44	NS		NS				0.52
306			21%		79%				0.00			100%			0.00	38%	51%	11%				0.08
384				7%			94%		0.00	NS					0.79					74%	26%	0.00
395				4%	96%				0.00		70%		30%		0.00	85%	15%					0.00
505							19%	81%	0.00	100%					0.00				25%	39%	35%	0.00
520					98%	2%			0.00		13%			87%	0.00	43%	57%					0.00
592				100%					0.00			100%			0.00		100%					0.00
768	84%	17%							0.00	56%	44%				0.00	100%						0.00
1223						100%			0.00			100%			0.00			100%				0.00

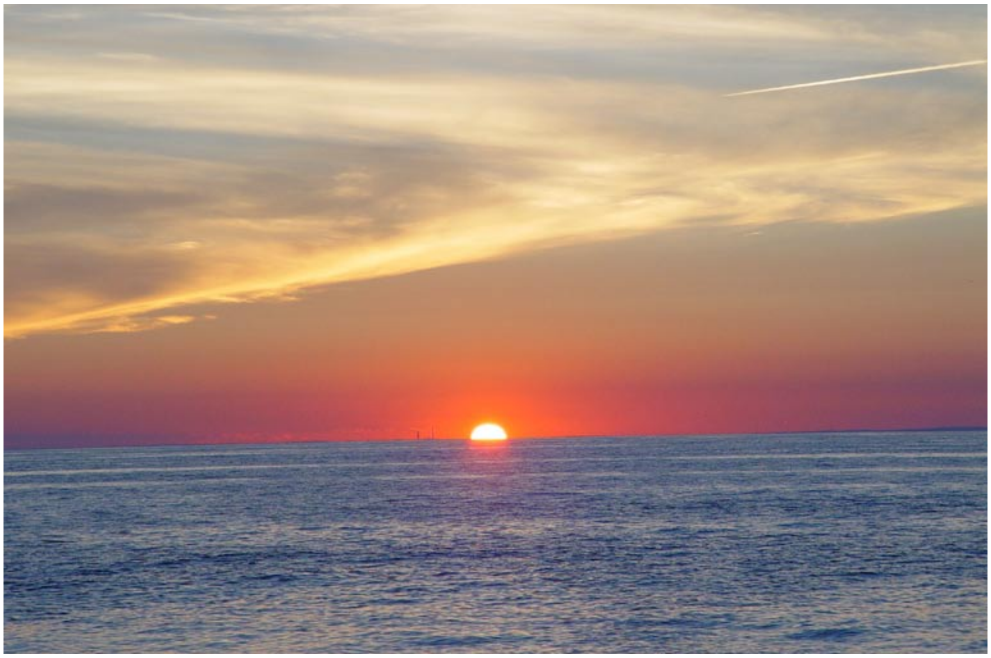
**Groups were combined due to few sampling points.

CHAPTER 4

Physical Oceanography

Caroly Shumway, Kevin Ruddock, and Melissa Clark

Introduction



This chapter provides an overview of the large-scale physical processes occurring in the Northwest Atlantic. Oceanographic processes are important predictors of marine species distribution and abundance, from phytoplankton to predatory pelagic fish to whales. For example, variation in seawater density (the combination of temperature and salinity) is one of the major factors governing large scale circulation patterns on the United States East Coast (Epifanio and Garvine 2001). The influence of the Labrador Current and terrestrial freshwater sources along the coast causes water on the Continental Shelf to be generally cooler and fresher than water beyond the Continental Slope, which is more influenced by the Gulf Stream. These two distinct water masses meet at the shelf break front, which can be a barrier to exchange of nutrients and plankton (Townsend et al. 2006). The interrelationship between oceanographic processes and structural features, such as the shelf-slope break or seamounts, leads to distinctive habitats for a range of species (Roff and Evans 2002). Note that the chapter does not address finer-scale current patterns along the coast, which play a role in larval settlement and correspondingly, marine connectivity (Epifanio and Garvine 2001). We recommend that such patterns be examined in the future.

Technical Team Members

Kathryn Jessen-Eller, Ph.D, University of Rhode Island
Grant Law, Ph. D, Oregon Health and Science University
Dan Morse, The Nature Conservancy, Eastern Division
Anna Pfeiffer-Herbert, University of Rhode Island
Kevin Ruddock, The Nature Conservancy, Rhode Island
Caroly Shumway, Ph.D, Boston University

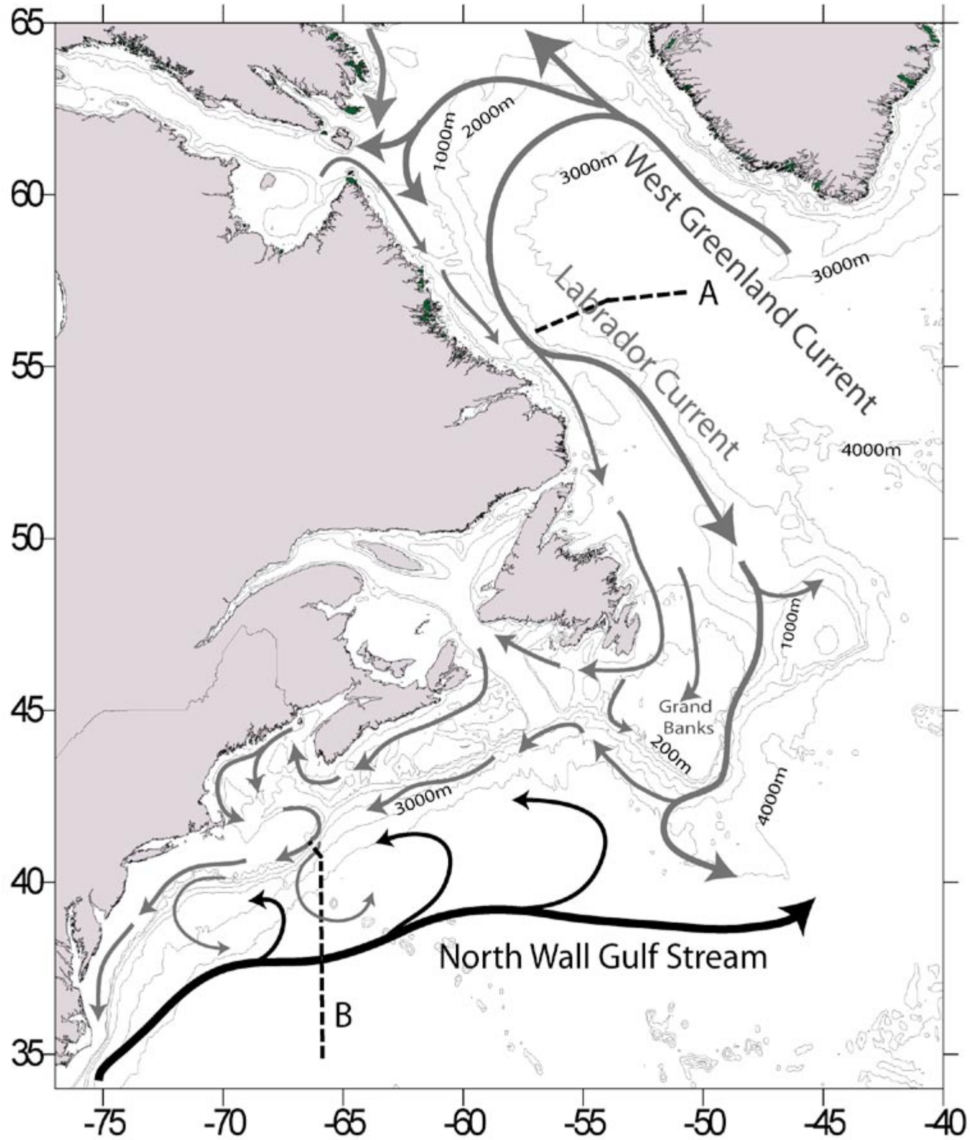


Figure 4-1. Currents in the Northwest Atlantic region (reprinted with permission from Townsend et al. 2006).

shelf. This current switches between two modes of circulation that are related to its position relative to the Continental Slope (Townsend et al. 2006). When the Gulf Stream is positioned farther offshore, it has more active meanders that can split from the current as warm water eddies, known as warm core rings or filaments, which are transported onto the shelf (Townsend et al. 2006). The Labrador Current originates in the Arctic, where it is fed by Greenland ice melt and continental fresh water sources, giving it a cold, low salinity signature (Townsend et al. 2006). It diverges around the Grand Banks, and part of it becomes Labrador slope water that flows into the Gulf of Maine and further south to the Mid-Atlantic Bight (Longhurst 2007).

The Gulf of Maine is isolated from the broader scale North Atlantic circulation by Browns and Georges Banks (Townsend et al. 2006). Water enters the Gulf of Maine primarily through the Northeast Channel that divides the two banks, and average circulation is counter-clockwise around the Gulf (Townsend et al. 2006). The inner shelf region of southern New England from Buzzards Bay to Long Island Sound is also semi-isolated by the presence of land. Long Island Sound has an estuarine circulation pattern due to freshwater input (Townsend et al. 2006). Circulation on the inner shelf of the Mid-Atlantic Bight is also influenced by low density water from Delaware and Chesapeake bays (Townsend et al. 2006). At the southern end of the region, very little water is exchanged past Cape

Circulation Patterns

Large-scale currents transport larvae of numerous oceanic species and determine habitat connectivity at a broad scale (Shanks 1995). The broad, non-tidal circulation of the western Atlantic (Figure 4-1; Townsend et al. 2006) is dominated by two major current systems, the Gulf Stream and the Labrador Current. The Gulf Stream, characterized by relatively warm temperatures and high salinities, flows northward past Cape Hatteras and turns to the east below the southern New England

Hatteras, between the Mid-Atlantic and South-Atlantic bights (Townsend et al. 2006).

The circulation patterns of this region are influenced by the North Atlantic Oscillation (NAO), an atmospheric phenomenon that changes the strength of major wind patterns (Longhurst 2007). During periods of negative NAO, the Gulf Stream shifts to the south and the Labrador Current increases in volume, penetrating farther down the coast (Townsend et al. 2006; Longhurst 2007). In contrast, during periods of positive NAO, the Gulf Stream shifts to the north and the Labrador Current weakens (Townsend et al. 2006; Longhurst 2007). The shifting balance between these two currents has significant implications for biological communities because it can expose those communities to very different temperature and salinity regimes (Townsend et al. 2006).

Wind forcing on seasonal and shorter time scales also affects circulation of the northwestern Atlantic shelf. Winds from the north, which are common in winter, push the colder shelf water to the inner shelf (Longhurst 2007). Winds from the south push surface water out away from the coast, which in some places causes upwelling of deep water near the coast (Longhurst 2007). The Mid-Atlantic Bight is frequently in the path of cyclones, which cause vertical mixing and thus resupply nutrients to the surface layer (Townsend et al. 2006).

Tidal Influence

Tides have an obvious effect at the shoreline, where marine organisms must adapt to exposure to air, but they also influence ecosystem processes further offshore. For example, tides can prevent stratification (i.e., layering of different water masses). Strong tidal mixing in the Gulf of Maine prevents stratification over shallow areas such as Georges Bank (Longhurst 2007). Such areas often serve as spawning and nursery grounds for fish because they tend to be characterized by high biological productivity and have recirculating currents that retain larvae (Mann and Lazier 2006). When stratification persists over the shelf, the tide interacts with the sharp change in topography at the shelf break to generate internal waves which help mix nutrients through the water column and are one mechanism for transporting larvae across the shelf (Mann and Lazier 2006).

Tides can also play a major role in sediment mobility, which affects bottom communities. If energy from tides exceeds a certain threshold, it disturbs sediments on the sea floor. Tidal energy varies with the range in tidal height and the amount of constriction by bottom topography. The energy needed to move sediment depends on the sediment grain size and density, seabed roughness, and how well the sediment grains are cemented together (Porter-Smith et al. 2004).

It is important to note that tides are just one process for mobilizing sediment. Storm waves, for example, also can cause rapid sediment transport that exceeds the amount of transport caused by normal wave and tidal energy over the course of months (Porter-Smith et al. 2004). Sediment mobility has implications for the types of benthic communities found in a given area and the persistence or stability of these communities over time. Mobile sediments tend to be dominated by a single opportunistic species that can quickly recolonize following a disturbance, while stable sediments, such as gravel, tend to support greater species diversity (Newell et al. 1998).

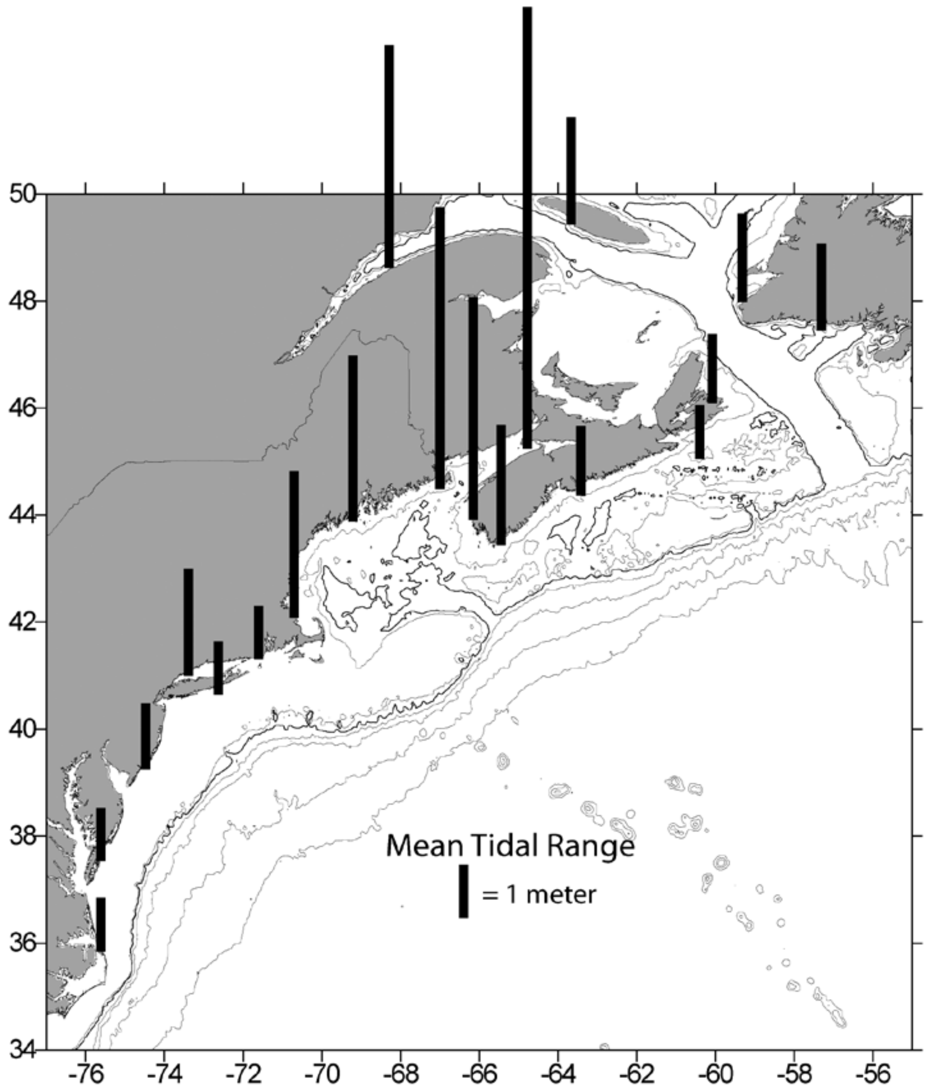


Figure 4-2. Mean tidal range in the Northwest Atlantic region (reprinted with permission from Townsend et al. 2006).

Figure 4-2 (from Townsend et al. 2006) shows the strength of tides within the Northwest Atlantic region. The height of the black bar indicates the strength of the tide at that point. The strongest tides are in the Gulf of Maine, particularly on the northern (Canadian) end by the Bay of Fundy. Penobscot Bay and Cape Cod Bay also have a strong tidal influence, as does the western end of Long Island Sound.

Oceanographic Analysis: An Overview of Methods

For all of the temperature-related analyses described below, source data was obtained from Dr. Grant Law, Center for Coastal Margin Observation and Prediction, Oregon Health and Science University. The dataset included temperature values plotted on a standard grid of three-dimensional point locations that has finer detail toward the shore and surface, where there is greater need for higher resolution. The data comprised seasonal climatologies (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Nov) to a depth of 2,500 m, from 1980-2007. Hydrographic observations were compiled from several sources, including Hydrobase, National Marine Fisheries Service (NMFS), and Department of Fisheries and Oceans Canada (DFO). An archive of South Atlantic Bight hydrographic data assembled by Brian Blanton at UNC was also included in the archive. All hydrographic data were quality checked, then archived into yearly files. While hydrographic data varied in spatial and temporal coverage, an interval of three months appeared to produce consistently useable climatologies. Climatologies were created by interpolating three months of observed hydrography to the standard grid using the OAX5 optimal-analysis application. OAX5 alters the weighting factors of nearest neighbors relative to the shape of the bathymetry, producing more physically reasonable solutions.

The specific methods for each set of analyses are provided in the sections below.

Sea Surface Temperature

Water temperature is an important predictor of species distribution. Sea surface temperature (SST) means are useful for understanding patterns of species assemblages and predicted ecosystem changes. Ectothermic organisms (i.e., cold-blooded species such as marine invertebrates and fish) have both physiological and behavioral preferences for certain temperatures. If temperatures become too warm, species can become physiologically stressed, influencing such processes as reproduction and feeding. Previous research has shown that mean SST is correlated with diversity of zooplankton (Rutherford et al. 1999) and distribution patterns of apex predators (tuna/billfish: Worm et al. 2005).

Methods

To display seasonal average sea surface temperature, data points of questionable accuracy were removed from the dataset and averages over all years were calculated for each season. The resulting surface temperature values were then interpolated using ordinary kriging in ArcGIS 9.1, creating a smooth data grid representing the average sea surface temperature for 1980 – 2007 for each season.

Results

Mean SST generally decreases with latitude, and varies seasonally. The warmest mean SST found in the Northwest Atlantic region is associated with the Gulf Stream, which carries warm subtropical water north along the Continental Slope. From the winter to spring months, cooler water spreads over the shelf, with a slight north-south temperature gradient (Figure 4-3a and 4-3b). In the summer, warmer water spread over the shelf and to the Georges Bank Gyre (Figure 4-3c). Fall showed little difference from summer, except for more extensive warming in the Mid-Atlantic Bight (Figure 4-3d).

The annual range in SST on the Continental Shelf has increased from the mid-20th century to the present as a result of increasing summer maximum SST and constant or decreasing winter minimum SST (Friedland and Hare 2008). However, temperature changes are still within the range of past temperatures (Friedland and Hare 2008). Worldwide, 11 of the last 12 years (1995 to 2006) were among the 12 warmest years of record (IPCC 2007). For the Northwest Atlantic region, warming trends are more pronounced in shallow coastal ponds or estuaries (not mapped in this analysis, but see Chesapeake: Preston 2004; Great Harbor, Woods Hole, MA: Nixon et al. 2004). Narragansett Bay, RI, has warmed over 1.1°C since 1970 (Nixon et al. 2003; Smith 2007).

Sea Surface Temperature Gradients

Maps of sea surface temperature gradients display the rate of change in surface temperature or 'fronts.' These maps show the locations of persistent, large scale gradients in surface temperature for the given decades, and also show how these patterns have changed over the time scale of the data. Sharp gradients in SST suggest the presence of a front between distinct water masses with different temperatures. Fronts are areas of particularly high biological activity due to cross-frontal mixing of nutrients, which stimulates high primary productivity (Mann and Lazier 2006). Fronts are the location of high densities of phytoplankton (Munk et al. 1995; Mann and Lazier 2006), zooplankton (Munk et al. 1995; Wishner et al. 2006), fish larvae (Munk et al. 1995), marine mammals (Etnoyer et al. 2004), and seabirds (Haney 1986). Worm et al. (2005) also showed that SST gradients are positively correlated with tuna and billfish diversity.

Methods

To calculate the gradient, SST was interpolated for each season of each year from 1980 through 2007. This was done at a relatively coarse scale of 10 km cell size and smoothed to eliminate small scale fluctuations and to focus on the larger scale patterns. To identify areas of relatively high gradient, a slope grid was calculated from each surface temperature grid. This captured the rate of temperature change for each 10 km cell. The resulting data were inspected to determine a reasonable division value to characterize each cell as either high gradient or low gradient. Any cell with a slope change greater than 0.0009 degrees was classified as high gradient. Each decade was then

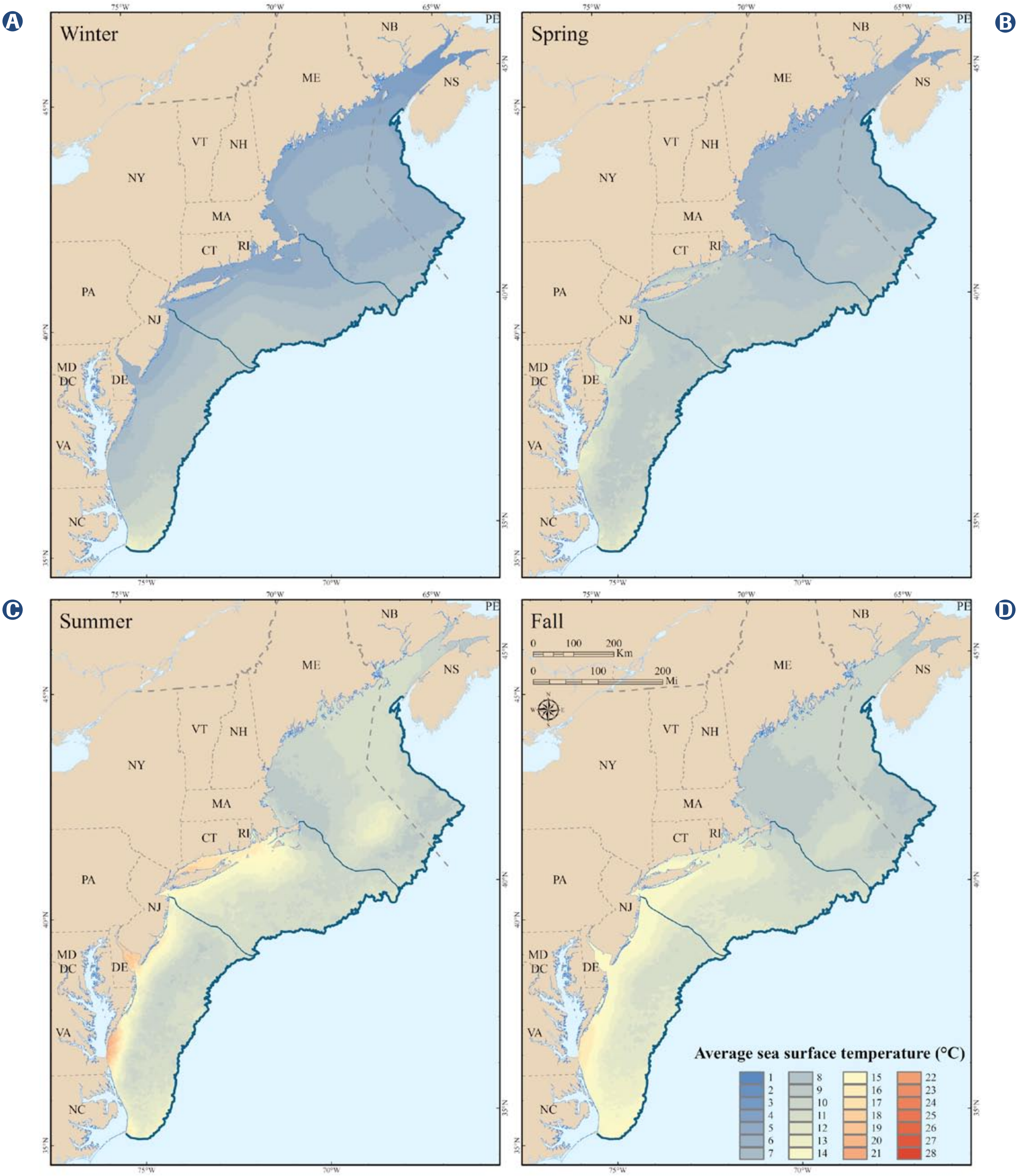


Figure 4-3. Average sea surface temperature by season.

classified by summing the number of years with a high gradient in each cell. Finally, the values from the earliest decade were subtracted from the values for the most recent decade to illustrate patterns of change between 1980 and 2007.

Results

Differences in the spatial and seasonal patterns of SST gradients are apparent (Figures 4-4, 4-5, 4-6 and 4-7). A shelf break front (red-brown area) located between the Southern New England subregion and Georges Bank was compact in the winter, extends northward to a larger area in the spring, shifts further northward in the summer, and was weak and patchy in the fall. Persistent SST gradients extended onto the Nantucket Shoals in the summer and fall. In the Mid-Atlantic Bight subregion, a mid-shelf front was a persistent feature in the winter, but disappeared in the spring. The mid-shelf front was replaced by persistent SST gradients over the inner shelf and shelf break in the summer, which disappeared again in the fall. A patch of high SST gradients began next to Cape Hatteras and extended to the north off of the shelf. This signature occured from winter to summer, but was absent in the fall.

A sharp front between cooler shelf water and warmer slope water is a common feature of the shelf break of eastern North America (Beardsley and Boicourt 1981; Mann and Lazier 2006). The water column above Georges Bank is well-mixed by tidal currents, while the water around the bank stratifies in the spring and summer, causing the development of a front between the cooler well-mixed water and warmer stratified water (Mann and Lazier 2006). This feature was apparent in the greater persistence of SST gradients around Georges Bank in the spring and summer, and the greater extent in the summer. The water column above Nantucket Shoals was also well-mixed by tides (Townsend et al. 2006), which explains the seasonally present SST gradients in that area. Wintertime fronts over the mid-shelf are a consistent feature south of Long Island (Ullman and Cornillon 2001; Townsend et al. 2006). In the Mid-Atlantic Bight subregion, the persistent SST gradients that extended offshore from Cape Hatteras likely demarcate the edge of the Gulf Stream. The Gulf Stream is closest to shore at Cape Hatteras and varies in offshore position to the north, as well as over time (Townsend et al. 2006).

Because fronts are associated with concentrated primary production and foraging by zooplankton and fish, changes in the persistence of thermal fronts may impact both secondary production and the life history cycles of fish (Roman et al. 2005). Figure 4-4d, 4-5d, 4-6d and 4-6d showed the change in SST gradient patterns over the past few decades. These figures compared the 2000-2007 period and the 1980-1989 period. Differences between these two decades may indicate changes in environmental forcing from climate oscillations (i.e. the North Atlantic Oscillation) and/or longer-term climatic warming trends. The SST gradient at the shelf break weakened over time in all seasons from 1980-1989 to 2000-2007. In winter, SST gradients over the mid-shelf also weakened. SST gradients over the Continental Slope strengthened over time, especially in the winter. The SST gradients associated with the Gulf Stream wall strengthened in the spring-fall. SST gradients also strengthened on the Nantucket Shoals and Block Island Delta of Southern New England in spring-fall. SST gradients in the Georges Bank area strengthened in the fall and summer, but weakened in the winter.

Stratification

Stratification is the layering of different water masses, with warmer water at the top. Measures of stratification tell us how well-mixed the water is. In the Northwest Atlantic region, like other temperate regions, stratification is greatest during the warmer months. Stratification traps phytoplankton in the warm surface waters, enabling them to utilize the nutrients. Winter winds can cause stratification to break down and mixing to occur, which brings more nutrients from deeper water to the surface to replenish those being used in the upper layers.

Why is stratification biologically important? The degree of stratification of the water column affects three important ecosystem processes:

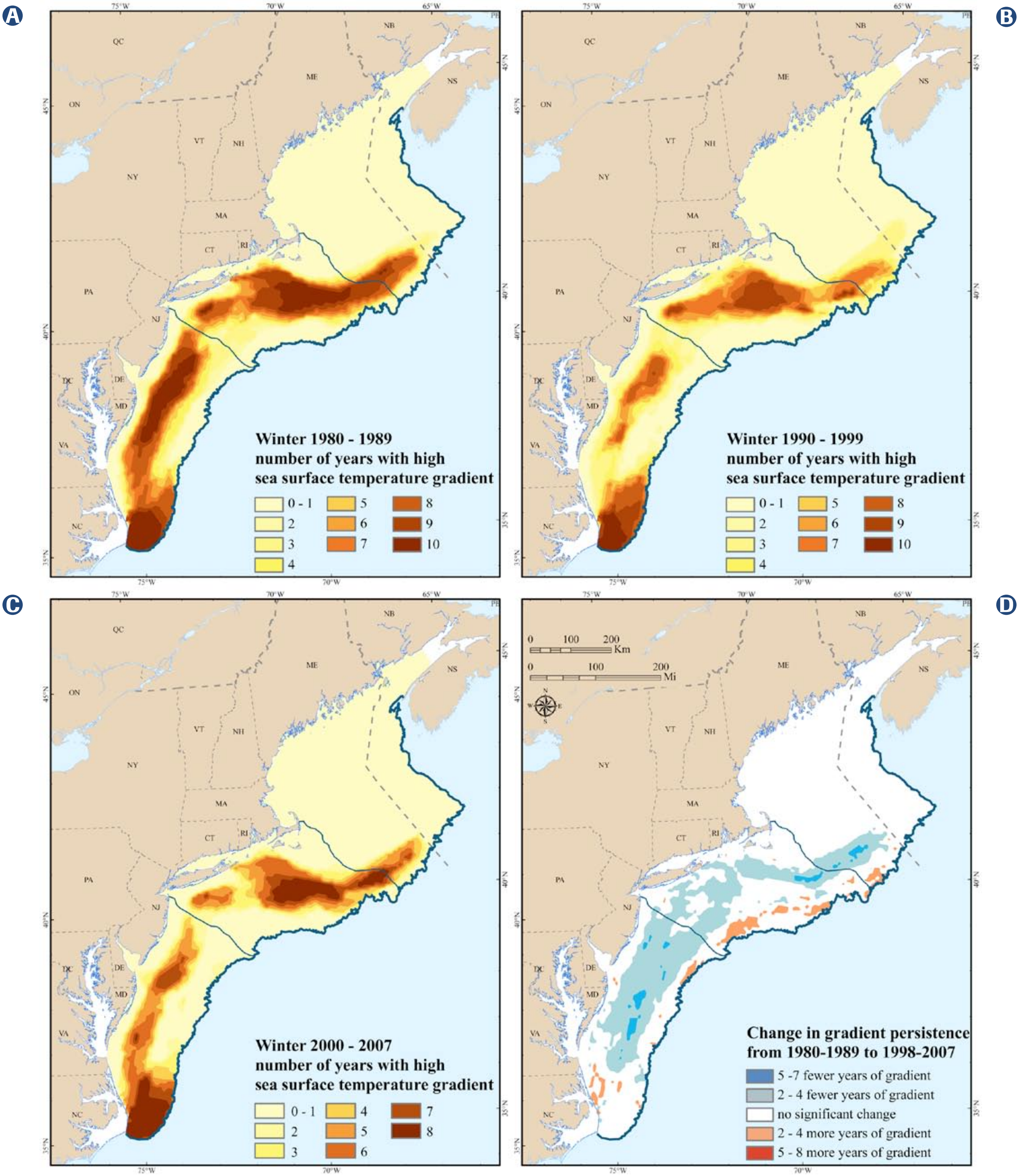


Figure 4-4. Winter sea surface temperature gradients by decade (a, b, c); Change in gradient persistence from 1980-1989 to 1999-2007 (d).

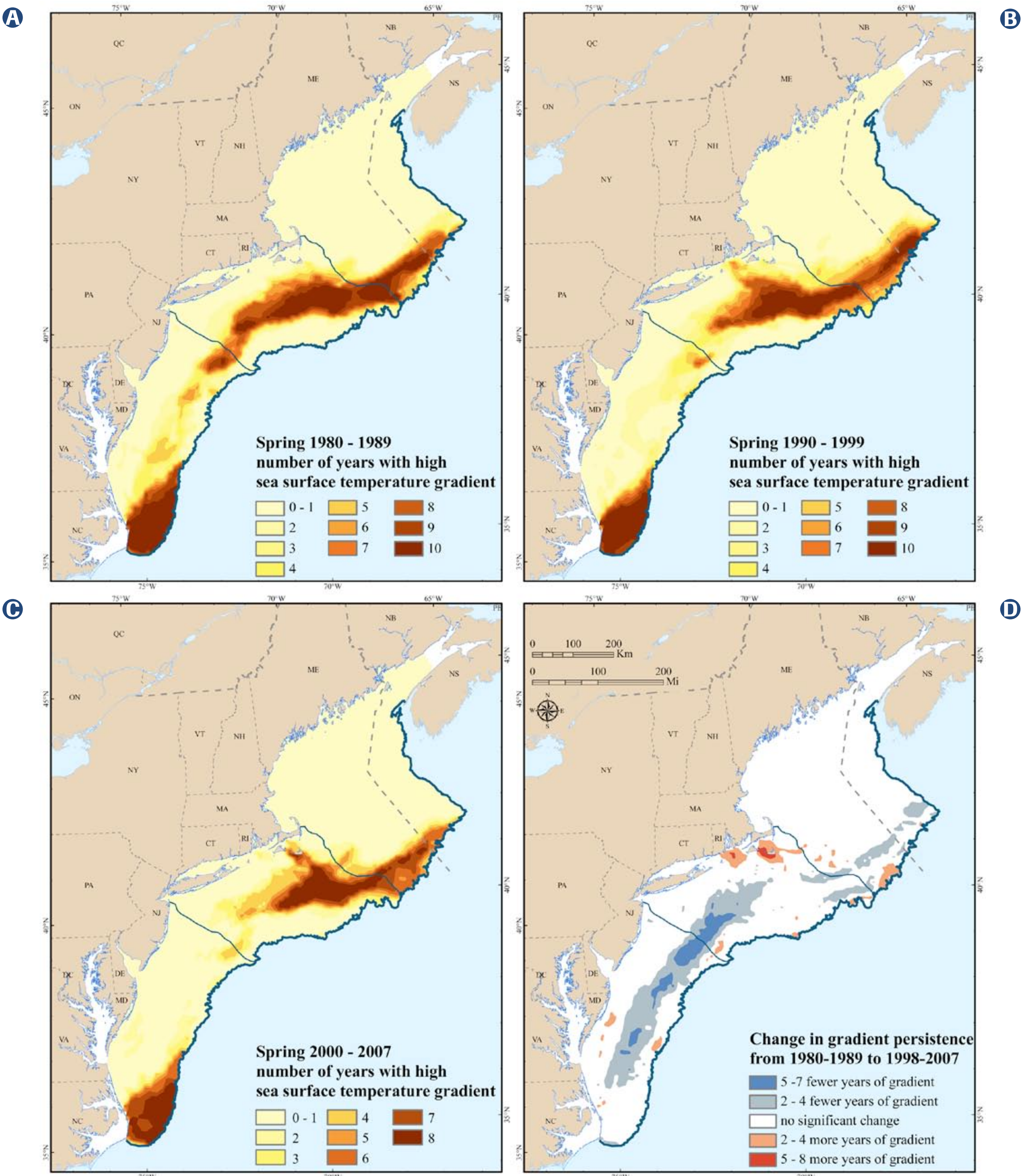


Figure 4-5. Spring sea surface temperature gradients by decade (a, b, c); Change in gradient persistence from 1980-1989 to 1999-2007 (d).

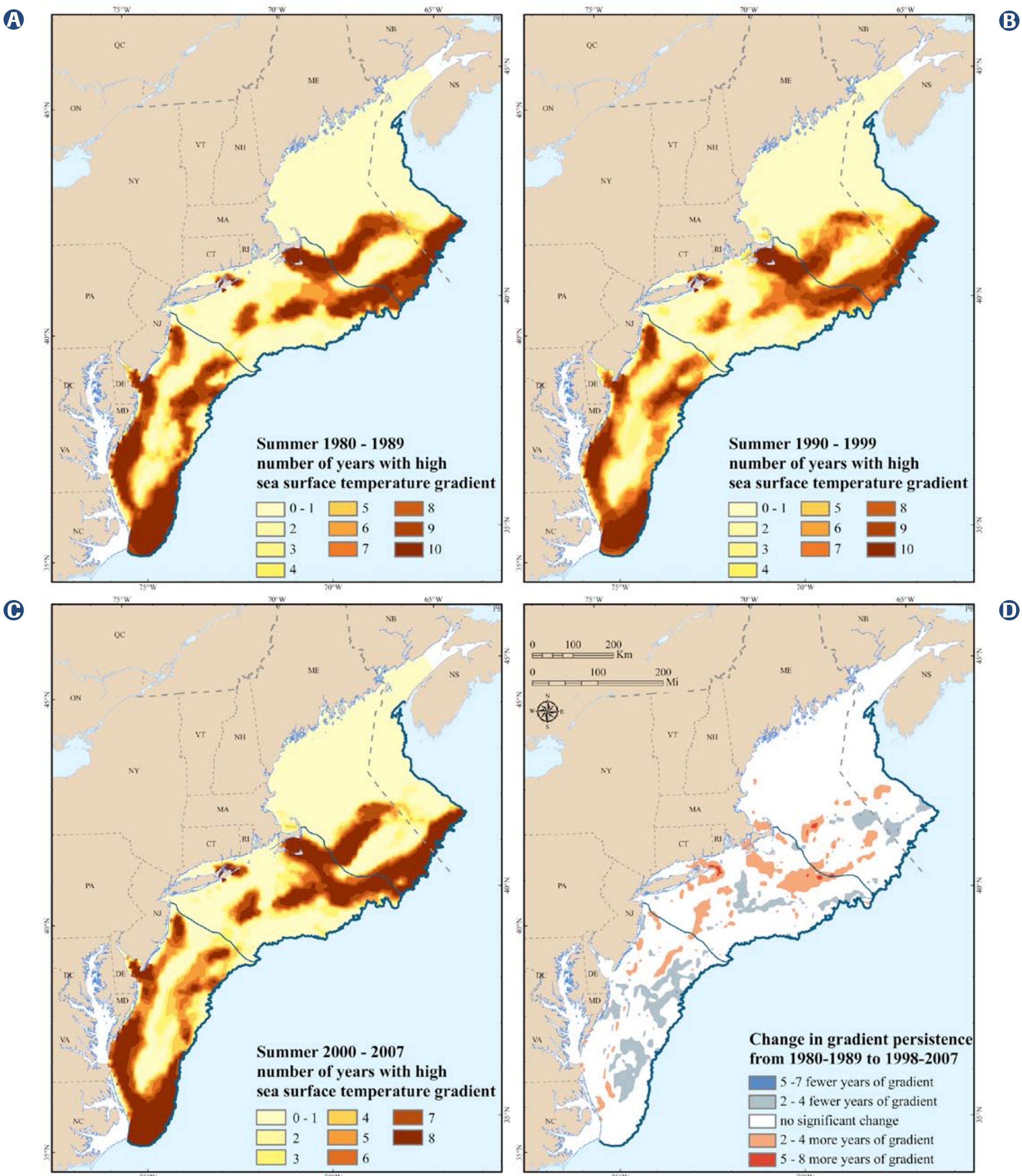


Figure 4-6. Summer sea surface temperature gradients by decade (a, b, c); Change in gradient persistence from 1980-1989 to 1999-2007 (d).

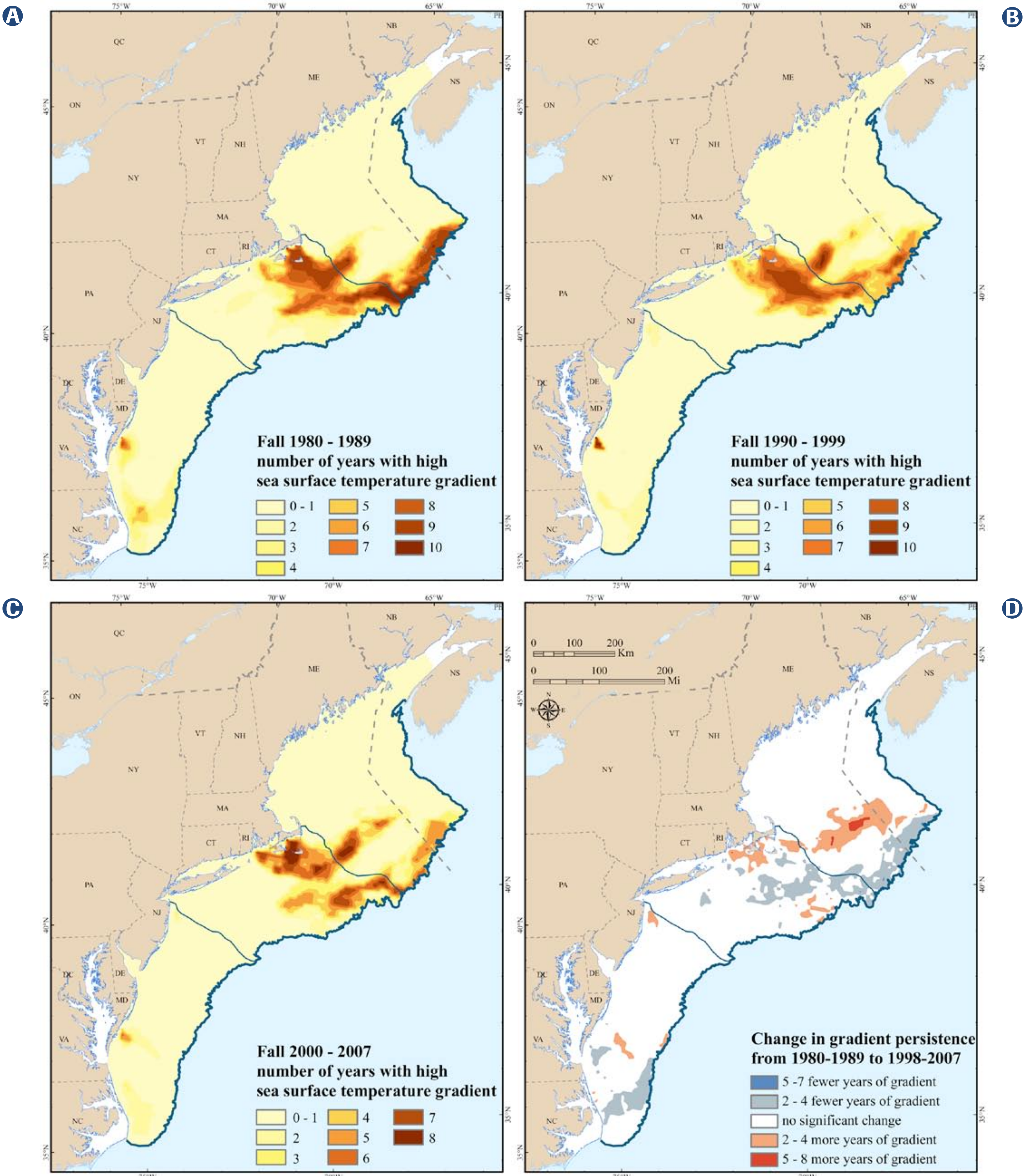


Figure 4-7. Fall sea surface temperature gradients by decade (a, b, c); Change in gradient persistence from 1980-1989 to 1999-2007 (d).

- Stratification increases the stability of the water column, providing conditions for seasonal accumulation of high density patches of phyto plankton, which may provide a rich food source for higher trophic levels (McManus et al. 2003). However, if stratification extends too long, the water masses become depleted of nutrients. Fortunately, winter winds cause stratification to break down. This has the advantage of enabling nutrients from deeper, colder waters to come to the surface.
- Stratification controls the development of phytoplankton blooms. Because the surface layer is well mixed down to the pycnocline (the depth of maximum change in density), phytoplankton are physically mixed throughout the layer (Mann and Lazier 2006). If the surface layer is much thicker than the euphotic zone (the vertical zone where light intensity is high enough for photosynthesis to occur), phytoplankton populations cannot grow. Conversely, if the surface layer is thin enough relative to the euphotic zone, phytoplankton populations can grow rapidly, forming a bloom. This is the mechanism responsible for the spring phytoplankton bloom in the North Atlantic Ocean (Mann and Lazier 2006).
- Stratification also increases the potential for hypoxia by preventing deep water from exchanging with the atmosphere (Rabalais et al. 2002). Hypoxia causes the exclusion of fish and other mobile organisms and mortality of many benthic organisms (Rabalais et al. 2002).

Methods

Stratification was calculated by subtracting the density at 50 m from the surface density. Where the seafloor is shallower than 50 m, stratification was calculated as the density difference between the seafloor and the surface. The resulting stratification values were then interpolated using ordinary kriging in ArcGIS 9.1, creating a smooth data grid representing the average degree of density stratification for 1980 – 2007 for each season.

Results

The maps produced by this analysis agree with observed seasonal patterns of stratification. In the winter (Figure 4-8a), the water column was mixed by winds from the surface down to 50-100 m (Longhurst 2007). The water over the shelf was nearly completely mixed, except for a narrow band of stratification near the coast. The highest stratification during these months (dark red) occurred at the Hudson outflow, in Delaware Bay, and between Chesapeake Bay and Cape Hatteras. In the spring (Figure 4-8b), the water column becomes stratified and formed a thinner surface layer due to solar heating and increased freshwater inputs (Longhurst 2007). The map of spring stratification showed stratified conditions throughout the ecoregion, except north of Penobscot Bay in the Gulf of Maine. The broadest extent of stratification occurred in the Mid-Atlantic Bight, extending to the 50 m isobath throughout.

In the summer (Figure 4-8c), stratification greatly intensified and extended throughout the Gulf of Maine, but not on Georges Bank or Bay of Fundy. In the Southern New England subregion, only parts of the Great South Channel remained mixed. All of the Mid-Atlantic Bight subregion was very stratified, with the exception of the southeastern end of the region. As water over the shelf stratifies in the summer, a pool of cold, higher nutrient deep water remained isolated (Townsend et al. 2006). This cold pool is distinctly colder and fresher than the water mass over the Continental Slope. The cold pool flows to the south, bringing a supply of nutrients to the southern end of the Mid-Atlantic Bight (Townsend et al. 2006).

In the fall (Figure 4-8d), increased wind events cause mixing throughout the Gulf of Maine, Georges Bank, by the Block Island Delta (Southern New England subregion) and the outer shelf. The inner shelf of the Southern New England subregion from Narragansett Bay south and the Mid-Atlantic Bight remained moderately stratified (yellow); the coast just south of Chesapeake Bay showed a small patch of increased stratification (red).

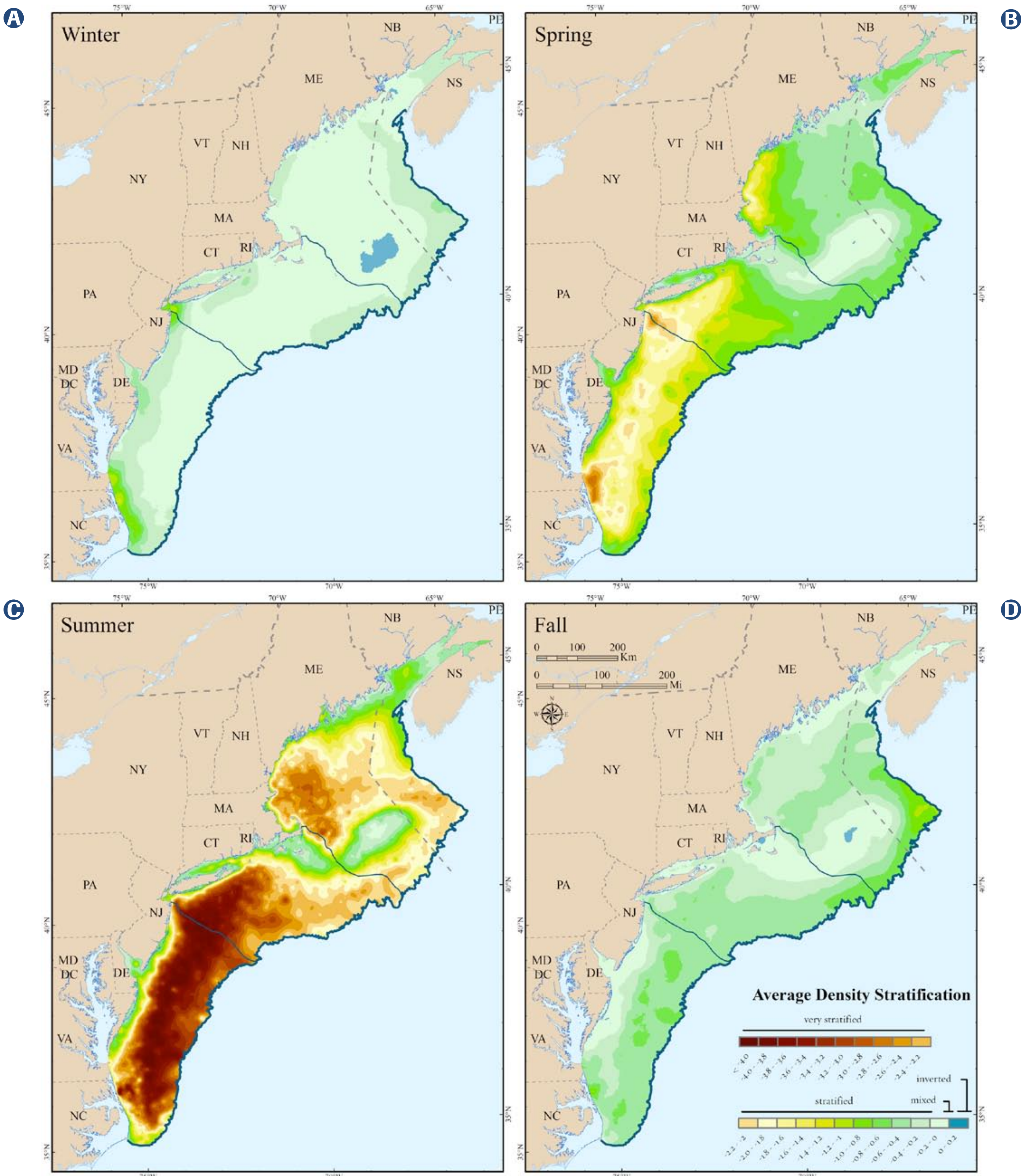


Figure 4-8. Average sea surface temperature stratification by season.

Marine Plankton

Plankton are free-floating aquatic organisms which drift or swim with the movement of water. This group includes microscopic single-celled organisms from the kingdoms Archaea, Bacteria, Plantae and Protista, as well as multi-cellular larval and adult forms of animals. Phytoplankton are primary producers in both coastal and open-ocean marine ecosystems. Zooplankton feed on phytoplankton, and are secondary consumers. The third broad category of plankton are bacterioplankton, which decompose organic matter and help recycle carbon and essential nutrients.

Plankton are important for many reasons:

- Phytoplankton and zooplankton support commercially and ecologically important fisheries (including shellfish);
- Increases in phytoplankton abundance is a good indicator of commercially productive waters;
- Plankton play a critical role in global biogeo chemical cycles, including those of essential nutrients and carbon;
- Artificially-introduced nutrients (nutrient loading), particularly nitrate in marine systems, cause phytoplankton blooms (eutrophication) that can reduce bottom oxygen levels to hypoxic or anoxic levels in stratified water, causing fish kills if anoxic for periods of time;
- Species composition and abundance can be used as a) historic or current indicators or predictors of ecosystem or fishery health and b) to assess changes in climate, sea level, and biogeochemistry; and
- Blooms of toxic algae can harm both marine life and people.

Climate change can dramatically influence both coastal and offshore plankton biomass. Subsequent changes in currents, sea level, and storm frequency can alter nutrient availability.
In the Southern New England region, for example, increased invasions of boreal phytoplankton (from the north) along with those from the south (Greene et al. 2008) have been documented.

Phytoplankton

Methods

Phytoplankton concentration was determined by measuring chlorophyll a, which can be detected using remote sensing techniques. To measure chlorophyll by satellite, images from the Sea Viewing Wide Field-of-View Sensor (SeaWiFS) obtained from NASA were used. These images have a 1.1 km^2 nominal resolution. These data were processed by Dr. Tim Moore at the Ocean Process Analysis Laboratory, University of New Hampshire in order to improve the estimation of chlorophyll in the coastal zone. The chlorophyll data were derived from a regionally-parameterized empirical algorithm which follows the functional form:

$$X=\log(\max(Rrs443,Rrs490,Rrs510)/Rrs555)$$

$$\mathrm{Log}(Chl)=a0+a1^{*}X+a2^{*}X^{2}+a3^{*}X^{3}+a4X^{4}$$

where the exponential coefficients were fitted to a regional subset of the NASA bio-Optical Marine Algorithm Data (NOMAD) set. The data were processed in MATLAB and delivered in .HDF format. The data were converted from .HDF to MATLAB using Marine Geospatial Ecology tools (Roberts et al. 2009). In each image, land and clouds were removed, so as to not skew the calculation.

Seasonally averaged chlorophyll images were created for the time period January 1998 – December 2006. The data time series ranges are monthly for January 1997 – February 2007. Years with inconsistent monthly data were eliminated (1997 and 2007). The seasons are defined to be consistent with other target data: winter, January – March; spring, April – June; summer, July – September; fall, October – December.

Results

Throughout the Northwest Atlantic region, large-scale spatial patterns in plankton biomass are driven by local currents and topography, seasonal nutrient loading. In general, in all seasons the highest levels of chlorophyll a were found in the coastal areas, with the highest concentrations at the tips of the Bay of Fundy, various harbors within the Gulf of Maine, Long Island Sound, New York Bight, Delaware Bay, Albemarle Sound and Pamlico Sound. Overall, high concentrations of plankton were observed within inshore bays and sounds fed by freshwater rivers and mixed by tides (e.g. Bay of Fundy, Long Island Sound, Chesapeake Bay, etc.) and where currents cause upwelling over the Continental Shelf (e.g. Georges Bank and Nantucket Shoals). The lowest levels of chlorophyll a were found seaward of the shelf-slope break and the deep waters of the Gulf of Maine.

In the Bay of Fundy, the northern edges remain highly productive throughout the year. The almost continuous productivity within the bay is due to the extremely high tidal action (tides in the Bay of Fundy are the highest in the world) and the presence of submerged ledges, islands, and channels which cause upwelling. This upwelling brings deep water nutrients to the surface, even during the summer when other shelf areas are experiencing stratification.

Figure 4-9a shows productivity in the winter months. For the two northerly subregions, less productivity was observed compared to the other seasons. Reduced productivity was also observed along the coast and on Georges Bank, Nantucket Shoals, and Long Island Sound. In the Gulf of Maine/Georges Bank subregion, this difference was most noticeable between Penobscot Bay and Cape Cod Bay as well as on Georges Bank. In the Southern New England subregion, Nantucket Shoals continued to exhibit medium-high concentrations because the water is shallow, but close to cooler southern-flowing waters from the Labrador Current, causing blooms to persist into winter.

Figure 4-9b shows spring productivity when phytoplankton biomass is expected to be highest for the Northwest Atlantic Ocean. At this time of year, levels of phytoplankton were high in coastal bays and sounds because of increased nutrient availability from rain and subsequent river run-off and increased light availability. Phytoplankton hot spots were also evident over Georges Bank within the Gulf of Maine and Nantucket Shoals within the Southern New England subregion.

During the summer months, many of the bays and sounds throughout the region showed high to very high levels of productivity (orange to red) (Figure 4-9c). Enclosed coastal areas were more prone to summer eutrophication when water is stratified, because they mix less with open water and are constantly receiving nutrients from land runoff. In the Gulf of Maine, areas that retained high productivity well into the summer include the Bay of Fundy (discussed above) and coastal areas (about equal to fall levels). The eutrophication in the Gulf of Maine is thought to be due to coastal upwelling-induced nutrient enhancement, not human causes. Elsewhere in the Northwest Atlantic region, eutrophication was observed during the summer months in Long Island Sound, Delaware Bay and Chesapeake Bay, where anthropogenic nutrient loading and subsequent hypoxia are well documented. While Albemarle and Pamlico Sounds in the Mid-Atlantic Bight showed high levels of productivity year-round, eutrophication conditions are currently considered "unknown" by NOAA (Bricker et al. 2007). Offshore, productivity was lowest in the summer. Along the shelf-slope break, the lowest levels of primary productivity were observed. In both the Gulf of Maine and Southern New England subregions, the fall bloom was smaller than that which occurs in the spring (Figure 4-9d).

Zooplankton

Methods

Zooplankton biomass data were obtained from the COPEPOD database (NOAA) for 1977-2007. The sampling stations are indicated as black points on Figure 4-10. Data were grouped into 1977-1979, 1980s, 1990s, and 2000-2001. The samples did not include inshore bays or sounds. Voronoi polygons were constructed around the location of each sample point and the value of each point was assigned to each polygon. Voronoi polygons are created so that every location within a polygon is closer to the sample point in that polygon than any other sample point, so that the data were accurately represented. Zooplankton counts were displayed as follows: very high (>1 ml/m³; red), high (0.5-1 ml/m³; pink); moderate (0.2-0.5 ml/m³; yellow), low (0.1-0.2 ml/m³; light blue) or very low (<0.1 ml/m³; dark blue). Note that limited winter sampling took place in the Gulf of Maine and Southern New England subregions in 2000-2001.

Results

Figures 4-10, 4-11, 4-12, and 4-13 shows zooplankton concentrations for the four time groups, separated by season. Compared to the chlorophyll maps, zooplankton exhibited much greater variability both by season and by decade. In addition to being affected by seasonally-changing variables influencing phytoplankton growth (e.g., nutrient availability, temperature, light intensity), zooplankton populations can be altered by predators feeding upon them. Shellfish, fish, jellyfish, ctenophores, and baleen whales use zooplankton as a food source.

In general, zooplankton densities were generally highest inshore to the 50 m isobath. The densities decreased as one moves offshore. Hot spots of zooplankton biomass included Georges Bank, Cape Cod Bay, Nantucket Shoals, the New York Bight (Hudson outflow), and along the Delaware coast and offshore from Chesapeake Bay.

In the winter, zooplankton levels were at moderate to low levels in the Gulf of Maine (Figure 4-10a–4-13a). In the Southern New England subregion, a high-density patch was observed south of the Nantucket Shoals. In recent years, in the Mid-Atlantic Bight, zooplankton levels were obviously higher, as evidenced by the very thin strip of high (red) levels appearing in the area just south of the New York Bight (Hudson outflow), Delaware Bay, and Virginia's eastern shore.

Zooplankton levels were highest in the spring, following the phytoplankton bloom (Figure 4-10b–4-13b). In the Gulf of Maine/Georges Bank subregion, the broadest spatial extent of high to very high zooplankton occurred over Georges Bank. High levels were also observed from Jeffreys Ledge to Stellwagen Bank. In the Southern New England subregion, zooplankton density was high across Nantucket Shoals, Block Island Sound, and the New York Bight. In the Mid-Atlantic Bight subregion, high to very high levels of zooplankton biomass were consistently observed at the New York Bight (Hudson outflow) extending south to Delaware Bay.

During the summer, zooplankton biomass was noticeably reduced across most of the Gulf of Maine and Southern New England (Figure 4-10c–4-13c). However, high regions remained over Georges Bank, inshore, and within the New York Bight. In the Mid-Atlantic Bight, very high levels were observed around Delaware and Chesapeake Bays.

In the fall, zooplankton levels are reduced to moderate levels across most of the Gulf of Maine. Moderate levels of zooplankton remain in Cape Cod Bay, and from Narragansett Bay south to the end of the Northwest Atlantic region (Figure 4-10d–4-13d). In the Mid-Atlantic Bight, small hot spots remained south of Chesapeake Bay. During this time, high zooplankton levels were observed throughout the region from the coast to approximately the 50 m isobaths.

Comparing the maps across decades, a striking difference was observed in winter levels of zooplankton across the Northwest Atlantic region. In the 1970s, primarily low to medium levels were observed. In the 1980s and 1990s, slightly higher patterns were observed, particularly in Georges Bank and Nantucket Shoals in the Southern New England subregion, Delaware and Chesapeake Bays, and the Virginia eastern shore. The spring bloom showed an increasing trend in some areas. The offshore hot spots on Georges Bank, Nantucket Shoals, and the Virginia coast were visible throughout the time period, and the spatial extent of high concentrations has increased.

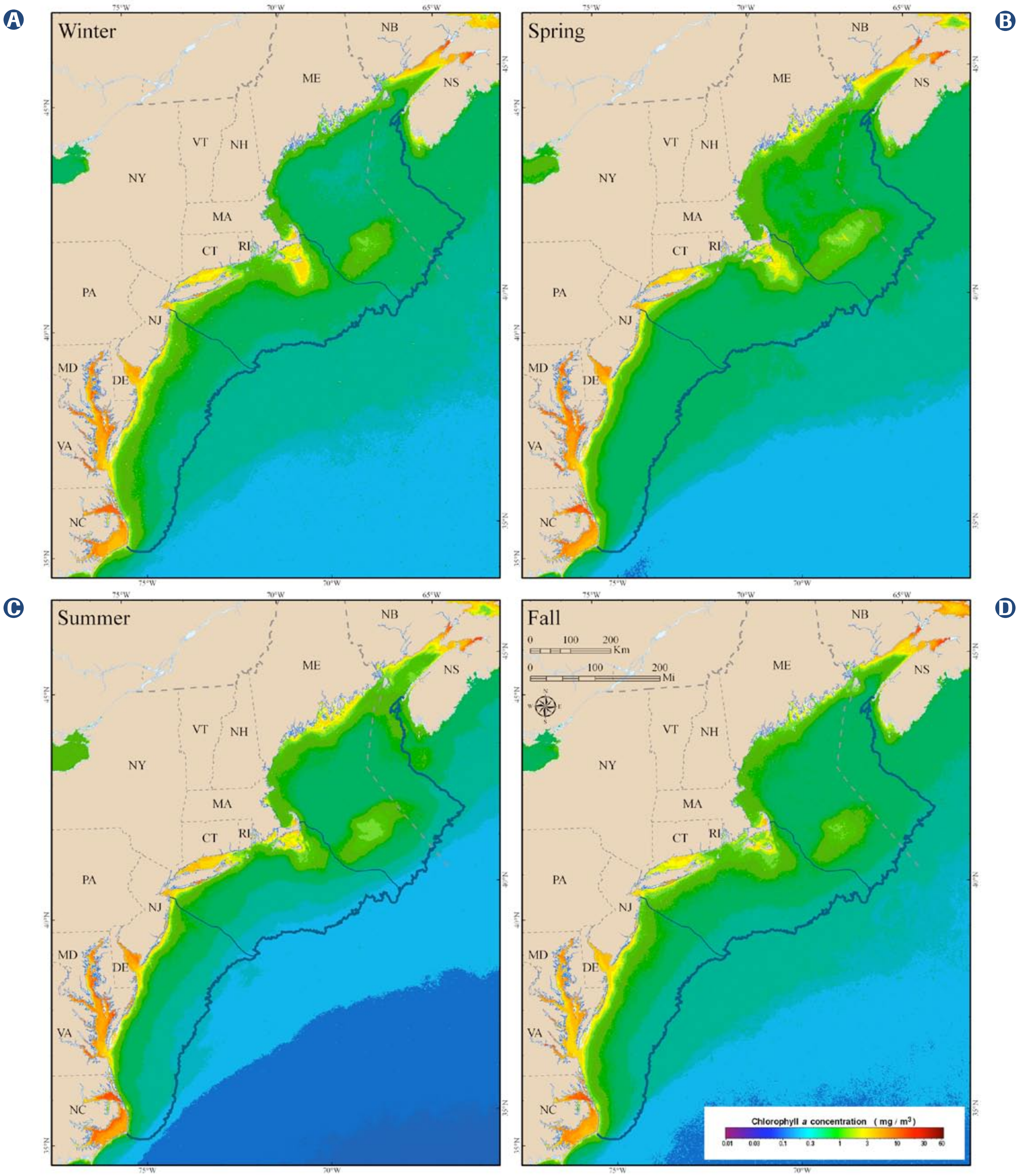


Figure 4-9. Average phytoplankton concentration (chlorophyll a) by season.

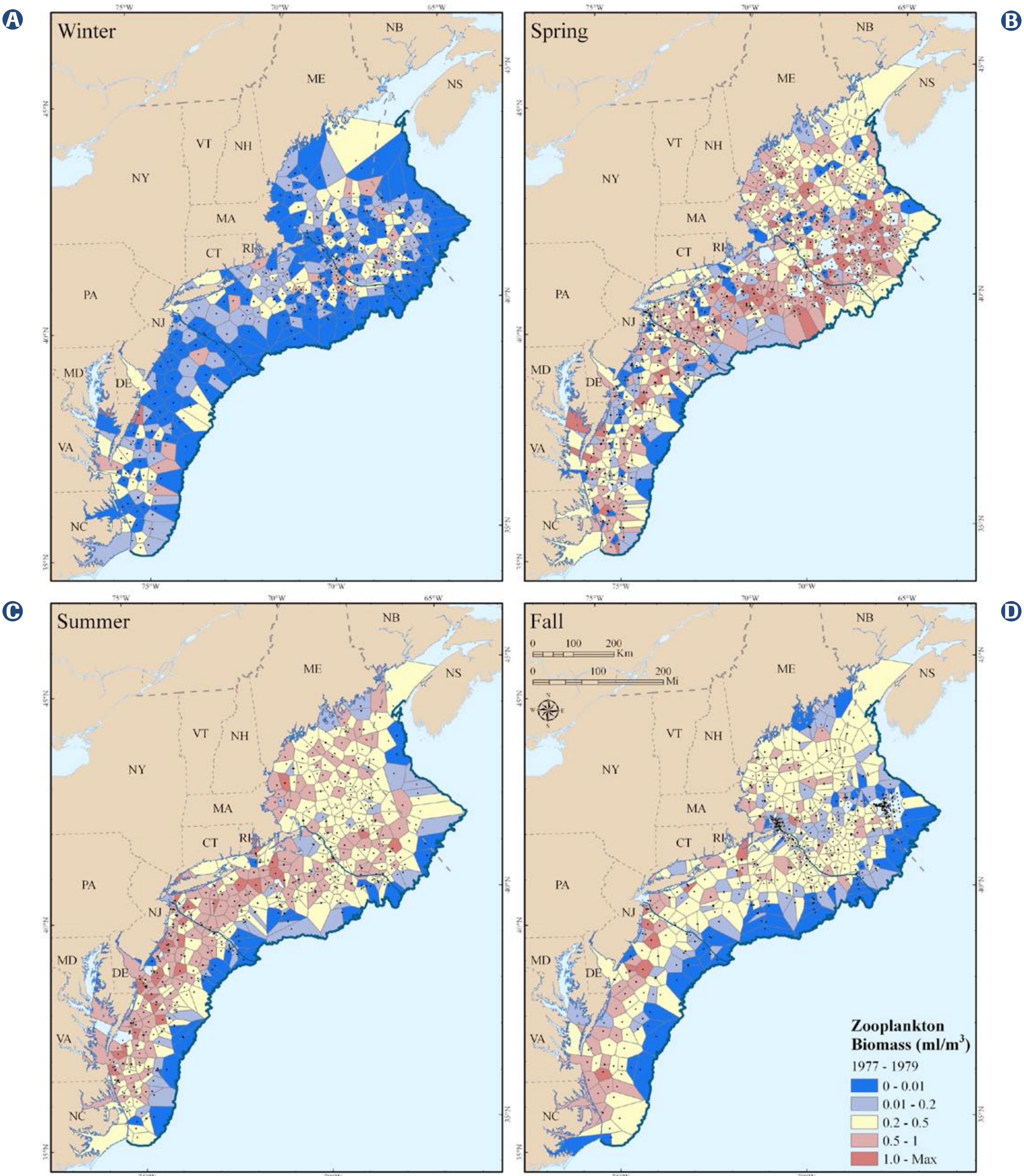


Figure 4-10. Mean zooplankton biomass from 1977-1979 (shown as Voronoi polygons). Black points represent sample locations.

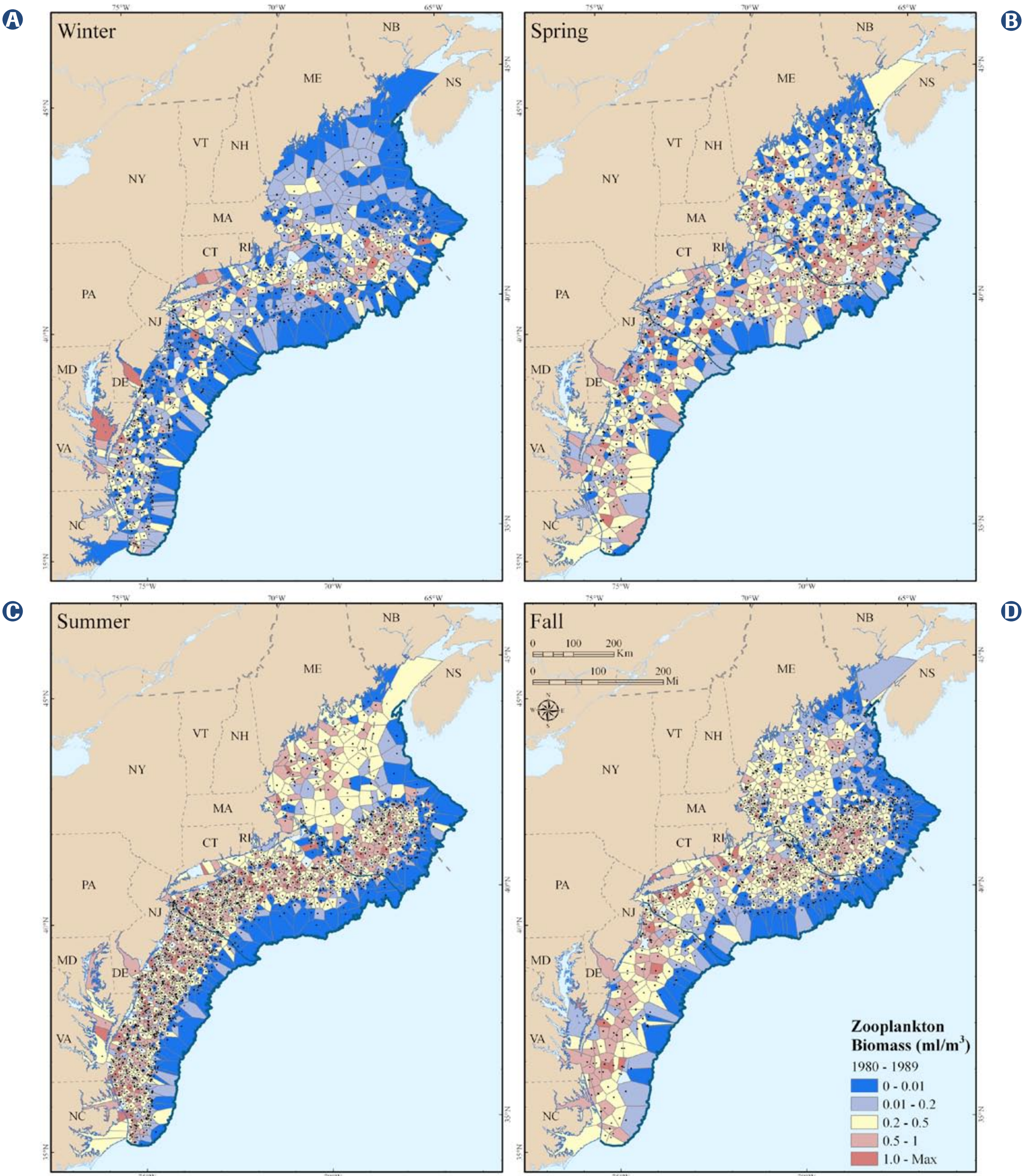


Figure 4-11. Mean zooplankton biomass from 1980-1989 (shown as Voronoi polygons). Black points represent sample locations.

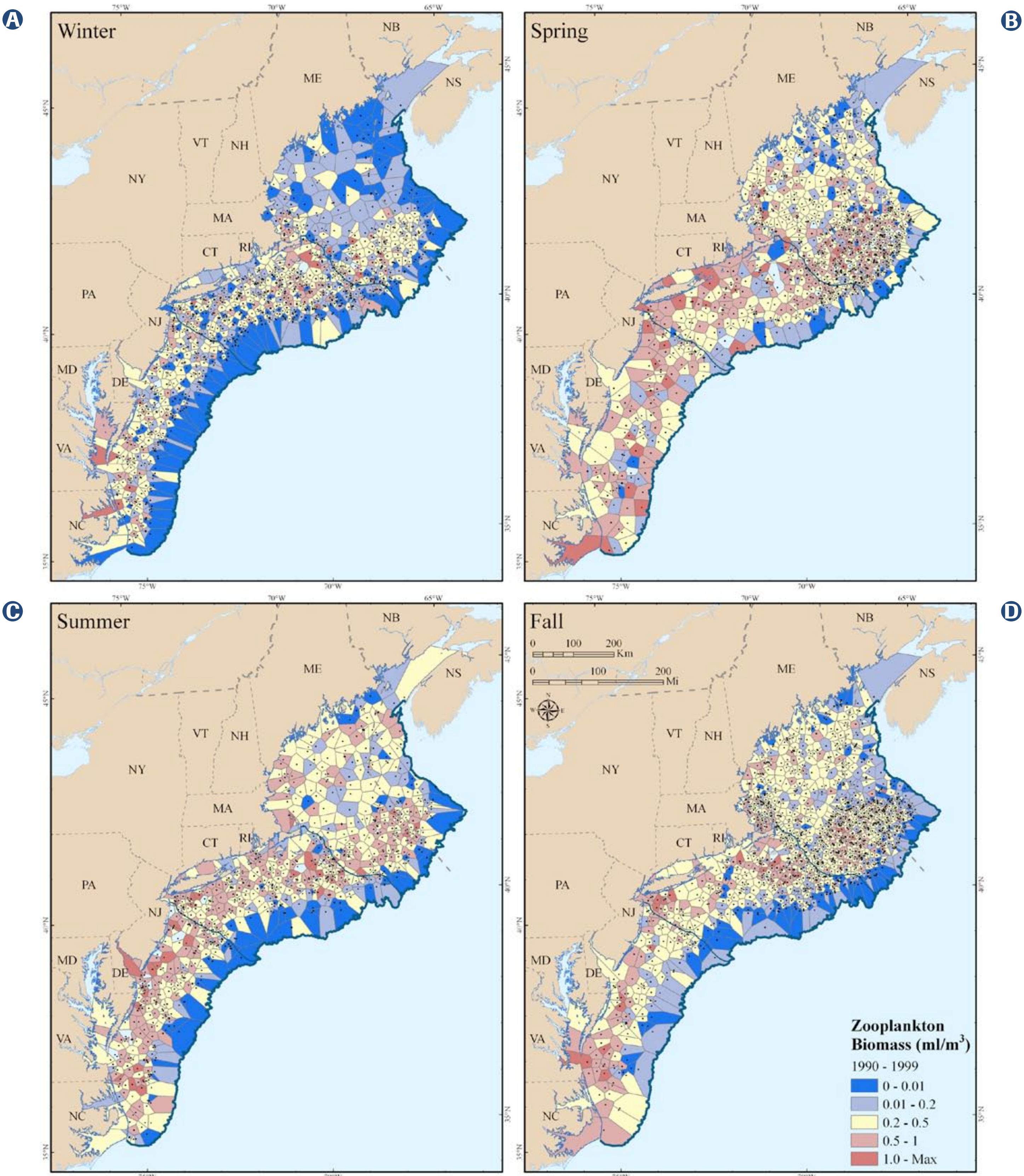


Figure 4-12. Mean zooplankton biomass from 1990-1999 (shown as Voronoi polygons). Black points represent sample locations.

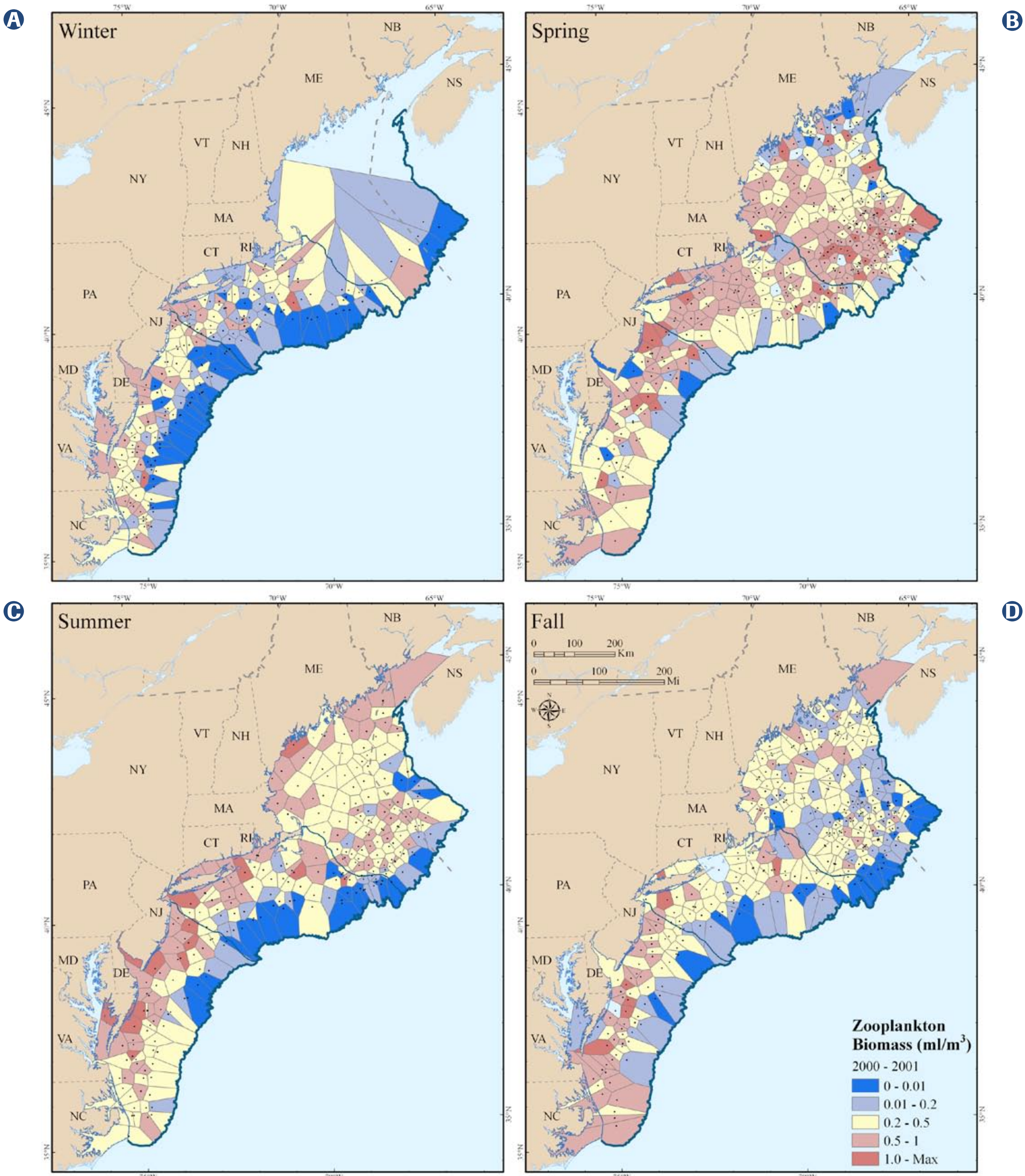


Figure 4-13. Mean zooplankton biomass from 2000-2001 (shown as Voronoi polygons). Black points represent sample locations.

Literature Cited

Beardsley, R. C., and W. C. Boicourt. 1981. On estuarine and continental-shelf circulation in the Middle Atlantic Bight. Pages 198-233 in B. A. Warren and C. Wunsch, eds. Evolution of Physical Oceanography. MIT Press, Cambridge, Massachusetts.

Bricker, S., B. Longstaff, W. Dennison, A. Jones, K. Boicourt, C. Wicks, and J. Woerner. 2007. Effects of nutrient enrichment in the nation's estuaries: A decade of change. NOAA Coastal Ocean Program Decision Analysis Series No. 26. National Centers for Coastal Ocean Science, Silver Spring, MD. 328 pp.

CCSP (Climate Change Science Program). 2008. Scientific assessment of the effects of global change on the United States. Report of the Committee on Environment and Natural Resources National Science and Technology Council. Available from http://www.climatescience.gov/Library/scientific-assessment (accessed October 2008).

Epifanio, C. E., and R. W. Garvine. 2001. Larval transport on the Atlantic continental shelf of North America: a review. Estuarine, Coastal and Shelf Science 52: 51-77.

Etnoyer, P., D. Canny, B. Mate, and L. Morgan. 2004. Persistent pelagic habitats in the Baja California to Bering Sea (B2B) Ecoregion. Oceanography 17: 90-101.

Friedland, K. D., and J. A. Hare. 2008. Long-term trends and regime shifts in sea surface temperature on the continental shelf of the northeast United States. Continental Shelf Research 27: 2313-2328.

Greene, C. H., A. J. Pershing, T. M. Cronin, and N. Ceci. 2008. Arctic climate change and its impacts on the ecology of the North Atlantic. Ecology 89(11) Supplement: S24–S38.

Haney, J. C. 1986. Seabird segregation at Gulf Stream frontal eddies. Marine Ecology Progress Series 28: 279-285.

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate change 2007: The physical science basis. Contribution of Working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M.
Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)] Cambridge University Press, Cambridge, United Kingdom and New York, NY.

Longhurst, A. 2007. Ecological Geography of the Sea. 2nd edition. Academic Press, Amsterdam.

Mann, K. H., and J. R. N. Lazier. 2006. Dynamics of Marine Ecosystems. 3rd edition. Blackwell, Malden, Massachusetts, USA.

McManus, M.A., A.L. Alldredge, A.H. Barnard, E. Boss, J. F. Case, T.J. Cowles, P.L. Donaghay, L.B. Eisner, D.J. Gifford, C.F. Greenlaw, C.M. Herren, D.V. Holliday, D. Johnson, S. MacIntyre, D.M. McGehee, T.R. Osborn, M.J. Perry, R.E. Pieper, J.E.B. Rines, D.C. Smith, J.M. Sullivan, M.K. Talbot, M.S. Twardowski, A. Weidemann, J.R. Zaneveld. 2003. Characteristics, distribution and persistence of thin layers over a 48 hour period. Marine Ecology Progress Series. 261: 1-19.

Munk, P., P. O. Larsson, D. Danielsen, and E. Moksness. 1995. Larval and small juvenile cod Gadus morhua concentrated in the highly productive areas of a shelf break front. Marine Ecology Progress Series 125: 21-30.

Newell, R. C., L. J. Seiderer, and D. R. Hitchcock. 1998. The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. Oceanography and Marine Biology: an Annual Review 36: 127-178.

Nixon, S. W., S. Granger and B. Buckley. 2003. The warming of Narragansett Bay. 41°N A Publication of Rhode Island Sea Grant and Land Grant Programs 2:18-20.

Nixon, S. W., S. Granger, B. A. Buckley, M. Lamont, and B. Rowell. 2004. A one hundred and seventeen year coastal temperature record from Woods Hole, Massachusetts. Estuaries 27: 397-404.

Porter-Smith, R., P. T. Harris, O. B. Andersen, R. Coleman, D. Greenslade, and C. J. Jenkins. 2004. Classification of the Australian continental shelf based on predicted sediment threshold exceedance from tidal currents and swell waves. Marine Geology 211: 1-20.

Preston, B. L. 2004. Observed winter warming of the Chesapeake Bay estuary (1949-2002): implications for ecosystem management. Environmental Management 34: 125-139.

Rabalais, N. N., R. E. Turner, and W. J. Wiseman Jr. 2002. Gulf of Mexico hypoxia, a.k.a. "the dead zone." Annual Review of Ecology and Systematics 33: 235-263.

Roberts, J. J., B. D. Best, D. C. Dunn, E. A. Treml, and P. N. Halpin. (in review). Marine Geospatial Ecology Tools: An integrated framework for ecological geoprocessing with ArcGIS, Python, R, MATLAB, and C++. Environmental Modeling & Software. http://mgel.env.duke.edu/tools.

Roff, J. C. and S. M. J. Evans. 2002. Frameworks for marine conservation – non-hierarchical approaches and distinctive habitats. Aquatic Conservation Marine Freshwater Ecosystems 12: 635-648.

Roman, M., X. Zhang, C. McGilliard, and W. Boicourt. 2005. Seasonal and annual variability in the spatial patterns of plankton biomass in Chesapeake Bay. Limnology and Oceanography 50: 480-492.

Rutherford, S., S. D'Hondt, and W. Prell. 1999. Environmental controls on the geographic distribution of zooplankton diversity. Nature. 400: 749-753.

Shanks, A.L. 1995. Mechanisms of cross-shelf dispersal of larval invertebrates and fish. pp. 323–368 in: Ecology of Marine Invertebrate Larvae, L.R. McEdward (ed). CRC Press, Boca Raton, Florida.

Smith, L. 2007. The Effects of Global Climate Change on the Coastal Ecosystems of Rhode Island. URI IGERT white paper.

Townsend, D.W., A.C. Thomas, L.M. Mayer, M.A. Thomas, J.A. Quinlan. 2006. Oceanography of the Northwest Atlantic continental shelf. Chapter 5 in A.R. Robinson and K.H. Brink, eds. The Sea: the Global Coastal Ocean: Interdisciplinary Regional Studies and Syntheses. Harvard University Press, Cambridge, Massachusetts.

Ullman, D. S., and P. C. Cornillon. 2001. Continental shelf surface thermal fronts in winter off the northeast US coast. Continental Shelf Research 21: 1139-1156.

Wishner, K. F., D. M. Outram., and D. S. Ullman. 2006. Zooplankton distributions and transport across the northeastern tidal front of Georges Bank. Deep-Sea Research II 53: 2570-2596.

Worm, B., M. Sandow, A. Oschlies, H. K. Lotze, and R. A. Myers. 2005. Global patterns of predator diversity in the open oceans. Science 309: 1365-1369.

CHAPTER

5

Marine Fishes: Introduction & Methods

Mark Anderson, Arlene Olivero, Geoffrey Smith, Jennifer Greene, Jay Odell, and Caroly Shumway

Introduction

The North Atlantic region is known for its highly productive waters, a result of its strong tidal flows, complex circulation patterns, varied seafloor topography and diverse sediment types. Accordingly, large and sustained catches of demersal and pelagic fish have fueled regional economies for centuries. The diversity of fishes in the region may be explained by the variety of available habitats combined with the extraordinary adaptability of these creatures - the most diverse class of living vertebrates.

© Andrew J. Martinez, NOAA

Distinctive fish habitats are places where singular oceanographic processes occur on a regional or local scale. Often, these correlate with physical or structural features such as anomalies of temperature, areas of high primary productivity, regions of diverse seafloor topography, or geographically isolated settings. For demersal fish, species abundance has been found to be associated with depth, temperature, sediment type, sediment diversity, and habitat complexity (Mahon et al. 1998; Stevenson et al. 2004; Auster et al. 2001; Lough et al. 1989; Charton and Perez-Ruzafa 1998; DeLong and Collie2004; Lindholm et al. 1999.) Similarly, the abundance of pelagic fish is correlated with thermal fronts (Etnoyer et al. 2004).

This assessment focuses on identifying those places in the region that have been consistently important to fish productivity and diversity over decades. The deep basins, shallow banks, and major channels of the Gulf of Maine, for example, are tied to water masses with distinct layering and corresponding diversity. Farther south, the broad continental margin, large estuaries, and deep submarine canyons, function as nursery areas for estuary dependent fishes and migratory pathways for large pelagic species. The extremely heterogeneous aspect of the region ensures that not all areas are equivalently important with respect to fish productivity. In the chapters that follow - demersal fish, diadromous fish, small and large pelagic fish - we use a single consistent methodology, based on the persistence of individual species over decades, to identify areas that may be particularly important for the conservation of each species. We chose to focus on persistence, weighted by abundance, because the latter varies greatly from year to year, reflecting temporal variation in population sizes, fluctuating prey bases, and other factors unrelated to the physical structure of the region. In contrast, places where a species persists over decades are more likely to correlate with perennial factors important to productivity and diversity. When possible, however, we weighted the persistence score by the abundance of the species in each decade studied, to identify areas where a species not only persisted, but persisted at high abundance.

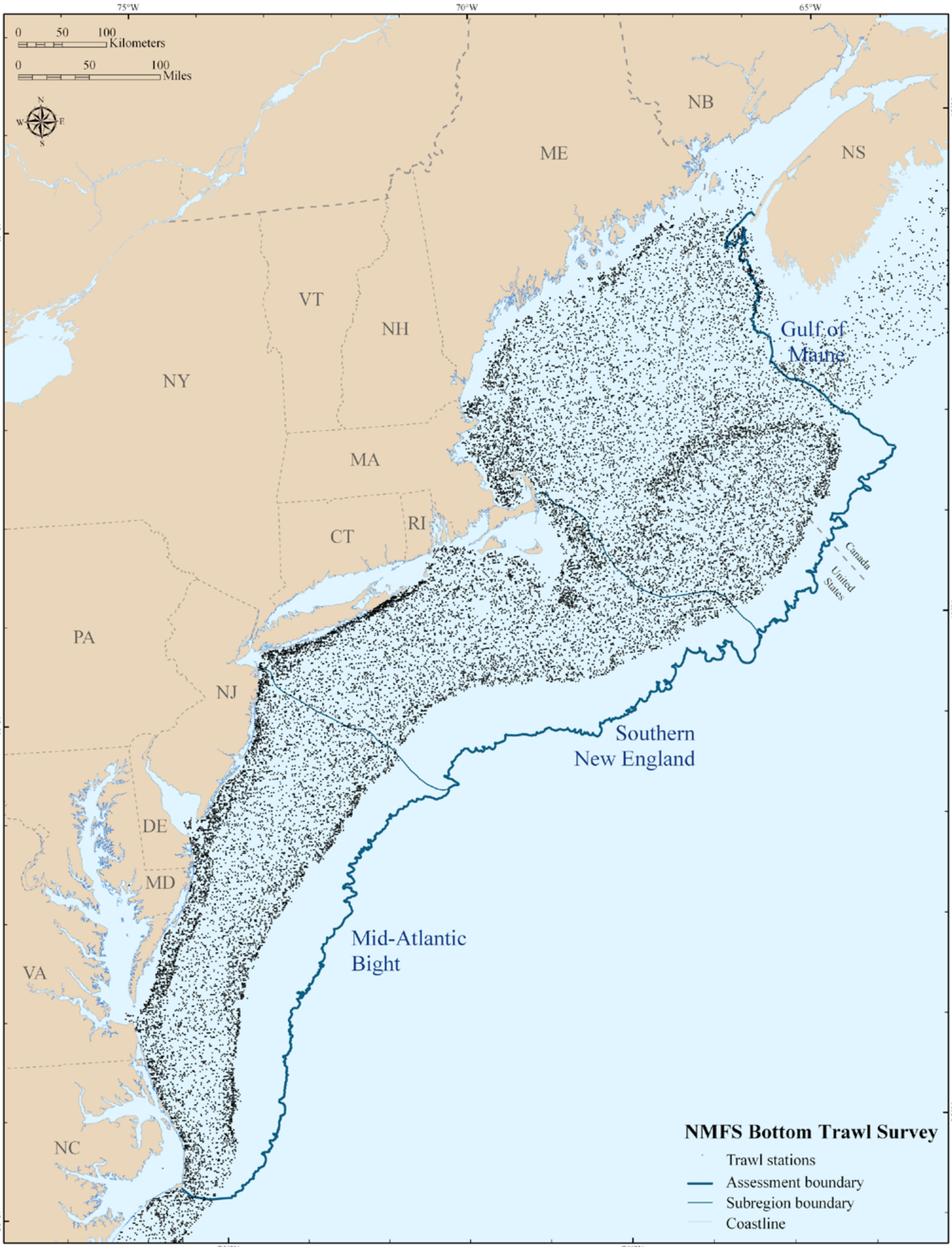


Figure 5-1. Map showing the distribution of all bottom trawl survey points used in this analysis.

Methods

In each of the following fish chapters we discuss how the target species were selected and examine their distribution, abundance trends, and areas of persistence in the region. Specifically, three questions concerning the distribution of fish species in the Northwest Atlantic were addressed with this analysis:

- What is the general distribution of the species in the region? (distribution)
- Where in the region has the abundance been increasing or decreasing? (trends in abundance)
- Where in the region has the species been consistently found over time at the highest abundances? (weighted persistence)

Data

To answer these questions, data from the National Marine Fisheries Service (NMFS) spring and fall bottom trawl surveys (1968 – 2006) were analyzed (Figure 5-1). All analyses were conducted on a species by species basis to account for differences in the catchability of each species. Comparisons among species were not performed. We limited the data to valid records collected in the fall or spring as these two seasons were surveyed using similar gear and methods over a similar geographic area. To ensure that each record was comparable, the number of fish per tow was adjusted based on correction factors developed by NOAA's Northeast Fisheries Science Center to account for changes in survey vessels, trawl net design, and trawl doors over time.

Binning data by decades

Individual trawl survey points do not overlap from year to year. Thus, in order to calculate temporal trends in abundance and persistence the region was partitioned into a grid of ten minute squares (TMS), with each square containing multiple survey points covering a range of years. The binned data set was examined to determine the smallest time interval (annual, biannual, 5-yrs, 10-yrs) for which consistent values could be calculated for most squares. The 10-yr decadal period was selected because it allowed for a robust analysis that included almost all of the TMS in the region. In other words, most squares contained at least one survey point from each decade (1970-1979, 1980-1989, 1990-1999, and 2000-2006). TMS that did not have survey points in at least three or four decades were excluded from the analysis. For the remaining TMS, each one was scored based on the presence of the species of interest within each decade.

Data limitations

A limitation of these surveys is that different species demonstrate varying degrees of susceptibility to being caught by the survey gear (i.e., catch coefficients for cod are much higher than those for wolffish or other species). Otter trawl systems like the one utilized to conduct survey sampling are specifically designed to capture a variety of demersal fish species, including many of the species analyzed in this assessment. It is important to note, however, that the catch rates for various species within the group are variable. Catchability coefficients are generally higher for demersal, round-bodied species (e.g., Atlantic cod, haddock, pollock), and lower for flat-bodied fish (e.g., Atlantic halibut, summer flounder) and pelagic species (e.g., bluefin tuna, Atlantic herring). In additional, catch rates at any given location can be heavily influenced by day/night differences in species distribution within in the water column, and by seasonal variations in species distribution within their geographic range. Some species are also able to avoid capture in trawls by using sensory or behavioral capabilities.

Additionally, trawl samples are particularly difficult to conduct in areas of high habitat complexity, such as boulder fields, canyons, or the seamounts just outside the Northwest Atlantic region. The survey also may miss key nearshore areas and some offshore areas (e.g., Nantucket Sound) due to survey vessel depth limitations. Many of these coastal areas, especially bays and estuaries, are critical for earlier life stages of fish. For future analyses, a goal is to merge inshore trawl sampling conducted by individual states with the results presented here. As such, it should be recognized that while analyses derived from the trawl survey database are indeed informative, results obtained from other data sources should also be considered. Finally, any shifts in movement due to changes in temperature caused by climate change may not be reflected in these snapshots.

Distribution

A basic distribution map was created for each species that shows the trawl survey points where the species was captured weighted by its relative abundance (Figure 5-2a). All spring and fall trawl data from the years 1968 through 2006 were used and the maps were produced by season. Because the data were skewed toward low abundances, the raw catch values were transformed into a cumulative percentile. Tows in which the target species was caught were then divided into four quartiles based on percentage of the total catch of that species per season. This transformation allows the abundance patterns to be displayed in meaningful units.

Trends in Abundance

Using the binned data described above, trends in average abundance over four decades were calculated for each TMS for each species. Only squares with four decades of sampling were used. For this analysis, a linear regression line was fit to the average abundance values for each of the four successive decades. Regression lines with a p-value less than 0.1 (90% probability) were considered to show a significant trend. Positive slopes indicated an increasing trend in abundance, negative slopes indicated a decreasing trend, and insignificant regressions indicated no trend. By mapping these results for each species, the spatial locations where changes in abundance were detected were highlighted (for an example, see Figure 5-3).

Regressions were also used to analyze overall trends in species abundances based on the individual (unbinned) samples. From these analyses, significant changes in abundance of a given species in a given season across the full 36-year period were detected for many species. Note that although sometimes there is a significant change in the abundance of a species when spatial location is not considered, for some species changes in abundance were only revealed by studying the spatially linked regression map results. By using both of these trend results, both overall population trends and the distinct changes in the spatial locations of abundance over time were explored.

Persistence

Persistence refers to the consistency with which a species was caught in the same general area over time. To be included in this analysis, a TMS had to have data from at least one survey point from each of three or four decades. Those TMS that did not meet these criteria were excluded from the analysis. For the remaining TMS, we scored each one based on the presence of the species of interest within each decade.

Score 1 = The species was present in 1 out of the sampled decades
Score 2 = The species was present in 2 out of the sampled decades
Score 3 = The species was present in 3 out of the sampled decades
Score 4 = The species was present in 4 out of the sampled decades

For example, a TMS with a persistence score of 4.00 indicated that the species was caught in the trawl survey at least once in each of the 4 decades sampled (Figure 5-2c).

Weighted Persistence

The weighted persistence score is a variation of the persistence score in which each decade is weighted by the average abundance of the species over the decades it was present. Abundance was measured as the numbers of individuals of a given species caught per sampling tow. Because the abundance data were skewed toward low abundances with a few very high abundances, values were log-transformed and mean log abundance were calculated for each decade within each TMS. These decadal mean scores were averaged across all decades to obtain a grand average for each TMS. The grand average was then normalized across all TMS for the species of interest to create a metric of abundance ranging between 0.0 and 1.00 for each TMS, with low abundance defined as 0-0.49 and high abundance defined as 0.50 – 0.99 (Figure 5-2b)

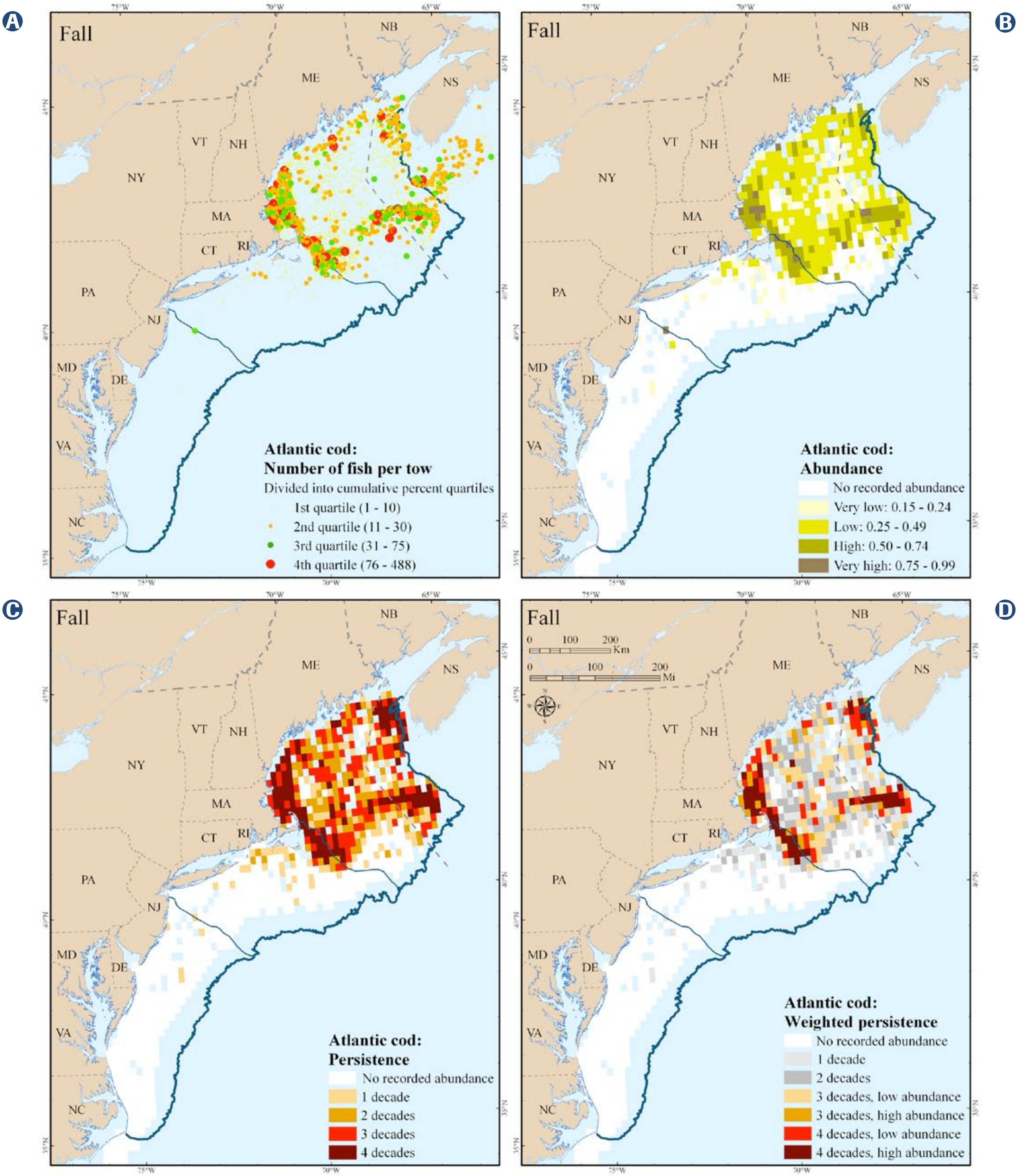


Figure 5-2. a. Point distribution map of Atlantic cod, b. Abundance map of Atlantic cod binned by ten minute squares, c. persistence map of Atlantic cod, d. weighted persistence map of Atlantic cod.

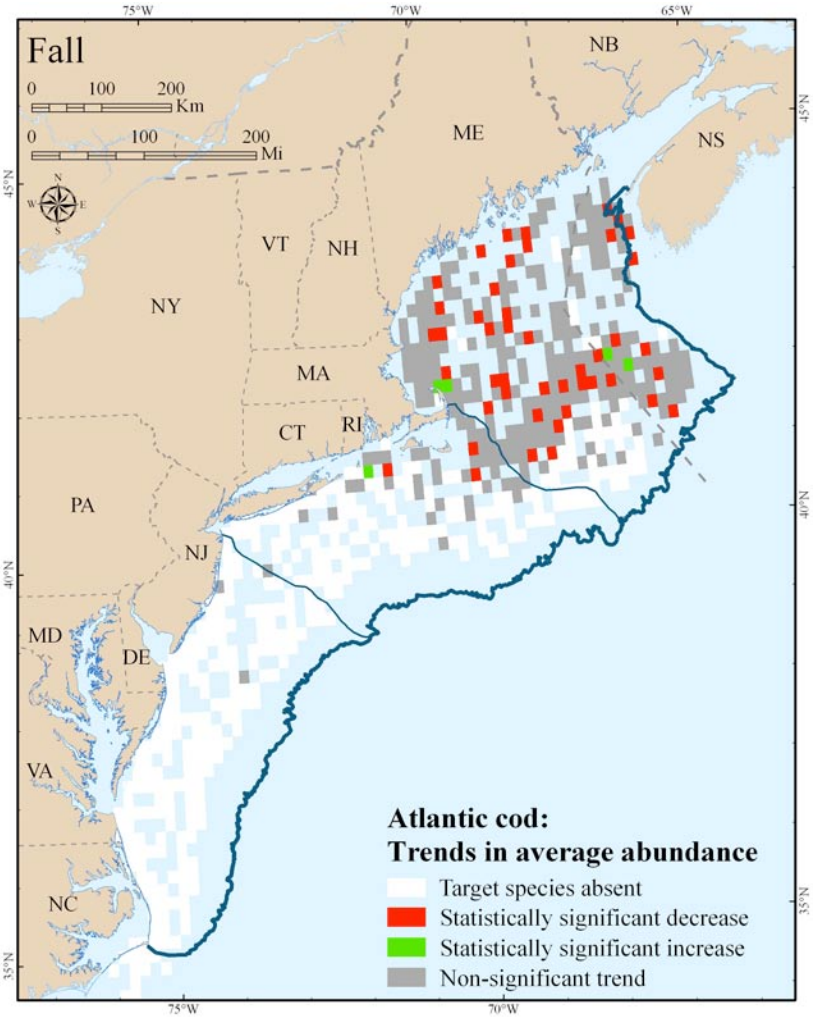


Figure 5-3. Maps showing trend in average abundance for Atlantic cod.

The weighted persistence score was calculated by adding the persistence and relative average abundance. In the resulting metric, the integer part of the score is the persistence score while the decimal part of the score is the relative grand average abundance value (Figure 5-2d)

Limitations to the persistence maps

The use of the ten minute squares (TMS) to bin the trawl data smoothed out some of the noise in the data to provide a straightforward picture of obvious robust trends in persistence. A species had only to be caught once per decade to be tagged as present. However there is variability in how many times a particular square was sampled per decade, with samples per decade ranging from 1 to 36 depending on the TMS. Squares that were sparsely sampled may have failed to catch a species that was actually present. This distribution of these sparsely sampled TMS is centered on the deep central region of the Gulf of Maine (Figure 5-4). In consequence, the results are valid for detecting persistent areas (true positives) in all TMS but may underestimate actual persistence values in areas of sparse sampling (false negatives).

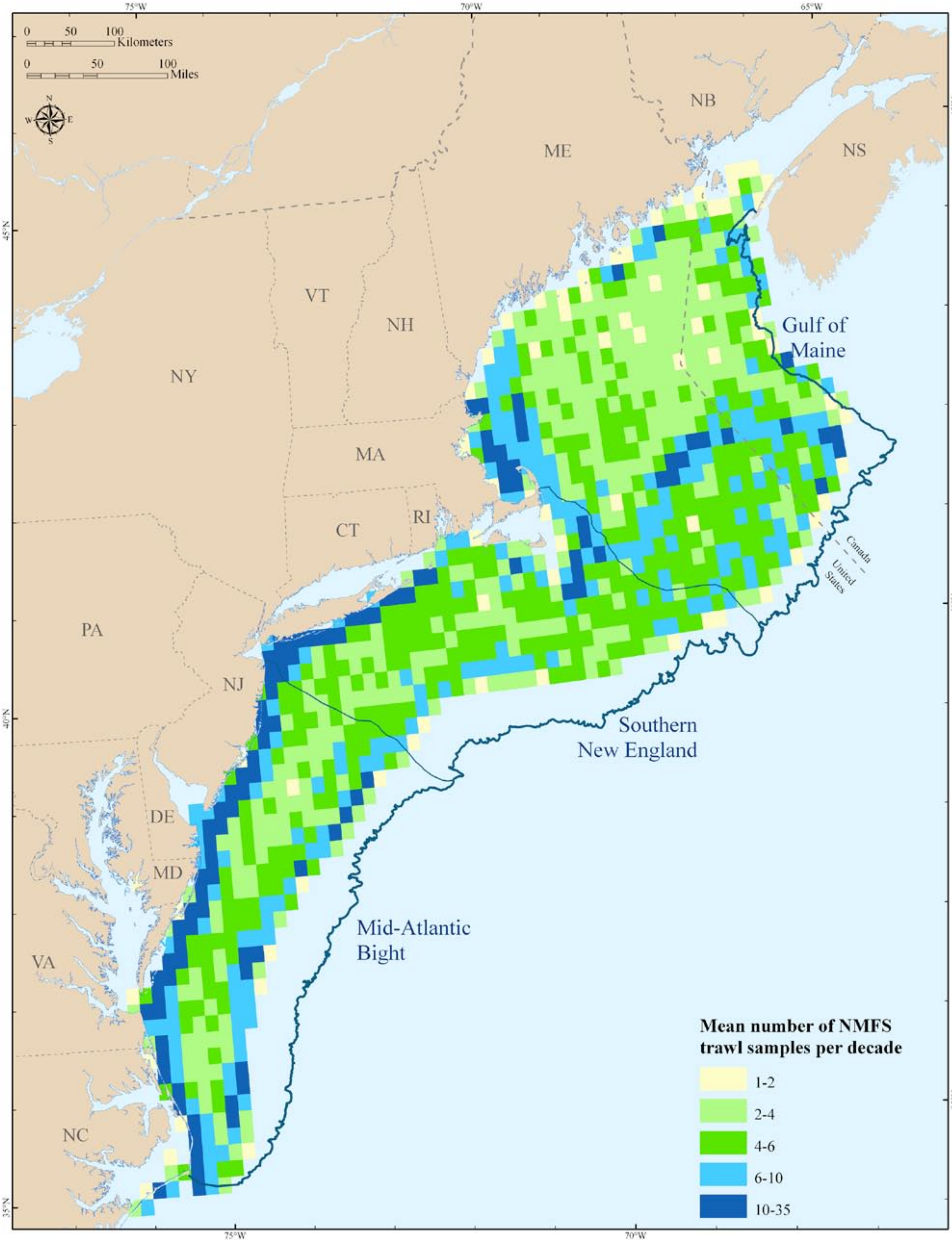


Figure 5-4. Combined mean sampling effort for spring and fall. Ten minute squares shown in yellow were sampled on average only once or twice per decade. Actual persistence may be underestimated in these areas.

Literature Cited

Auster, P.J., K. Joy, and P.C. Valentine. 2001. Fish species and community distributions as proxies for seafloor habitat distributions: the Stellwagen Bank National Marine Sanctuary example (Northwest Atlantic, Gulf of Maine). Environmental Biology of Fishes. 60:331-346.

Charton, J.A. and A. Perez Ruzafa. 1998. Correlation between habitat structure and a rocky reef fish assemblage in the southwest Mediterranean. Marine Ecology. 19:111-128.

DeLong, A.K. and J.S. Collie. 2004. Defining Essential Fish Habitat: A Model-Based Approach. Rhode Island Sea Grant, Narragansett, R.I.

Etnoyer, P., D. Canny, B. Mate, and L. Morgan. 2004. Persistent pelagic habitats in the Baja California to Bering Sea (B2B) Ecoregion. Oceanography. 17:90-101.

Lindholm, J.B., P.J. Auster, and L.S. Kaufman. 1999. Habitat-mediated survivorship of juvenile (0-year) Atlantic cod Gadus morhua. Mar. Ecol. Prog. Ser. 180:247-255.

Lough, R.G., P.C. Valentine, D.C. Potter, P.J. Auditore, G.R. Bolz, J.D. Neilson, and R.I. Perry. 1989. Ecology and distribution of juvenile cod and haddock in relation to sediment type and bottom currents on eastern Georges Bank. Marine Ecology Progress Series. 56:1-12.

Mahon, R., S.K. Brown, K.C.T. Zwanenburg, D.B. Atkinson, K.R. Buja, L. Clafin, G.D. Howell, M.E. Monaco, R.N. O'Boyle, and M. Sinclair. 1998. Assemblages and biogeography of demersal fishes of the east coast of North America. Canadian Journal of Fisheries and Aquatic Sciences. 55:1704-1738.

Stevenson D., L. Chiarella, D. Stephan, R. Reid, K. Wilhelm, J. McCarthy, and M. Pentony. 2004. Characterization of the fishing practices and marine benthic ecosystems of the northeast US shelf, and an evaluation of the potential effects of fishing on essential habitat. NOAA Tech Memo NMFS NE 181; 179 p.

Diadromous Fish

Alison Bowden

Introduction


© William W. Hartley, U.S. Fish & Wildlife

Diadromous fish share one major attribute. They exploit both freshwater and saltwater habitats during distinct phases of their life cycles. The distance they travel in order to do this varies widely among species, from the rainbow smelt that lives its entire life within about a mile of the coast up to the head of tide in rivers, to the Atlantic salmon that travels thousands of miles from the ocean waters off Greenland to headwater streams hundreds of miles inland. Because their life histories link terrestrial, freshwater, and marine ecosystems, they are an ideal conservation target for ecosystem-scale initiatives. The stress and depletion of energy stores required to transition between fresh and salt water render these species extremely vulnerable to habitat degradation within freshwater and marine migratory corridors, and much of their historic freshwater spawning habitat is no longer accessible, having been blocked by dams and other barriers. The combination of habitat impacts, excessive predation and fishing pressure, both from directed fisheries and bycatch, has caused significant declines in populations of these species. For example, American shad is estimated to occupy about half of its historic spawning rivers coastwide at 10% of historic abundance (ASMFC 2007). The cultural importance of these species is evident: Several of these species have been featured in popular literature, from Henry David Thoreau's lament of the loss of herring runs due to dam construction on the Concord River in 1839 to John McPhee's account (2002) of the natural and social history of American shad in *The Founding Fish.*

Technical Team Members

Colin Apse, The Nature Conservancy, Eastern Division
Michael Armstrong, Ph.D., Massachusetts Division of Marine Fisheries
Alison Bowden, The Nature Conservancy, Massachusetts
Mark Bryer, The Nature Conservancy, Maryland
Mari-Beth DeLucia, The Nature Conservancy, New York
Michele DePhilip, The Nature Conservancy, Pennsylvania
Andrew Manus, The Nature Conservancy, Delaware
Jake Kritzer, Ph.D., Environmental Defense Fund
Martha Mather, Ph.D., University of Massachusetts/USGS Cooperative Fish and Wildlife Unit
Jay Odell, The Nature Conservancy, Virginia
Arlene Olivero, The Nature Conservancy, Eastern Division
Joshua Royte, The Nature Conservancy, Maine
George Schuler, The Nature Conservancy, New York
Geoffrey Smith, The Nature Conservancy, Maine
Adam Whelchel, Ph.D., The Nature Conservancy, Connecticut

Selection of Target Species

All diadromous fish species were initially considered for inclusion as targets, but those that are apparently stable or increasing in number were ultimately not included. The species included as primary targets show evidence of significant decline or are already recognized as globally rare. Based on these criteria, eleven species of diadromous fish were selected as primary targets for this assessment:

- Alewife *(Alosa pseudoharengus)*
- American eel *(Anguilla rostrata)*
- American shad *(Alosa sapidissima)*
- Atlantic salmon (Salmo salar)
- Atlantic sturgeon *(Acipencer oxyrhinchus)*
- Atlantic tomcod *(Microgadus tomcod)*
- Blueback herring *(Alosa aestivalis)*
- Hickory shad *(Alosa mediocris)*
- Rainbow smelt *(Osmerus mordax)*
- Sea-run brook trout *(Salvelinus fontinalis)*
- Shortnose sturgeon *(Acipencer brevirostrum)*

Population Status and the Importance of Northwest Atlantic region

The Northwest Atlantic populations of some of these species are particularly important because the global range of seven of the 11 target diadromous species is limited to the Atlantic coast of the United States and Canada.

The conservation status of each of these species varies among conservation programs (including among the International Union for the Conservation of Nature (IUCN), FishBase, and Natureserve programs; Table D1). The two species of sturgeon have a Natureserve global rank of G3, considered "globally rare." The sturgeons are consistently recognized as highly threatened or vulnerable; shortnose sturgeon is listed as Threatened under the Endangered Species Act (ESA), and Atlantic sturgeon is a candidate for listing (currently a National Oceanic and Atmospheric Administration (NOAA) Species of Concern, defined as a species about which the agency has concerns regarding status and threats but for which insufficient information is available to list the species under the ESA). This designation does not carry any procedural or substantive protections under the Endangered Species Act (NMFS OPR 2009).

Because of their complex history of extirpation and restocking, Atlantic salmon have a variety of legal statuses within the region, but they are generally regarded as imperiled. Atlantic salmon is considered stable in the northern portions of its global range in Canada and Europe, and is ranked G5, of "least concern." However, the status of populations within the Northwest Atlantic region in southern Canada and the United States is poor. The only remaining wild Atlantic salmon populations in the U.S are found in Maine. In 2000, all naturally reproducing remnant populations of Atlantic salmon from the Kennebec River downstream of the former Edwards Dam site northward to the mouth of the St. Croix River were added to the Federal endangered species list as a Distinct Population Segment (DPS) (NMFS USFWS 2005). In 2009 the Gulf of Maine DPS was expanded to include fish in the Penobscot, Kennebec, and Androscoggin rivers and their tributaries (NMFS OPR 2009). The Gulf of Maine DPS has a global rank of G5T1Q, denoting that this population segment of the species is critically imperiled. Inner Bay of Fundy populations in New Brunswick and Nova Scotia are ranked G5TNR (not yet ranked), but they were listed as Endangered by the Committee on the Status of Endangered Wildlife in Canada in April 2001 (COSEWIC 2008).

The remaining species are all ranked G5, or "globally secure" by Natureserve, but Fishbase vulnerability ranks vary from moderate to very high. Like Atlantic sturgeon, alewife, blueback herring, and rainbow smelt are listed by NOAA as Species of Concern. A 2004 petition to list the American eel under the ESA was found to be "not warranted" but noted numerous stressors in declines; ASMFC is currently conducting a stock assessment, due in 2010 (ASMFC 2005). The American shad stock assessment found that stocks are currently at all-time lows and do not appear to be recovering (ASMFC 2007). Recent declines of American shad were reported for Maine, New Hampshire, Rhode Island, and Georgia stocks, and for the Hudson (New York), Susquehanna (Pennsylvania), James (Virginia), and Edisto (South Carolina) rivers. Low and stable stock abundance was indicated for Massachusetts, Connecticut, Delaware, the Chesapeake Bay, the Rappahannock River (Virginia), and some South Carolina and Florida stocks. Stocks in the Potomac and York Rivers (Virginia) have shown some signs of recovery in recent years.

Other important Atlantic coast diadromous species like striped bass and sea lamprey play an important role in the ecosystem of the northwest Atlantic, but populations appear to be stable, therefore were not included in this Assessment. They are also likely to benefit from efforts to protect target species with similar life histories. More detail on the individual life histories of target species may be found in the species accounts in Appendix XX.

Ecosystem Interactions and Ecological Dependencies

Riverine habitats and communities may be strongly influenced by migratory fauna that provide a significant source of energy input. Pacific salmon have been recognized as key elements of riparian (streamside) and terrestrial as well as freshwater systems (Gende et al. 2002); Atlantic coast species like alewife appear to play an equally important role in their freshwater spawning habitats, providing nutrients that assist microbes in the breakdown of leaf litter and the resulting release of that stored energy to consumers (Durbin et al. 1979). Specific associations between diadromous fish and other species also exist. For example, many freshwater mussels are dependent upon migratory fishes as hosts for their parasitic larvae (Neves et al. 1997; Vaughn and Taylor 1999), such that loss of upstream migratory fish habitat is a major cause of mussel population declines (Williams et al. 1992; Watters 1996).

These historically abundant species serve as prey in rivers and estuaries for larger predatory fish such as bluefish and striped bass, gulls, osprey, cormorants, river otter, and mink, and at sea for seals, sea birds, and a wide range of piscivorous (fish-eating) marine fish. In one study tomcod accounted for 59% of the diet by weight of young-of-year bluefish, along with juvenile shad, blueback herring, and similar species (Juanes et al. 1993). Clupeids (shad and river herring) are an important food source for striped bass, making up a majority of their diet in late spring and early summer (Dovel 1968).

The 2005 Recovery Plan for Gulf of Maine Atlantic salmon identified diminished runs of clupeids and sea lamprey as factors impacting recovery of salmon. The authors suggest that an abundance of other diadromous species provided three categories of ecosystem services to salmon: prey buffering (providing an alternative forage base such that no individual prey species becomes overly depleted), marine derived nutrient cycling (all sea lamprey and 20% or more of clupeids die after spawning, enriching freshwater habitats), and habitat modification and enhancement (sea lamprey build nests that are used preferentially as spawning sites for salmon).

Northwest Atlantic Distribution and Important Areas

Methods

Marine Distribution

See methods overview in Chapter 5.

Data Limitations of Marine Data

It is important to note that using trawl data from bottom surveys to determine distributions of pelagic fish, e.g. river herring, could underestimate numbers or biomass of fish that are expected to be distributed throughout the water column. However, the National Marine Fisheries Service (NMFS) trawl data is the only long term fishery-independent data set available for examining marine distributions of these species. This information is necessary, but it must be interpreted with caution and results must be compared with other sources. In order to address this issue with the data set, marine distributions were mapped and analyzed only for species that occurred in at least 5% of trawls: alewife, American shad, and blueback herring. More than 3,000 individuals of each of these species were recorded in the database.

Freshwater Distribution
Freshwater/estuarine distributions were determined from several data sources including NatureServe (2007) data based on occurrences at the coarse, HUC-8 watershed level and Estuarine Living Marine Resources (ELMR) data for estuaries (NOAA 1994). Both datasets were mapped for presence/absence only. The ELMR dataset includes qualitative abundance data for multiple life stages of several species, but the team concluded that presence/absence offered the greatest confidence and clarity of information. Eastern Brook Trout Joint Venture (2006) data were used to map brook trout distribution and status. Sea-run brook trout were not mapped separately for that effort, but the coastal distribution of the species corresponds with the United States range of the sea-run form (note that resident and sea-run forms often occur in the same river).

More detailed information on status of runs from the Delaware River to mid-coast Maine is available in the North Atlantic Coast Ecoregional Plan (Anderson 2006). A variety of other sources is available for freshwater distributions of some species at multiple scales, including coastwide information on alosines compiled by ASMFC (2004). Some states, e.g. Maine, have detailed maps of habitat use for multiple species, but these have not been developed at the scale of this plan. The current effort focuses on developing a marine portfolio for the Northwest Atlantic marine region and thus river data sets compiled by others were utilized.

Maps, Analysis, and Areas of Importance

Because the fish included in this target are migratory, moving extensively from spawning to feeding to overwintering areas, critical areas for these species can vary in time and space, and maps of data for a few weeks of the year in spring and fall cannot provide a complete picture of habitat use. Surveys of striped bass, which have been the subject of intensive tagging, have indicated widely varying distribution and abundance patterns depending on when sampling was conducted relative to the fishes' seasonal coastal movements. The general pattern of movement, north in spring, south in fall, has long been understood, but with increasing information the complexities of fish abundance and distribution becomes clearer. Fish behavior varies depending on many factors that probably vary by year (Martha Mather, personal communication). It will be important to update these maps and conservation plans as more detailed data become available for the species discussed here. The following discussion is provided with these caveats in mind.

Alewife

Alewife spawn in coastal watersheds throughout the region (Figure 6-1), which represents most of their native range. Estuaries are used by adults prior to entering and after leaving spawning rivers in the spring, and by juveniles during seaward migration in later summer and fall and possibly as overwintering habitat. The species' range is apparently contracting northward: the southern limit of the range has changed from South Carolina to North Carolina, as surveys indicate no current spawning in South Carolina (ASMFC 2008). The 2008 status review also indicated historical and recent declines in abundance for alewife and blueback herring based on available run size estimates, declines in mean length-at-age of alewife and blueback herring, and decline in maximum age of male and female alewife by one to two years. A river herring stock assessment report is due in 2012 (because they are similar in appearance and life history, alewife and blueback herring are often referred to collectively as river herring).

In spring, alewife are concentrated in a wide band off Long Island and Rhode Island, and in two smaller areas in the Gulf of Maine near Cape Ann and the Kennebec River (Figure 6-2a). Catches occurred all along the coast and out to the shelf edge. In fall, alewife are tightly clustered along the Massachusetts coast from Cape Cod to Cape Ann, and in a small area around Block Island (Figure 6-2b). This pattern seems to indicate a northward movement in summer in order to utilize the Gulf of Maine as a feeding area, and a southward movement in fall to overwinter. It also approximates the observed areas of bycatch of river herring from 2005-2007 (Cieri et al. 2008).

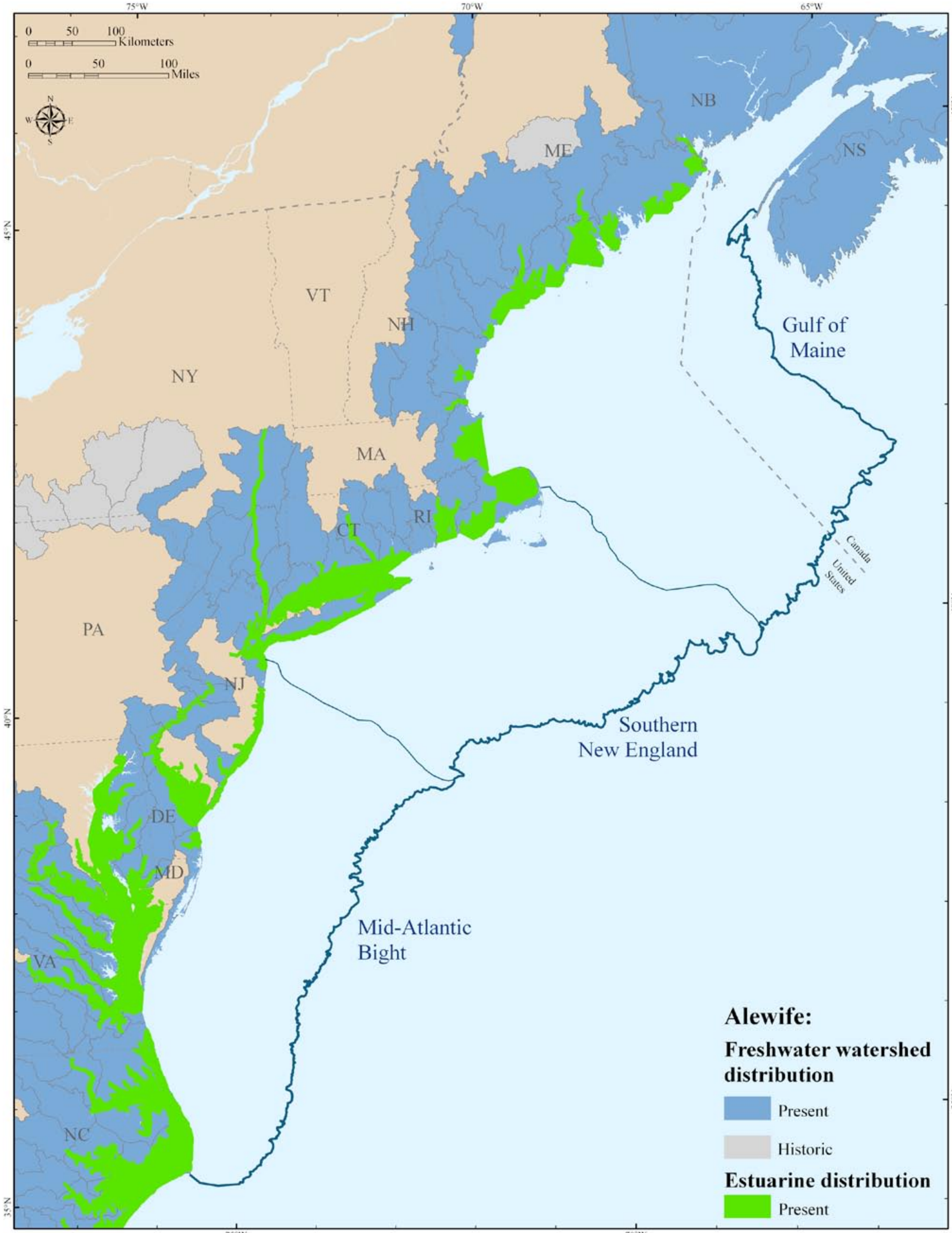


Figure 6-1. Freshwater and estuarine distribution for alewife.

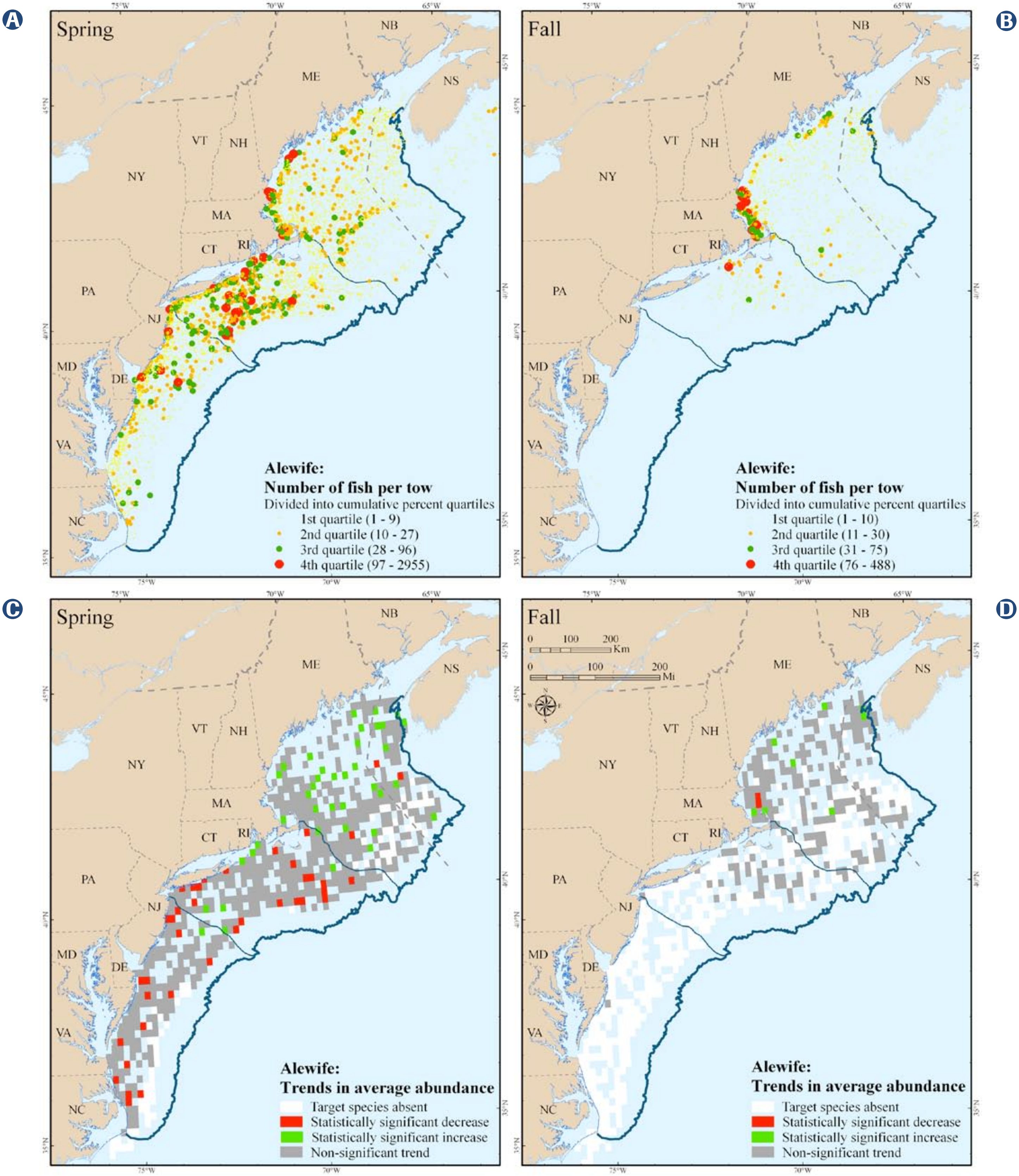


Figure 6-2. Trends in average abundance over 40 years for alewife during the spring and fall seasons.

No trend in abundance in spring or fall was observed for the majority of sampled ten minute squares (Figures 6-2c, 6-2d). There is evidence of a declining trend in spring in the southern portion of the region, and an increasing trend in the Gulf of Maine. Spring distributions at least partially reflect fish aligning themselves with natal watersheds for spawning runs so this pattern is consistent with observed declines in the southern range. In the fall, in a small area north of Cape Cod alewife increased in some TMS and decreased in some TMS. Since alewife is a northern species that is believed to respond to temperature cues by moving or migrating, these trends could be related to changes in ocean temperature, i.e., preferred temperature zones might be shifting in a way that makes alewife more or less likely to be captured by bottom-tending gear.

Alewife were highly persistent along the entire coast in spring, and consistently found in greatest abundances across southern New England, Georges Bank, and Cape Ann (Figure 6-3a). In fall, strongest persistence and abundance were in coastal waters along the Massachusetts coast north of Cape Cod and off downeast Maine and the mouth of the Bay of Fundy (Figure 6-3b). The combination of habitats represented by these maps is a reasonable representation of important habitat areas for alewife in three seasons; it may miss areas further south or offshore that are used for overwintering.

Important Marine Areas for Alewife

Spring: Southern New England, Georges Bank, and Cape Ann

Fall: Massachusetts coast north of Cape Cod, Downeast Maine, mouth of the Bay of Fundy

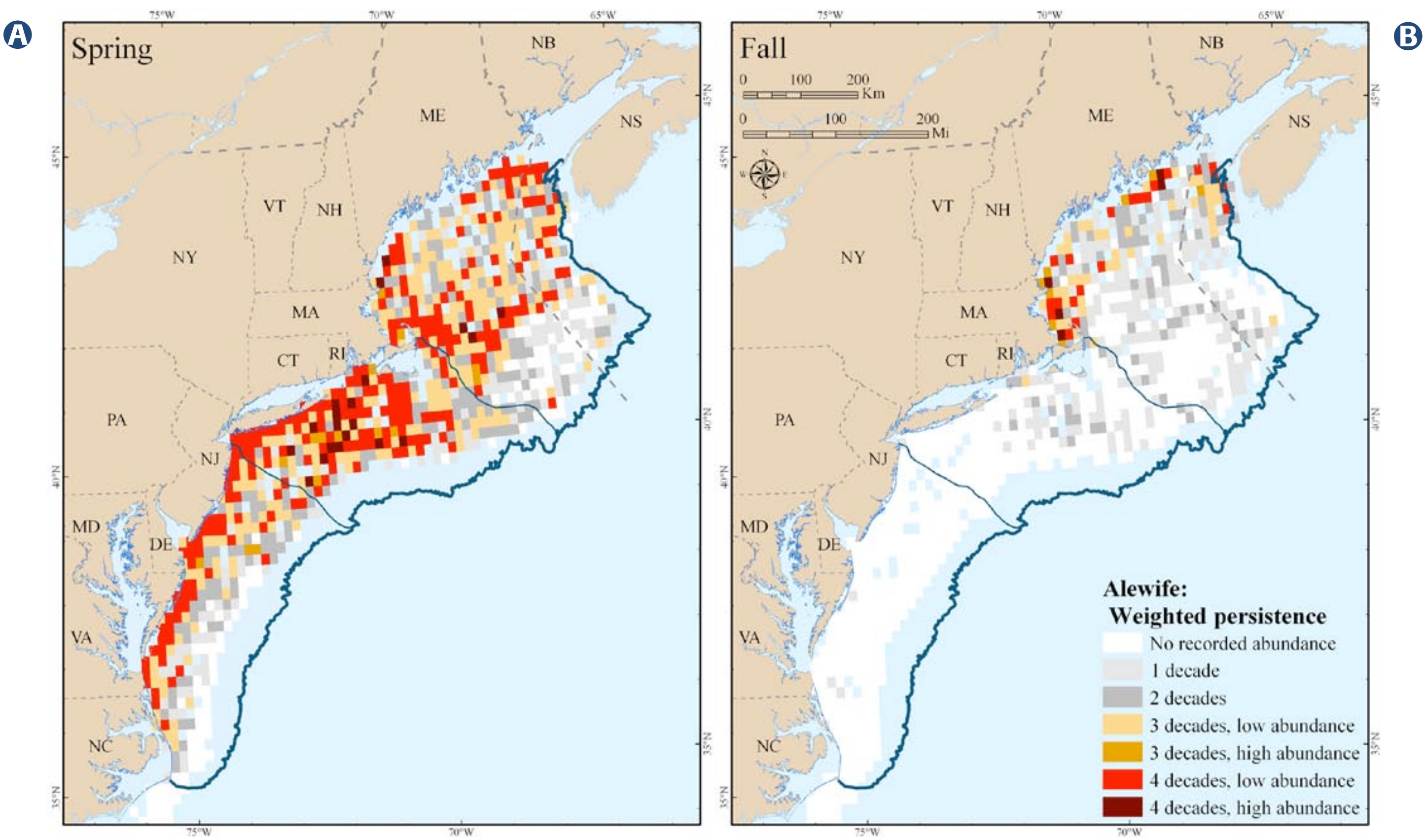


Figure 6-3. Areas with high persistence and abundance over 40 years for alewife during the spring and fall seasons.

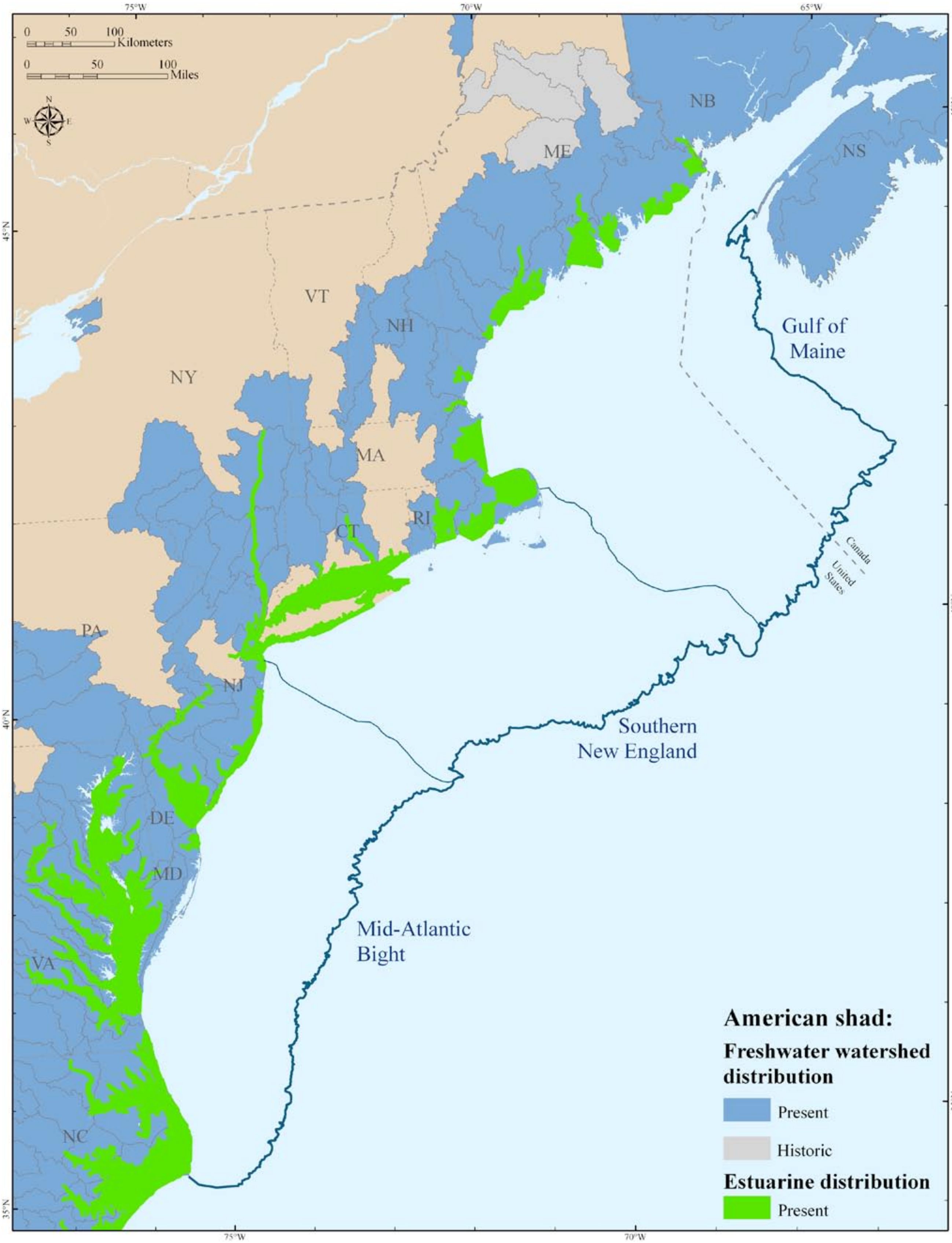


Figure 6-4. Freshwater and estuarine distribution for American shad.

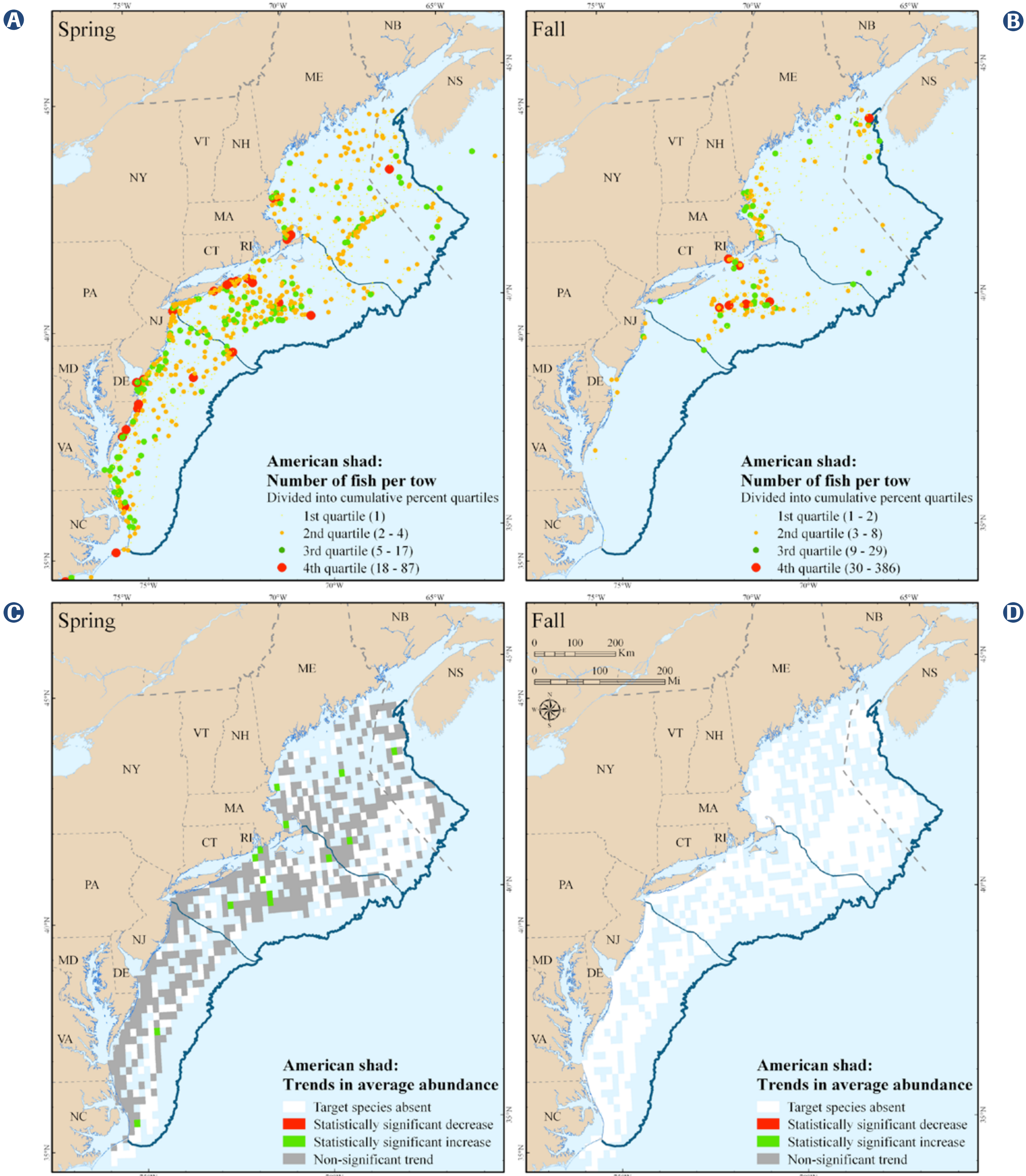


Figure 6-5. Trends in average abundance over 40 years for American shad during the spring and fall seasons.

American Shad

American shad may still occur in each of the drainages represented (Figure 6-4), but it is important to note that accessible, suitable spawning habitat is greatly reduced. For example, in the Merrimack River watershed in Massachusetts and New Hampshire, dams with ineffective fish ladders prevent shad from accessing habitats beyond the second dam at Lowell, Massachusetts.

In spring American shad abundances were greatest in coastal waters near Chesapeake and Delaware Bays, Hudson River, Long Island, and Massachusetts Bay (Figure 6-5a), and in fall in small areas off Rhode Island and near the mouth of the Bay of Fundy (Figure 6-5b). Trends in shad abundance exhibit only a weak spatial signature, despite evidence from surveys of spawning runs that shad have suffered huge declines. In spring where there is a trend at all it is generally increasing (Figure 6-5c); in fall the few places with a trend are evenly split between increases and decreases (Figure 6-5d). These data are clearly not informative with regard to overall abundance of shad; it is also possible that the number of shad caught overall may be too small to represent trends in shad distribution.

The spring persistence pattern (Figure 6-6a) is consistent with spawning locations (Figure 6-4) in the Chesapeake, Delaware, and Hudson River for the Mid-Atlantic subsection, and it is likely that coastal waters near spawning rivers are important for staging of adults and/or overwintering for juveniles. In the two northern subsections, the areas of spring persistence are further offshore. In fall (Figure 6-6b), areas of persistence and abundance in the northern Gulf of Maine reflect the more northern summer distribution in the Bay of Fundy and Gulf of St. Lawrence indicated by tagging data (Dadswell et al. 1987). Additional important areas for shad not represented here include wintering areas in deeper offshore waters.

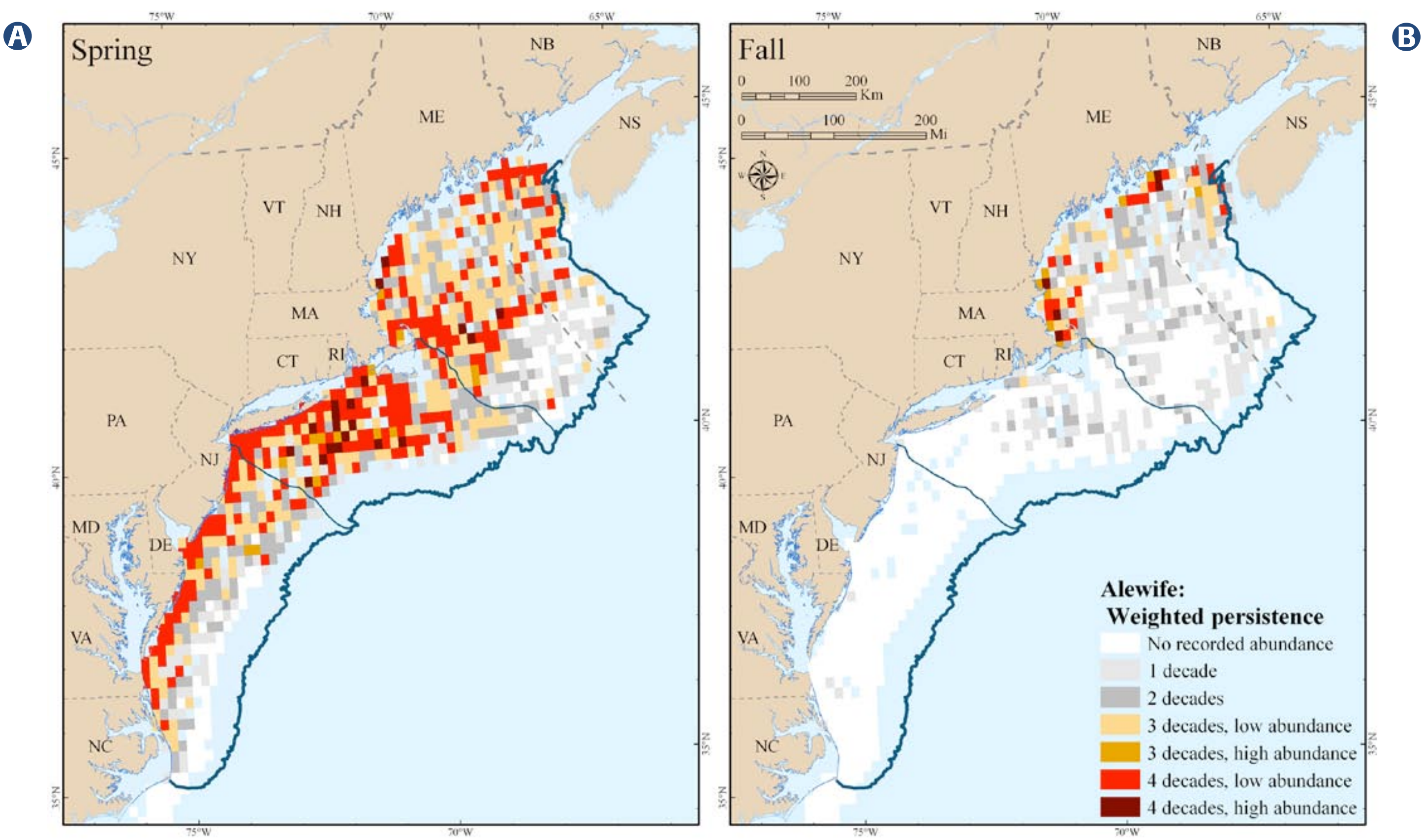


Figure 6-6. Areas with high persistence and abundance over 40 years for American shad during the spring and fall seasons.

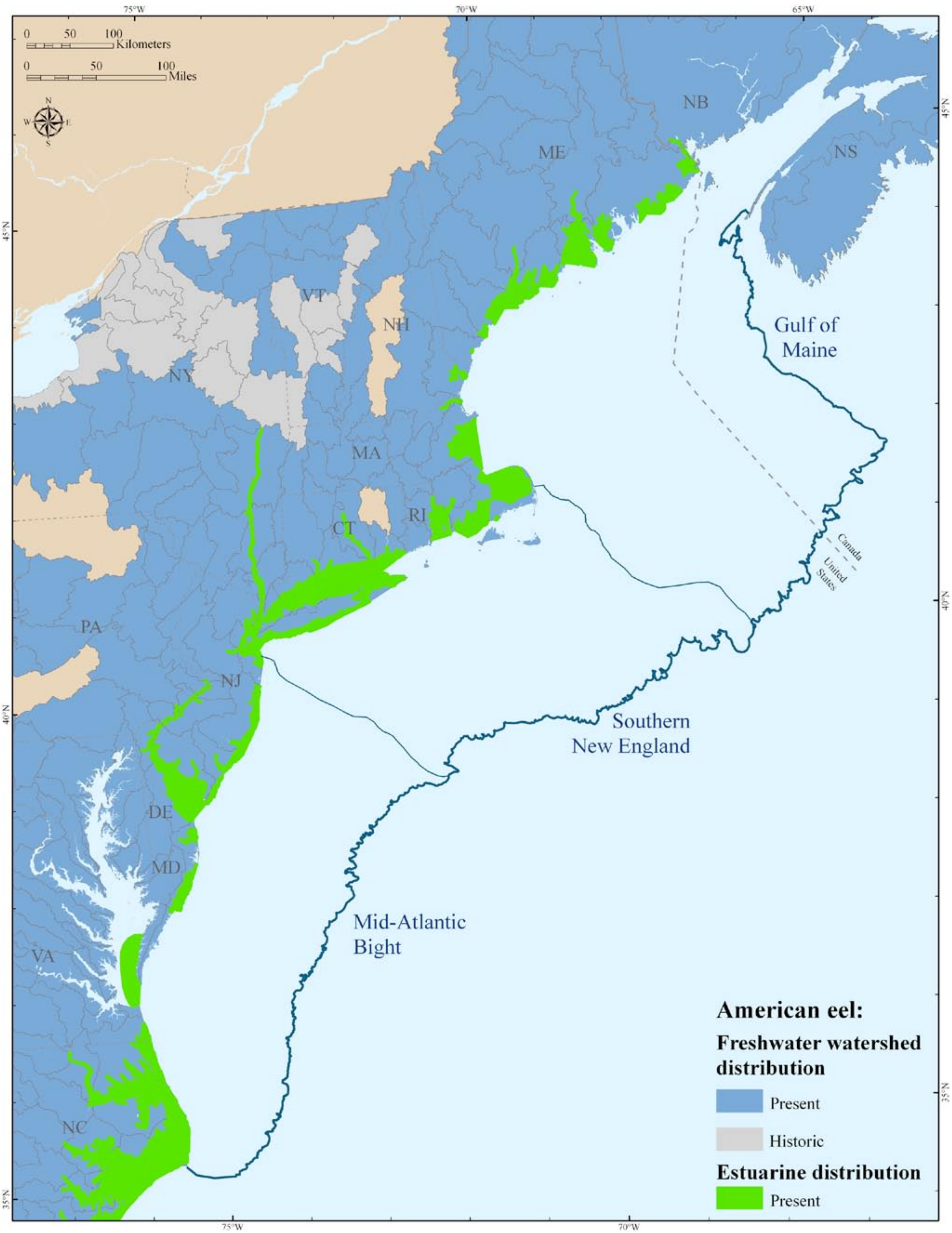


Figure 6-7. Freshwater and estuarine distribution for American eel.

Important Marine Areas for American Shad

Spring: Chesapeake, Delaware and Hudson rivers and adjacent coastal waters

Fall: Northern Gulf of Maine

American Eel

American eel occurs throughout the coastal drainages, up to hundreds of miles inland, as well as in all estuaries in the region (Figure 6-7). The Northwest Atlantic region represents a relatively small portion of the global range, from the St. Lawrence River, Canada to Venezuela. This species is greatly diminished at the northern limit of its range in Canada; no data are available from the southern limit of the range.

There are too few records of American eel in the NOAA trawl surveys to interpret. Adult eels presumably migrate quickly through this geography on their way to the Sargasso Sea and thus have low probability of being detected in a trawl survey. The listing finding (USFWS 2007) summarized available information on ocean distribution of larval (leptocephali) and silver eels. The majority of leptocephali enter the Florida Current just south of Cape Hatteras directly from the Sargasso Sea. The remainder may enter the Florida Current by a more southern route. Other than this likely current transport, little is known. Similarly, actual distances, routes, and depths of migration for adult eels are unknown.

Important Marine Areas for American Eel

Not enough data to determine

Atlantic Salmon

Long Island Sound and the Connecticut River are the southern limit of the range of Atlantic salmon in the United States (Figure 6-8). Salmon in New England rivers outside Maine (Connecticut, Pawcatuck, Merrimack) were extirpated and recovery efforts continue through stocking and passage improvements. Wild salmon still exist in the Gulf of Maine (Penobscot, Kennebec and eight eastern Maine rivers) and Bay of Fundy. A widespread collapse in Atlantic salmon abundance started around 1990. In the past decade, United States salmon returns across all rivers have averaged 1,600 fish; returns in 2005 were 1,320 fish. All stocks are extremely small, with only the Penobscot River population at a viable level. Most populations are still dependent on hatchery production and current marine survival regimes are compromising the long-term prospects of even these hatchery-supplemented populations (Kocik and Sheehan 2006).

For this Assessment, marine distribution of Atlantic salmon could not be mapped with NOAA data, but adults are known to congregate in the waters off Greenland and migrate to spawning rivers from the Connecticut River northward (NMFS USFWS 2005). Post smolt surveys have also tracked movements in coastal waters (Kocik and Sheehan 2006).

Important Marine Areas for Atlantic Salmon

Not enough data to determine

Atlantic Sturgeon

Atlantic sturgeon spawning populations occur in each sub-section of the region, but in only a handful of large rivers, e.g., Kennebec, Hudson, and Delaware Rivers (Atlantic Sturgeon Status Review Team 2007). Most watersheds where they occur (Figure 6-9) host only wandering juveniles, although occasionally in substantial numbers. All rivers and estuaries where they occur represent important habitat.

Some fishery-dependent data are available regarding Atlantic sturgeon habitat use. A 2007 ASMFC report shows concentrations of sturgeon bycatch in shallow waters in a few locations including Massachusetts Bay, off the east shore of Cape Cod, Rhode Island coastal waters, New York Bight, and the Delmarva Peninsula. The authors note that seasonal trends were confounded with fishery behavior, e.g. type of net used, but the data provides a useful indication of the locations and types of coastal habitats used by sturgeon.

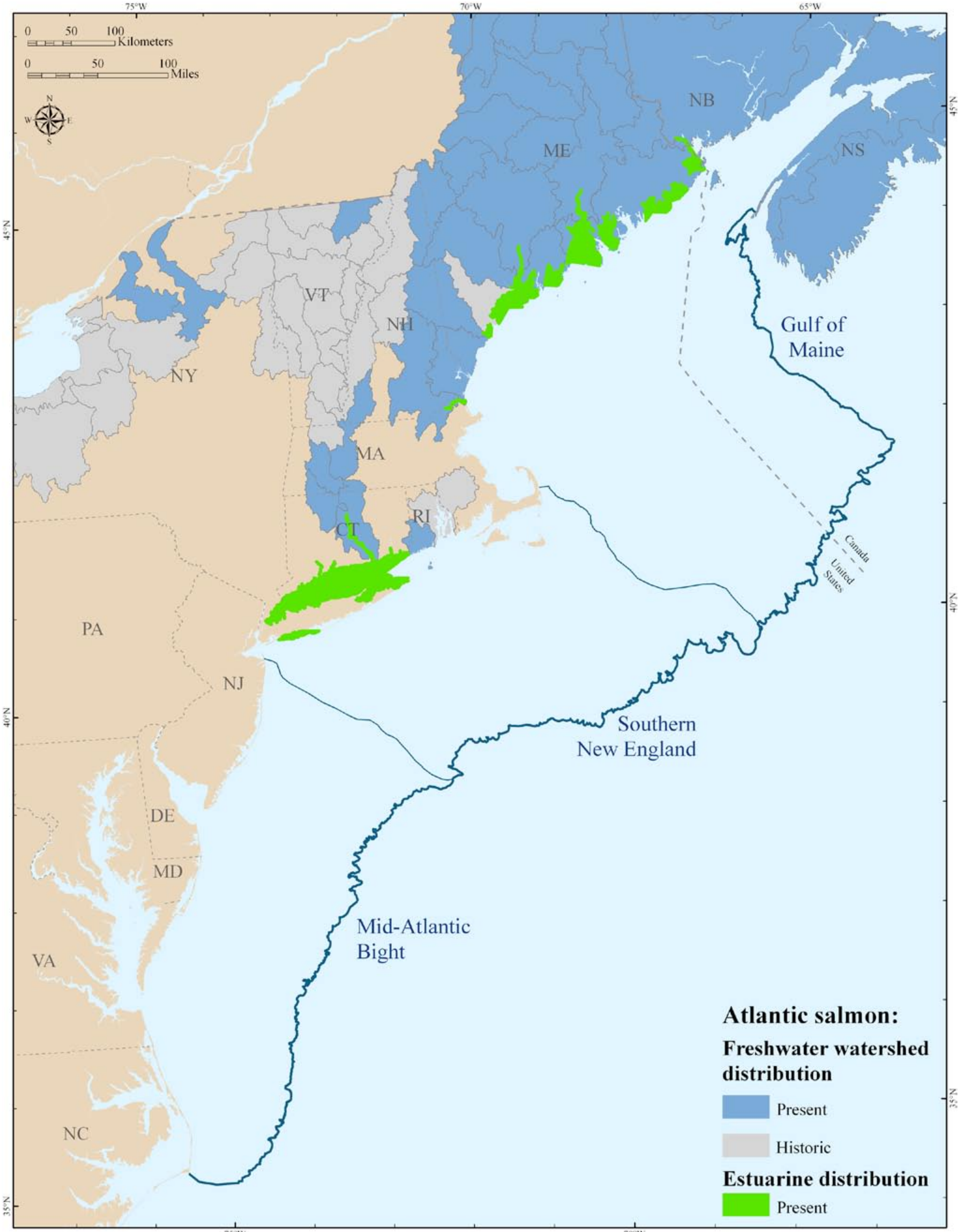


Figure 6-8. Freshwater and estuarine distribution for Atlantic salmon.

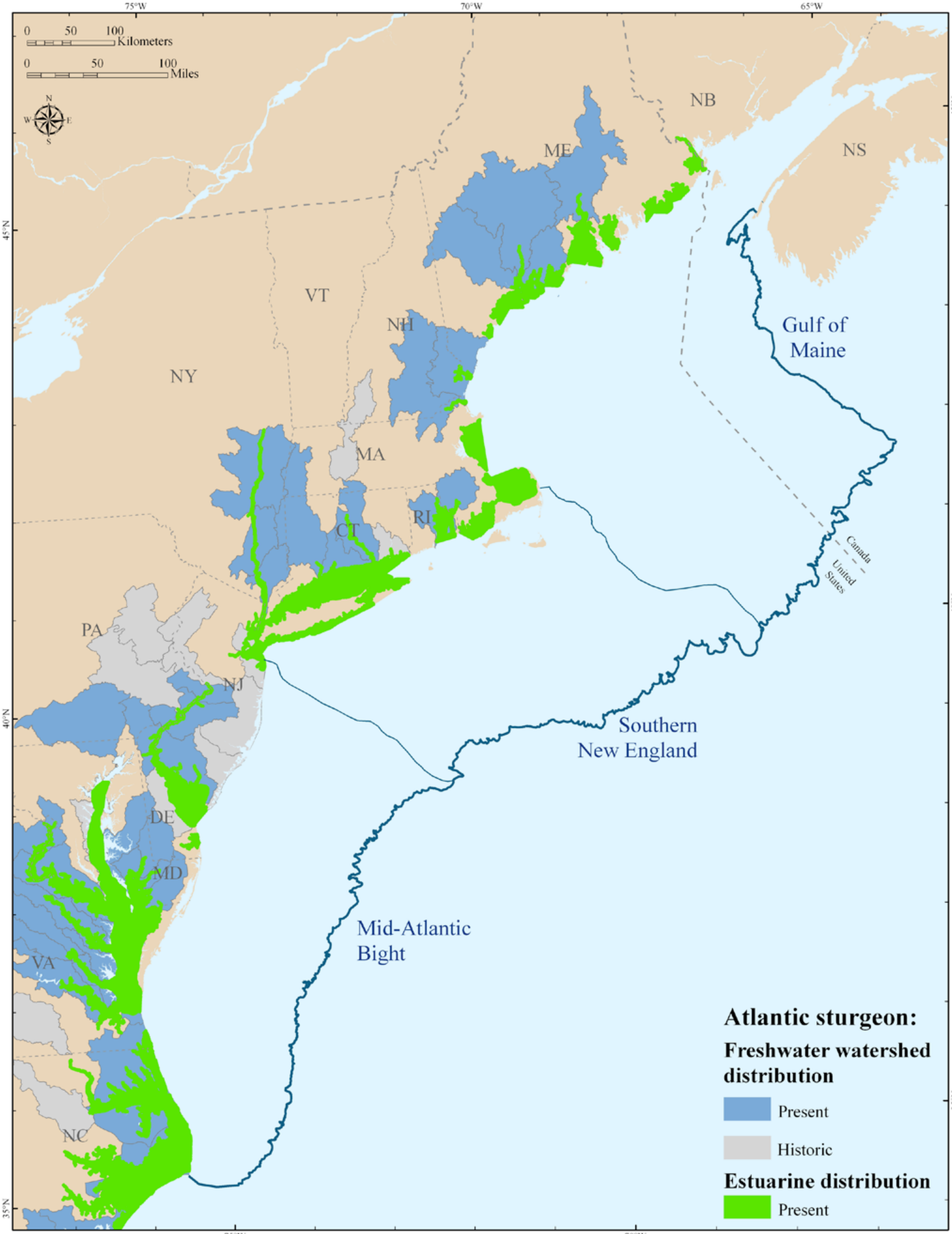


Figure 6-9. Freshwater and estuarine distribution for Atlantic sturgeon.

Important Marine Areas for Atlantic Sturgeon:

Coastal waters of Massachusetts Bay, east Cape Cod, Rhode Island, New York Bight, Delmarva peninsula

Atlantic Tomcod

Atlantic tomcod historically occurred in low numbers as far south as Chesapeake Bay (Figure 6-10), with the Hudson River being the southernmost major spawning area (Klauda et al. 1981). Levinton and Waldman (2006) report that tomcod has declined significantly in the Hudson River in recent years, suggesting that the species' range may be continuing to contract northward. Atlantic tomcod is primarily an inshore fish that does not usually travel to offshore waters, therefore was not sampled adequately in the NOAA trawl survey.

Important Marine Areas for Atlantic Tomcod

Not enough data to determine

Blueback Herring

Blueback herring occurs in coastal drainages, as well as in all estuaries in the region (Figure 6-11). Blueback herring were captured all along the coast in spring, with concentrations at several locations along the Mid-Atlantic coast and in Massachusetts Bay (Figure 6-12a); in the fall bluebacks were strongly concentrated in Massachusetts Bay (Figure 6-12b). Most TMS showed no trend, but in spring a number of TMS show decreasing trends, while all the northern TMS with trends are increasing (Figure 6-12c). The spring distribution seems consistent with other accounts and with the location of spawning rivers (Figure 6-12d). In spring there were a few areas of high persistence and abundance in each subsection, predominantly in the Mid-Atlantic (Figure 6-13a). In the fall, only Massachusetts Bay showed high persistence, with high abundance in three of the sampled decades (Figure 6-13b). In contrast, ASMFC (2008) reported that blueback herring populations have declined to extremely low levels in some places (e.g. fewer than 100 fish were counted at Holyoke Dam on the Connecticut River in 2006-2008, in contrast to ~500,000 in the 1980s) and there is evidence of coastwide decline.

Important Marine Areas for Blueback Herring

Spring: Individual areas in the Mid-Atlantic

Fall: Massachusetts Bay

Hickory Shad

Hickory shad (Figure 6-14) has a limited spawning distribution in the Gulf of Maine and southern New England. They are most common and widely distributed south of Delaware Bay. This species' estuarine distribution is not included in the Estuarine Living Marine Resources database. Levinton and Waldman (2006) observe that hickory shad abundance in New York Bight and Long Island Sound increased substantially through the 1990s, which they suggest is likely due to increased immigration from other sources rather than to local reproduction. Similarly, Gephard and McMenemy (AFS Monograph #9 2004) report these fish becoming increasingly more common in the Connecticut River, possibly reflecting a climate-driven northward range expansion.

The marine distribution and habits of hickory shad are often described as similar to other alosines. Collette and Klein-MacPhee (2002) report that hickory shad are caught off New England primarily in the fall, which might indicate southward movement from feeding grounds in the Gulf of Maine like American shad. Perhaps it is a result of their relative rarity that they are not often found at sea with the other species, or they could be less susceptible to certain gear types. There are some records of hickory shad in the NOAA trawl data but too few to interpret.

Important Marine Areas for Hickory Shad

Not enough data to determine

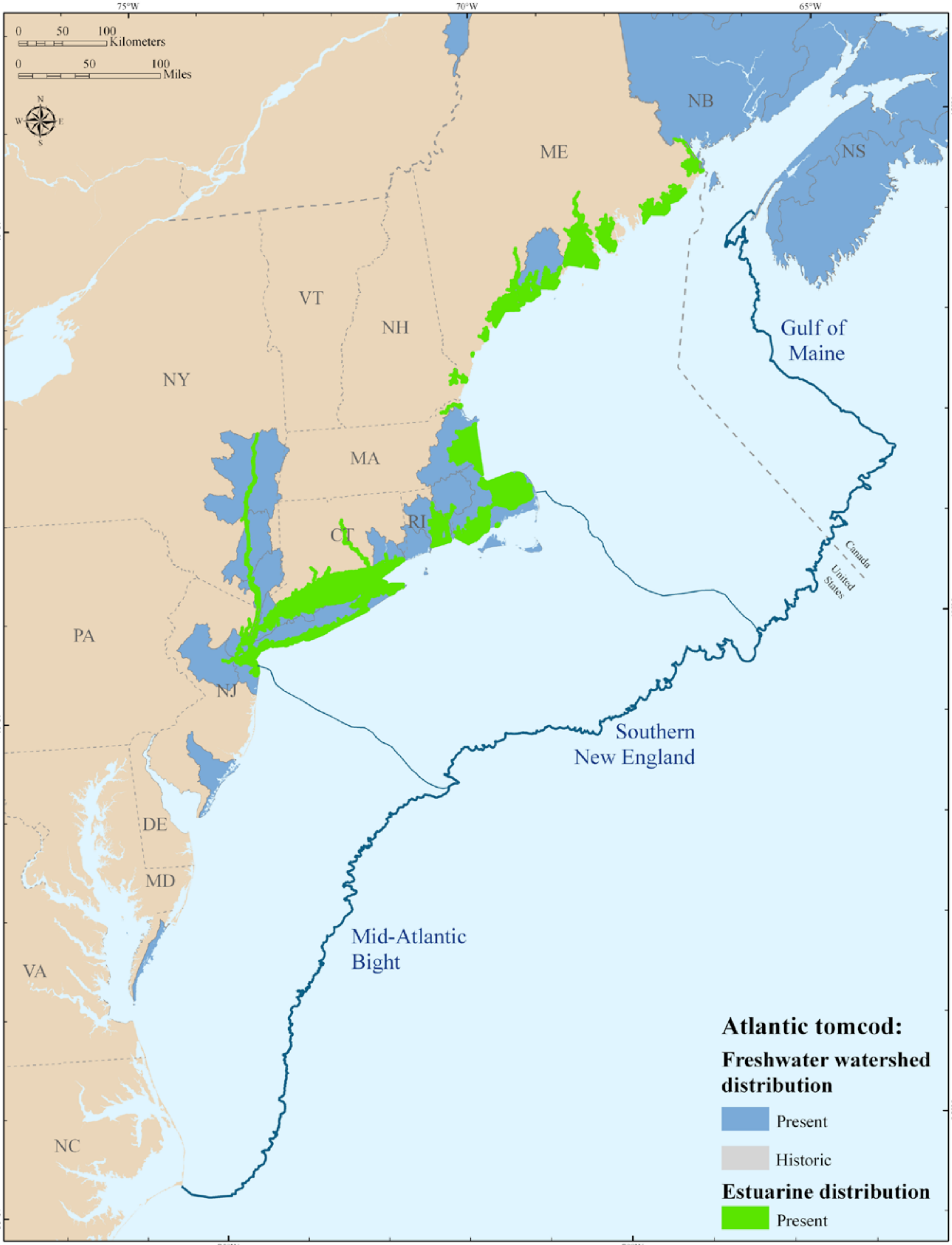


Figure 6-10. Freshwater and estuarine distribution for Atlantic tomcod.

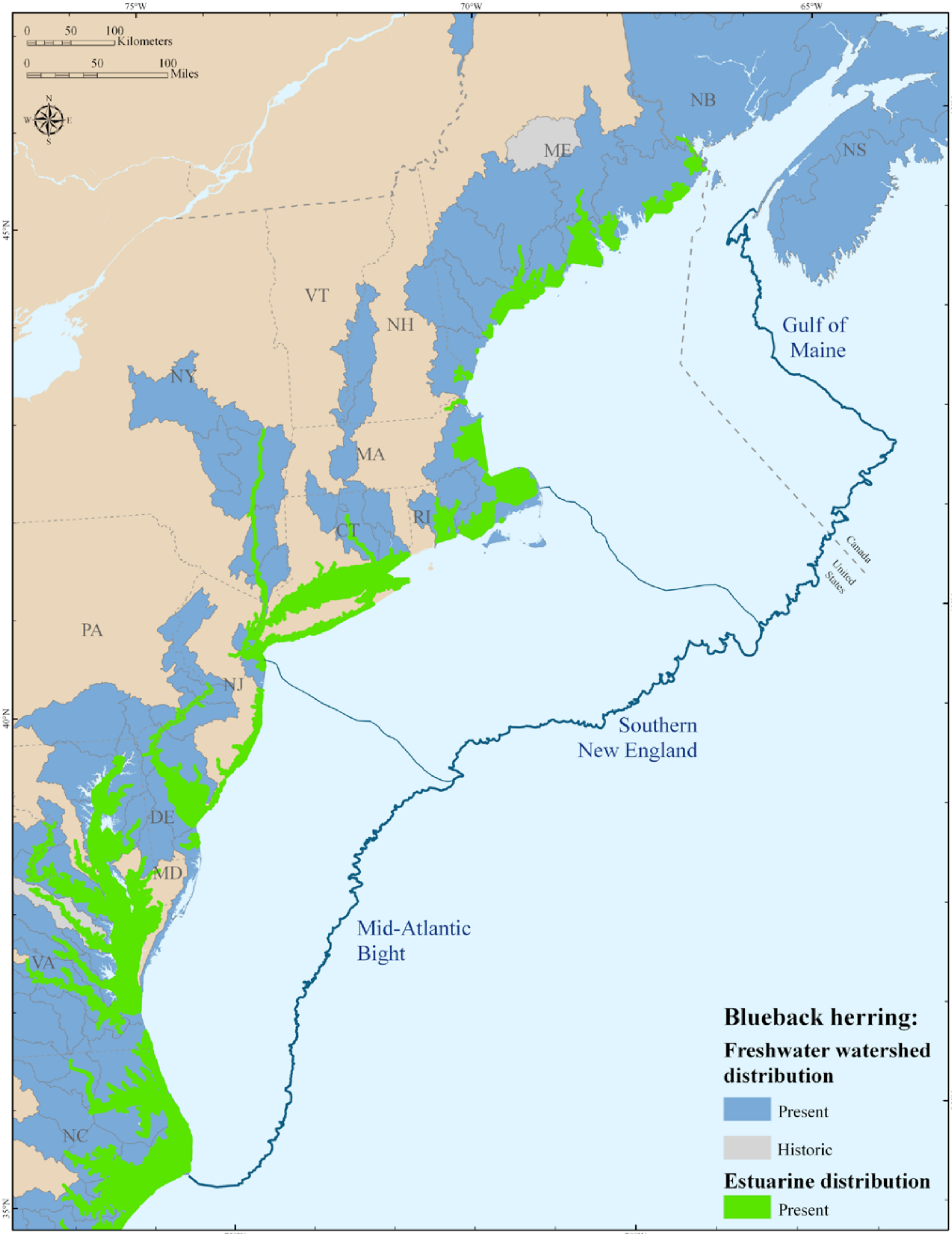


Figure 6-11. Freshwater and estuarine distribution for blueback herring.

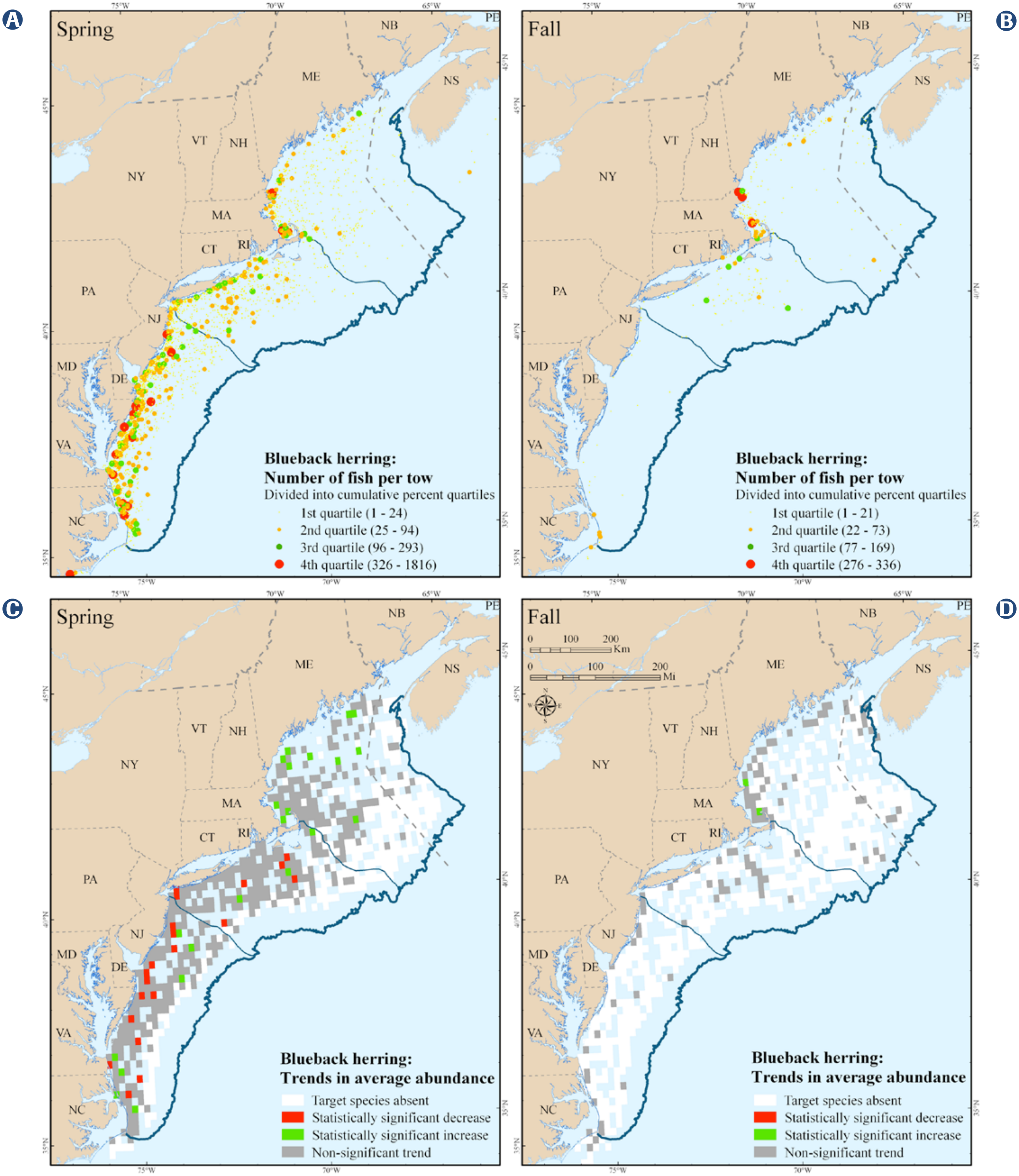


Figure 6-12. Trends in average abundance over 40 years for blueback herring during the spring and fall seasons.

Rainbow Smelt

Rainbow smelt spawning has been documented near the head of tide in rivers all along the coast from the Hudson River northward; the species becomes more widely distributed (Figure 6-15) and common north of Cape Cod. There is evidence of significant, recent range contraction. Levinton and Waldman (2006) report that rainbow smelt declined through the late 1900s and were extirpated from the Hudson River by 2000. A survey by a University of Connecticut graduate student in 2005 failed to document any smelt runs in Connecticut and the species is now listed by the state as "Threatened" (Gephard, not dated). Until the 1960s, there were many abundant runs of rainbow smelt in rivers across coastal Connecticut. Buchsbaum et al. (1994) also noted a marked decline in smelt between 1965 and 1994 samples taken in Plum Island Sound on the north shore of Massachusetts.

Rainbow smelt is primarily an inshore fish that does not usually travel to offshore waters, therefore was not sampled adequately in the NOAA trawl survey.

Important Marine Areas for Rainbow smelt

Not enough data to determine

Sea-run Brook Trout (eastern brook trout, sea-run form)

Coastal populations of eastern brook trout are limited to the two northern subsections of the region, with significant reductions in abundance and distribution at the southern limit of the range (Figure 6-16). The sea-run form is currently documented in very few locations in southern New England (Anderson et al. 2006), but becomes more common in small coastal streams northward through the Saint Lawrence River. Typically, anadromous

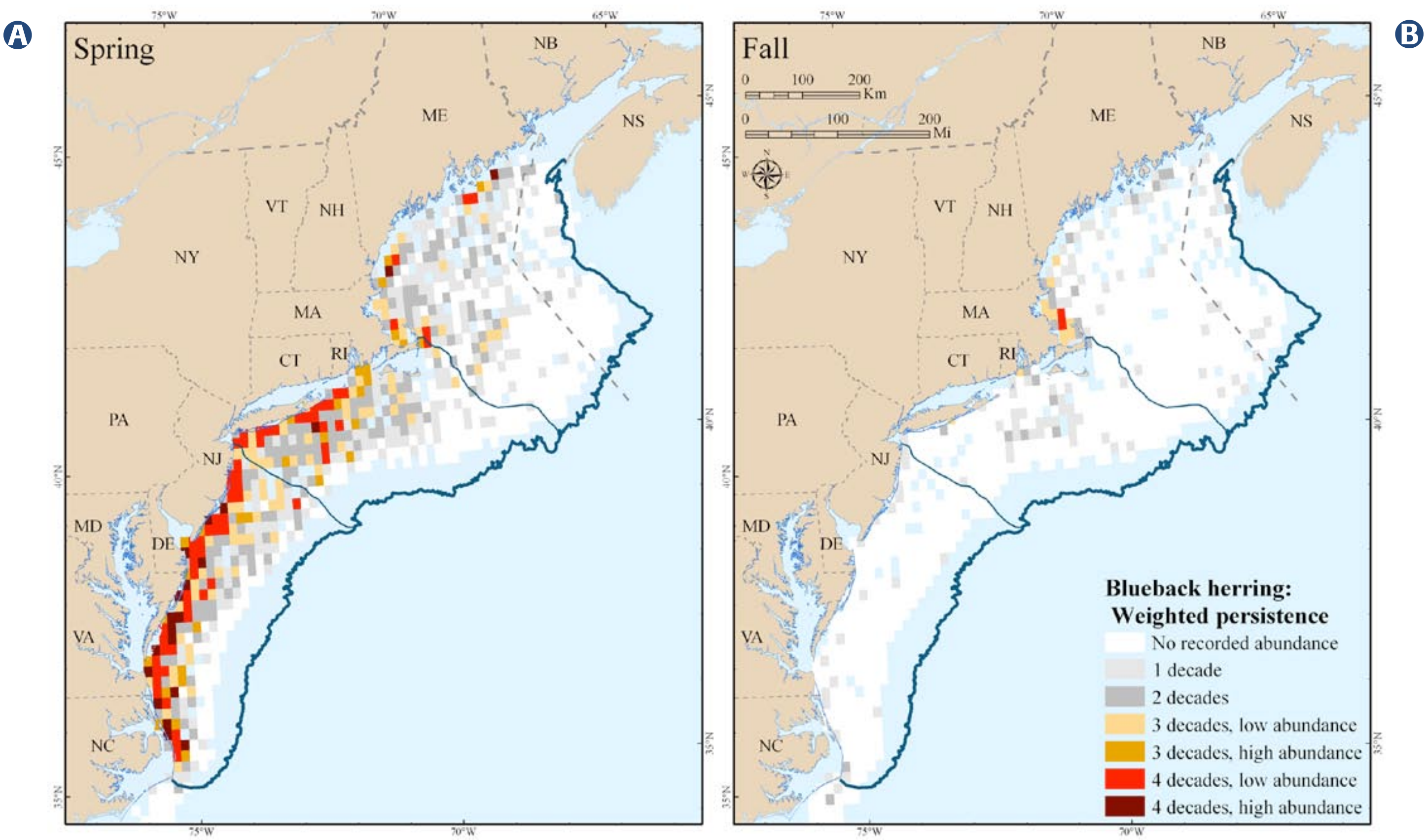


Figure 6-13. Areas with high persistence and abundance over 40 years for blueback herring during the spring and fall seasons.

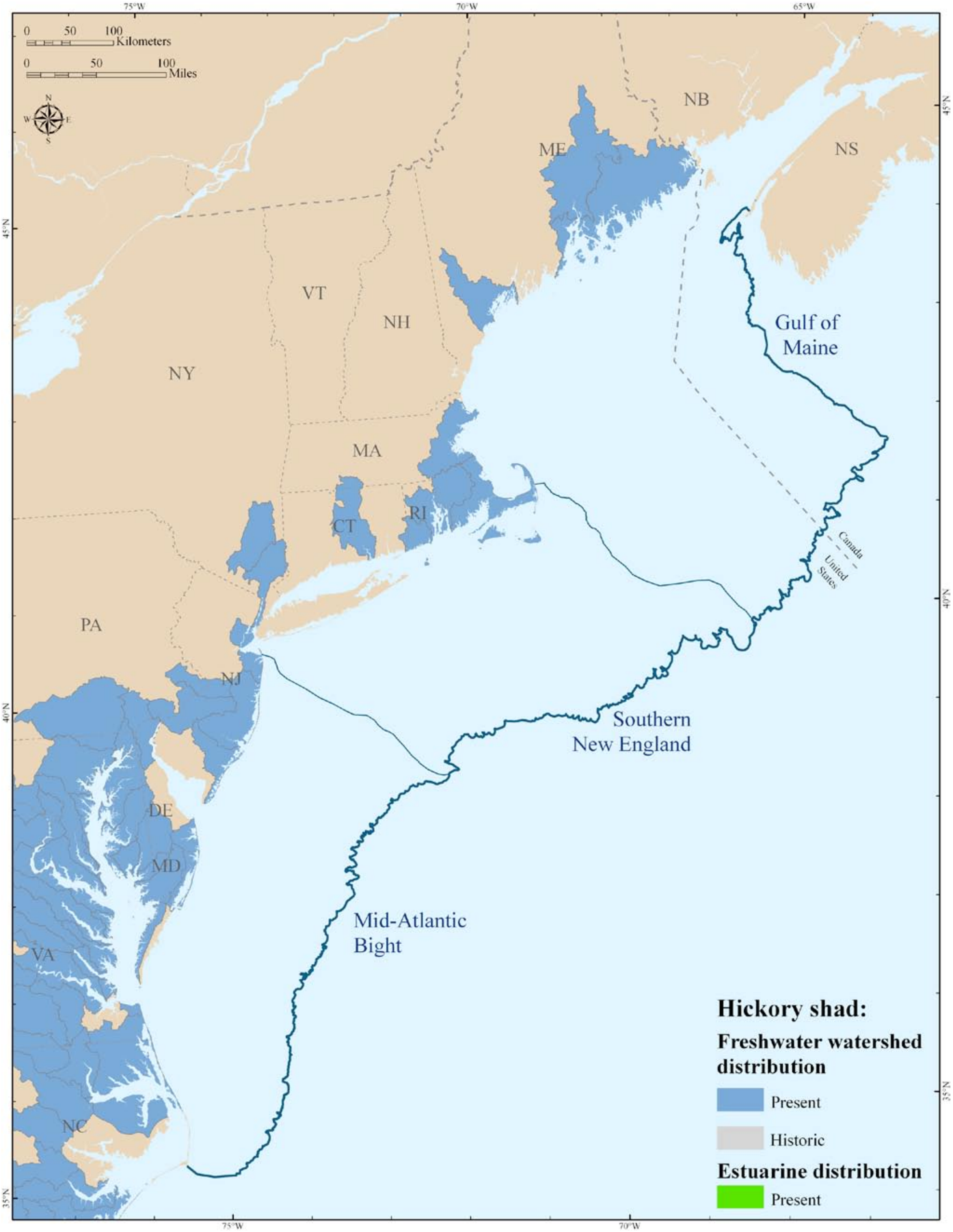


Figure 6-14. Freshwater and estuarine distribution for hickory shad.

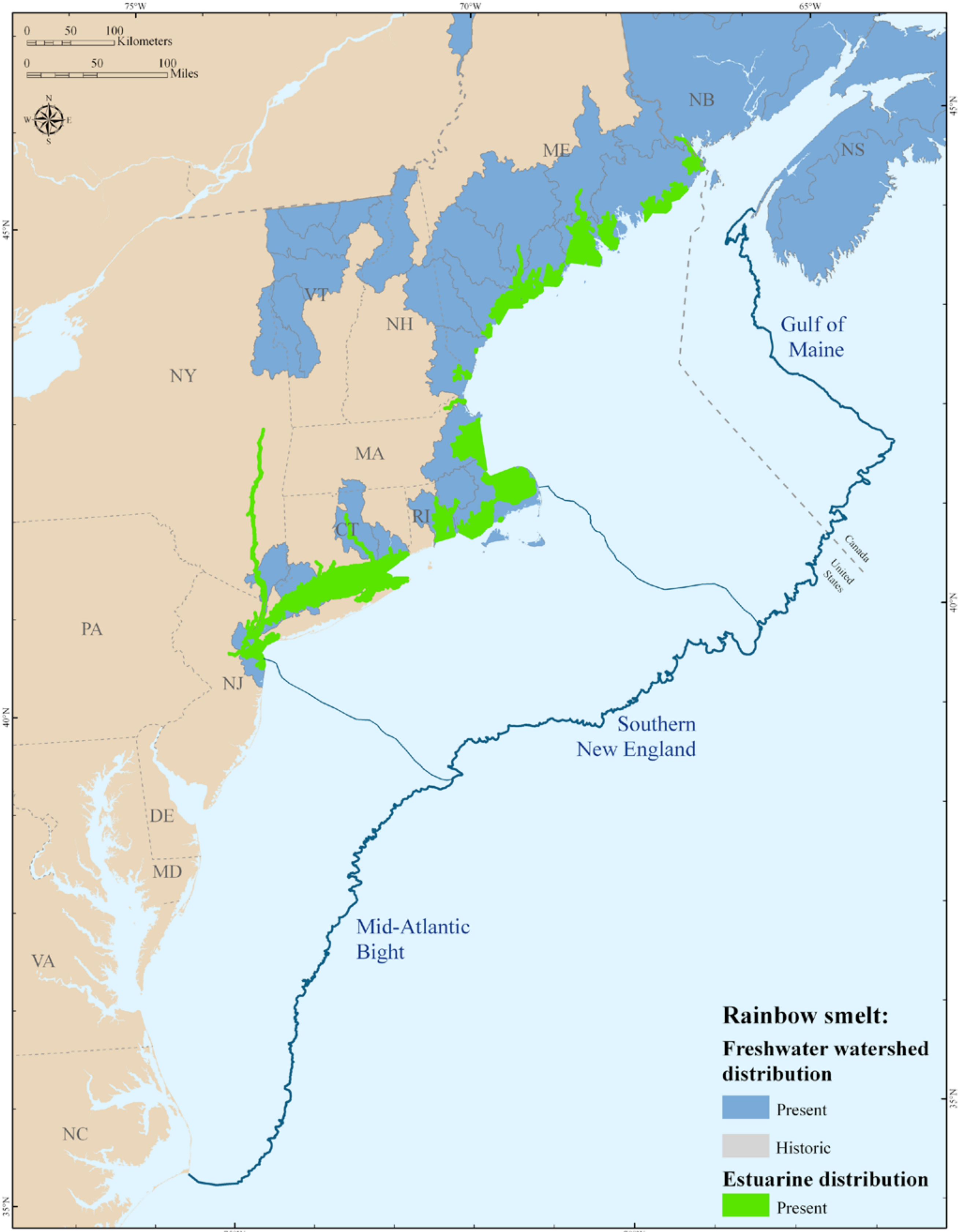


Figure 6-15. Freshwater and estuarine distribution for rainbow smelt.

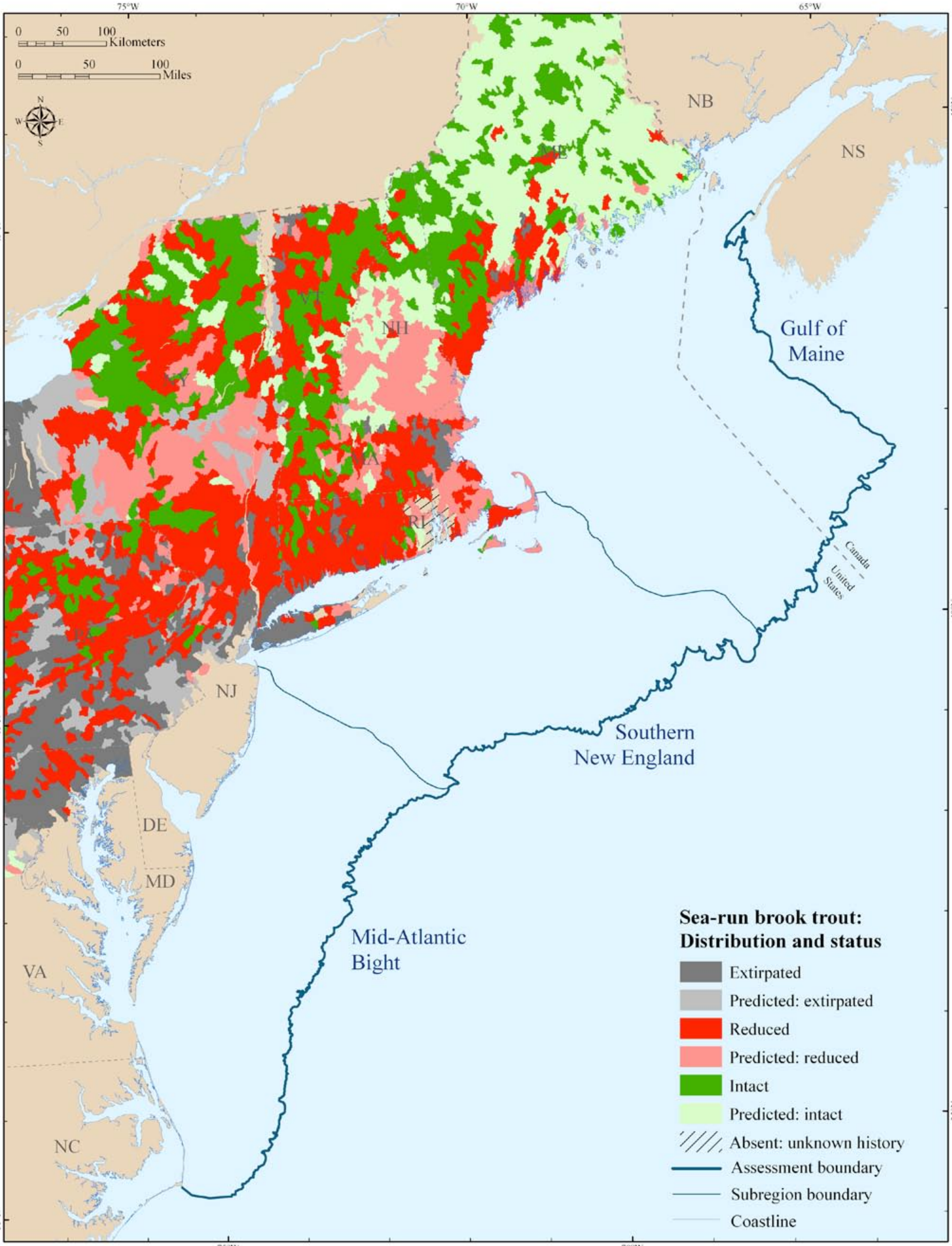


Figure 6-16. Distribution and status of sea-run brook trout.

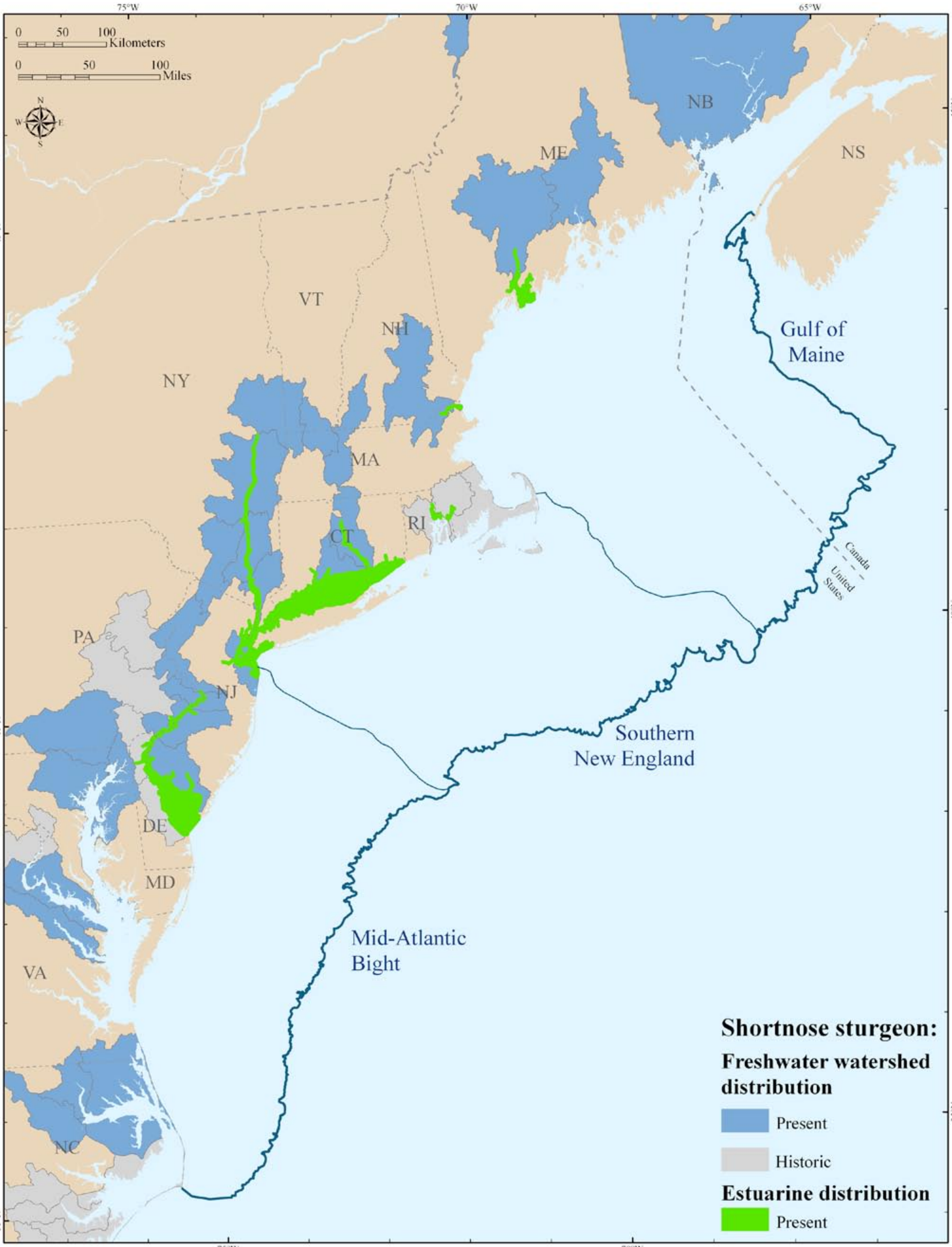


Figure 6-17. Freshwater and estuarine distribution of shortnose sturgeon.

behavior is most prevalent at northern latitudes because the ocean is more productive than adjacent freshwater habitats in temperate and Arctic zones. For a number of facultative anadromous species (e.g., Arctic char, Dolly Varden, brook trout, brown trout, and threespine stickleback) anadromous behavior declines in frequency or ceases toward the southern portion of the distributional range of the species (McDowall 1987). Sea-run trout have been caught up to 45 km away in open ocean or in other estuaries (Collette and Klein-MacPhee 2002).

Important Marine Areas for Sea-run brook trout

Not enough data to determine

Shortnose Sturgeon

Shortnose sturgeon currently have spawning populations in each of the three subsections (Figure 6-17). The global range of this species is limited to the Atlantic coast from the St. John River in New Brunswick to St. Johns River in Florida. About half of the extant populations are within the Northwest Atlantic region, including the two largest, in the Hudson and St. John Rivers (NMFS 1998).

Important Marine Areas for Shortnose Sturgeon

Not enough data to determine

Human Interactions

Historic and current threats to this group of species have been described at length in the literature and in various stock assessments and status reviews cited here. Because of variations in life history traits, such as distance traveled in freshwater and marine environments, feeding preferences, and geographic range, the most acute threats vary somewhat among species, but the general pattern appears to be the same: Excessive mortality of adults through overharvest and other direct impacts combined with reduced access to spawning grounds and impacts of pollution, power plant operations, and other factors on reproduction and recruitment have led to broad scale population declines.

Across all species, frequently cited threats include dams (lack of access to spawning habitat; flow alteration affecting cues and/or egg development; direct mortality due to passage through hydroelectric turbines; increased predation especially due to delays at inefficient fish passage facilities); impingement and entrainment due to operations that require cooling water; overharvest (directed and/or bycatch); and toxins and "emerging pollutants," e.g. endocrine disruptors (chemicals that interact with hormone receptors, thereby disrupting the endocrine system).

Invasive species probably also pose a threat. Introduction of fishes like catfish and snakeheads to freshwater habitats present new predators or competitors to which native diadromous species are not adapted. Non-native plants that create infestations in rivers or ponds can degrade spawning/nursery habitat or restrict migratory pathways.

Climate change (warming waters) is implicated in the documented range contractions of the species adapted to cool waters: alewife, Atlantic salmon, Atlantic tomcod, rainbow smelt, and sea-run trout. Shifts in the North Atlantic Oscillation, also linked to climate change, have been hypothesized to be one cause of the decline of American eel at the northern edge of its range.

Case Study: Atlantic sturgeon

Atlantic sturgeon provides a useful case study of the historic impacts humans have had on diadromous fish in the region. This species' status changed rapidly from abundant to globally rare. Historical records from Massachusetts and Maine indicate an important and abundant sturgeon fishery dating to the 1600s. After a caviar market was established in 1870, fishing intensity increased greatly, with record landings from Atlantic coastal rivers of 3350 metric tons reported in 1890. The fishery collapsed in 1901, when less than 10% (295 mt) of its 1890 peak landings were reported (Atlantic Sturgeon Status Review Team 2007). Fishing continued, however, until the fishery was closed by ASMFC in 1998, when a coastwide fishing moratorium was imposed for 20-40 years, or at least until 20 year classes of mature female Atlantic sturgeon were present (ASMFC 1998). The Hudson and Altamaha Rivers are presumed to be the healthiest populations within the United States and are the only rivers with abundance estimates: for the Hudson, approximately 870 spawning adults/yr and for the Altamaha, approximately 343 spawning adults/yr. Populations in the St. John and St. Lawrence Rivers in Canada still support fisheries.

Because sturgeon are a long-lived, slow growing fish with a late age of first reproduction, they rely on high survival of adults to maintain the population. Today, though protected from directed fishing, a greatly reduced number of adults face a variety of ongoing threats. All of the habitats (oceanic, estuarine, and riverine) used by various life

© Bridget Besaw

stages of Atlantic sturgeon are necessary for species survival. However, riverine habitat where spawning occurs may be the most critical to maintenance of the species. The 2007 status review concluded that the principal threats to the survival of Atlantic sturgeon are modifications to or loss of spawning and nursery habitat, poor water quality, and contaminants. Dredging causes physical alteration of habitat, increases siltation, and may reduce food availability. The dams on most major river systems have severely restricted the amount of spawning habitat available to Atlantic sturgeon; dams close to the river mouth are the most problematic because they preclude nearly all-upriver movement and can create unsuitable conditions for egg hatching and survival. To date, fish passage devices for Atlantic sturgeon have been unsuccessful.

In addition to these habitat impacts, direct mortality from dredging activities, ship strikes, and bycatch in estuaries and coastal waters were cited. A 2007 ASMFC report on bycatch in coastal fisheries for 2001-2006 found concentrations of sturgeon bycatch in sink gillnet fisheries in a few locations including Massachusetts Bay, off the east shore of Cape Cod, Rhode Island coastal waters, New York Bight, and the Delmarva Peninsula at depths less than 50 m. As a result of the population status and multiple ongoing threats, Atlantic sturgeon is a candidate for listing under the Endangered Species Act.

Please see the historical chapter beginning on page xx for additional information.

Management and Conservation

Regulatory Authorities

ASMFC is an interstate compact of the fifteen Atlantic coast states formed in 1942. Since 1994, ASMFC has been responsible for implementing fishery management requirements for all Atlantic coast interjurisdictional fisheries under the Atlantic Coastal Fisheries Act, which established cooperative management among ASMFC, NMFS and the United States Fish and Wildlife Service (USFWS). There are 22 species regulated under this program, including the diadromous species American eel, American shad, hickory shad, blueback herring, alewife, Atlantic sturgeon, and striped bass.

For species that have significant fisheries in both state and federal waters, e.g., Atlantic herring, the Commission works cooperatively with the East Coast Regional Fishery Management Councils to develop fishery management plans. The Commission also works with NMFS to develop compatible regulations for the federal waters of the exclusive economic zone (from three miles to 200 miles offshore; from the shoreline to three miles offshore is the jurisdiction of the individual coastal states). The 1988 fisheries management plan (FMP) for Atlantic salmon established explicit United States management authority over all Atlantic salmon of United States origin to complement state management programs in coastal and inland waters and federal management authority over salmon on the high seas conferred as a signatory nation to the North Atlantic Salmon Conservation Organization. An extensive hatchery program initiated in the 1960s sustains re-introduced runs in New England from the Connecticut River northward. Shortnose sturgeon was listed as an endangered species by the USFWS in 1967; NMFS assumed jurisdiction in 1974. The species is managed under a 1998 recovery plan.

Rainbow smelt, Atlantic tomcod and sea-run trout, species that live mostly within the three mile limit of state waters and are not federally protected, are managed by fisheries agencies within states. Freshwater fisheries for migratory fish may be managed by state marine fisheries agencies, state inland fisheries agencies, and/or local commissions.

© USFWS

Across all species there is a dizzying array of additional federal, state and local entities with jurisdiction over different aspects of habitat, water quality and fish passage, e.g. Federal Energy Regulatory Commission, Army Corps of Engineers, Environmental Protection Agency, state fisheries agencies. And town herring wardens). There is increasing recognition of the need to coordinate fisheries management with these other authorities across all life stages and habitats in order to meet recovery goals. For example, ASMFC recently passed a resolution on the importance of fish passage.

Current Conservation Efforts

Diadromous fish have been the subject of many conservation and recovery efforts, and there appears to be a strong and growing interest in coordination across habitats and political boundaries in recognition of both the importance and stressed condition of many of these species. ASMFC and its member institutions and partners have played a critical leadership role in these interjurisdictional efforts. In winter 2009 ASMFC published *Atlantic Coast Diadromous Fish Habitat: A Review of Utilization, Threats, Recommendations for Conservation, and Research Needs,* a comprehensive compilation of habitat information for the seven diadromous species it manages. In addition, the Atlantic Coast Fish Habitat Partnership, an entity that grew out of the ASMFC Habitat Committee, and individual Commission species technical committees have undertaken efforts to characterize the amount, location, and gear involved in bycatch of managed species, and a fish passage working group has been convened.

Fishing impacts are being addressed for many of these species. In United States waters, fishing for Atlantic sturgeon, shortnose sturgeon, and Atlantic salmon is prohibited, and the ocean-intercept fishery for American shad was closed in 2004. In May 2009, Amendment 2 to the FMP for American shad and river herring established a coastwide moratorium for river herring with exceptions for sustainable fisheries. Draft Amendment 3offers the same provision for shad, among other alternatives, was released for public comment in August 2009, and will likely be finalized in 2010.

Several states have included diadromous fish in State Wildlife Action Plans, and some have opted to work together on specific projects to promote species recovery. For example, in 2006, Maine, New Hampshire, and Massachusetts received a NMFS Proactive Conservation Program grant to develop a comprehensive conservation program for Atlantic sturgeon, Atlantic salmon, and rainbow smelt in the Gulf of Maine.

Private conservation organizations also play an important role in conservation of these species. The Nature Conservancy has conservation programs in all 15 coastal states, and has identified diadromous fish as conservation priorities coastwide. TNC programs are working on a wide variety of site-based and policy efforts, from dam removal and stormwater management projects to serving on the ASMFC Habitat Committee and Shad and River Herring Advisory Panel. Environmental Defense Fund serves on the Habitat Committee and American Eel Advisory Panel. American Rivers works coastwide on barrier removal projects and policies to enable river restoration. Additional groups such as Trout Unlimited, Cape Cod Commercial Hook Fishermen's Association, and local watershed associations also play important roles in raising awareness of the conservation needs of these species, collecting data, and improving their management.

Species Accounts

Alewife *(Alosa pseudoharengus)*

Alewife spawn in rivers from northeastern Newfoundland to South Carolina, but are most abundant in the Mid-Atlantic and northeastern states. A wide range of habitats and substrates is utilized, including large rivers, small streams, ponds, and lakes with substrates of gravel, sand, detritus, or submerged vegetation. The distance traveled to spawn also varies widely, from a few meters to reach back-barrier ponds to hundreds of kilometers as on the Saint John River (Collette and Klein-Macphee 2002). Most alewife are believed to return to their natal river or pond after about three or four years at sea.

After the eggs hatch, the young-of-the-year spend two to six months in freshwater nursery areas before they begin to migrate to sea. Adult and juvenile alewives are planktivorous, although they occasionally eat insects and fish larvae, including larval alewives. Seasonal migrations in the ocean may be related to zooplankton abundance and water temperature (Neves 1981). Winter catches in the northwest Atlantic are made between 40 and 43oN latitude; in spring alewife move inshore and northward and occur most frequently over the continental shelf between Nova Scotia and North Carolina. During summer and fall catches are concentrated in three areas north of 40o latitude: Nantucket Shoals, Georges Bank, and the perimeter of the Gulf of Maine. At sea, alewife congregate in schools of thousands of fish, sometimes mixing with other herring species (Collette and Klein-Macphee 2002).

American eel *(Anguilla rostrata)*

Adult eel migrate to spawning grounds located in the Sargasso Sea, a large portion of the western Atlantic Ocean east of The Bahamas and south of Bermuda. The Gulf Stream then transports and disperses fertilized eggs and larval eel, called leptocephali, along the entire United States East Coast and into Canadian waters. Bigelow and Schroeder (1953) described the distribution of eels in Gulf of Maine tributaries as universal — occurring in every stream, estuary, and tidal marsh and sometimes the open coast. American eel is classified as catadromous (living in freshwater and migrating to marine waters to spawn), but it has been suggested recently that this may be a facultative trait, that is, rather than having its growth phase restricted to fresh water, some eels complete their life cycle in brackish or marine waters without ever entering fresh water (USFWS 2007).

American eel life history is complex. The species exhibits a multitude of life stages including leptocephalus, glass eel, elver, yellow eel, and silver eel stages. Leptocephali metamorphose into glass eel as they migrate toward land and freshwater bodies. Glass eel develop into the pigmented elver stage as they move into brackish or freshwater. Usually by age two, elvers make the transition into the yellow eel stage. Yellow eel inhabit bays, estuaries, rivers, streams, lakes, and ponds where they feed primarily on invertebrates and smaller fishes. Sexual maturity of yellow eel can occur any time between eight and 24 years of age according to data in the Mid-Atlantic region. When yellow eel reach sexual maturity they begin a downstream migration toward the Sargasso Sea spawning grounds. During this migration yellow eel metamorphose into the adult silver eel phase, undergoing several physiological changes that enable the animals to move from a freshwater to a saltwater environment. Adult silver eel are believed to spawn in the Sargasso Sea during winter and early spring (USFWS 2007), although spawning has never been observed.

American shad *(Alosa sapidissima)*

The spawning range of American shad is from Florida to the St. Lawrence River. Shad ascend tributaries in the spring when water temperatures reach 16.50C to 190C and spawn preferentially in shallow water over gravel or rubble substrates (Collette and Klein-MacPhee 2002). Pelagic shad eggs are carried downstream by the current. Larvae and early juveniles use natal rivers during summer and begin downstream migration to the sea in response to decreasing water temperatures in the fall (Weiss-Glanz et al. 1986). In the northern part of their range, shad may spawn up to five times. The percentage of adults that live to be repeat spawners decreases with decreasing latitude; south of Cape Hatteras shad are semelparous (reproduce only once during their lifetime; Collette and Klein-MacPhee 2002).

Shad form seasonal aggregations and undertake extensive oceanic migrations; fish tagged in the summer in the Bay of Fundy have been recaptured in rivers all along the coast, up to 3,000 km from the tagging location (Dadswell et al. 1987). By late June immature shad are in coastal waters of the inner Bay of Fundy, the Gulf of St. Lawrence, and north to Newfoundland while the spawning fish are upstream in coastal rivers. In late fall and winter shad move to deeper waters further offshore, up to 175 km from the nearest land. Young of the year are thought to overwinter near the mouths of their natal streams (Collette and Klein-MacPhee 2002). At sea they eat zooplankton, small benthic crustaceans, and occasionally, small fish.

Atlantic salmon *(Salmo salar)*

Atlantic salmon are found in coastal waters on both sides of the North Atlantic, from Spain to the Arctic circle, Long Island Sound to Labrador, and a few rivers in western Greenland (Collette and Klein-McPhee 2002). Atlantic salmon spend their first few years in small streams and rivers feeding primarily on aquatic insects. These young, mostly solitary fish are called “parr.” After reaching a size of about four inches, the fish become “smolts” in the spring and begin migrating to the ocean. It takes two to five years to become a smolt, less in the southern portion of the range and more in the north where growing seasons are short. During their downstream migration smolts begin schooling and develop the salinity tolerance needed to survive in the ocean. Fish becomes a larger proportion of their diet as they grow.

Feeding while they migrate, the salmon move toward their major feeding grounds in the North Atlantic near Greenland and Iceland. After spending one or two years at sea, salmon begin their journey back to their natal rivers. Salmon may reenter fresh water in spring, summer, or fall, but spawning occurs in the fall. Unlike Pacific salmon, Atlantic salmon typically do not die after spawning.

Interestingly, a small group of salmon native to Nova Scotia, New Brunswick streams in the inner Bay of Fundy region are thought to utilize Gulf of Maine waters most of the year and don’t undertake long ocean migrations. These “resident” salmon stocks, like the long-distance migrants, are impacted by degradation of freshwater habitat by flow alteration and acid precipitation. Atlantic salmon are among a small group of diadromous fish that require access into remote upstream tributaries up to hundreds of miles from the sea. The extent of habitats required to support a salmon throughout its life cycle led to the species’ extirpation from all but a few of its native rivers in the United States by the time of the Industrial Revolution.

Atlantic sturgeon *(Acipenser oxyrinchus)*

Historically, Atlantic sturgeon were present in approximately 38 rivers in the United States from St. Croix, Maine to the Saint Johns River, FL, 35 of which have been confirmed to have had a historical spawning population. Atlantic sturgeon are currently present in the same 35 rivers, and spawning occurs in at least 20 of these rivers (Atlantic Sturgeon Status Review Team 2007).

Sturgeons are members of the ancient family Acipenseridae, large, slow-growing, and late maturing anadromous fish that migrate from the ocean into coastal estuaries and rivers to spawn. Adhesive eggs are attached to firm substrates in oligohaline (brackish) and tidal fresh waters (Collette and Klein-MacPhee 2002). Juveniles may spend several years in fresh water in some rivers, but in others fish move to brackish water in the fall. The lower portions of rivers and estuaries are important for growth. The distribution and residence times of larval, post-larval, and young juveniles in upstream areas are unknown, but aggregations of juveniles at the freshwater/saltwater interface suggest that this is a nursery area. Juveniles remain within riverine estuarine systems for periods of about one to six years before migrating to the coast and onto the continental shelf where they grow to maturity. Tagging and genetic data indicate that subadult and adult Atlantic sturgeon may travel widely once they emigrate from rivers, wandering among shallow coastal and estuarine habitats. Coastal features or shorelines where migratory Atlantic sturgeon commonly aggregate include the Bay of Fundy, Massachusetts Bay, Rhode Island, New Jersey, Delaware, Delaware Bay, Chesapeake Bay, and North Carolina (Atlantic Sturgeon Status Review Team 2007).

Sturgeons are benthic feeders, with a subterminal mouth (located on the underside of the head) and barbels (fleshy feelers) well designed for sensing and capturing benthic invertebrates. Historically, abundant and widely distributed, the combination of slow rates of population growth and high economic demand for flesh and roe made Atlantic sturgeon especially vulnerable to over-harvesting.

Atlantic tomcod *(Microgadus tomcod)*

Atlantic tomcod are distributed in shallow, inshore waters along the Atlantic coast from southern Labrador to Chesapeake Bay, spawning in brackish or fresh areas of rivers from November to February (Collette and Klein-MacPhee 2002). Atlantic tomcod are not truly anadromous but amphidromous (utilizing both fresh and marine habitats but not necessarily requiring both habitats). Tomcod can survive and reproduce with access only to brackish water. Eggs sink and stick to gravel, stones, or plants, hatching after 24-30 days. Larvae and juveniles eat mostly copepods; as they grow they eat a variety of crustaceans, worms, and larval fishes. Tomcod are benthic, estuarine residents, and as a result are subject to stress from a variety of pollutants. Detailed studies from the Hudson River show elevated levels of PCBs, metals, and pesticides in tomcod tissues as well as high rates of liver cancer and shortened life spans (Collette and Klein-MacPhee 2002). Data on distribution and abundance of tomcod are limited but anecdotal reports indicate that these fish were ubiquitous in coastal waters a century ago and supported some substantial fisheries, but today they are less plentiful.

Blueback herring *(Alosa aestivalis)*

Blueback herring spawn from Nova Scotia to northern Florida, but are most numerous in warmer waters from Chesapeake Bay south. Blueback herring prefer to spawn in swift flowing sections of freshwater tributaries, channel sections of fresh and brackish tidal rivers, and Atlantic coastal ponds, over gravel and clean sand substrates (ASMFC 1999). Similar in appearance, alewife and blueback herring are collectively known as river herring. Mature river herring broadcast their eggs and sperm simultaneously into the water column and over the substrate. Immediately after spawning, adults migrate downstream. Juveniles remain in freshwater nursery areas in spring and early summer, feeding mainly on zooplankton, but larvae are tolerant of salinity early in life and may utilize both freshwater and marine nurseries (Collette and Klein-MacPhee 2002). As water temperatures decline in the fall, juveniles move downstream to more saline waters. Little information is available on the life history of subadult and adult blueback herring after they emigrate to the sea as young-of-year or yearlings, and before they mature and return to spawn. In summer and fall bluebacks are concentrated in shelf areas north of 40oN latitude, along Georges Bank and the perimeter of the Gulf of Maine; in winter between 40o N and 43o N, and in spring across the continental shelf from Cape Hatteras to Nova Scotia as migration toward spawning rivers begins (Neves 1981). Recruitment to the spawning population takes place between ages 3 and 6, usually age 5 (Collette and Klein-MacPhee 2002).

Hickory shad *(Alosa mediocris)*

Hickory shad occur along the Atlantic coast from the Bay of Fundy, Canada to the Saint John's River, Florida (Levinton and Waldman 2006), but spawning is reported in rivers from Maryland to Florida (Harris et al. 2007). Adult hickory shad appear to spawn in a diversity of physical habitats ranging from backwaters and sloughs, to tributaries, to mainstem portions of large rivers in tidal and non-tidal freshwater areas (AMSFC 1999). In Chesapeake Bay, hickory shad spawning runs usually precede American shad runs, typically beginning in March and April. Repeat spawning in hickory shad appears to be common, but tends to vary among river systems. Spawning hickory shad females (ages 3 and 4) broadcast a large quantity of eggs into the water column which are fertilized by males (ages 2 and 3). After spawning, adults return to the sea, but their distribution and movements in the ocean are essentially unknown. It is believed that they are highly migratory and follow a pattern similar to the coastal migrations of American shad, moving northward from the Mid-Atlantic and southeast after spawning. Hickory shad are predators, consuming small fishes, crabs, and squid.

Rainbow smelt *(Osmerus mordax)*

Smelt occur on the Atlantic coast from Labrador to New Jersey, but are most abundant from the southern Canadian Maritime Provinces to Maine. Their range, which formerly extended to the Delaware River, appears to be contracting northward; state status ranks vary from SH or "possibly extirpated" in Pennsylvania; to S1 in Connecticut and Rhode Island; to S3 in Massachusetts and S4-S5 northward (Natureserve 2008). Coastal smelt stocks throughout New England declined markedly by the 20th century, due to the construction of dams and reduction in water quality. Two concerns identified for many rivers in Massachusetts Bay are structural impediments to spawning habitat and chronic degradation of spawning habitat from stormwater inputs (Chase and Childs 2001).

Smelt are a pelagic, schooling species that spends most of its time in shallow nearshore waters and may make ocean migrations, but little is known about this part of its life history. Their movement patterns are associated with seasonal changes in water temperatures. In summer, schools move to deeper, cooler, waters; in the fall they enter bays and estuaries where they actively feed until the onset of winter. Most spawning occurs in fast flowing, turbulent water in stream sections dominated by rocks, boulders, and aquatic vegetation, about the time ice breaks up in late winter. After hatching, larvae move passively downstream in freshwater currents until reaching estuarine waters (Collette and Klein-MacPhee 2002). By mid-summer, juveniles reside in the deeper waters of estuaries, particularly during daylight hours. Larvae and juveniles feed upon zooplankton, particularly microscopic crustaceans. Adult smelt feed primarily on small crustaceans and fish. Smelt in turn are an important prey for a variety of predatory fish, including, striped bass and bluefish, and several bird and marine mammal species.

Sea-run brook trout *(Salvelinus fontinalis)*

Brook trout are native to eastern North America from Labrador southward to Georgia along the Appalachian chain (Natureserve 2008). Like many other salmonids, including brown trout and rainbow trout introduced to the East Coast as sport fish, brook trout life histories are highly variable. Brook trout once exhibited anadromous behavior in many streams of eastern Canada southward to Long Island, but few sea run populations remain and most continue to decline (Doucet et al. 1999). Historical accounts suggest that sea-run brook trout were common prior to the 1700s, and that they suffered the same fate as other anadromous fish when subjected to damming and pollution of rivers. They are now documented in a handful of sites in Massachusetts, Maine, and maritime Canada but may still persist as far south as Long Island.

Sea-run trout typically remain near the mouth of their natal stream, but have been found up to 45 km away in open ocean habitats or in other estuaries (Collette and Klein-MacPhee 2002). Technically most of these fish are amphidromous, spending substantial time feeding and growing in freshwater but frequently visiting saltwater. Few authors agree on the specific mechanism that initiates anadromy or on the relatedness of resident and sea-run brook trout in mixed populations; possible factors include environmental conditions, food availability, and density-dependent behavior (Doucet et al. 1999).

Shortnose sturgeon *(Acipenser brevirostrum)*

Shortnose sturgeon are found in rivers and estuaries from the Saint John River in New Brunswick to the Saint John's River in Florida (Collette and Klein-Macphee 2002). There are currently 19 spawning populations that are considered to be viable; the largest known population is the Hudson River with 38,000 individuals, the second largest is 18,000 in the Saint John River (NMFS 1998). Adult shortnose sturgeon exhibit freshwater amphidromy (i.e., adults spawn in freshwater but regularly enter salt-water habitats) in some rivers in the northern part of their range but are generally estuarine anadromous in southern rivers (Kieffer and Kynard 1993). At least one population, in the Connecticut River, is landlocked above the Holyoke Dam 128.7 km upstream and never enters salt water (Hartel et al. 2002). Fish move upriver to spawning grounds in the spring, then return to lower freshwater or brackish reaches. Spawning occurs in deep, fast currents over rocky substrate at or above the fall line (Collette and Klein-Macphee 2002). Shortnose sturgeon have recently been found to travel moderate distances between river systems; in 2006 a sturgeon tagged in the Savannah River in Georgia was found 300 miles (483 km) away in the Santee-Cooper River system in South Carolina (Amanda Wrona, personal communication).

Shortnose sturgeon reach maturity at progressively later ages from south to north, and females mature two to three years later than males. In Georgia, males mature at age 2-3, while females in New Brunswick may not reproduce until age 13. After maturity, males spawn every one to two years and females every three years. Shortnose sturgeon are opportunistic benthic foragers, feeding on crustaceans, mollusks, insects, and worms (Collette and Klein-Macphee 2002).

Literature Cited

Anderson, M. G., K. Lombard, J. Lundgren, B. Allen, S. Antenen, D. Bechtel, A. Bowden, M. Carabetta, C. Ferree, M. Jordan, S. Khanna, D. Morse, A. Olivero, N. Sferra, and A. Upmeyer. 2006. The North Atlantic Coast: Ecoregional Assessment, Conservation Status Report and Resource CD. The Nature Conservancy, Eastern Conservation Science, Boston, Massachusetts.

ASMFC (Atlantic States Marine Fisheries Commission). 2007. Special Report to the ASMFC Atlantic Sturgeon Management Board: Estimation of Atlantic Sturgeon Bycatch in Coastal Atlantic Commercial Fisheries of New England and the Mid-Atlantic.

ASMFC (Atlantic States Marine Fisheries Commission). 2005. Public information document for potential changes to the Interstate Fishery Management Plan for American eel.

ASMFC (Atlantic States Marine Fisheries Commission). 1999. Amendment 1 to the Interstate Fishery Management Plan for Shad & River Herring.

ASMFC (Atlantic States Marine Fisheries Commission). 1998. Amendment 1 to the Interstate Fishery Management Plan for Atlantic Sturgeon. Fishery Management Report No. 35.

ASMFC (Atlantic States Marine Fisheries Commission). 2008. River Herring Stock Status Report. ASMFC Stock Assessment Subcommittee.

ASMFC (Atlantic States Marine Fisheries Commission). 2007. American shad stock assessment report for peer review and Terms of Reference & Advisory Report to the American Shad Stock Assessment Peer Review. Stock Assessment Report No. 07-01.

Atlantic Sturgeon Status Review Team. 2007. Status Review of Atlantic sturgeon (Acipenser oxyrinchus oxyrinchus). Report to National Marine Fisheries Service, Northeast Regional Office. February 23, 2007. 174 pp.

Bigelow, H.B. and W.C Schroeder. 1953. Fishes of the Gulf of Maine. Fishery Bulletin. 53: 1-577.

Buchsbaum, R., L. Deegan, and R. H. Garritt. 2002. Changes in the fish community of Plum Island Sound from 1965 through 1994. In: The Marine Resources of the Parker River-Plum Island Sound Estuary: An Update after 30 Years. R. Buchsbaum et al. eds. Report to the Massachusetts Office of Coastal Zone Management.

Chase, B. C. and A. R. Childs. 2001. Rainbow Smelt (Osmerus mordax) Spawning Habitat in the Weymouth-Fore River. Massachusetts Division of Marine Fisheries Technical Report TR-5. 29pp.

Cieri, M., G. Nelson, and M. Armstrong. 2008. Estimates of River Herring Bycatch in the Directed Atlantic Herring Fishery. Massachusetts Division of Marine Fisheries.

Collette, B. B. and G. Klein-MacPhee, eds. 2002. Bigelow and Schroeder's fishes of the Gulf of Maine, 3rd Edition. Smithsonian Institution Press, Washington, DC. 748 pp.

COSEWIC. 2008. Canadian Wildlife Species at Risk. Committee on the Status of Endangered Wildlife in Canada. http://www.cosewic.gc.ca/eng/sct0/rpt/rpt_csar_e.cfm.

Dadswell, M. J., G. D. Melvin, P. J. Williams, and D. E. Themelis. 1987. Influences of origin, life history, and chance on the Atlantic coast migration of American shad. In: M.J. Dadswell et al. eds., Common strategies of anadromous and catadromous fishes. American Fisheries Society Symposium. 1:313-330.

Doucet, R. R., W. Hooper, and G. Power. 1999. Identification of anadromous and nonanadromous adult brook trout and their progeny in the Tabusintac River, New Brunswick by means of multiple-stable-isotope analysis. Transactions of the American Fisheries Society. 128:278-288.

Dovel, W.L. 1968. Predation by striped bass as a possible influence on population size of the Atlantic croaker. Transactions of the American Fisheries Society. 97:313-319.

Durbin, A. G., S. W. Nixon, and C. A. Oviatt. 1979. Effects of the spawning migration of the alewife, Alosa pseudoharengus, on freshwater ecosystems. Ecology. 60 (1): 8-17.

Gende, S. M., R. T. Edwards, M. F. Willson, and M. S. Wipfli. 2002. Pacific Salmon in Aquatic and Terrestrial Ecosystems. Bioscience. 52(10): 917-928.

Gephard, S. Not Dated. Potential Impacts of Global Warming on Diadromous Fishes of Connecticut (white paper). NEMO/University of Connecticut. http://nemo.uconn.edu/tools/fotc/fact_sheets/Global%20Warming%20Diadromous%20Paper.pdf. Accessed February 20, 2009.

Gephard, S. and J. McMenemy. 2004. An overview of the program to restore Atlantic salmon and other diadromous fishes to the Connecticut River with notes on the current status of these species in the river. Pages 287-318 in Jacobson, P.M., D.A. Dixon, W.C. Leggett, B.C. Marcy, Jr., R.R. Massengill. The Connecticut River Ecological Study re-visited: ecology of the lower Connecticut River 1973-2003. America Fisheries Society Monograph 9. Bethesda, Maryland.

Harris, J. E., R. S. McBride, and R. O.Williams. 2007. Life history of hickory shad in the St. Johns River, Florida. Transactions of the American Fisheries Society. 136:1463–1471.

Hartel, K. E, D. B. Halliwell, and A. E. Launer. 2002. Inland Fishes of Massachusetts. Massachusetts Audubon Society. Lincoln, MA. 328 pp.

Juanes, F., R. E. Marks, K. A. McKown, and D.O. Conover. 1993. Predation by age-0 bluefish on age-0 anadromous fish in the Hudson River Estuary. Transactions of the American Fisheries Society. 122:348-356.

Kieffer, M. and B. Kynard. 1993. Annual movements of shortnose and Atlantic sturgeons in the Merrimack River, Massachusetts. Transactions of the American Fisheries Society. 122:1088-1103.

Klauda, R. J., R. E. Moos, and R. E. Schmidt. 1981. Life history of Atlantic tomcod, Microgadus tomcod, in the Hudson River Estuary, with emphasis on spatio-temporal distribution and movements. In: Fisheries Research in the Hudson River. C. L. Smith, ed. Hudson River Environmental Society. SUNY Press.

Kocik, J. F. and T. F. Sheehan. 2006. Status of Fishery Resources off the Northeastern US: Atlantic Salmon. Northeast Fisheries Science Center, Gloucester, MA. http://www.nefsc.noaa.gov/sos/spsyn/af/salmon/archives/41_AtlanticSalmon_2006.pdf.

Levinton, J. S. and J. R. Waldman. 2006. The Hudson River Estuary. Cambridge University Press. New York, New York. 488 pp.

McDowall, R. M. 1987. The occurrence and distribution of diadromy among fishes. 1–13. In: Dadswell, M. J. , R. J. Klauda , C. M. Moffitt , R. L. Saunders , R. A. Rulifson , and J. E. Cooper , editors. Common Strategies of Anadromous and Catadromous Fishes. American Fisheries Society Symposium 1, American Fisheries Society. Bethesda, Maryland.

McPhee, J. 2002. The Founding Fish. Farrar, Straus, and Giroux. New York, New York. 368 pp.

National Marine Fisheries Service. 1998. Recovery Plan for the Shortnose Sturgeon (Acipenser brevirostrum). Prepared by the Shortnose Sturgeon Recovery Team for the National Marine Fisheries Service, Silver Spring, Maryland. 104 pp.

NMFS OPR (National Marine Fisheries Service Office of Protected Resources). 2009. Proactive Conservation Program: Species of Concern. http://www.nmfs.noaa.gov/pr/species/concern/. Accessed February 20, 2009

NMFS OPR (National Marine Fisheries Service Office of Protected Resources). 2009. Atlantic salmon (Salmo salar). http://www.nmfs.noaa.gov/pr/species/fish/atlanticsalmon.htm. Accessed February 21, 2009

NMFS USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 2005. Final Recovery Plan for the Gulf of Maine Distinct Population Segment of Atlantic salmon (Salmo salar). Gloucester, MA 325 pp. http://www.nero.noaa.gov/nero/hotnews/salmon/FinalATSRPlan.pdf.

NatureServe. 2009. An Online Encyclopedia of Life. http://www.natureserve.org/explorer/. Accessed February 21, 2009

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. In: Aquatic Fauna in Peril: The Southeastern perspective. Benz, G. W. and D. E. Collins, eds. pp. 45-86. Southeast Aquatic Research Institute, Decatur, GA.

Neves, R. J. 1981. Offshore distribution of alewife, Alosa psuedoharengus and blueback herring, Alosa aestivalis, along the Atlantic coast. Fishery Bulletin. 77:199-212.

Thoreau, Henry David. 1849. A Week on the Concord and Merrimack Rivers. James Munroe and Company. Boston, MA. 272 pp.

USFWS (United States Fish and Wildlife Service). 2007. 12-month Finding on a Petition To List the American Eel as Threatened or Endangered.

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.

Watters, G. T. 1996. Small dams as barriers to freshwater mussels (Bivalvia, Unionoida) and their hosts. Biological Conservation. 75:79-85.

Williams, J. D., M. L.Warren, Jr., K. S. Cummings, J. L. Harris, and R. J. Neves. 1992. Conservation Status of Freshwater Mussels of the United States and Canada. Fisheries. 18: 6-22.

Weiss-Glanz, L. S., J. G. Stanley, J. R. Moring, and D. Moran. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic), American shad. USFWS Biological Report. 82: 11-59.

CHAPTER

7

Demersal Fish

Geoffrey Smith

Introduction

The high rates of productivity within the Northwest Atlantic region provide an abundant food source for planktivores in the water column, while still allowing significant energy to reach the ocean floor to support benthic communities. As a result, demersal fish species, i.e., fish that live on or near the seafloor, are able to thrive on the abundance of available prey items. These demersal species (which include Atlantic cod, haddock, flounders, monkfish, sea bass, skates, tilefish, and several estuarine-dependent species) are characterized by their close association with the seafloor for critical life stages including feeding, juvenile nursery areas, and spawning. Historically, demersal fish in the region played a critical role as a dominant predator, heavily influencing lower trophic levels in the system (Steneck 1997).

The list of demersal fish species included in this assessment is comprised of teleosts (ray-finned fishes) and elasmobranchs (cartilaginous fishes) that utilize a variety of benthic habitats to complete various phases of their life histories. While the species within the group share the common attribute of close association with sea floor habitats, individual species utilize a variety of different habitats throughout the region. Atlantic cod and haddock demonstrate an affinity for more complex substrates including gravel, pebbles, and cobbles, while flounders and skates show a preference for finer-grained substrates such as sands and mud. In addition, many species within the group make distinct seasonal migrations, occupying shallower habitats in the spring and summer months, then moving offshore to deeper water habitats in the winter in response to changes in water temperature.

Demersal fish have also played a critical economic and cultural role in the region for centuries. Fisheries for cod, haddock, hake, and halibut are believed to be largely responsible for European settlement in North America some 500 years ago (Kurlansky 1997). Since then, demersal fish populations have helped support fishing communities up and down the east coast, providing a source of income, food, and community identity. Even today, demersal fisheries are important to the economies in many parts of the region despite significant declines in many commercially exploited demersal fishes.

Technical Team Members

Chris Bruce, The Nature Conservancy, Virginia
Dan Coker, The Nature Conservancy, Maine
Mark Gibson, Rhode Island Department of Fish and Wildlife
David Goethel, Commercial Fisherman and NEFMC Member, New Hampshire
Ryan Gordon, The Nature Conservancy, Maine
Kohl Kanwit, Maine Department of Marine Resources
Jeremy King, Massachusetts Division of Marine Fisheries
Jack Musick, Ph.D, Virginia Institute of Marine Sciences
Tom Nies, New England Fisheries Management Council
Jay Odell, The Nature Conservancy, Virginia
Paul Rago, Ph.D., Northeast Fisheries Science Center
Geoffrey Smith, The Nature Conservancy, Maine
David Stevenson, National Marine Fisheries Service

Selection of Target Species

The selection of target species was an iterative process undertaken by the TNC Team Lead and team members. Several factors were considered when selecting target species for this assessment, including: 1) distribution over a range of depths and substrate types, 2) variations in life history, including reproduction and food habits, 3) availability and quality of species-specific information, 4) current population status, and 5) distinct ecological roles within the Northwest Atlantic. Team members agreed it was important to develop a more inclusive suite of species representing the broad ecological role of demersal fish, rather than focusing more narrowly on those species in need of immediate conservation attention. As such, the species analyzed in this assessment range from those whose population status is of concern because of significant depletion relative to historic levels (e.g., cod, halibut, some flounders, and wolffish) to species that are relatively abundant and show signs of continued improvement (e.g., haddock, redfish, and summer flounder).

The 32 species chosen for this assessment were:

Gadids

- Atlantic cod *(Gadus morhua)*
- Cusk *(Brosme brosme)*
- Haddock *(Melanogrammus aeglefinus)*
- Pollock *(Pollachius pollachius)*
- Red hake *(Urophycis chuss)*
- Silver hake *(Merluccius bilinearis)*
- White hake *(Urophycis tenuis)*

Pleuronectids

- American plaice *(Hippoglossoides platessoides)*
- Winter flounder *(Pseudopleuronectes americanus)*
- Witch flounder (Glyptocephalus cynoglossus)
- Yellowtail flounder (Pleuronectes ferruginea)

Elasmobranchs

- Barndoor skate (Dipturus laevis)
- Clearnose skate (Raja eglanteria)
- Little skate *(Raja erinacea)*
- Rosette skate *(Leucoraja garmani)*
- Spiny dogfish (*Squalus acanthias*
- Thorny skate (*Amblyraja radiata*)

Offshore Wintering Guild

- Black sea bass (*Centropristis striata*)
- Northern sea robin (*Prionotus carolinus*
- Scup (*Stenotomus chrysops*)
- Summer flounder (*Paralichthys dentatus*)

Mid-Atlantic Estuarine

- Atlantic croaker (*Micropogonias undulatus*)
- Spot (*Leiostomus xanthurus*)
- Weakfish (*Cynoscion regalis*)

Other Species of Interest

- Acadian redfish *(Sebastes fasciatus)*
- Atlantic halibut *(Hippoglossus hippoglossus)*
- Atlantic wolffish *(Anarhichas lupus)*
- Golden tilefish *(Lopholatilus chamaeleonticeps)*
- Longhorn sculpin *(Myoxocephalus octodecimspinosus)*
- Monkfish *(Lophius americanus)*
- Ocean pout *(Zoarces americanus)*
- Tautog *(Tautoga onitis)*

Population Status and Importance of Northwest Atlantic Region

The global distribution of the demersal fish species included in the group is limited to the Atlantic Ocean, with the exception of spiny dogfish which are distributed throughout many of the world's oceans. Distributions are limited primarily to nearshore coastal waters and along the Continental Shelf and are controlled by a variety of factors, with water temperature among the most important. Variations in water temperature are especially important because thermal extremes have a greater effect on the distribution of most organisms than mean annual temperatures. Density and biomass are highest in areas with broad annual ranges in temperature, and lowest in areas with low annual ranges, although this distribution is probably influenced also by other chemical and physical properties of water masses (Cook and Auster 2007). Several species in the group occur in both the Northwest and Northeast Atlantic, with the Northwest Atlantic representing an important center of distribution. These species include Acadian redfish, Atlantic cod, Atlantic halibut, Atlantic wolfish, American plaice, cusk, haddock, and pollock. Distribution of all other species within the assemblage is limited to the western side of the Atlantic, with the exception of spiny dogfish noted above (Collette and MacPhee 2002).

Analysis of species distribution using National Marine Fisheries Service (NMFS) bottom trawl survey data and other sources reveals distinct differences in species abundance, distribution, and composition within the Northwest Atlantic region itself, with Georges Bank representing a significant transition zone between colder-water species to the north in the Gulf of Maine and more temperate species in Southern New England and the Mid-Atlantic. According to Cook and Auster (2007), there appears to be a reasonably strong consensus about the existence of five distinct biogeographic regions on the Continental Shelf of the eastern United States and Nova Scotia, including the Scotian Shelf/Grand Banks, Gulf of Maine, Georges Bank, Southern New England, and the Mid-Atlantic Bight. Each is characterized by a unique combination of oceanographic conditions, fish species assemblages, and a wide variety of invertebrate taxa. The boundary at Cape Cod appears to be so strong that some authorities consider it to be a break between two major provinces, the Eastern Temperate and Warm Temperate (Cook and Auster 2007). This transition zone at Georges Bank was also recognized by researchers studying benthic macroinvertebrates in the Northwest Atlantic, south of the Scotian Shelf. They found that the large majority of species off Nova Scotia and in the Gulf of Maine consists of boreal forms, whereas a significant component of the Georges Bank assemblage is temperate transitional or Virginian species because of the area's higher seasonal maximum temperatures (which preclude reproduction and/or growth of many subarctic or boreal species) (Theroux and Grosslein 1987).

The most recent peer reviewed stock assessments found that ten of the demersal species included in the stock assessment are overfished (less than half of biological goals for population size) and eight are subject to overfishing (fishing mortality rates exceed target levels) (NEFSC 2008). However, several species that were once severely depleted are successfully rebuilding, including Acadian redfish, haddock, and summer flounder (NEFSC 2008; ASMFC 2009). Trends in relative abundance for each of the 32 species varied. While many species in the assemblage are declining, some are holding steady and others are increasing. These trends are often specific to different portions of the species' ranges.

© Norm Despres

A number of demersal fish species included in this assessment have been identified as Species of Concern. NMFS defines these as species about which they have some concerns regarding status and threats, but for which insufficient information is available to indicate a need to list the species under the Endangered Species Act. Species of Concern included in the assemblage are Atlantic halibut, Atlantic wolfish, barndoor skate, cusk, and thorny skate. Of these five species, Atlantic halibut and barndoor skate are considered endangered by the IUCN and Atlantic wolffish and cusk are under status review by NMFS for potential Endangered Species Act listing (NMFS 2009a).

Ecosystem Interactions and Ecological Dependencies
The demersal species included in this assemblage are characterized by their close association with the seafloor for critical life stages and activities including feeding, usage of juvenile nursery areas, and spawning. High rates of productivity in the region provide an abundant food source for planktivores in the water column, while still allowing significant energy to reach the ocean floor to support benthic communities.

The trophic ecology of demersal fish species in the Northwest Atlantic is well studied. Many species are characterized as opportunistic generalists, feeding on a variety of prey items ranging from plankton to benthic macroinvertebrates or fishes depending on life stage (Link and Garrison 2002). Larval and juvenile life stages of many demersal fish are a significant food source for adult life stages of species, and cannibalism is not uncommon. Many demersal fishes exhibit ontogenetic (size-specific) shifts in diet, switch among prey items according to their availability, and exhibit dietary preference for small pelagic fish.

In contrast to other ecosystems, the food web of the northeast United States Continental Shelf ecosystem is highly connected and complex, consisting of weak species interactions (Link and Garrison 2002). It has been inferred that production in this region is tightly bound, with most of the fish production being consumed by other fish species (Sissenwine et al. 1982). These apparent energetic constraints can result in relatively stable levels of overall biomass and production of fish, although dramatic fluctuations at the individual species level are routinely observed. Such fluctuations were observed on Georges Bank in the mid- to late 1980s as populations of elasmobranchs (skates and dogfish) increased in response to significant declines in cod, haddock, and flounder populations due to fishing pressure (Fogarty and Murawski 1998). Similar changes in trophic dynamics were observed in coastal portions of the Gulf of Maine when depletion of cod and other large predatory fishes fundamentally altered the food web, leading to significant increases in lobsters, crabs, and sea urchins in the coastal zone (Steneck 1997). These studies and others demonstrate the degree to which populations of some species in the assemblage (and other marine species) are directly influenced by changes in the relative abundance of others.

In addition to species-specific trophic interactions, many demersal species in the assemblage display strong associations with a range of benthic habitats during various life stages. For example, survivorship of juvenile cod is known to be higher in substrates with greater structural complexity, and it has been suggested that gravel substrate may represent a limiting resource for the early life stages of cod and haddock (Fogarty and Murawski 1998). Nearshore coastal and estuarine habitats are especially important for a number of the Southern New England and mid-Atlantic species in the group. Atlantic croaker, summer flounder, spot, tautog, and winter flounder display obligate utilization of these habitats (they use them by necessity), and many others, including black sea bass and displaying facultative (non-obligatory) use. Golden tilefish are known to be important modifiers and creators of habitat on the outer Continental Shelf and along the slopes and walls of submarine canyons, creating elaborate "pueblo villages" of burrows within clay substrates, presumably to avoid predation (Able et al. 1982; Grimes et al. 1986). Tilefish burrows provide habitat for a variety of other species, including crustaceans, lobster, conger eel, cusk, hake, and ocean pout.

Northwest Atlantic Distribution and Important Areas

Methods

See methods overview in Chapter 5.

Data Limitations

Relative distribution, weighted persistence, and trends analyses for the demersal fish group were based upon data from the NMFS bottom trawl survey database. Otter trawl systems like the one utilized to conduct survey sampling are specifically designed to capture a variety of demersal fish species, including many of the species analyzed in this assessment. It is important to note, however, that the catch rates for various species within the group are variable. Catchability coefficients are generally higher for demersal, round-bodied species including Atlantic cod, haddock, pollock and hake and lower for flat-bodied fish and pelagic species. In additional, catch rates at any given location can be heavily influenced by day/night differences in species distribution within in the water column, and by seasonal variations in species distribution within their geographic range. As such, it should be recognized that while analyses derived from the bottom trawl survey database are indeed informative, results obtained from other data sources should also be considered.

Maps, Analysis, and Areas of Importance

Gadids

Atlantic cod (Figure 7-1a, b), haddock (Figure 7-3a, b), and pollock (Figure 5a, b) were distributed across the Gulf of Maine, Georges Bank and Southern New England, occurring in high numbers along the northern edge and Northeast Peak of Georges Bank. High numbers of Atlantic cod and pollock were also found to occur along the 50 fathom curve in the western Gulf of Maine. Statistical analyses indicated a declining trend for Atlantic cod (Figure 7-1c, d) and pollock (Figure 7-5c, d) across much of their range, though increasing trends were observed for Atlantic cod in parts of the Jeffreys Ledge and Stellwagen Bank area and in discrete areas around the perimeter of Georges Bank. Statistical analyses for haddock did not reveal significant trends across much of their range, though increasing trends were observed on parts of Georges Bank, in the Great South Channel, and shelf waters off the coast of New Jersey (Figure 7-3c, d). Haddock declined in the Gulf of Maine in small portions of the Jeffreys Ledge and Stellwagen Bank area and along the coastal shelf in eastern Maine off of Penobscot Bay.

Weighted persistence analyses identified the Northern Edge and Northeast Peak of Georges Bank, and the Great South Channel as important areas for Atlantic cod (Figure 7-2), haddock (Figure 7-4), and pollock (Figure 7-6). The southern flank of Georges Bank was also important for haddock. In the Gulf of Maine, nearshore waters of Massachusetts Bay, Jeffreys Ledge, and Stellwagen Bank were identified as important for these three species, as were the Cashes Ledge area, the coastal shelf off Penobscot Bay in eastern Maine, and the area between Grand Manan Banks and German Bank off of Nova Scotia.

Cusk were widely dispersed throughout the Gulf of Maine and along the northern perimeter of Georges Bank (Figure 7-7a, b). High numbers occurred in the deeper waters of the central Gulf of Maine, including waters extending from Cashes Ledge through the Jordan Basin and onto the Scotian Shelf in Canadian waters. Statistical analyses for cusk generally found no significant trend across much of their range, though declining trends were observed in portions of the Gulf of Maine, including near Franklin Swell, the northern tip of Jeffreys Ledge, off the southern coast of Nova Scotia near Grand Manan Banks and German Bank, and along the Northeast Peak of Georges Bank (Figure 7c, d). Weighted persistence analyses for cusk identified Jeffreys Ledge, waters west of Cashes Ledge to Sewell Ridge, the Northeast Channel, and the Northern Edge/Northeast Peak of Georges Bank as important areas (Figure 7-8).

High numbers of red hake were found on Jeffreys Ledge and Stellwagen Bank in the Gulf of Maine, along the perimeter of Georges Bank, along the Continental Shelf and Slope break in Southern New England as far south as

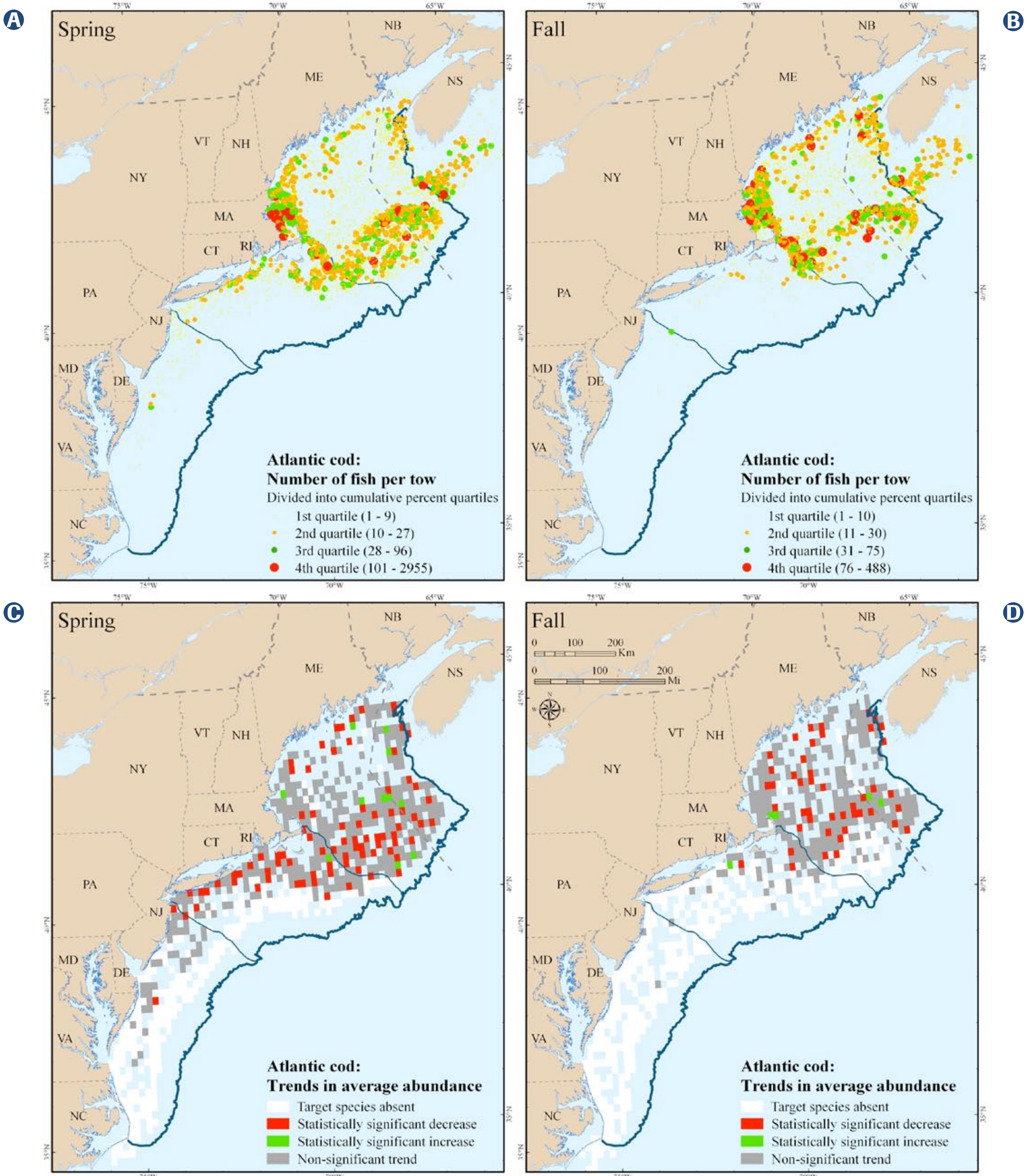


Figure 7-1. Trends in average abundance over 40 years for Atlantic cod during the spring and fall seasons.

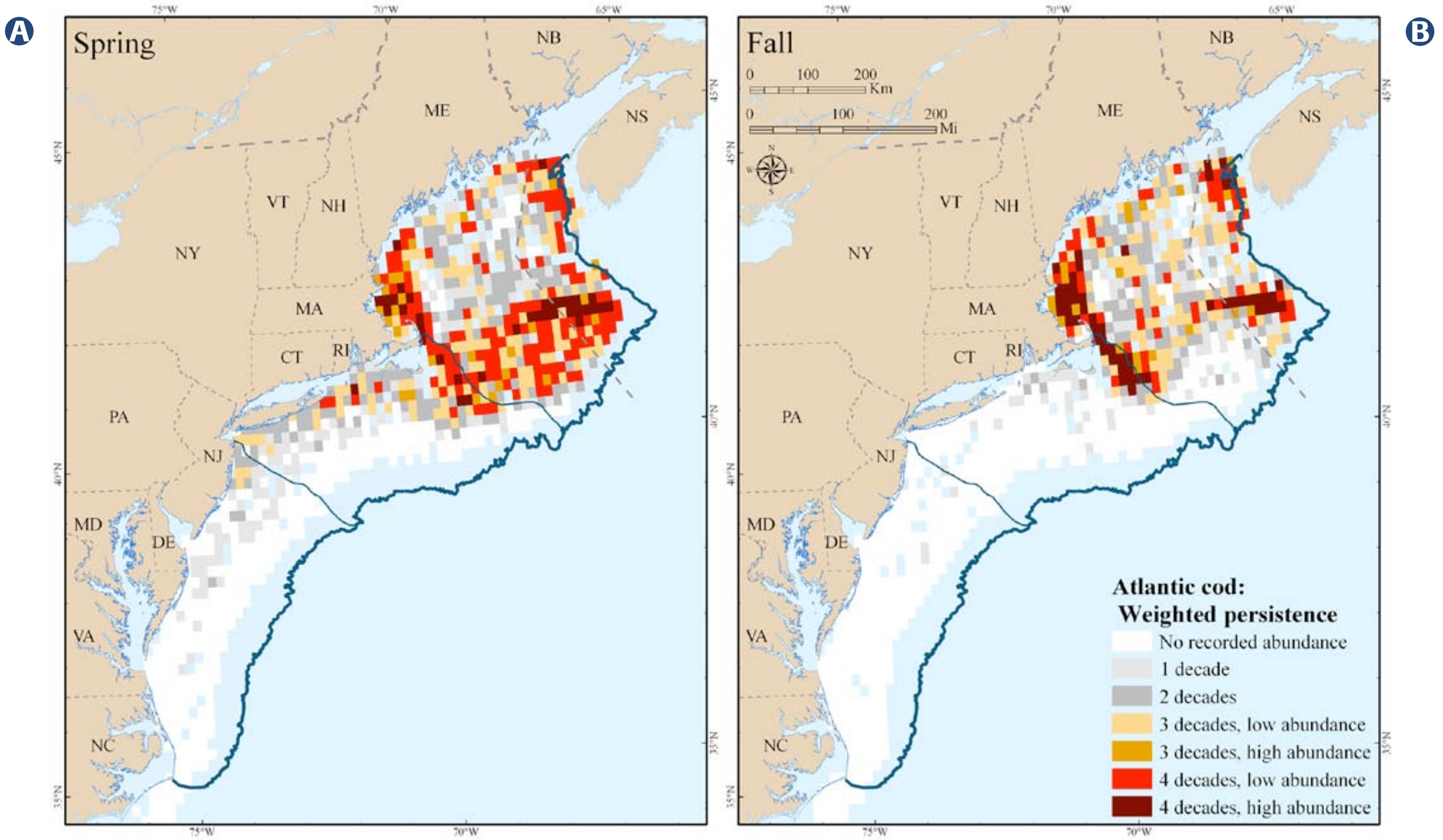


Figure 7-2. Areas with high persistence and abundance over 40 years for Atlantic cod during the spring and fall seasons.

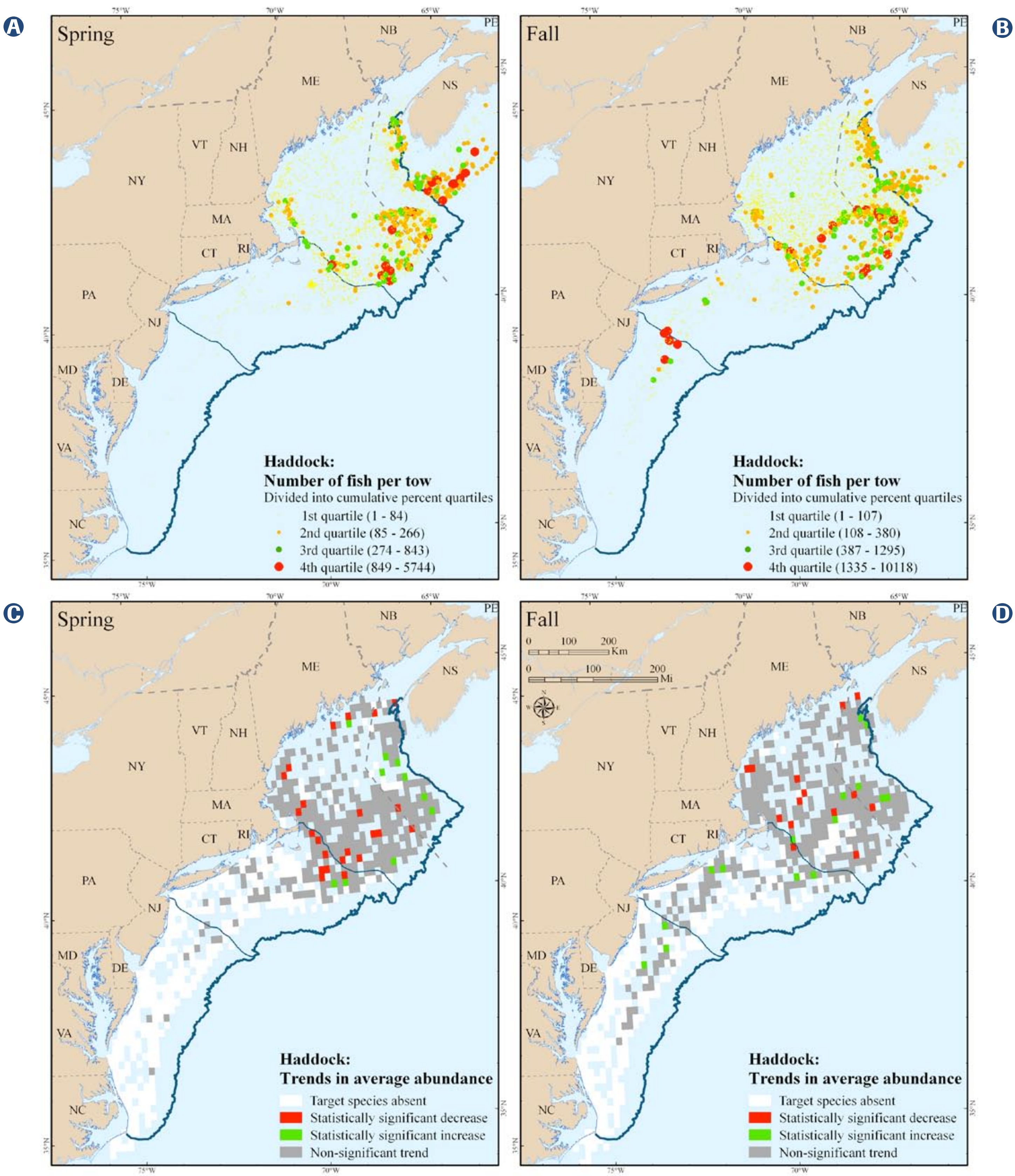


Figure 7-3. Trends in average abundance over 40 years for haddock during the spring and fall seasons.

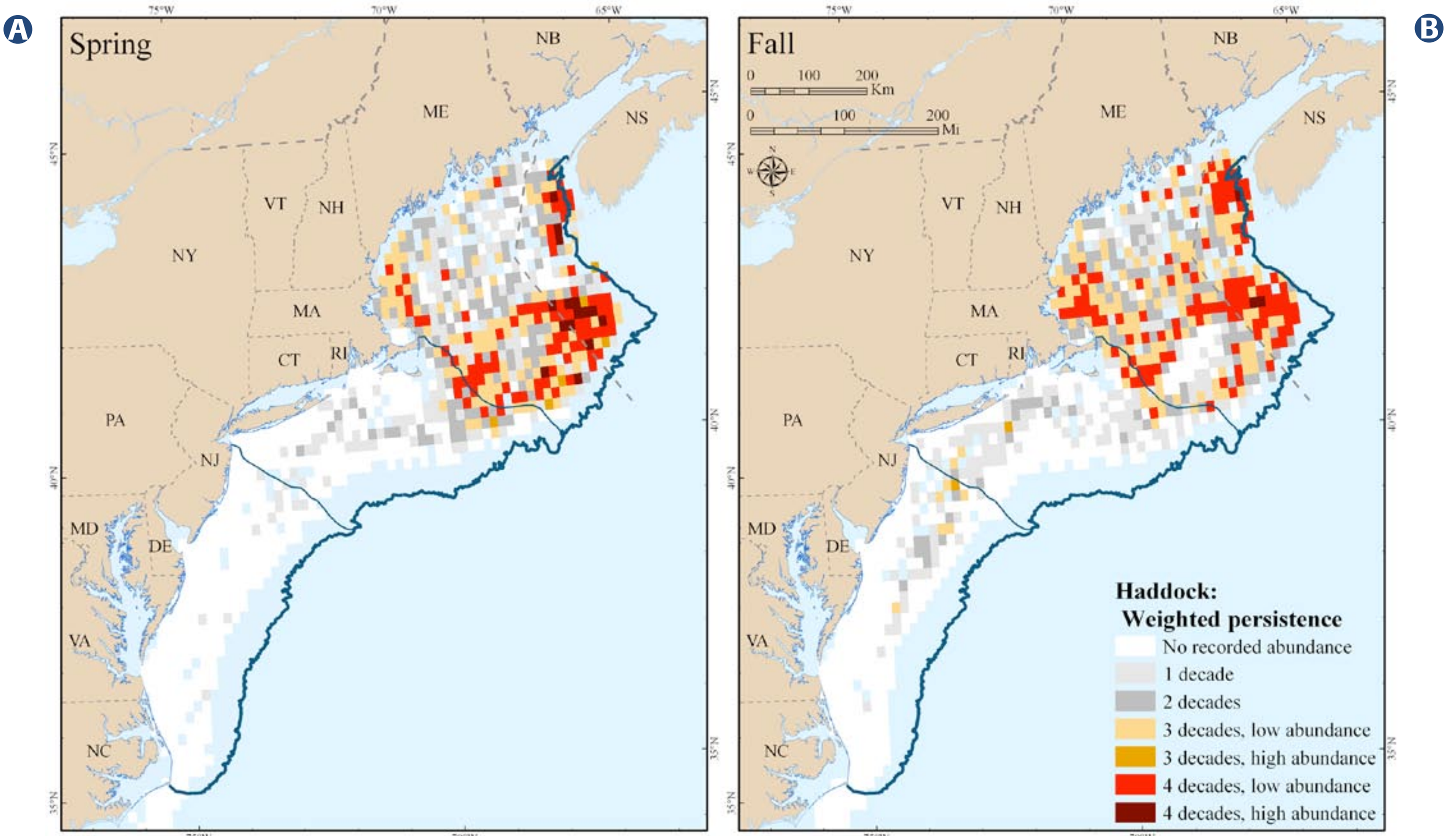


Figure 7-4. Areas with high persistence and abundance over 40 years for haddock during the spring and fall seasons.

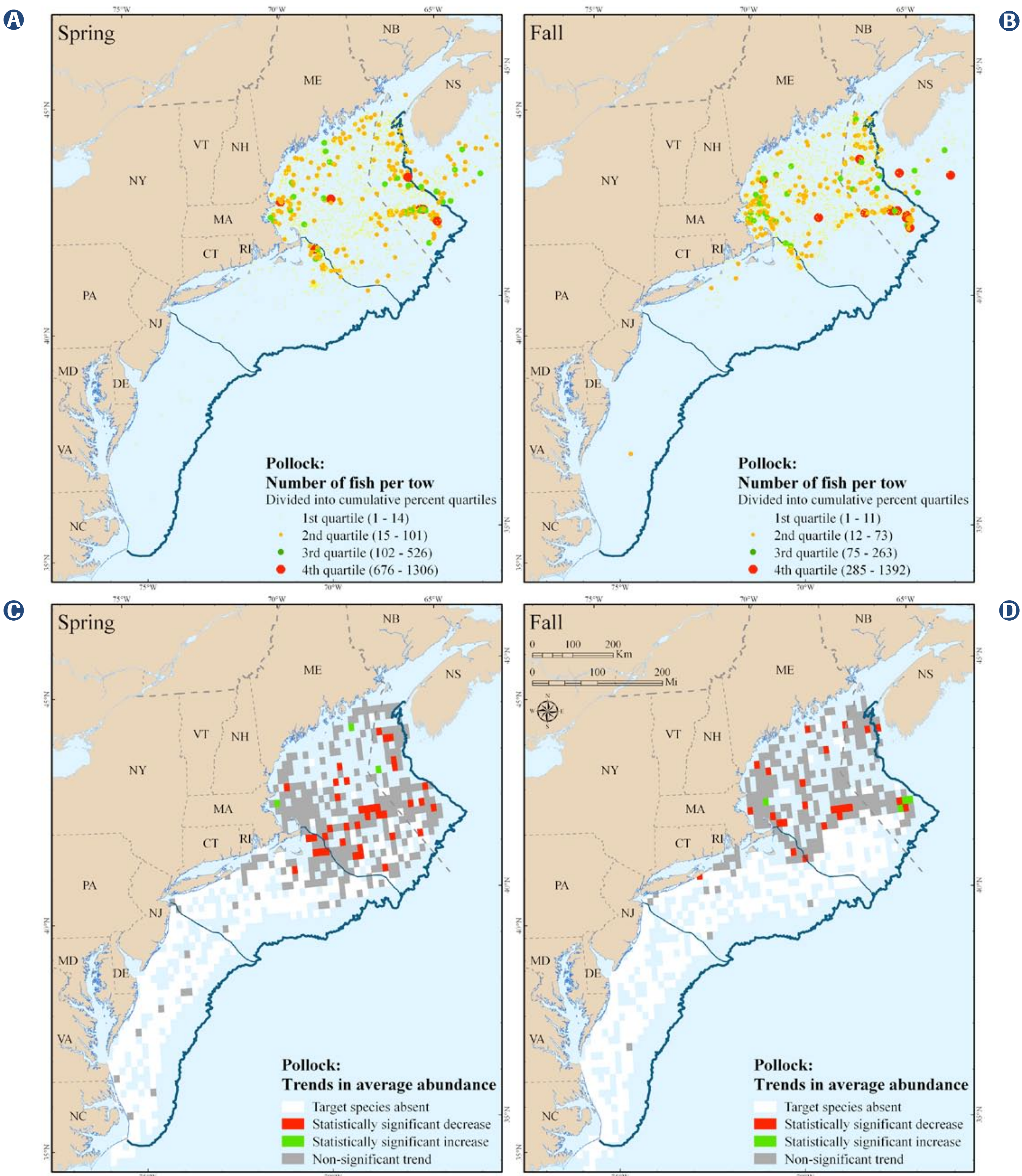


Figure 7-5. Trends in average abundance over 40 years for pollock during the spring and fall seasons.

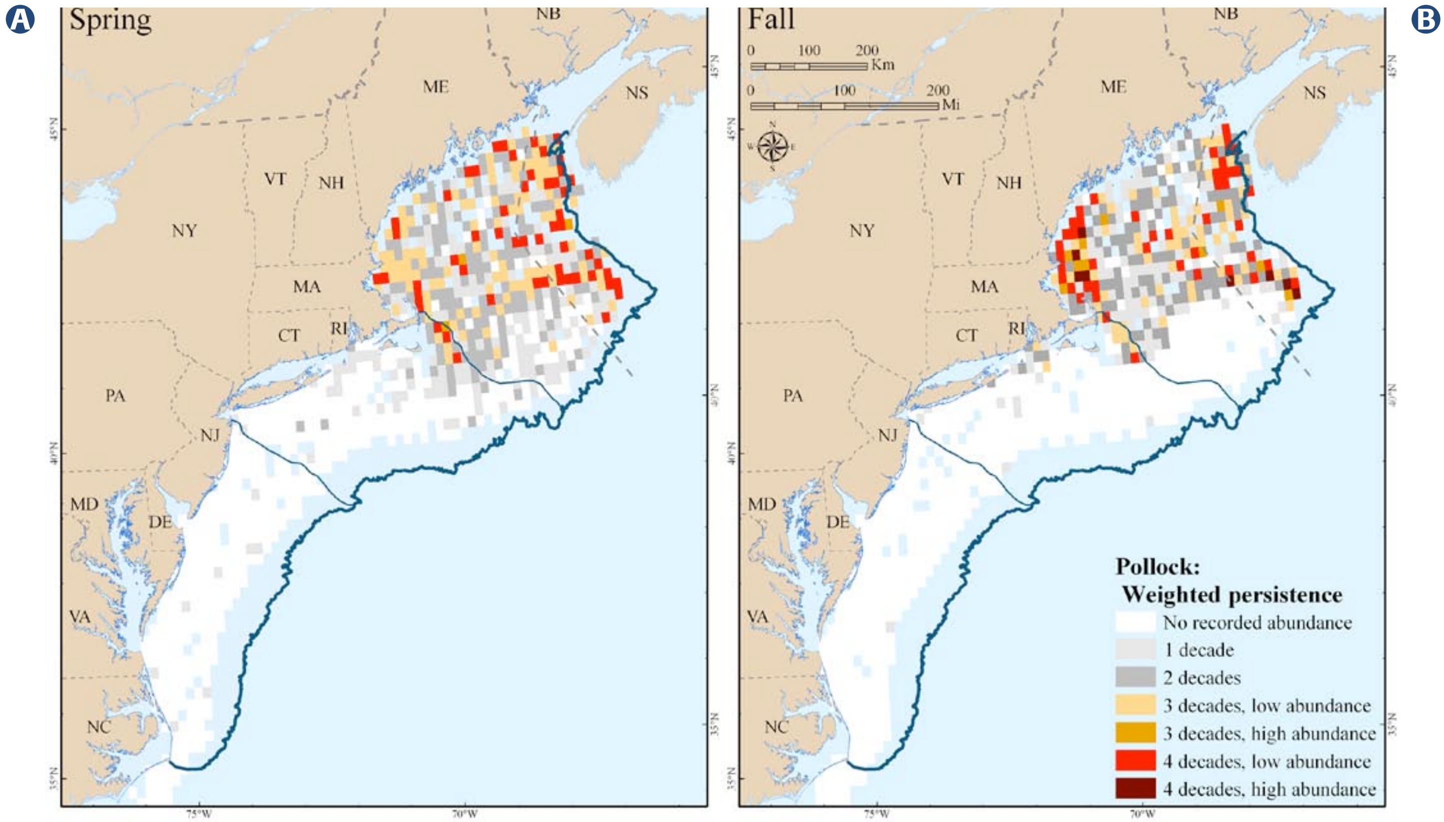


Figure 7-6. Areas with high persistence and abundance over 40 years for pollock during the spring and fall seasons.

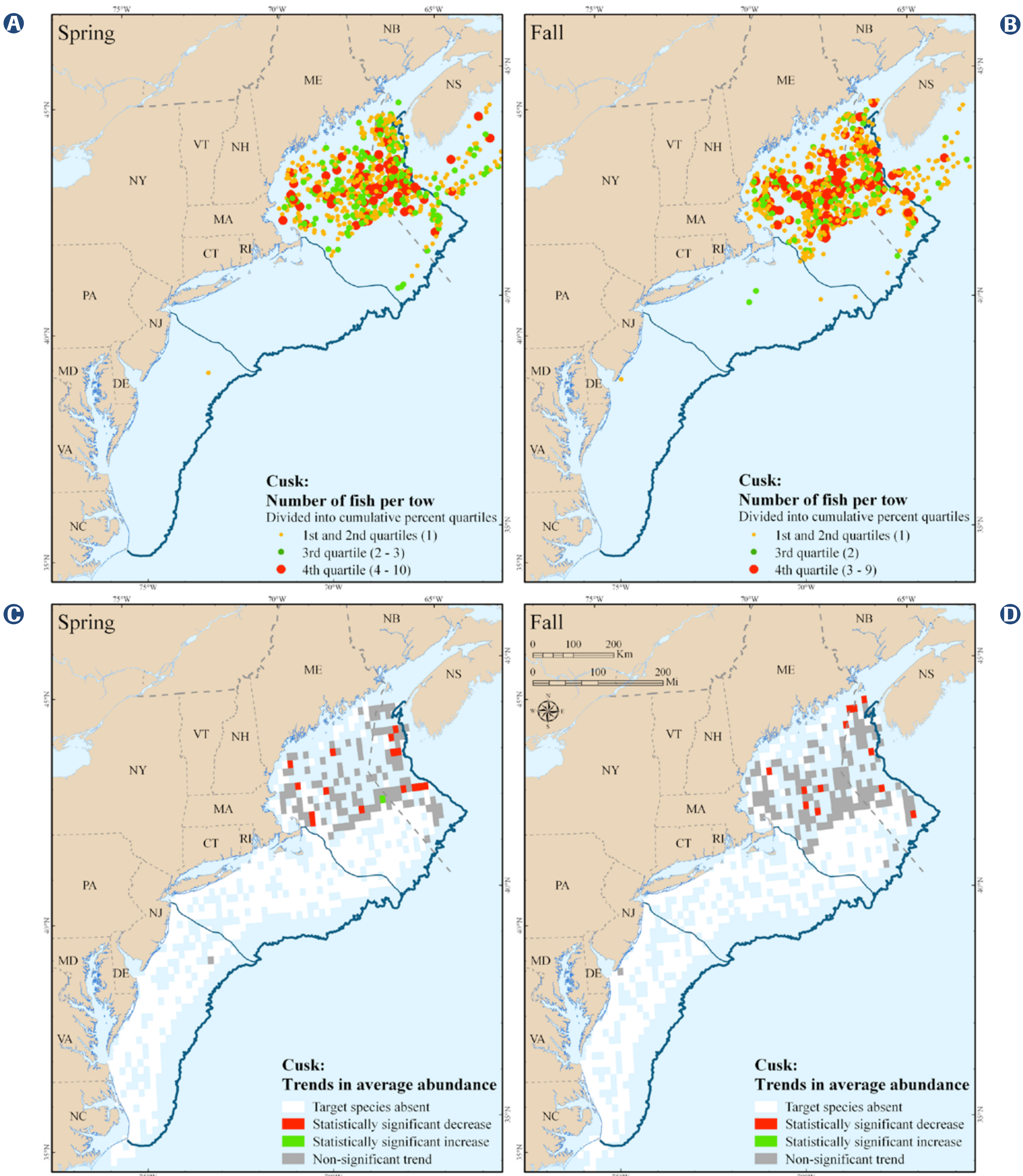


Figure 7-7. Trends in average abundance over 40 years for cusk during the spring and fall seasons.

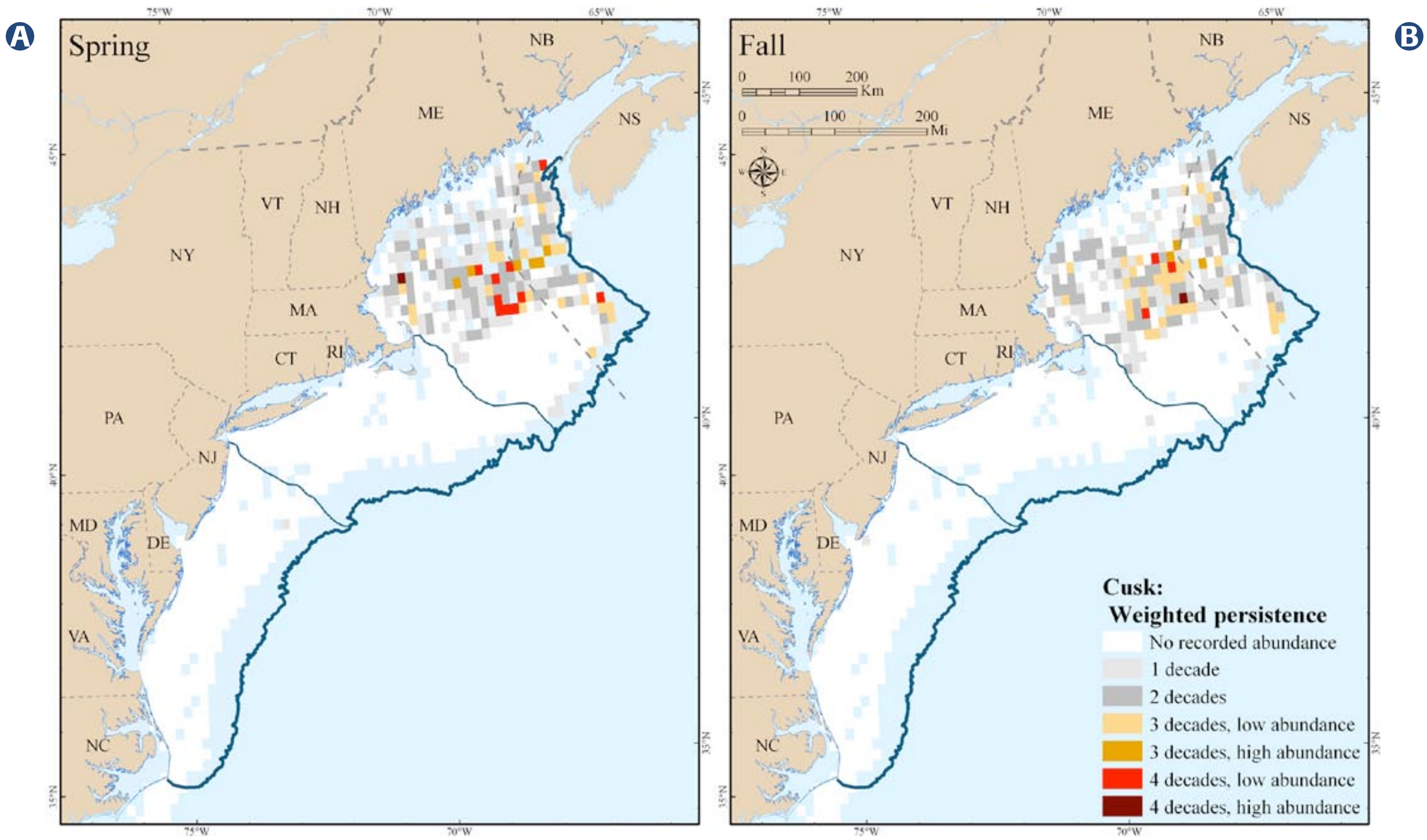


Figure 7-8. Areas with high persistence and abundance over 40 years for cusk during the spring and fall seasons.

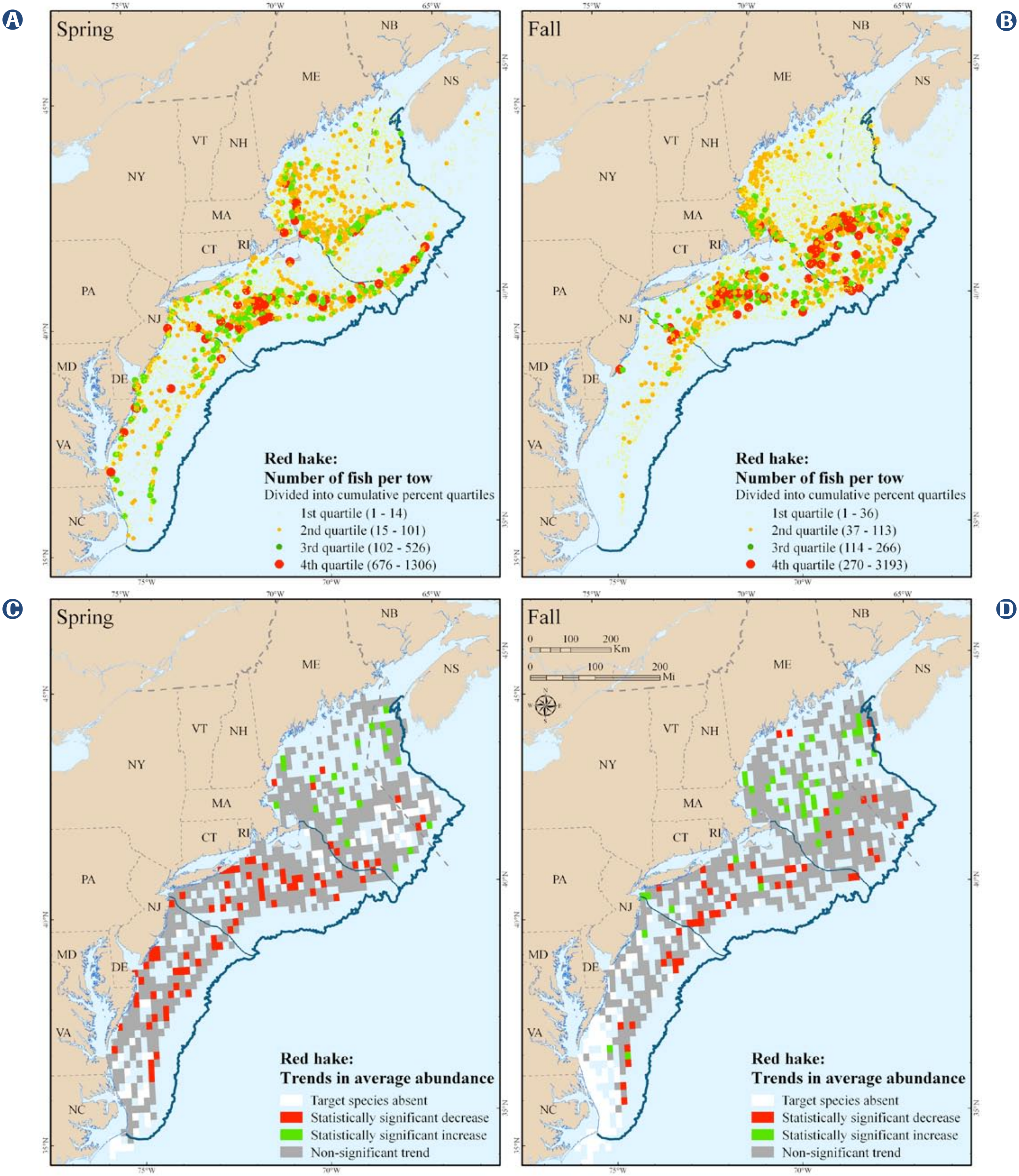


Figure 7-9. Trends in average abundance over 40 years for red hake during the spring and fall seasons.

Delaware Bay (Figure 7-9a, b). Statistical analyses indicated generally increasing trends for red hake in the Gulf of Maine and decreasing trends in much of Southern New England and the Mid-Atlantic Bight area, particularly along the shelf/slope break (Figure 7-9c, d). Weighted persistence analyses for red hake identified the 50 fathom curve from Jeffreys Ledge through the Great South Channel to the Northern Edge of Georges Bank, and a large area along the Continental Shelf extending from Long Island to Great Bay, New Jersey as important areas (Figure 7-10). In the spring, coastal waters from Delaware Bay to Cape Henry, Virginia were also important.

High numbers of silver hake were found in the deeper waters of the Gulf of Maine and along the coastal shelf from Jeffreys Ledge to Outer Schoodic Ridge and in shelf waters of Southern New England from Nantucket Shoals to Barnegat Bay, New Jersey (Figure 11a, b). Statistical analyses for silver hake revealed a pattern similar to red hake, with increasing trends observed in the Gulf of Maine and

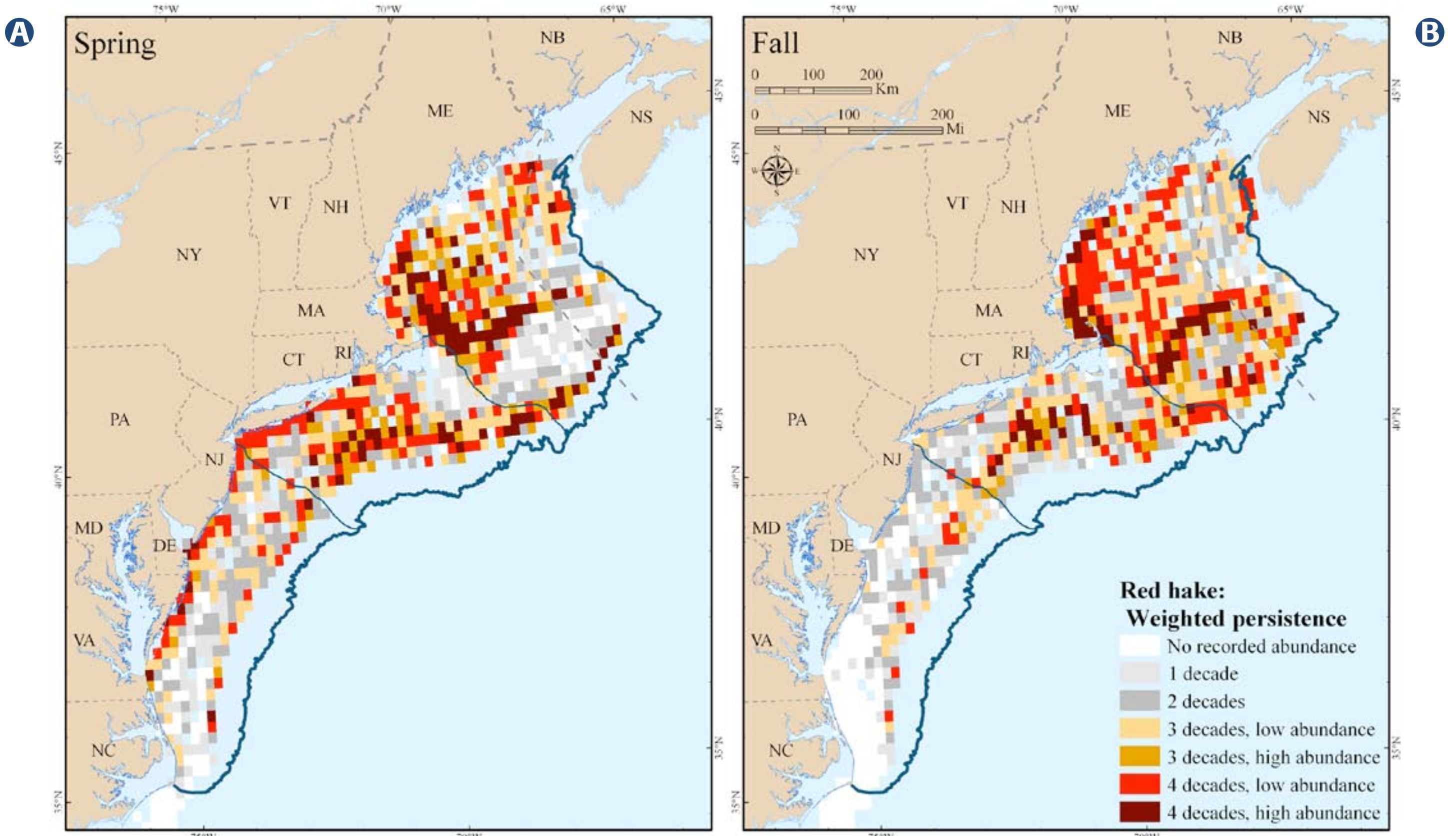


Figure 7-10. Areas with high persistence and abundance over 40 years for red hake during the spring and fall seasons.

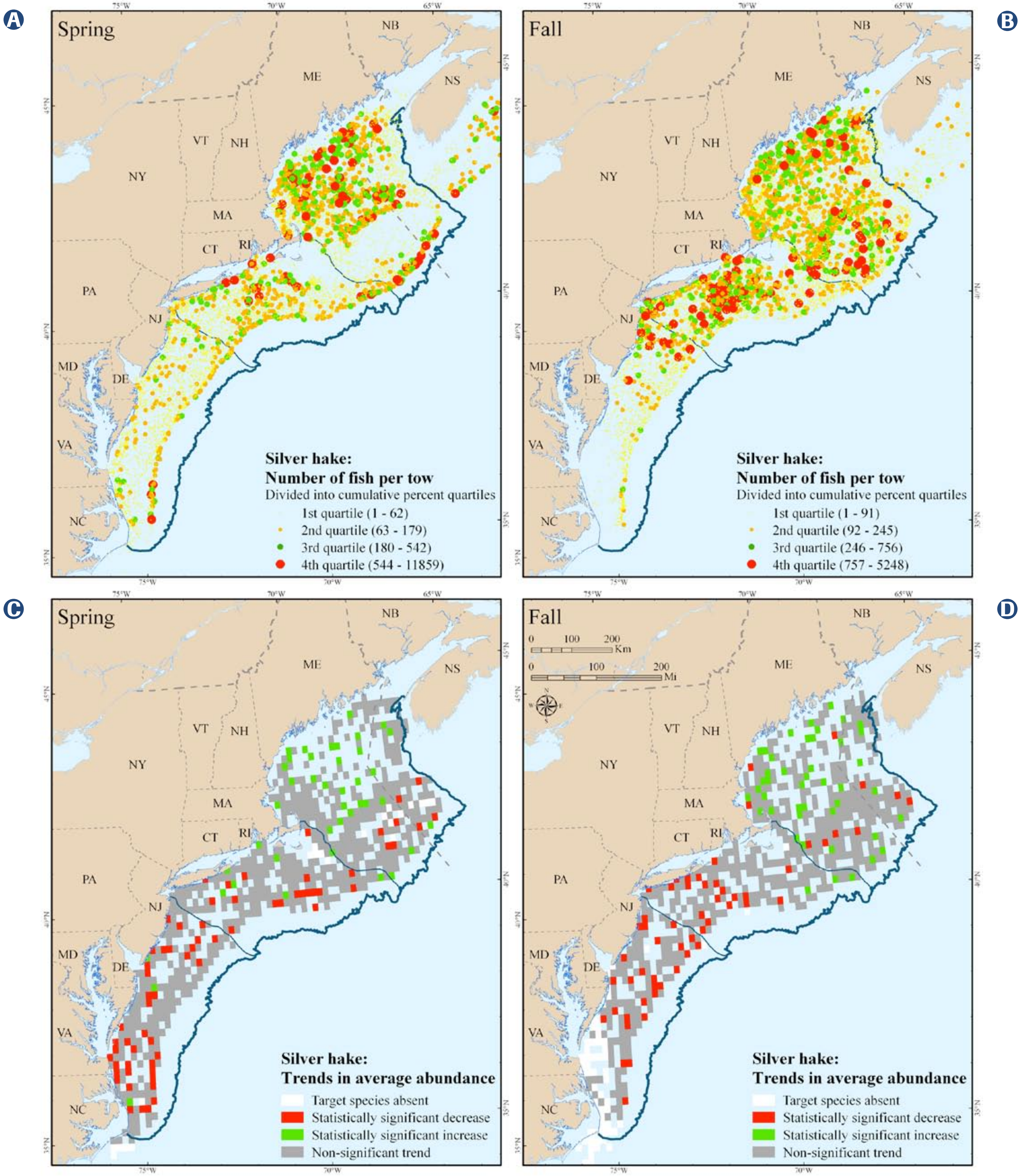


Figure 7-11. Trends in average abundance over 40 years for silver hake during the spring and fall seasons.

decreasing trends observed across much of the Southern New England/Mid-Atlantic Bight area (Figure 7-11c, d). Weighted persistence analyses for silver hake identified the coastal shelf and deeper basin waters in the Gulf of Maine, the Cultivator Shoals area on Georges Bank, and a large area along the Continental Shelf from the coast of Long Island to the Nantucket Lightship as areas of importance (Figure 7-12).

High numbers of white hake were found predominantly in the deep basins of the Gulf of Maine and along the perimeter of Georges Bank into Southern New England (Figure 7-13a, b). Statistical analyses for white hake generally found no significant trend across much of their range, though decreasing trends were observed at discrete locations along the 50 fathom curve in the Gulf of Maine, along the perimeter of Georges Bank, and along the shelf/slope break off of Long Island Sound (Figure 7-13c, d). Weighted persistence analyses for white hake identified Wilkinson Basin, Jordan Basin, Georges Basin, and shelf waters from Grand Manan Banks to German Bank as important areas (Figure 7-14).

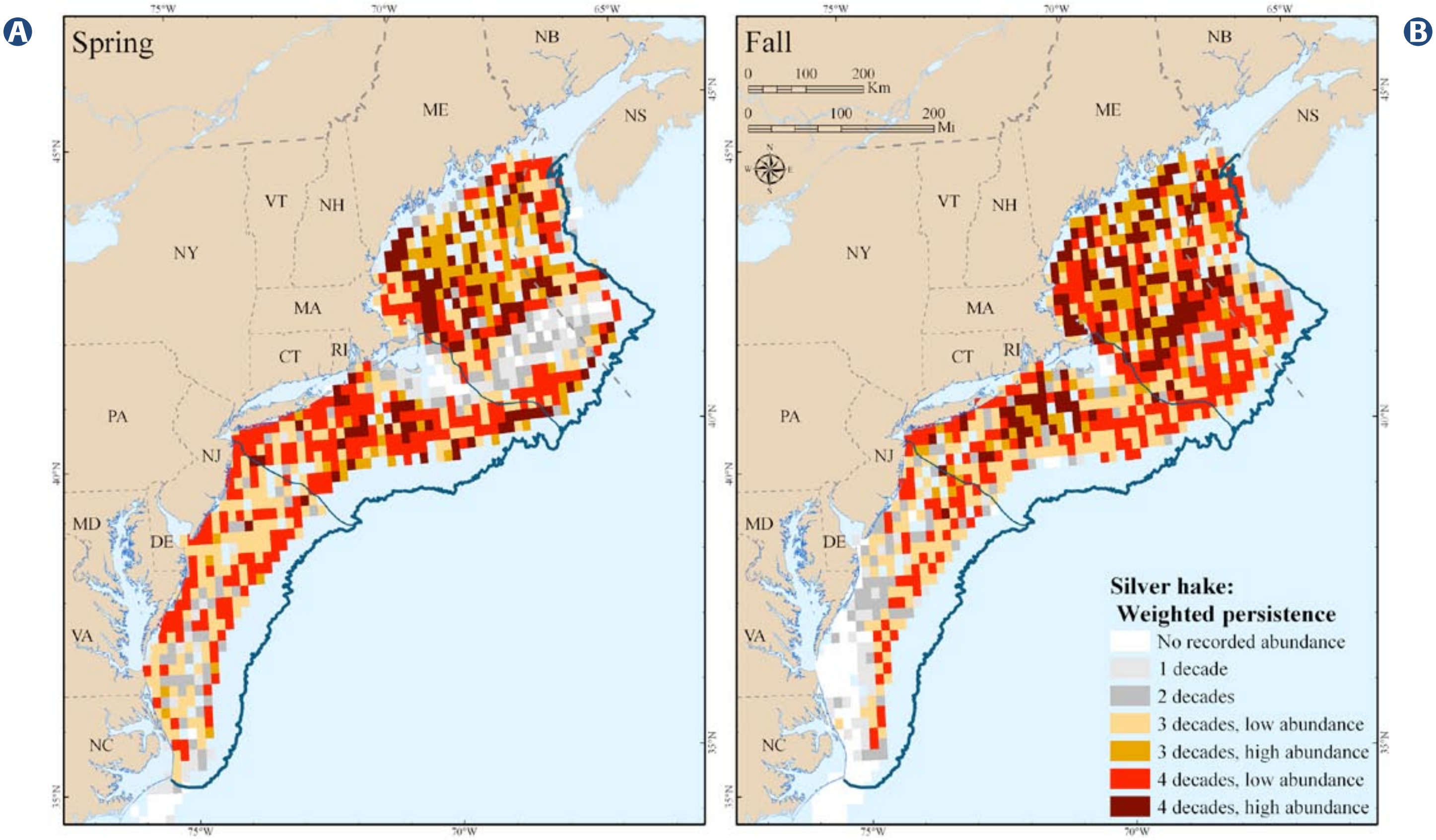


Figure 7-12. Areas with high persistence and abundance over 40 years for silver hake during the spring and fall seasons.

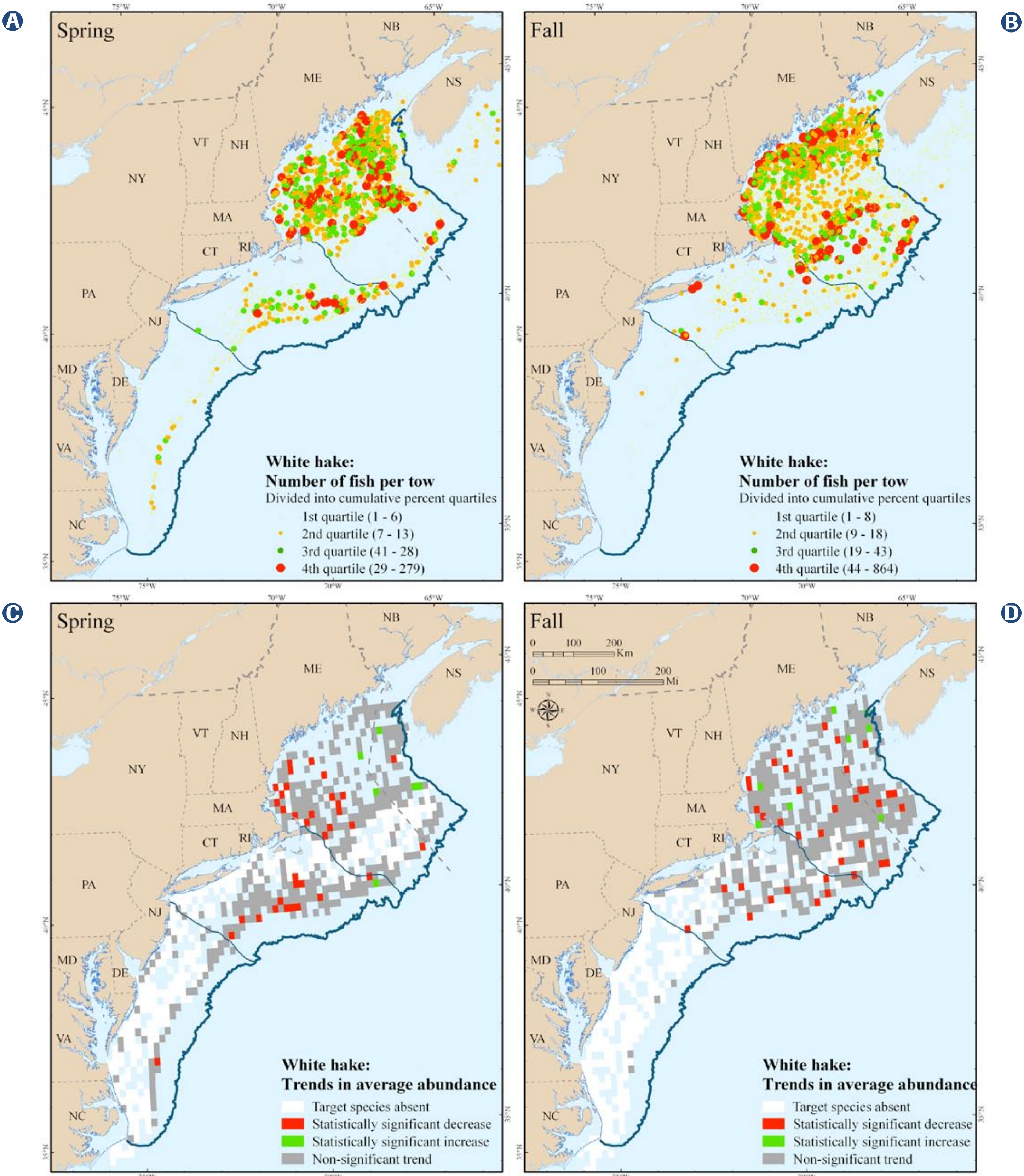


Figure 7-13. Trends in average abundance over 40 years for white hake during the spring and fall seasons.

A

B

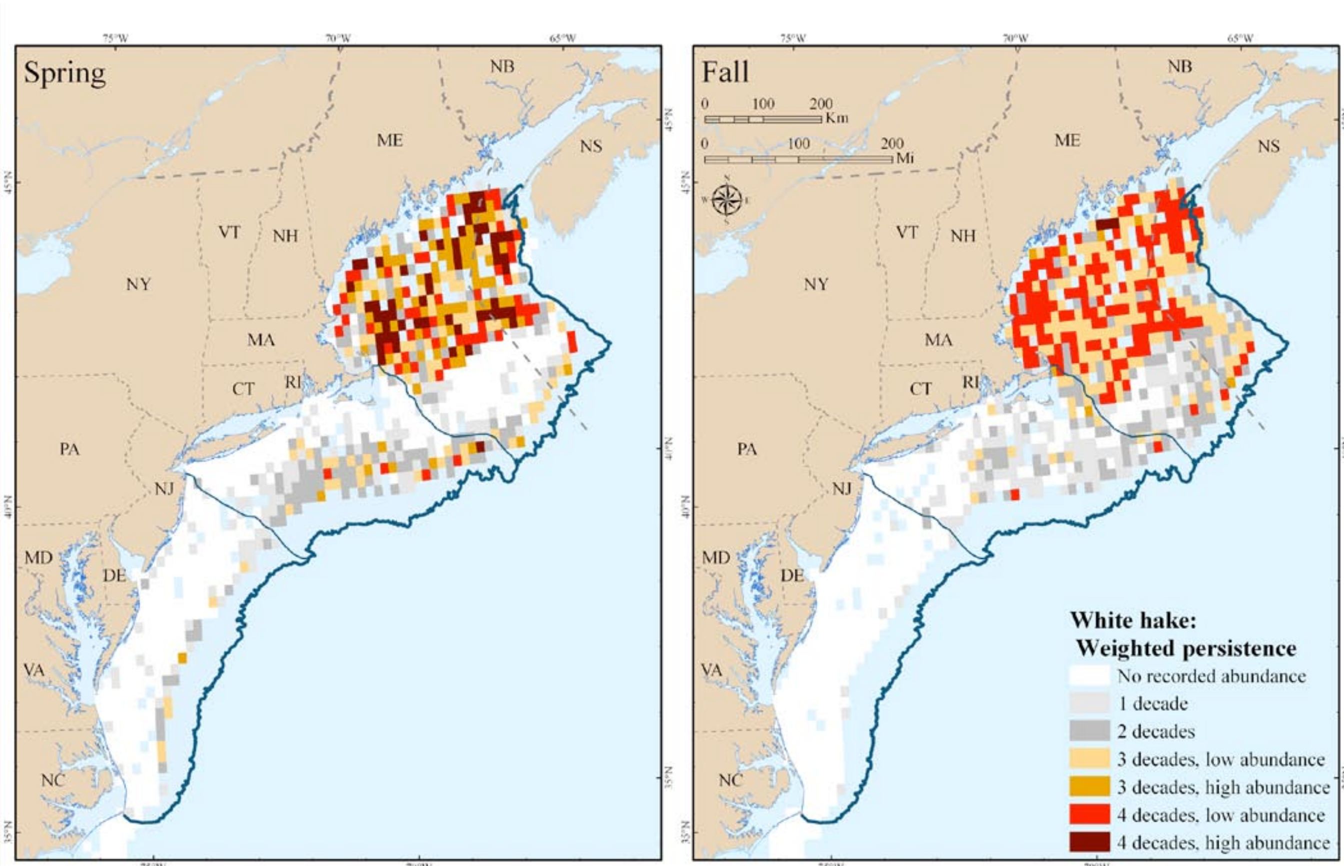


Figure 7-14. Areas with high persistence and abundance over 40 years for white hake during the spring and fall seasons.

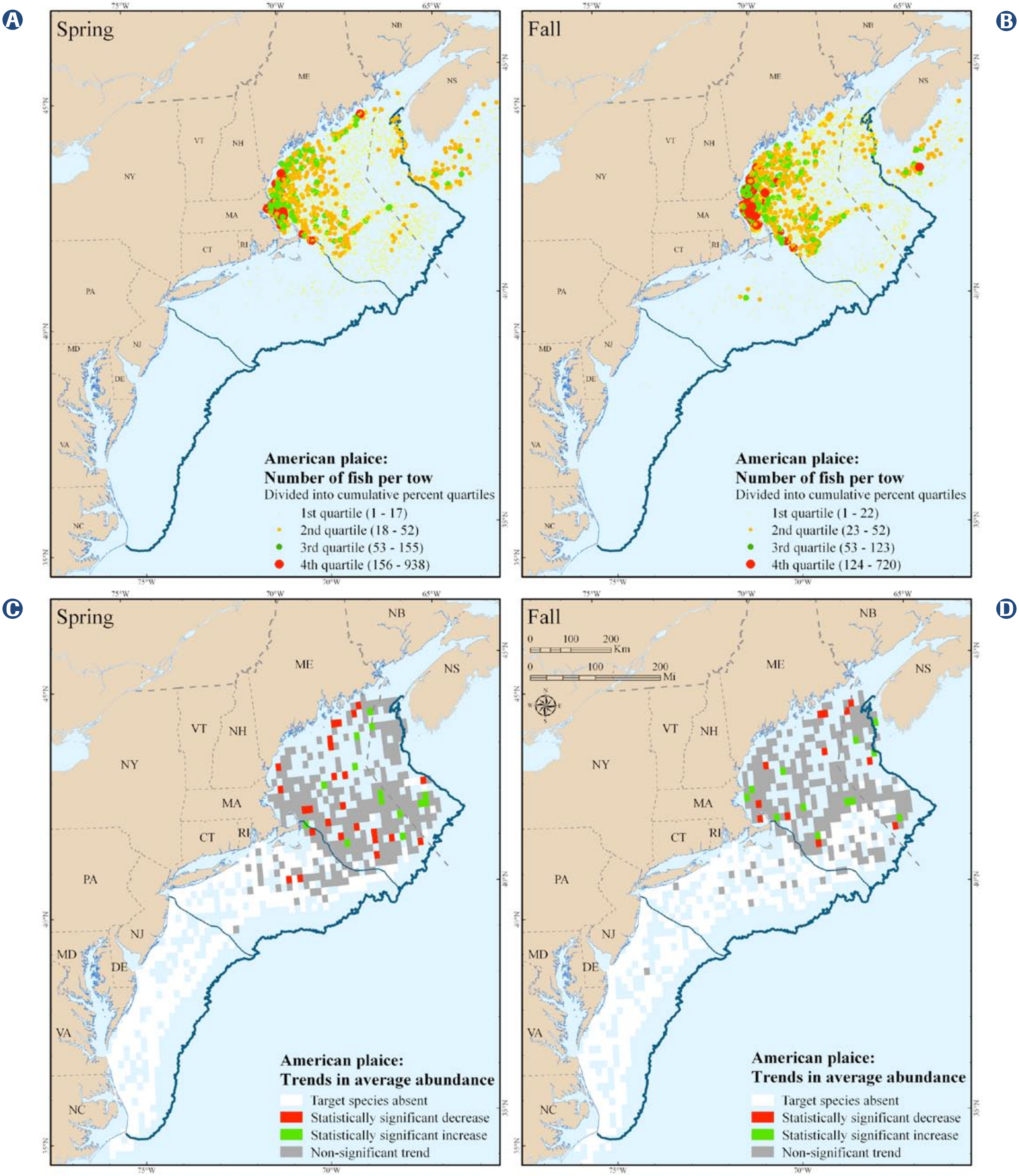


Figure 7-15. Trends in average abundance over 40 years for American plaice during the spring and fall seasons.

Plueronectids

The pluronectid (or flatfish) group was found across much of the Northwest Atlantic, although distinct differences in distributions within the region were apparent. American plaice were distributed across much of the Gulf of Maine and Georges Bank, with highest numbers occurring along the 50 fathom curve from Cape Cod to the northern tip of Jeffreys Ledge and in the northern portions of Wilkinson Basin (Figure7-15a, b). Very few were found south of Cape Cod. Statistical analyses did not identify any significant trends over the range during the time series, though decreasing trends were observed in the spring across many parts of the Gulf of Maine (Figure 7-15c, d). Weighted persistence analyses for American plaice identified waters along the 50 fathom curve in the western Gulf of Maine from Cape Cod Bay to Casco Bay, portions of the central Gulf of Maine including Wilkinson Basin and the Cashes Ledge area, and the eastern side of the Great South Channel and Cultivator Shoals as important areas (Figure 7-16).

Winter flounder were distributed from the Gulf of Maine south to Delaware Bay, with highest numbers occurring in nearshore waters in the western Gulf of Maine through the Great South Channel and into Southern New England as far south as Barnegat Bay, New Jersey (Figure 7-17a, b). Statistical analyses generally did not find significant trends over the time series, though declining trends were observed along the southern flank of Georges Bank to nearshore waters from Long Island Sound to Chesapeake Bay, while increasing trends were observed around Massachusetts Bay in the western Gulf of Maine and off the southwest coast of Nova Scotia (Figure 7-17c, d). Weighted persistence analyses for winter flounder identified waters from Grand Manan Banks to German Bank off the southwest coast of Nova Scotia, nearshore waters from Massachusetts Bay to Nantucket Shoals, and nearshore waters from Block Island to Sandy Hook, New Jersey as important areas (Figure 7-18).

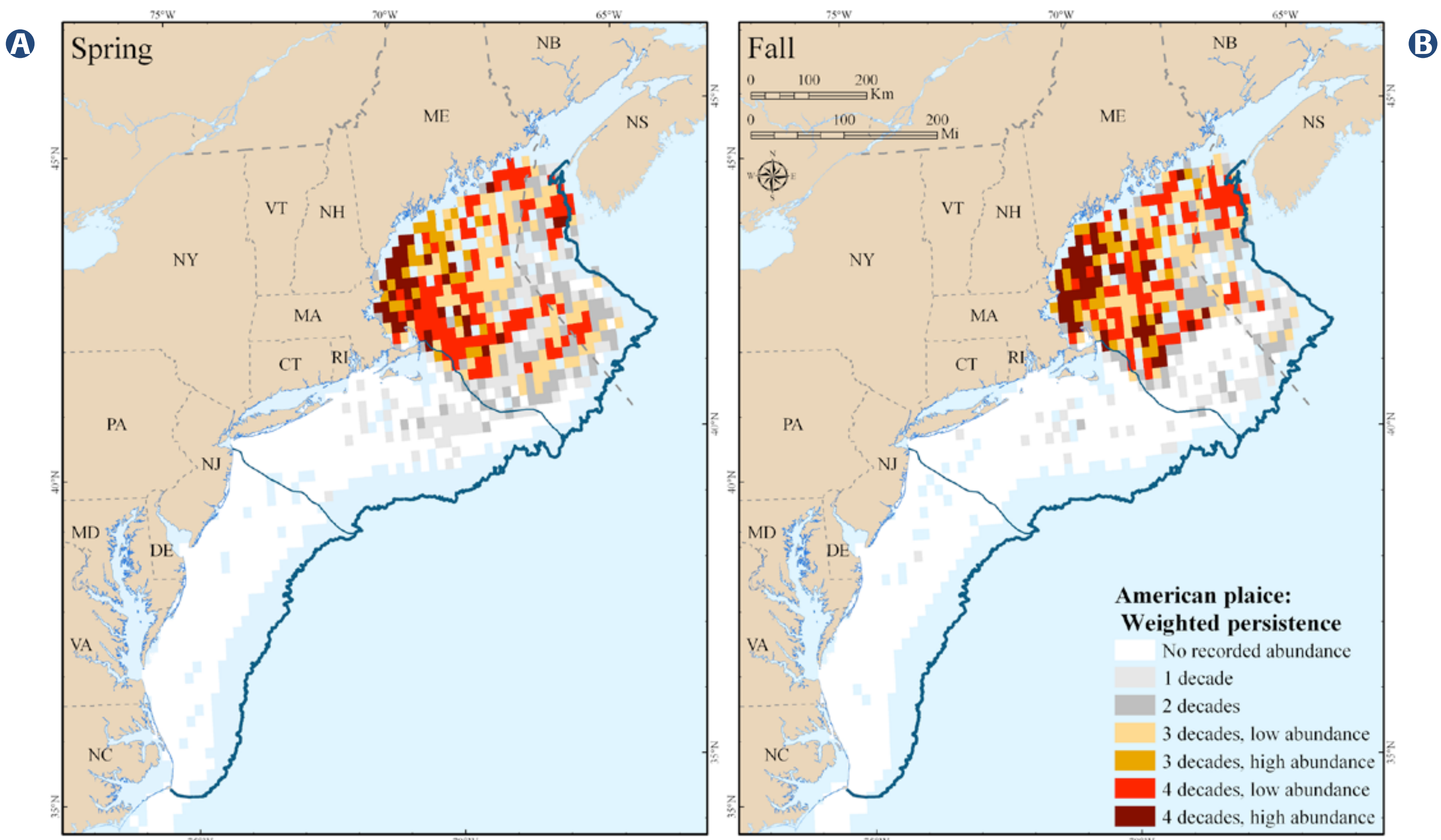


Figure 7-16. Areas with high persistence and abundance over 40 years for American plaice during the spring and fall seasons.

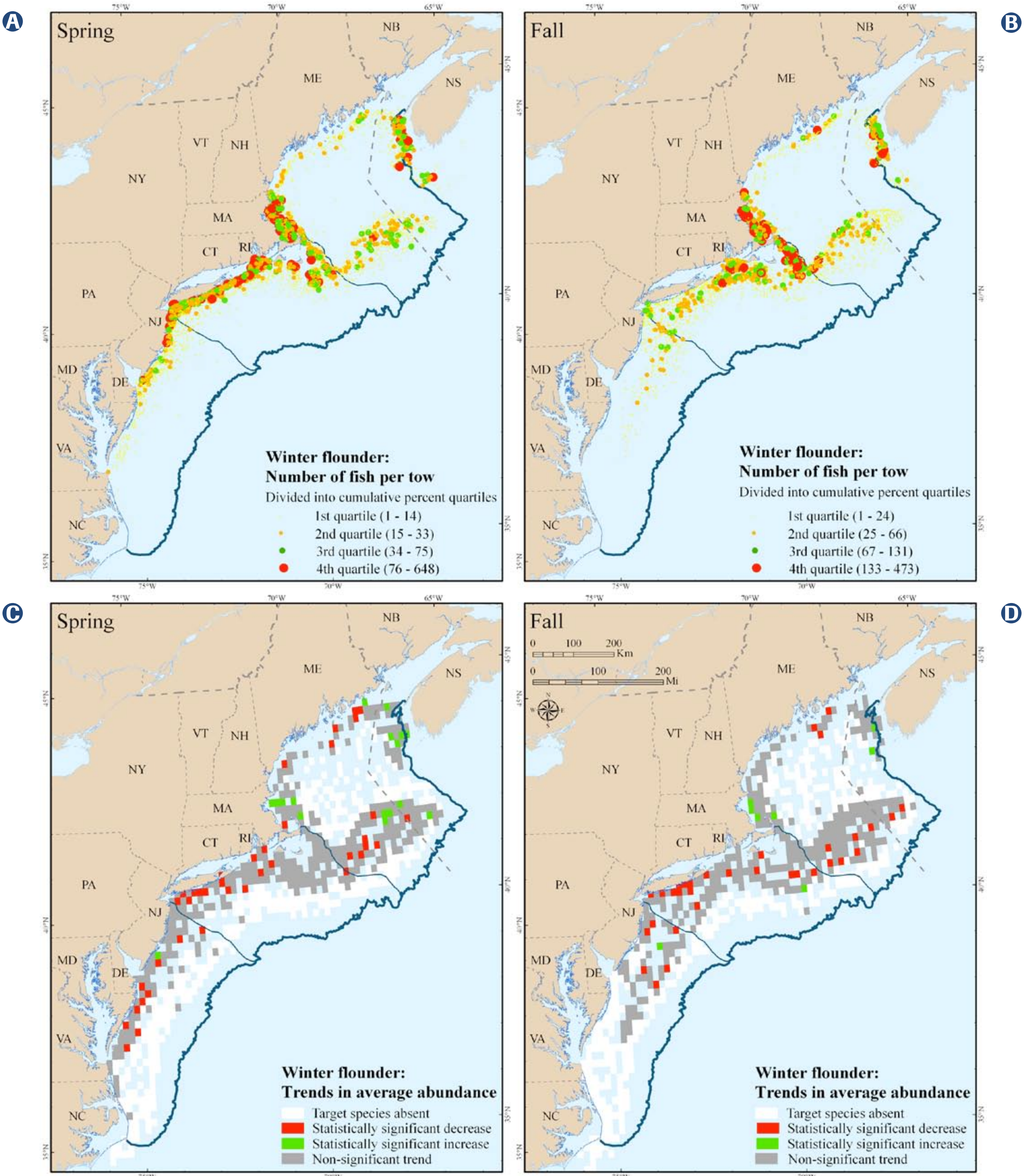


Figure 7-17. Trends in average abundance over 40 years for winter flounder during the spring and fall seasons.

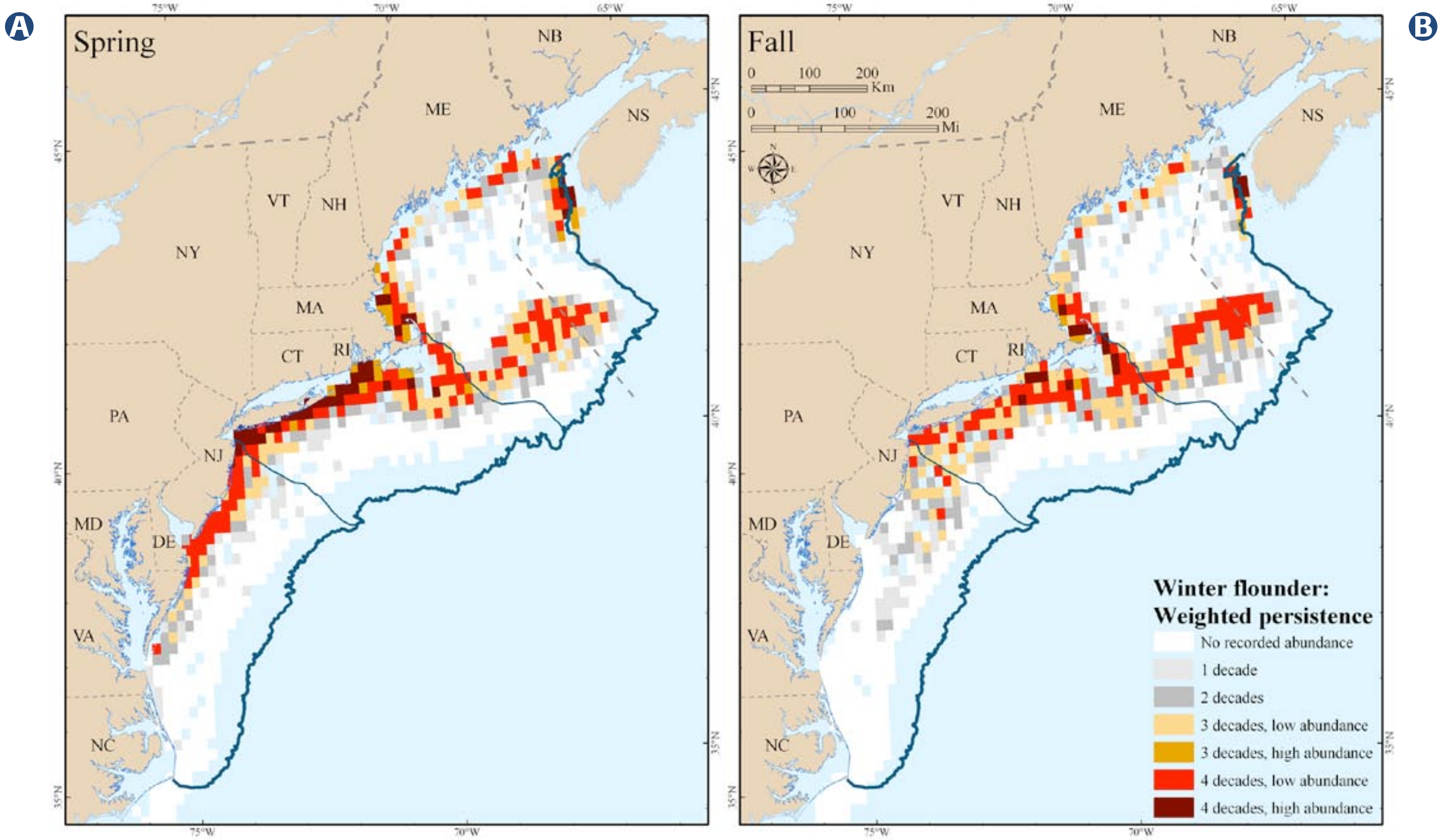


Figure 7-18. Areas with high persistence and abundance over 40 years for winter flounder during the spring and fall seasons.

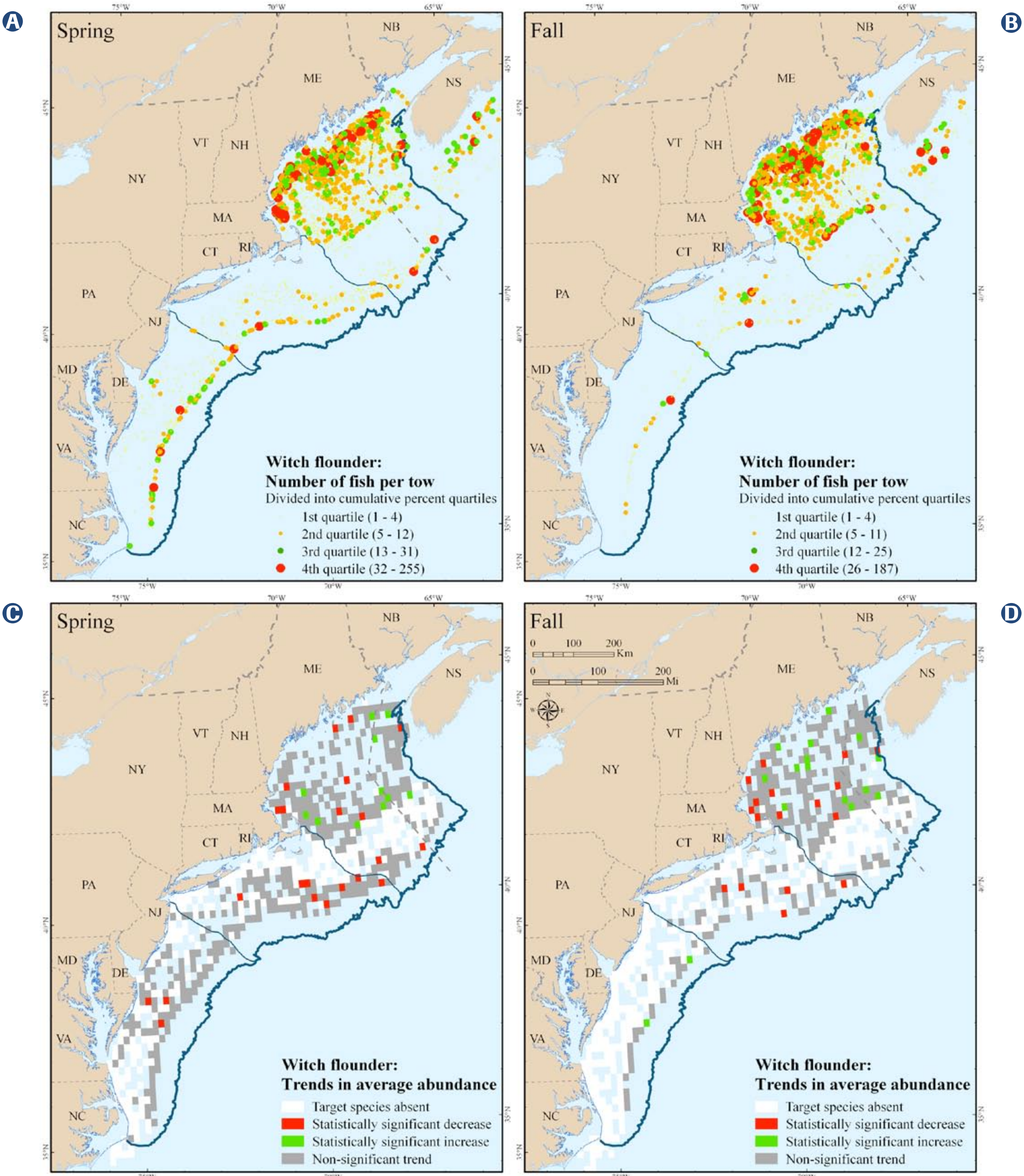


Figure 7-19. Trends in average abundance over 40 years for witch flounder during the spring and fall seasons.

Witch flounder were distributed throughout much of the Gulf of Maine and Georges Bank, although their range does extend south along the Continental Shelf to Albemarle Sound (Figure 7-19a, b). Highest numbers were found along the coastal shelf in the Gulf of Maine from Cape Cod to the Grand Manan Banks, in deeper waters near Jeffreys Bank and Jordan Basin, along the northern perimeter of Georges Bank, and along the shelf/slope break from Sandy Hook, New Jersey to Albemarle Sound. Statistical analyses generally did not identify any significant trend over the range during the time series, though increasing trends were observed in some portions of the central Gulf of Maine and decreasing trends were found in inshore areas from Massachusetts Bay to Casco Bay, Maine and in shelf waters of Southern New England south to Delaware Bay (Figure 7-19c, d). Weighted persistence analyses for witch flounder identified coastal shelf waters from Massachusetts Bay to Platts Bank, the area around Jeffreys Bank into Jordan Basin, and the mouth of the Bay of Fundy in eastern Maine as important (Figure 7-20).

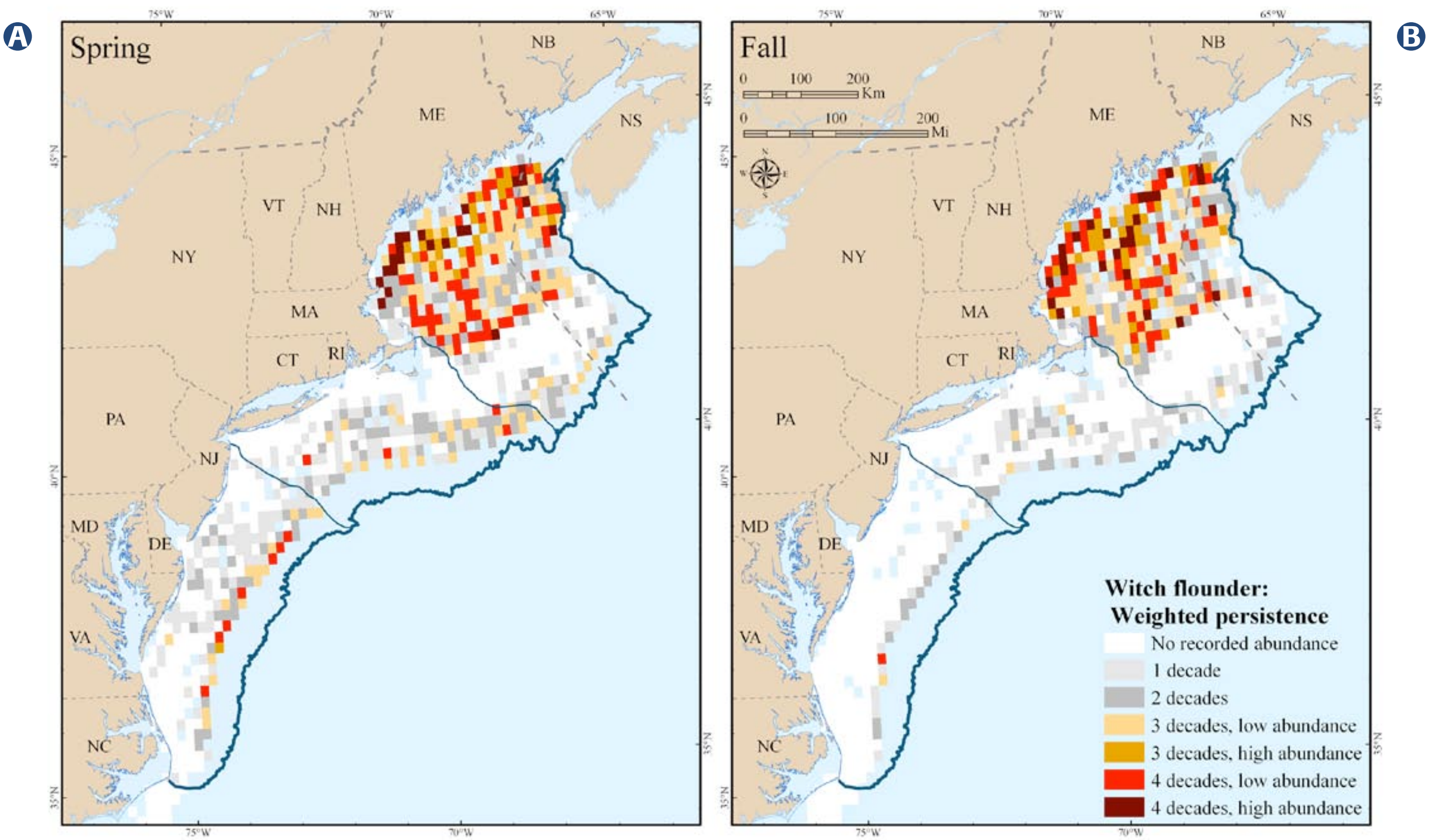


Figure 7-20. Areas with high persistence and abundance over 40 years for witch flounder during the spring and fall seasons.

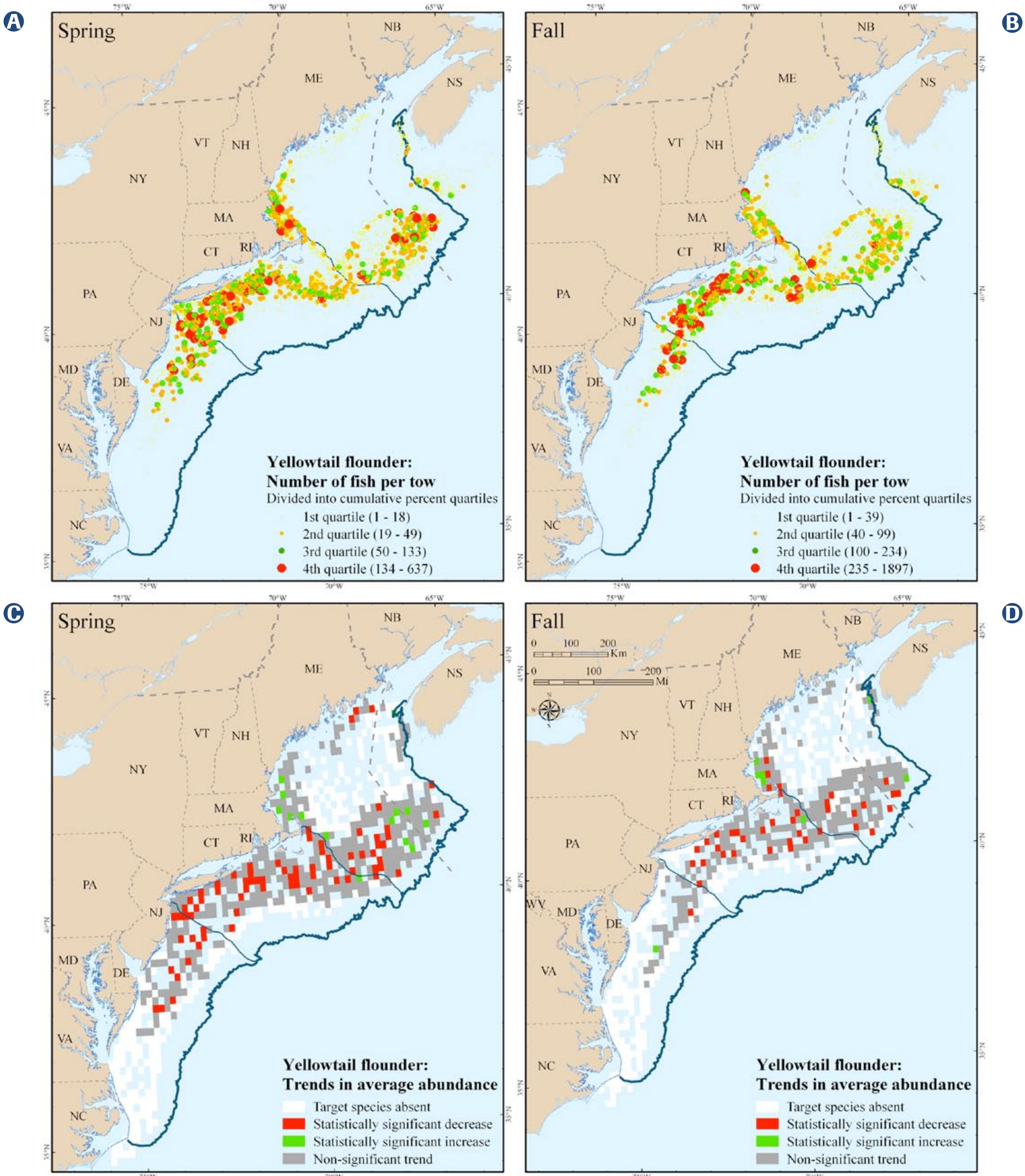


Figure 7-21. Trends in average abundance over 40 years for yellowtail flounder during the spring and fall seasons.

Yellowtail flounder were distributed throughout much of the region, with highest numbers occurring along the eastern part of Georges Bank and through Southern New England to shelf waters as far south as Delaware Bay (Figure 7-21a, b). High numbers were also found within the nearshore water of the Gulf of Maine, primarily around Massachusetts Bay and the Stellwagen Bank/Jeffreys Ledge area. Statistical analyses identified a declining trend over the time series over much of the Southern New England area and western Georges Bank, while trends were mixed on eastern Georges Bank and in the Gulf of Maine (Figure 7-21c, d). Weighted persistence analyses for yellowtail flounder identified nearshore waters from Massachusetts Bay to Chatham, Massachusetts, and the Northern Edge, Northeast Peak, and southern flank of Georges Bank, and a narrow band at 30-40 fathoms extending from the Great South Channel and Nantucket Shoals to Sandy Hook, New Jersey as important areas (Figure 7-22).

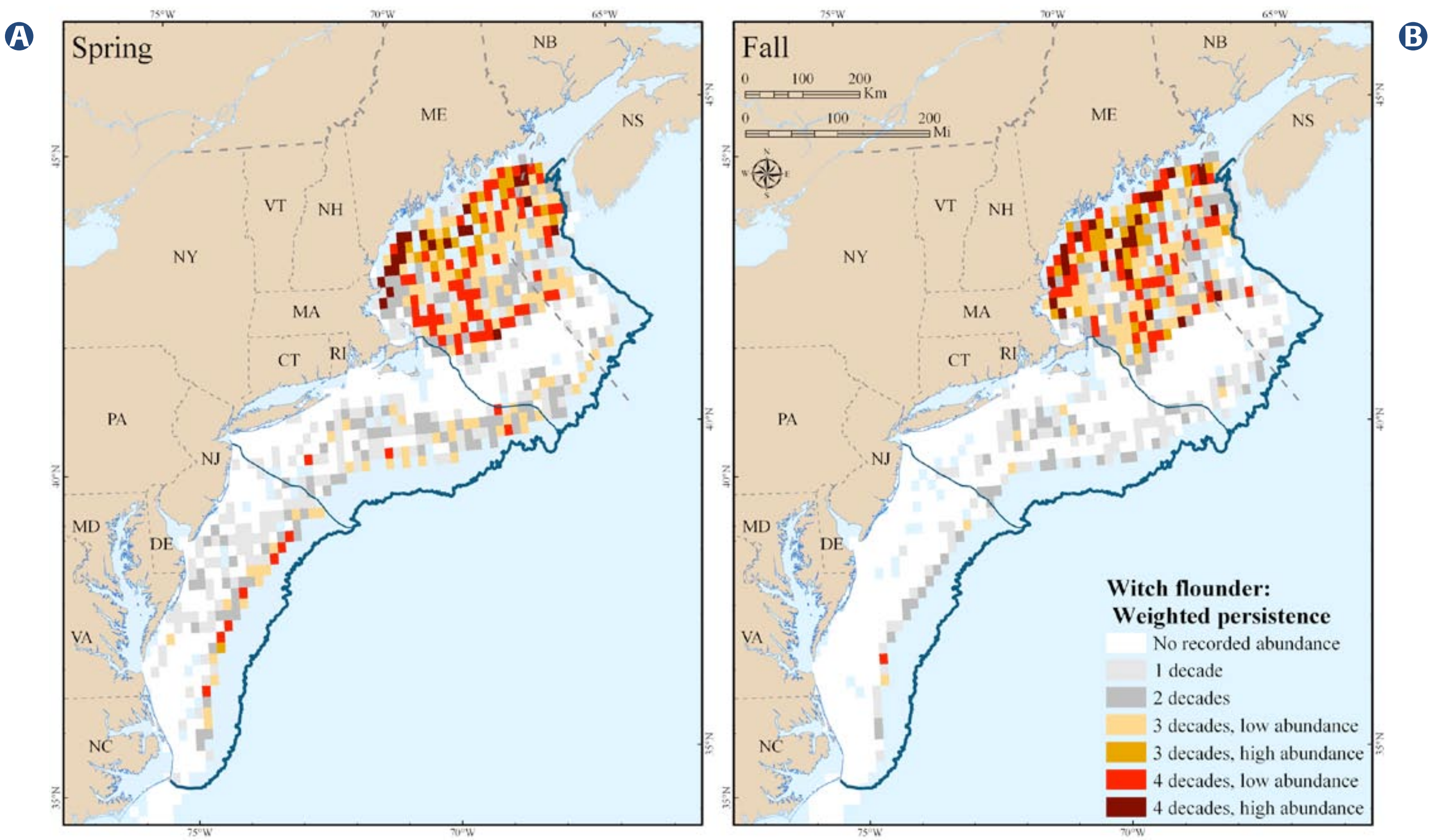


Figure 7-22. Areas with high persistence and abundance over 40 years for yellowtail flounder during the spring and fall seasons.

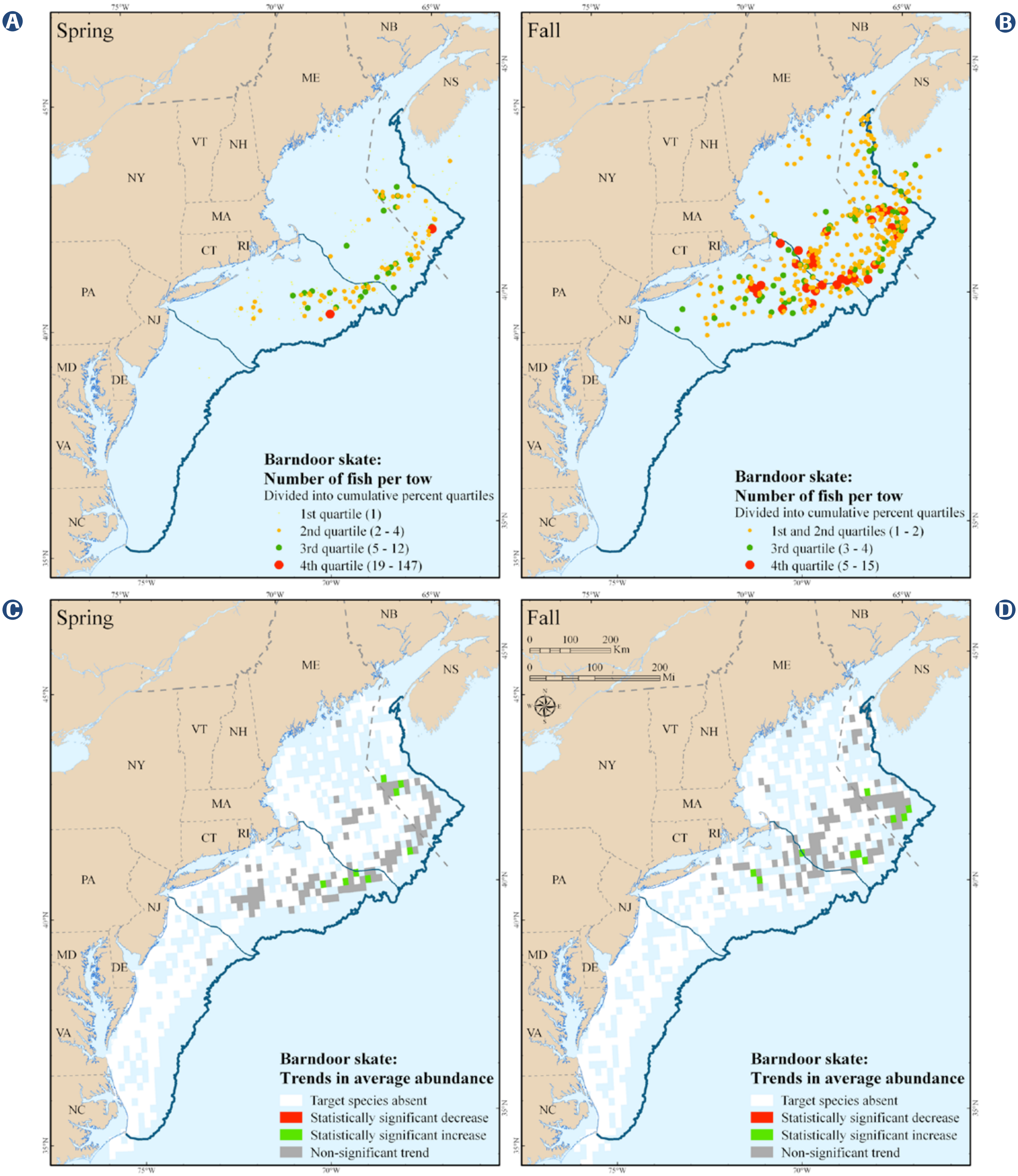


Figure 7-23. Trends in average abundance over 40 years for barndoor skate during the spring and fall seasons.

Elasmobranchs

Elasmobranchs were distributed across much of the Northwest Atlantic, displaying distinct differences in distributions depending on species. Within the region, barndoor skate occurred along the coastal shelf off the Gulf of Maine from the Bay of Fundy to Massachusetts Bay and along the southern flank of Georges Bank (Figure 7-23a, b). Highest numbers occurred around the perimeter of Georges Bank, particularly along the southern flank, in the Great South Channel, south of Nantucket Shoals, and in Continental Shelf waters off of Long Island in Southern New England. Statistical analyses identified increasing trends for barndoor skate in discrete locations from the Northeast Peak to the southern flank of Georges Bank, as well as offshore waters of Southern New England (Figure 7-23c, d). Weighted persistence analyses for barndoor skate identified an area extending from the Northeast Peak and southern flank of Georges Bank as important (Figure 7-24).

Clearnose skate occurred primarily in the southern portion of the region from Long Island to Pamlico Sound,

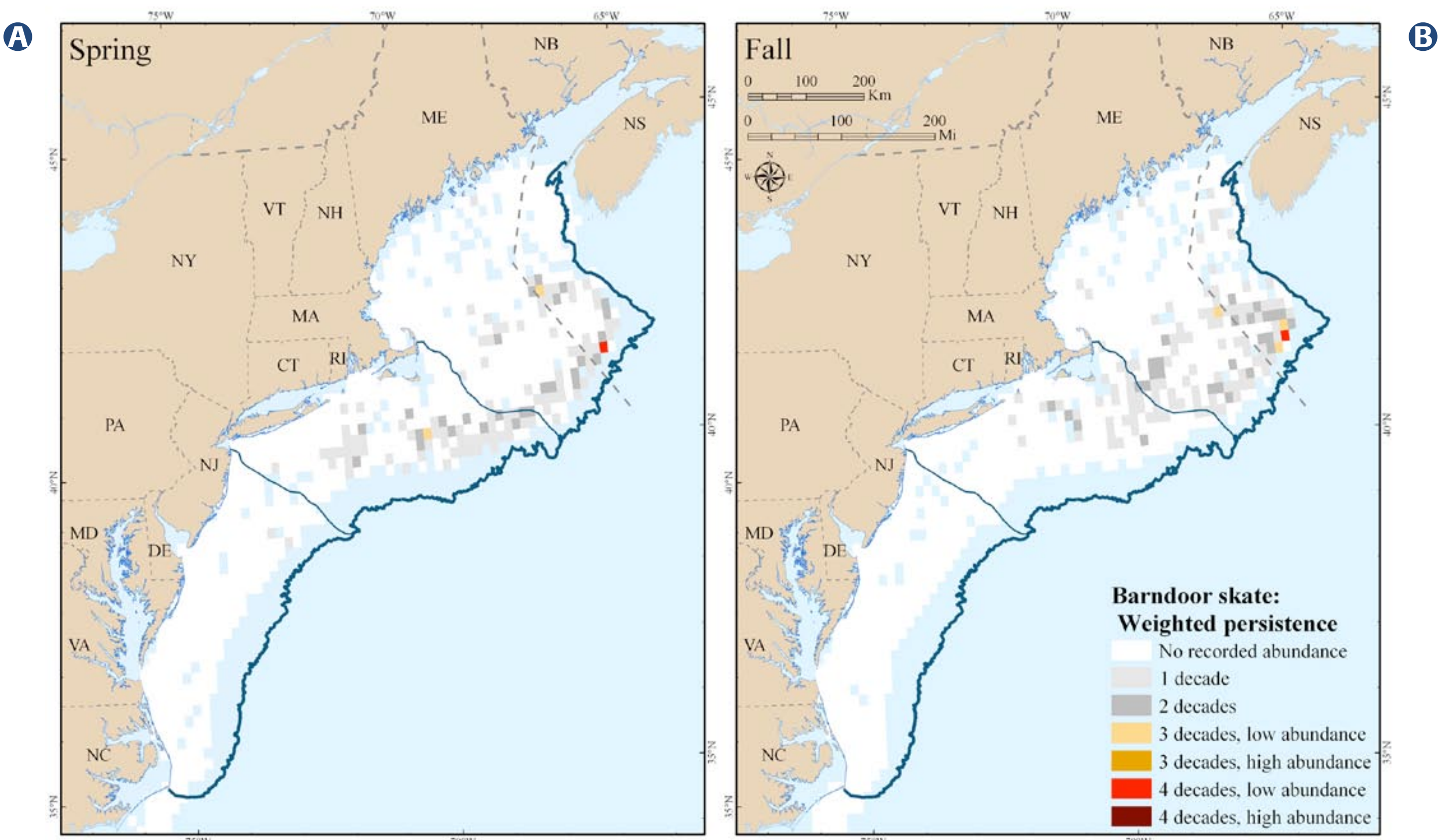


Figure 7-24. Areas with high persistence and abundance over 40 years for barndoor skate during the spring and fall seasons.

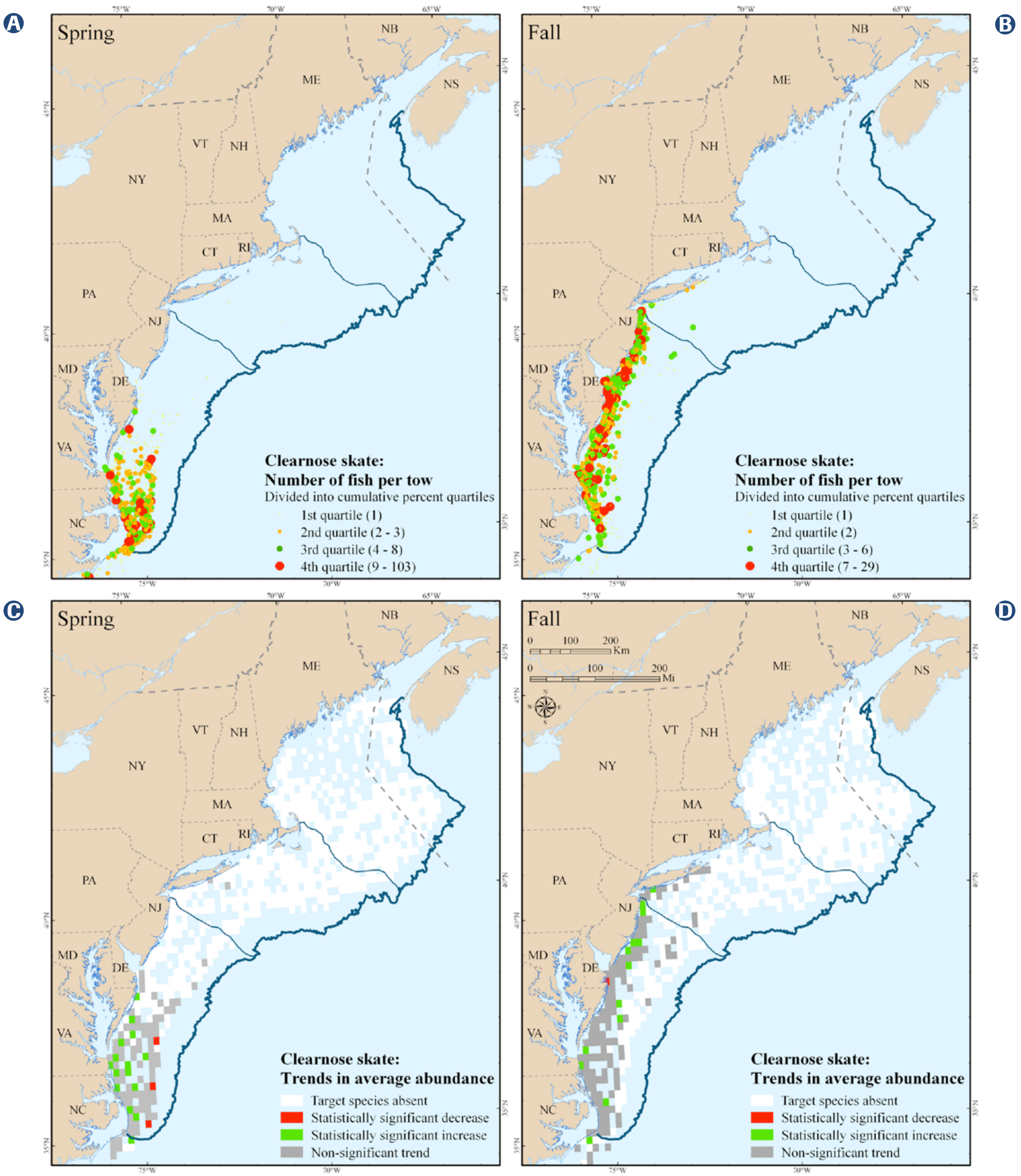


Figure 7-25. Trends in average abundance over 40 years for clearnose skate during the spring and fall seasons.

with highest numbers found in nearshore areas of the Mid-Atlantic from Sandy Hook, New Jersey to Pamlico Sound (Figure 7-25a, b). Statistical analyses did not identify significant trends over much of the range. Increasing trends were observed in some parts of the southern end of the range from the mouth of the Hudson River/Raritan Bay estuary to Cape Hatteras, while decreasing trends were observed in the spring at discrete locations along the shelf/slope break off Virginia and North Carolina (Figure 7-25c, d). Weighted persistence analyses for clearnose skate identified nearshore waters from the mouth of the Hudson River to Pamlico Sound as important. Seasonal differences were also observed; important areas were concentrated south of Chesapeake Bay and extended out to the shelf/slope break in the spring (Figure 26).

Little skate occurred throughout much of the region from Georges Bank to the Chesapeake Bay, with highest numbers occurring on the western part of Georges Bank and in Southern New England from Nantucket Shoals to Cape May, New Jersey (Figure 7-27a, b). Statistical analyses identified increasing trends in discrete areas from

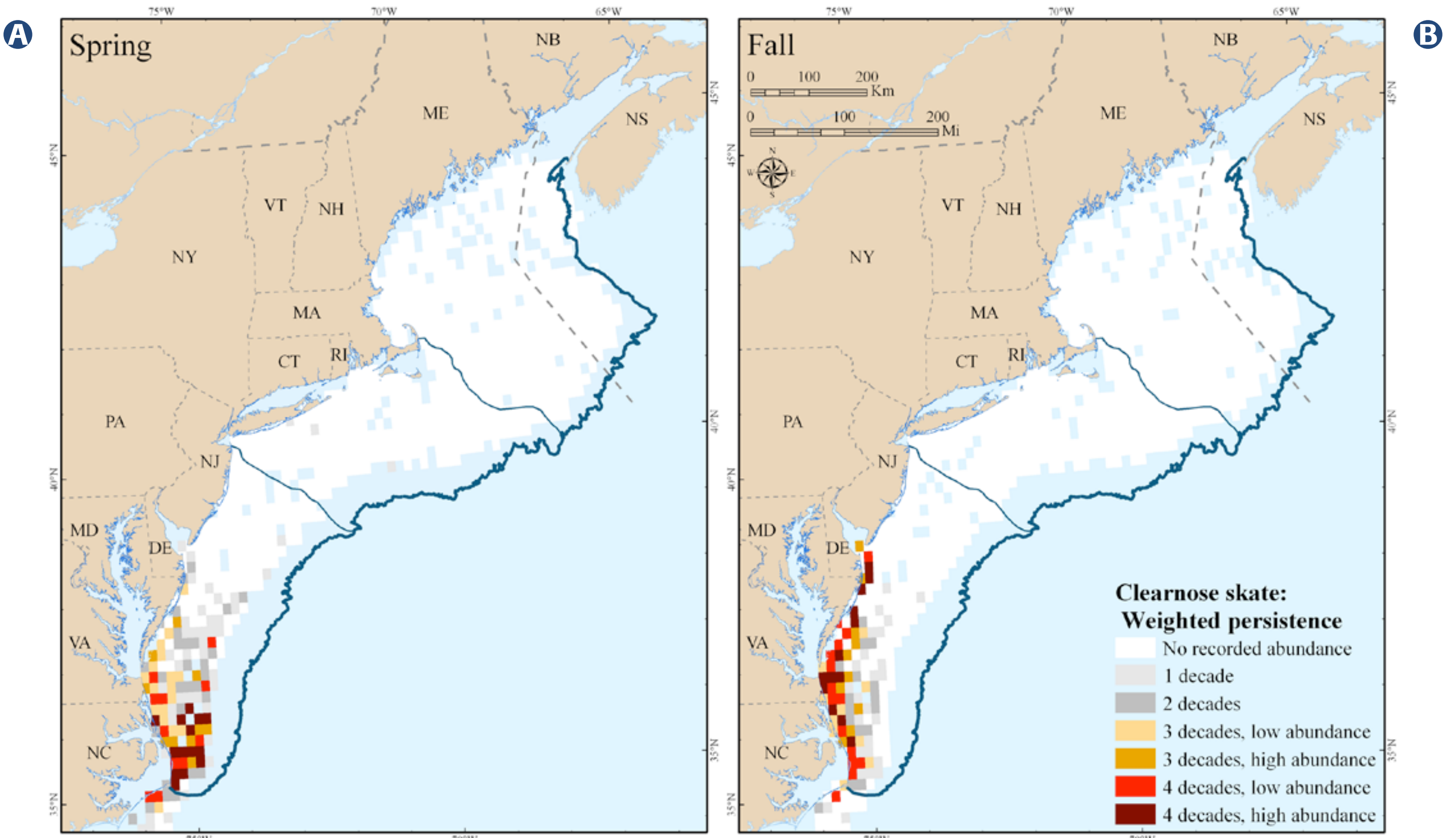


Figure 7-26. Areas with high persistence and abundance over 40 years for clearnose skate during the spring and fall seasons.

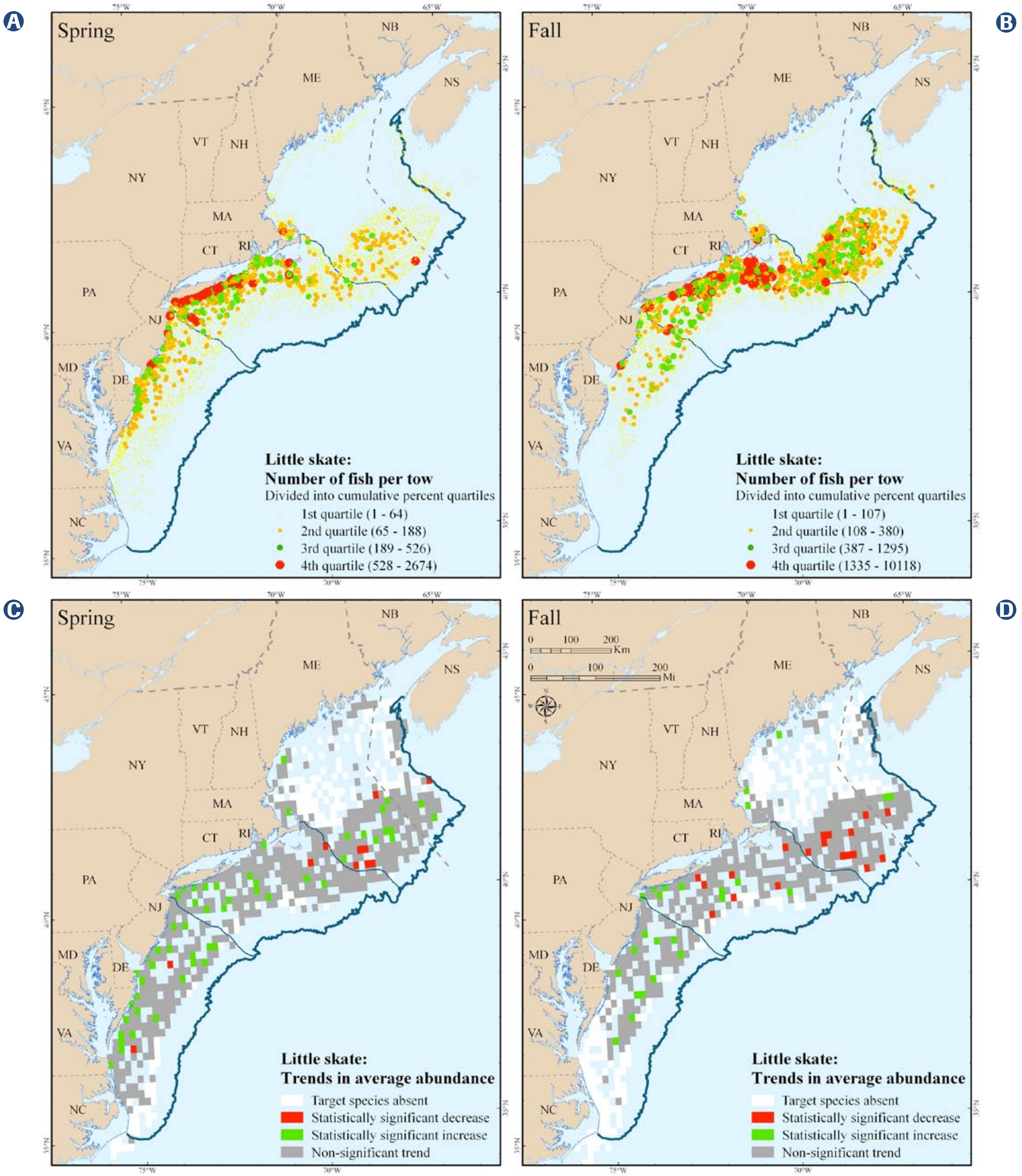


Figure 7-27. Trends in average abundance over 40 years for little skate during the spring and fall seasons.

Georges Bank to Chesapeake Bay over the time series during the spring, and more mixed results during the fall (Figure 7-27c, d). Weighted persistence analyses for little skate identified central portions of Georges Bank and the Great South Channel, waters south of Nantucket and Martha's Vineyard, nearshore waters along the southern shore of Long Island, and waters off the New Jersey shore and Delaware Bay as important. Seasonal shifts were also observed, with waters from Barnegat Bay to Chincoteague Inlet becoming important in the spring (Figure 7-28).

Rosette skate occurred primarily in the Mid-Atlantic from New Jersey to Pamlico Sound, with highest numbers observed in offshore waters along the Continental Shelf and Slope break from Delaware Bay to Albemarle Sound (Figure 7-29a, b). Statistical analyses did not identify significant trends over the time series (Figure 7-29c, d). Weighted persistence analyses for rosette skate clearly identified offshore waters along the shelf/slope break from Chincoteague Bay to Albemarle Sound as important areas (Figure 7-30).

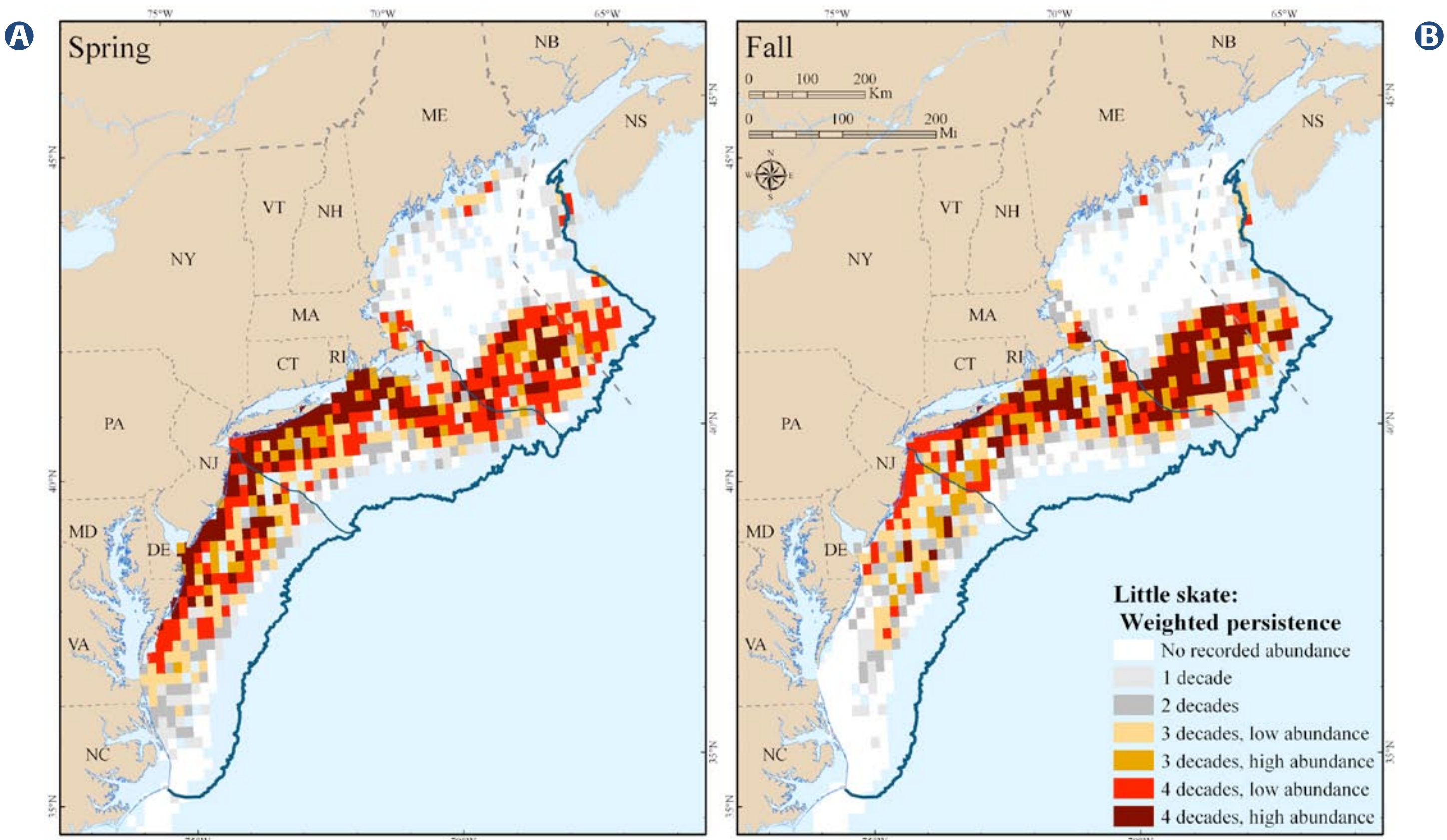


Figure 7-28. Areas with high persistence and abundance over 40 years for little skate during the spring and fall seasons.

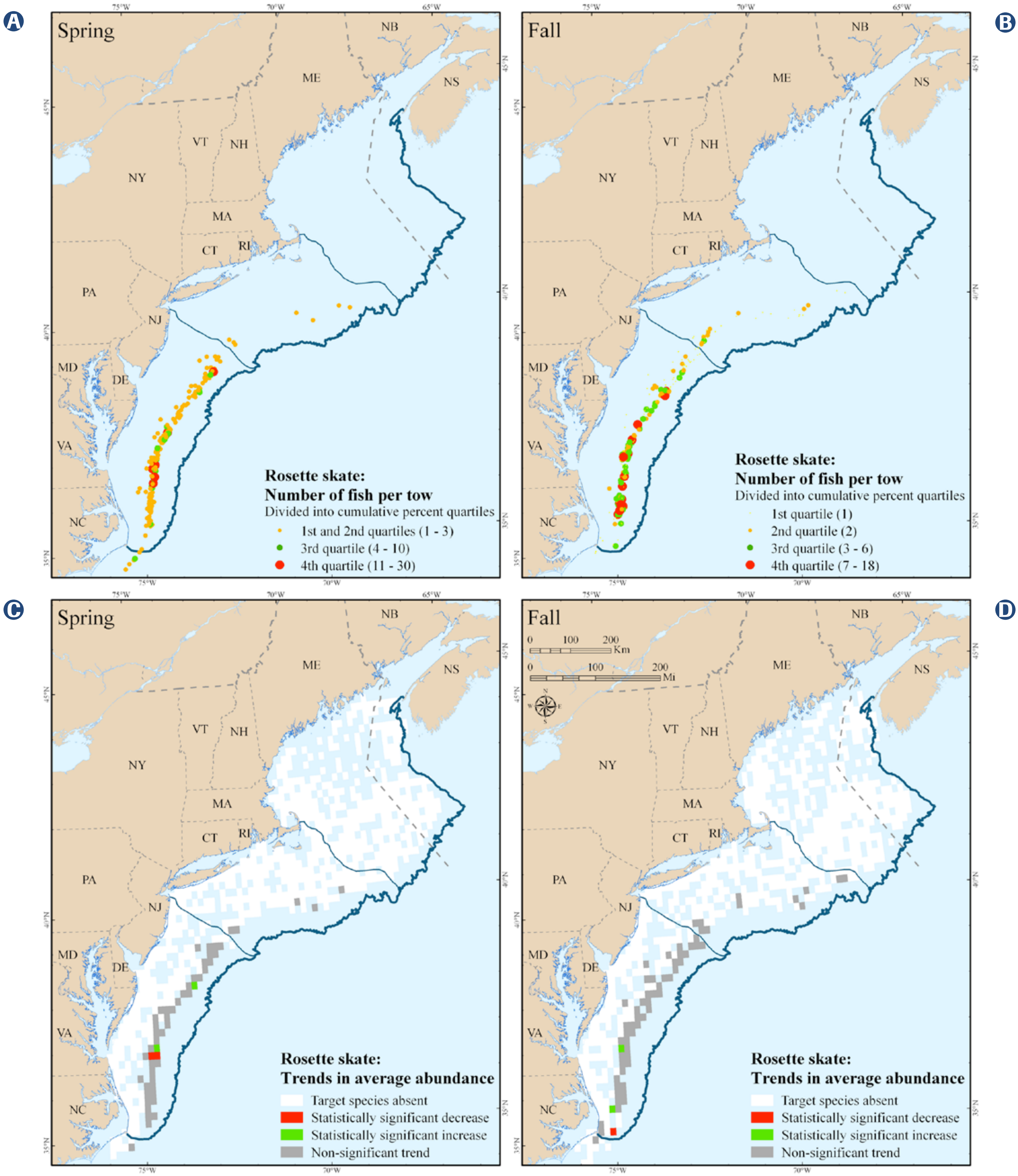


Figure 7-29. Trends in average abundance over 40 years for rosette skate during the spring and fall seasons.

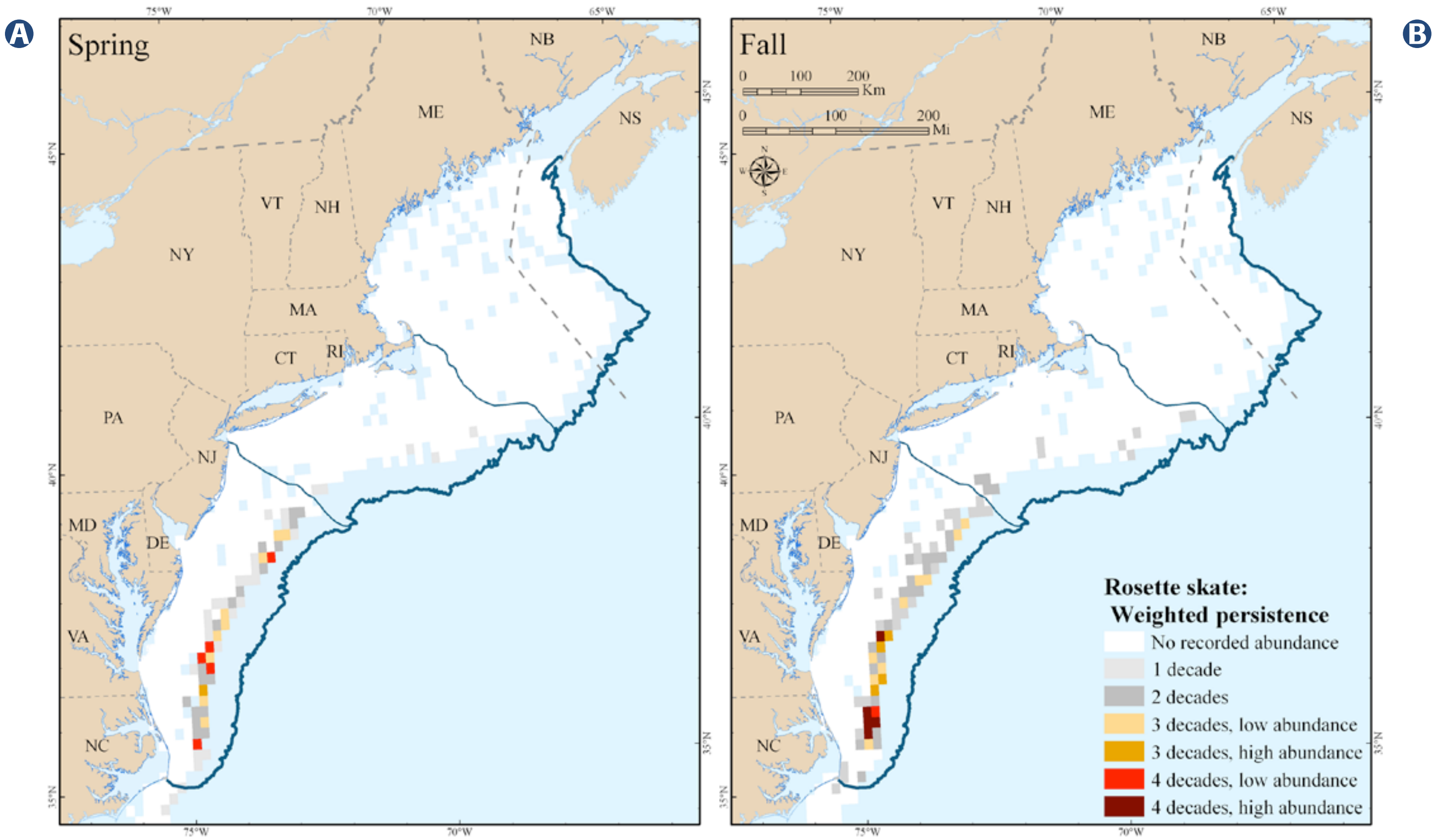


Figure 7-30. Areas with high persistence and abundance over 40 years for rosette skate during the spring and fall seasons.

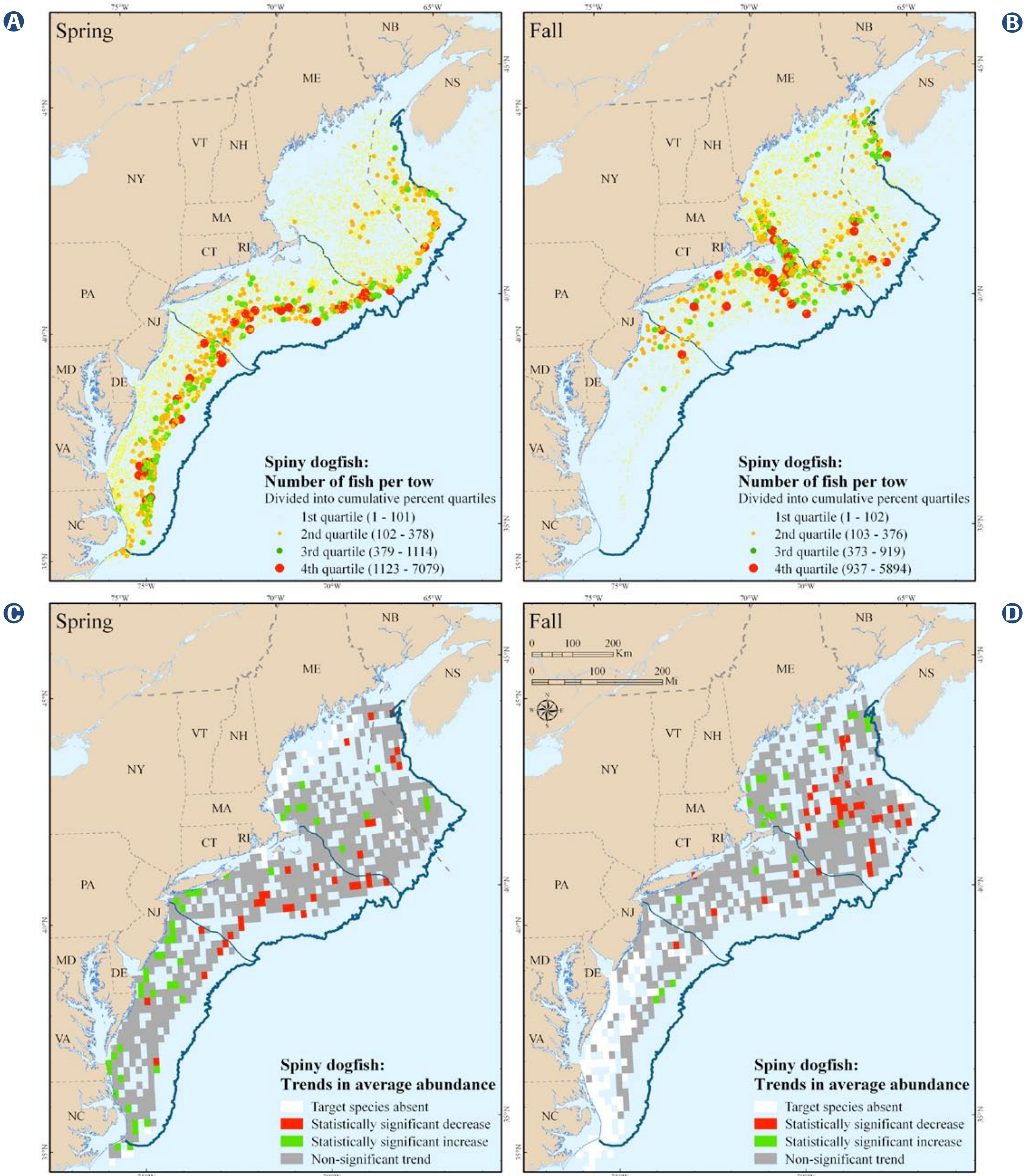


Figure 7-31. Trends in average abundance over 40 years for spiny dogfish during the spring and fall seasons.

Spiny dogfish occurred throughout the region, with highest numbers dependent on the time of year because of distinct seasonal migrations (Figure 7-31a, b). Highest numbers were found in the southern portion of the range offshore along the shelf/slope break in the spring and further north and nearshore in the fall. Increasing trends were observed in nearshore areas while decreasing trends were observed further offshore, although neither of these trends was statistically significant. Statistical analyses identified variable trends, with increases generally occurring in nearshore waters in the Gulf of Maine, Southern New England, and Mid-Atlantic and decreases observed in offshore waters of the Gulf of Maine, Georges Bank, and Southern New England (Figure 7-31c, d). Weighted persistence maps for spiny dogfish identified Massachusetts Bay, the Great South Channel, Georges Bank, Nantucket Shoals to Block Island Sound, and offshore waters along the shelf/slope break from the Hudson River/Raritan Bay estuary to Pamlico Sound as important. Distinct seasonal patterns were observed. Important areas were concentrated in the southern and offshore portions of the range in the spring and further north and nearshore during the fall (Figure 7-32).

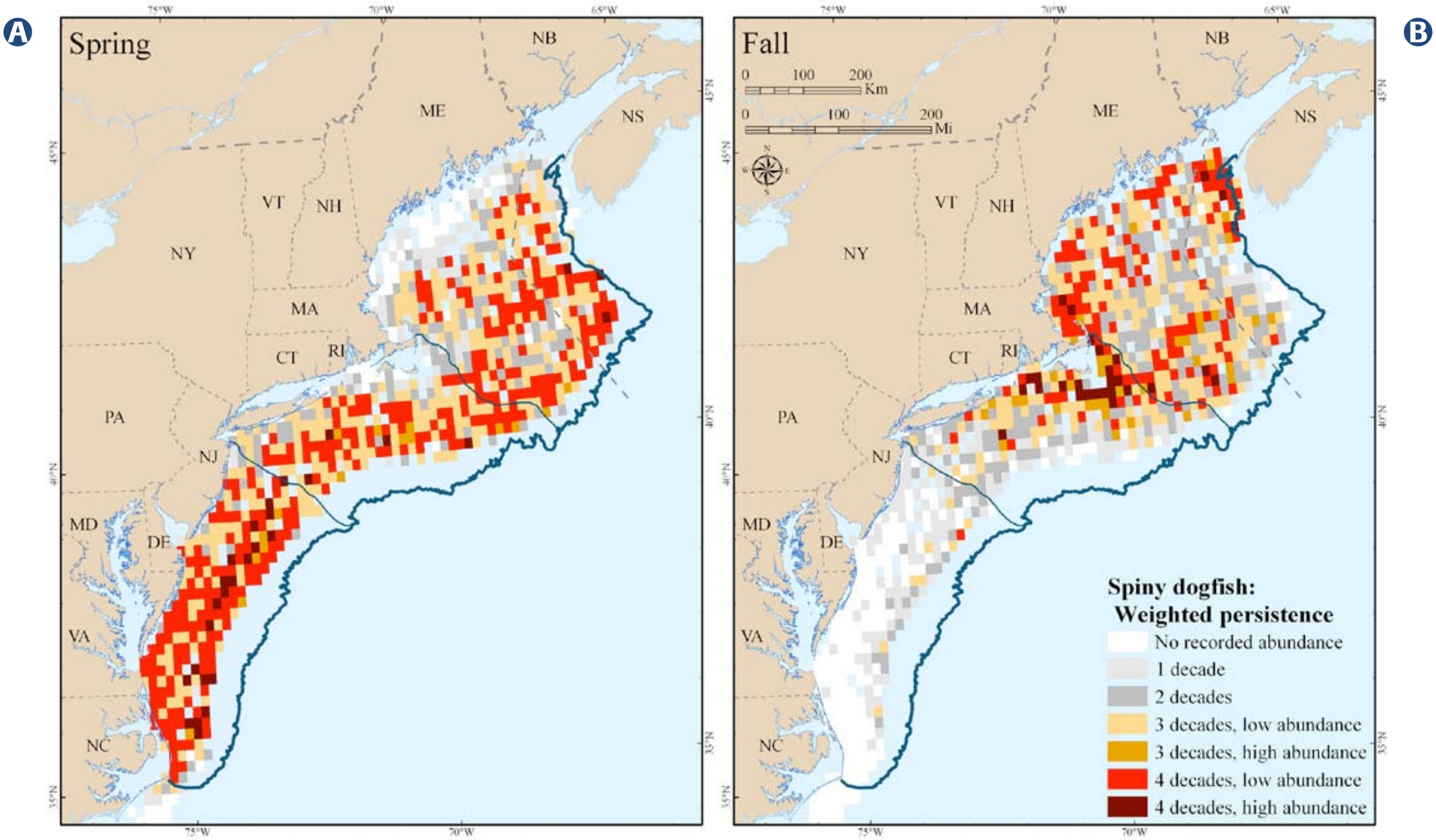


Figure 7-32. Areas with high persistence and abundance over 40 years for spiny dogfish during the spring and fall seasons.

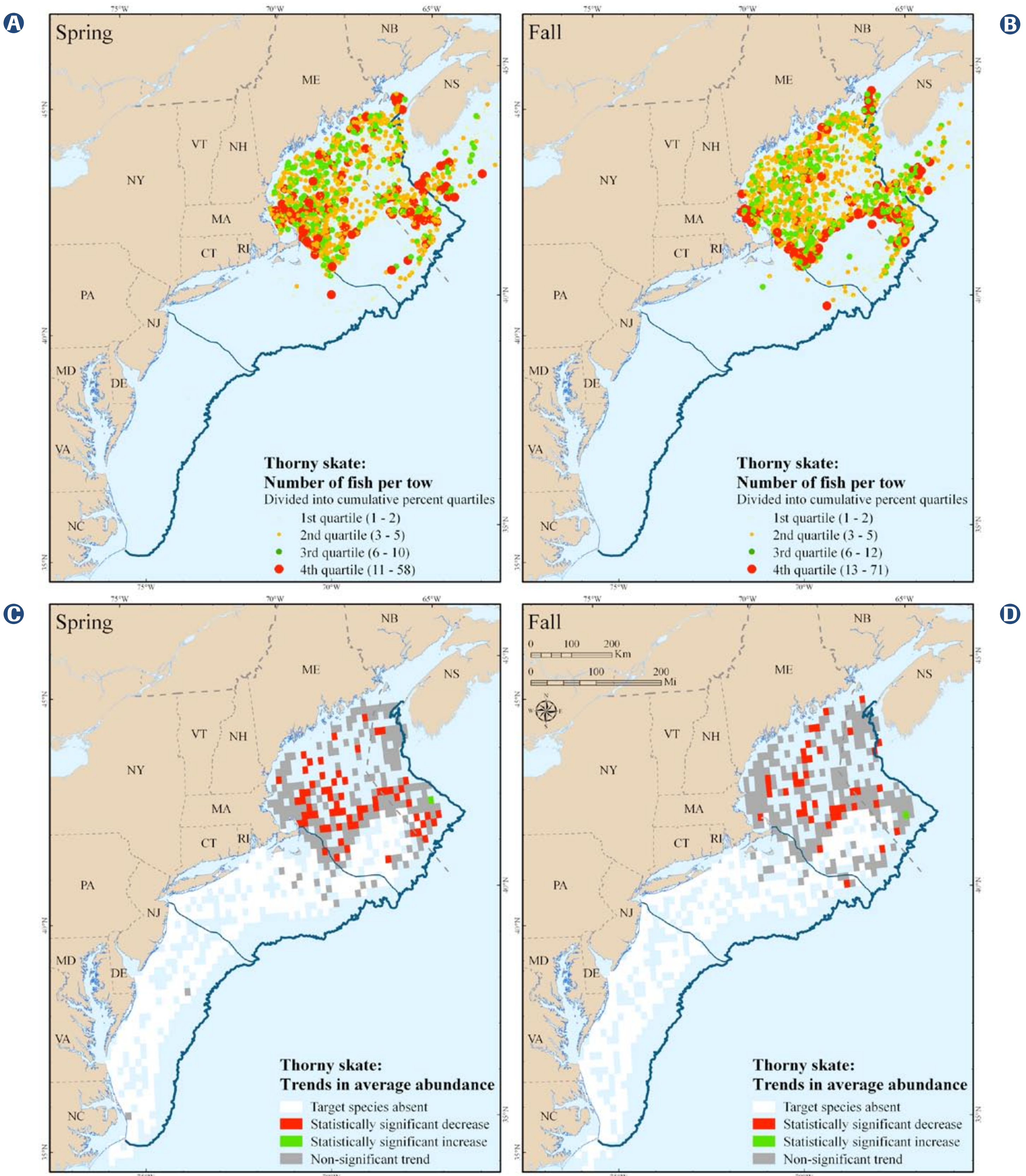


Figure 7-33. Trends in average abundance over 40 years for thorny skate during the spring and fall seasons.

Thorny skate occurred primarily in the Gulf of Maine and Georges Bank, with highest numbers found in the southern and central portions of the Gulf of Maine, east of Grand Manan Island, along Browns Bank and the Northeast Channel, in and around the Great South Channel, and along the northern edge and southern flank of Georges Bank (Figure 7-33a, b). Statistical analyses identified a declining trend in the time series across much of the range, including central and eastern portions of the Gulf of Maine and along much of the perimeter of Georges Bank (Figure 7-33c, d). Weighted persistence analyses for thorny skate identified waters north of the Great South Channel and Northeast Peak of Georges Bank, nearshore waters from Massachusetts Bay to Casco Bay, and Grand Manan Banks as important, with no distinct seasonal differences observed (Figure 7-34).

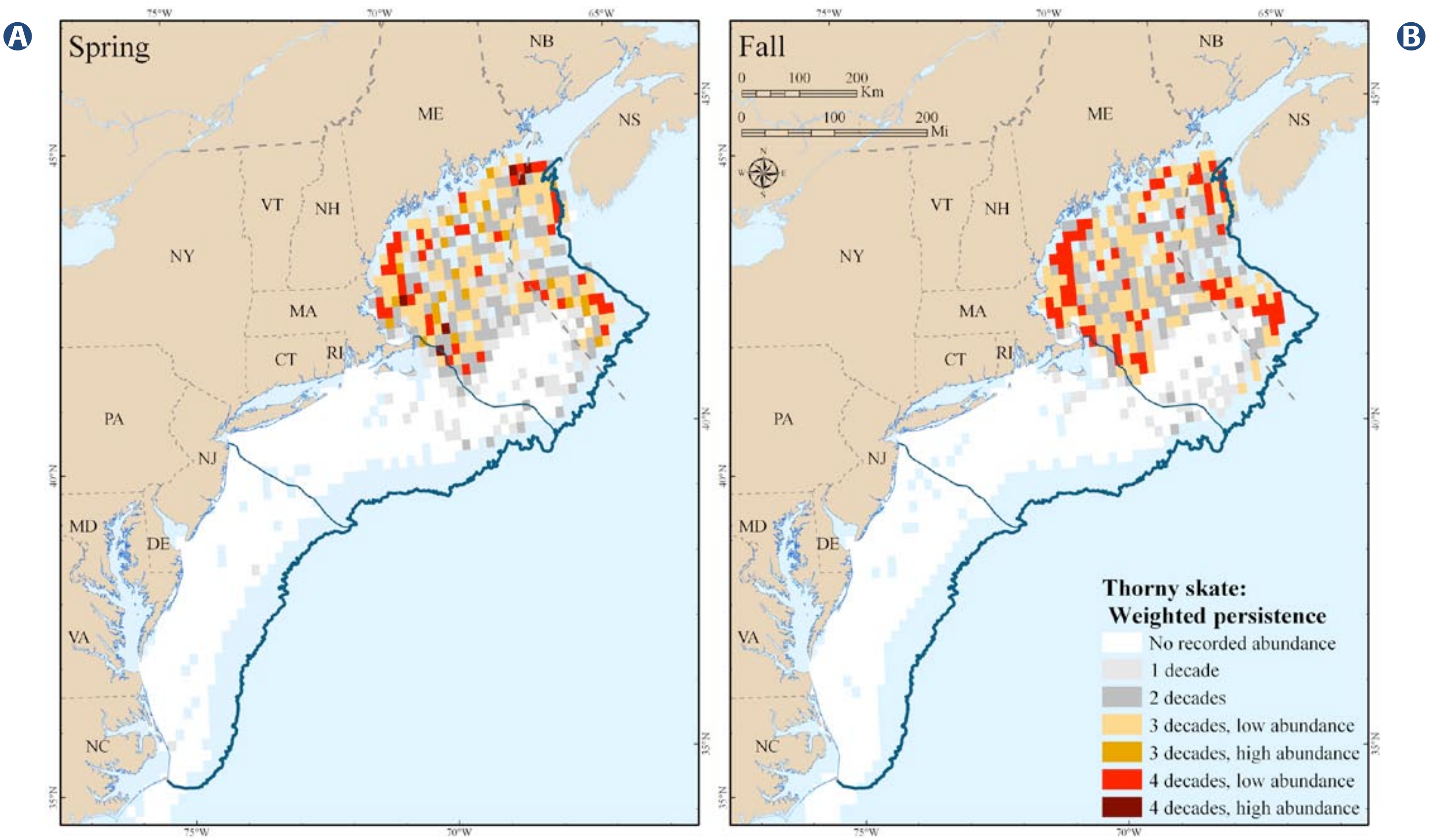


Figure 7-34. Areas with high persistence and abundance over 40 years for thorny skate during the spring and fall seasons.

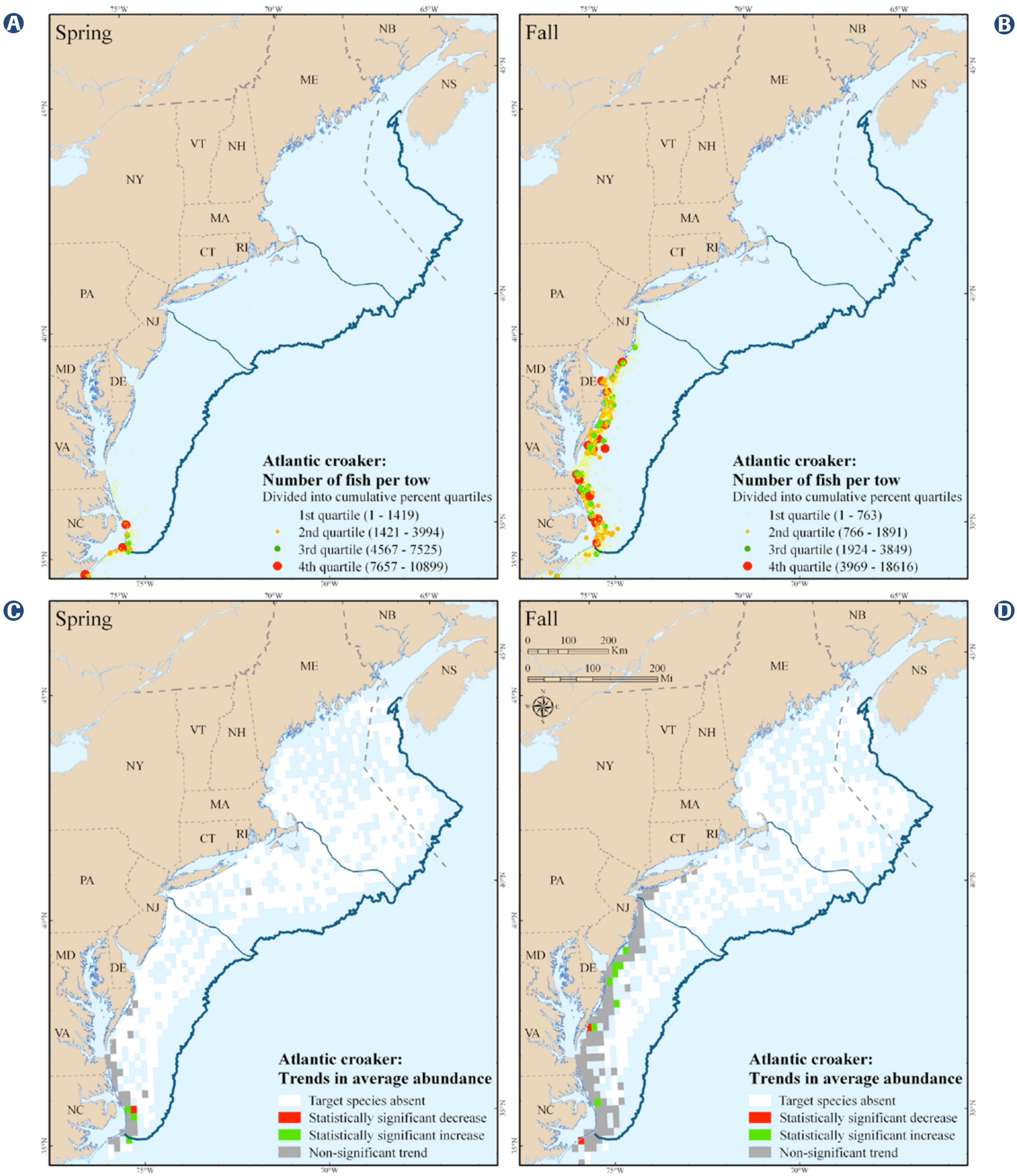


Figure 7-35. Trends in average abundance over 40 years for Atlantic croaker during the spring and fall seasons.

Mid-Atlantic Estuarine

Within the region, these species were predominantly found from Long Island Sound to Cape Hatteras, North Carolina with highest numbers of Atlantic croaker, spot, and weakfish occurring from Delaware Bay south to Chesapeake Bay. However, all species do occur along the perimeter of Georges Bank and the Great South Channel. They have occasionally been observed in the Gulf of Maine in and around Massachusetts Bay and the Jeffreys Ledge and Stellwagen Bank area. Highest numbers of croaker (Figure 7-35a, b), spot (Figure 7-37a, b), and weakfish (Figure 7-39a, b) occurred south of Delaware Bay to Pamlico Sound. Distinct seasonal patterns in distribution were also apparent for spot, croaker, and weakfish with higher numbers occurring in nearshore coastal waters during the fall.

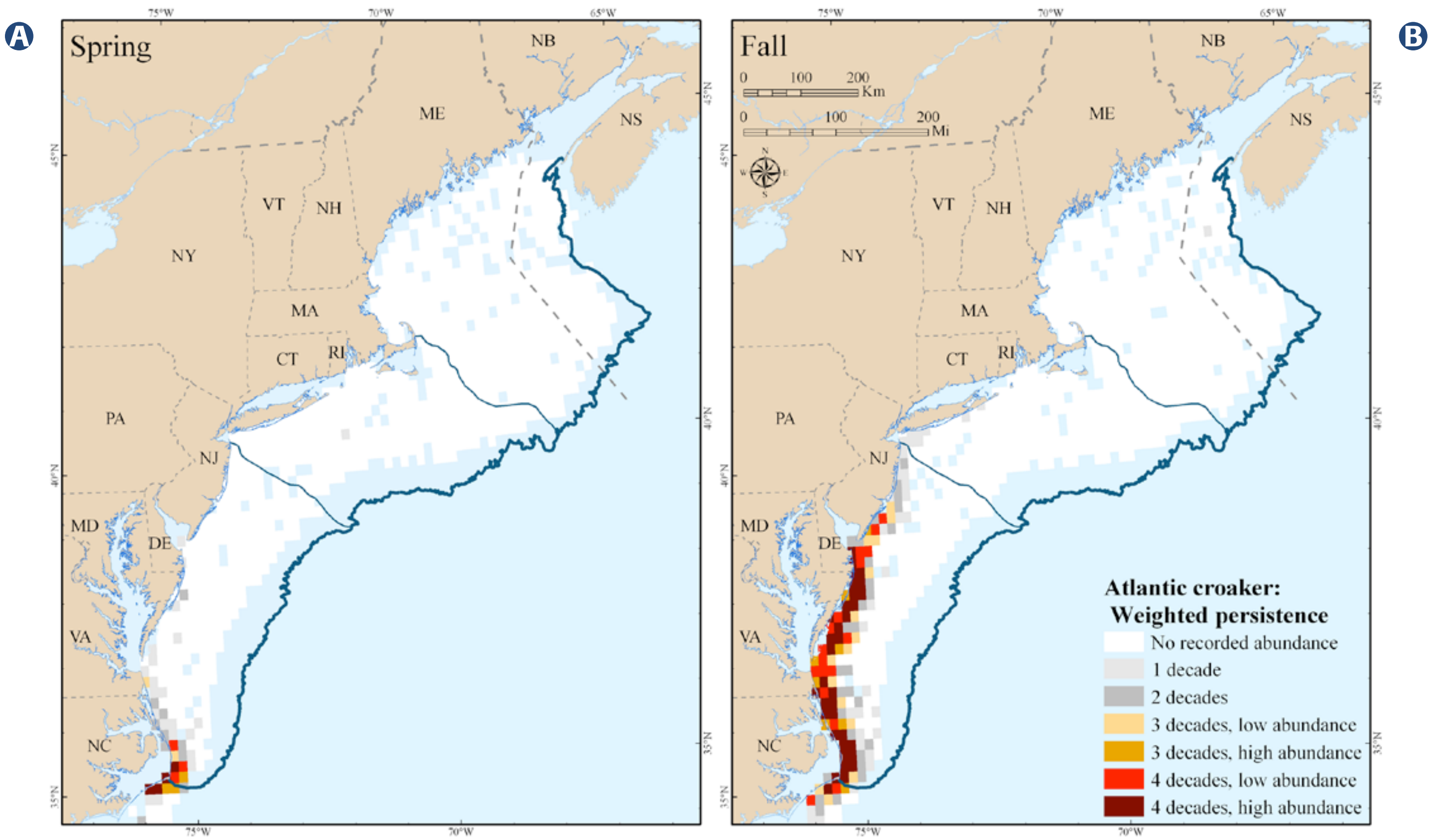


Figure 7-36. Areas with high persistence and abundance over 40 years for Atlantic croaker during the spring and fall seasons.

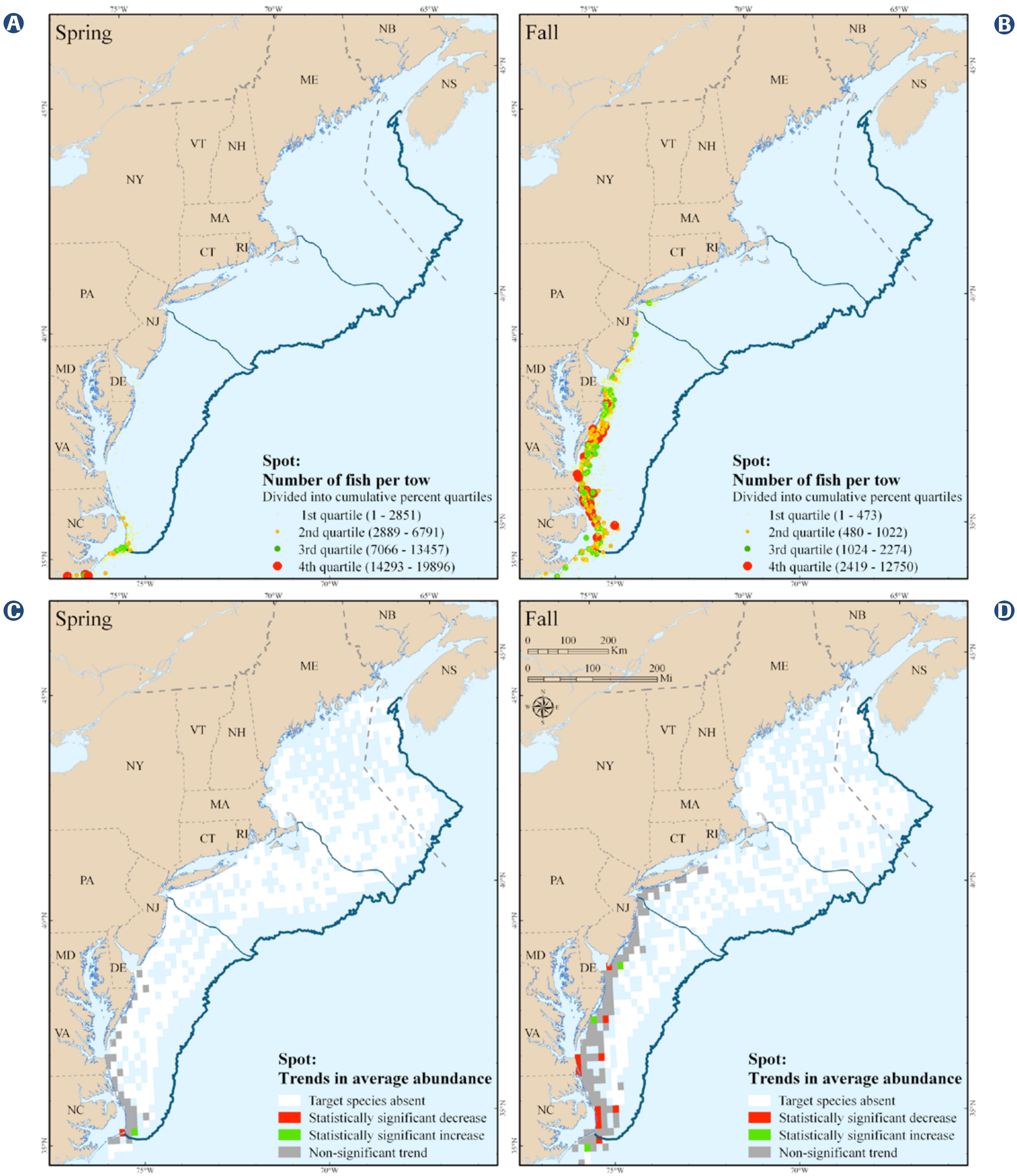


Figure 7-37. Trends in average abundance over 40 years for spot during the spring and fall seasons.

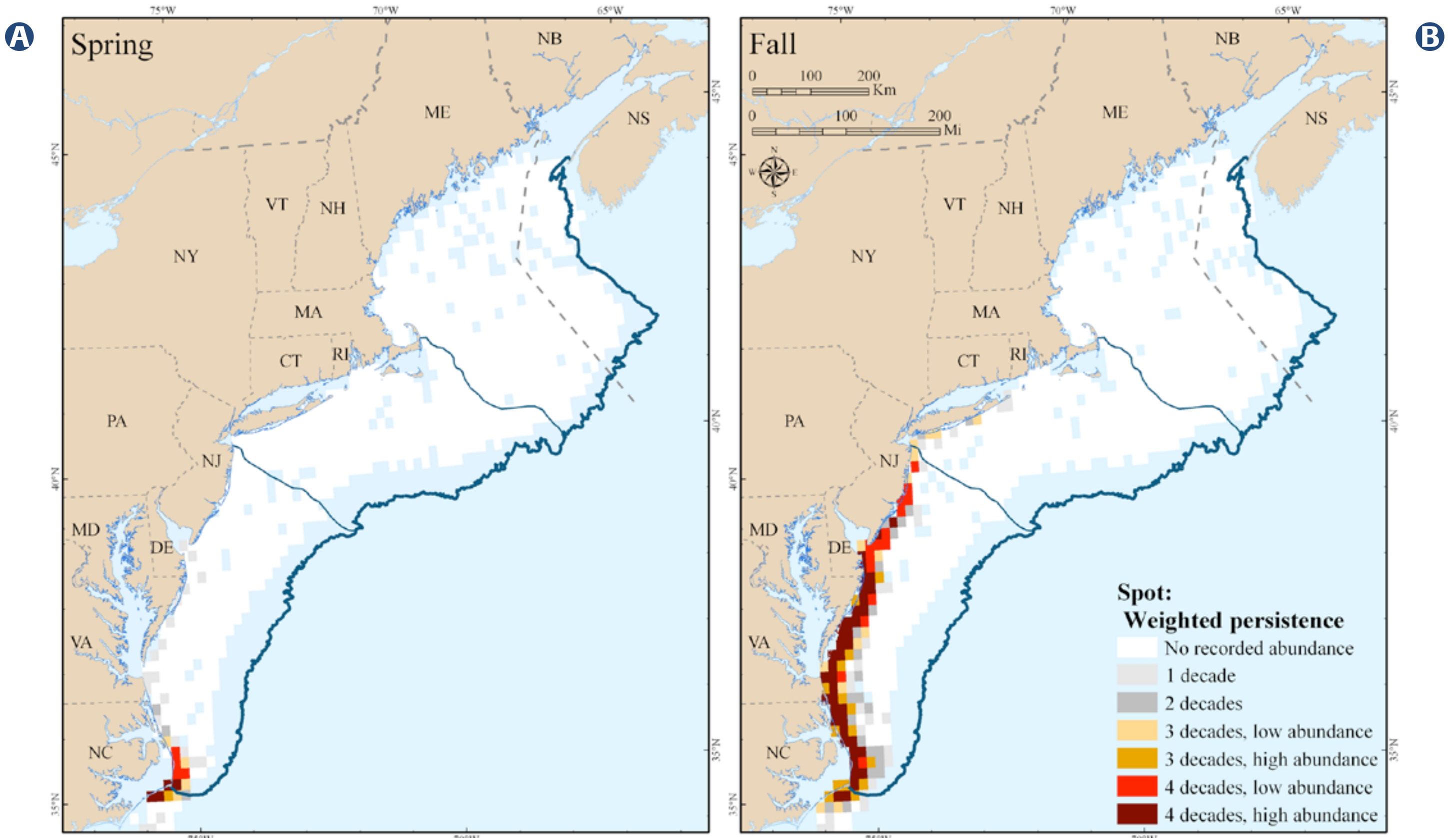


Figure 7-38. Areas with high persistence and abundance over 40 years for spot during the spring and fall seasons.

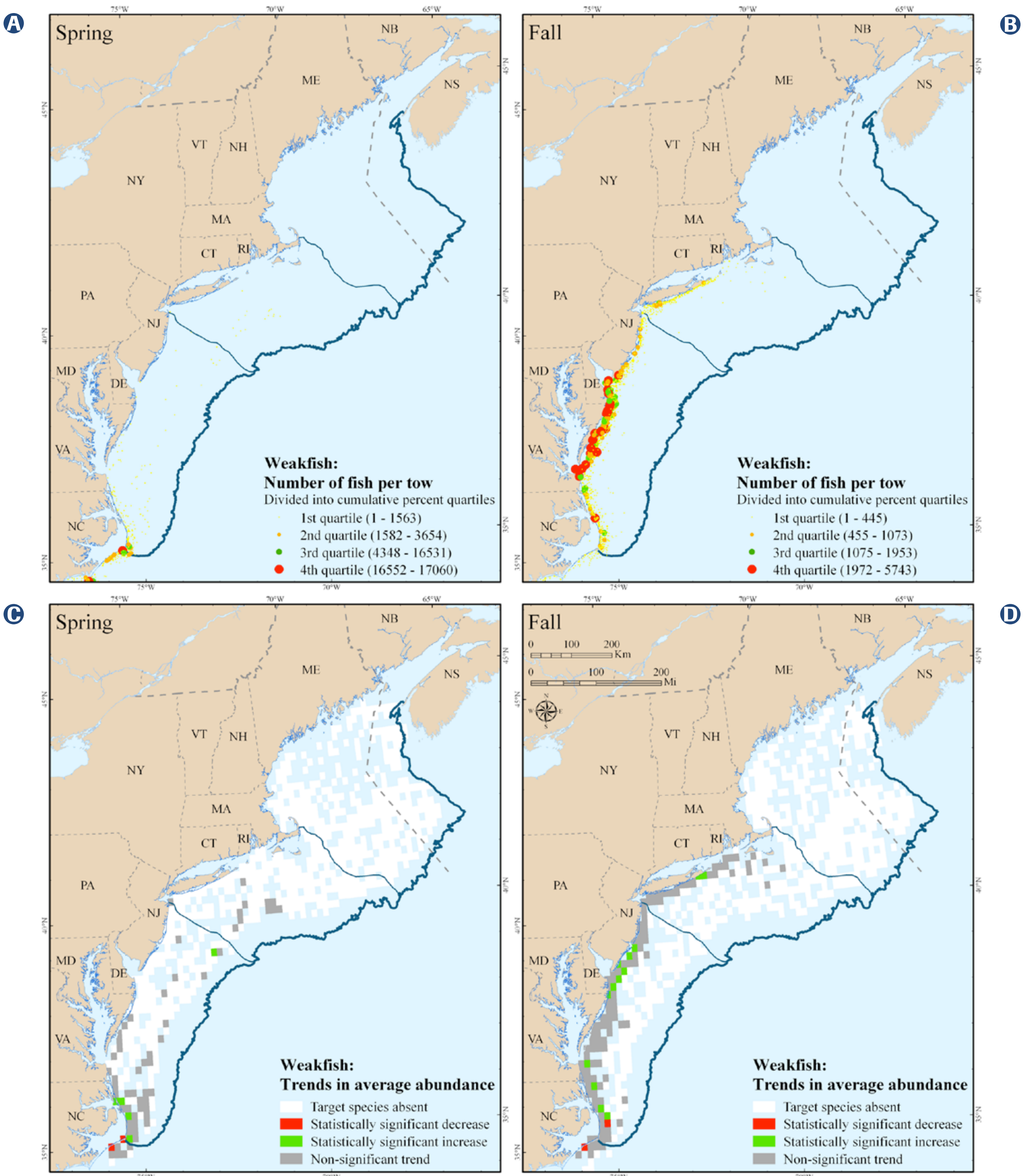


Figure 7-39. Trends in average abundance over 40 years for weakfish during the spring and fall seasons.

Statistical analyses did not identify significant trends in croaker abundance over much of the range, though increasing trends were observed in the fall in nearshore waters from Delaware Bay to Cape Charles, Virginia (Figure 7-35c, d). Statistical analyses did not identify significant trends for spot over much of the range, though decreasing trends were observed in nearshore waters from Delaware Bay south during the fall (Figure 7-37c, d). Statistical analyses did not identify significant trends in abundance over much of the range, though increasing trends were observed at discrete locations in nearshore waters from Great Bay, New Jersey south to Pamlico Sound (Figure 7-39c, d). Weighted persistence analyses for croaker (Figure 7-36) and spot (Figure 7-38) identified discrete locations in nearshore waters from Delaware Bay south to Pamlico Sound as important, particularly in the fall. Weighted persistence analyses for weakfish identified nearshore waters near Albemarle and Pamlico Sound as important in the spring and from Long Island south, especially from Delaware Bay to Pamlico Sound, as important in the fall (Figure 7-40).

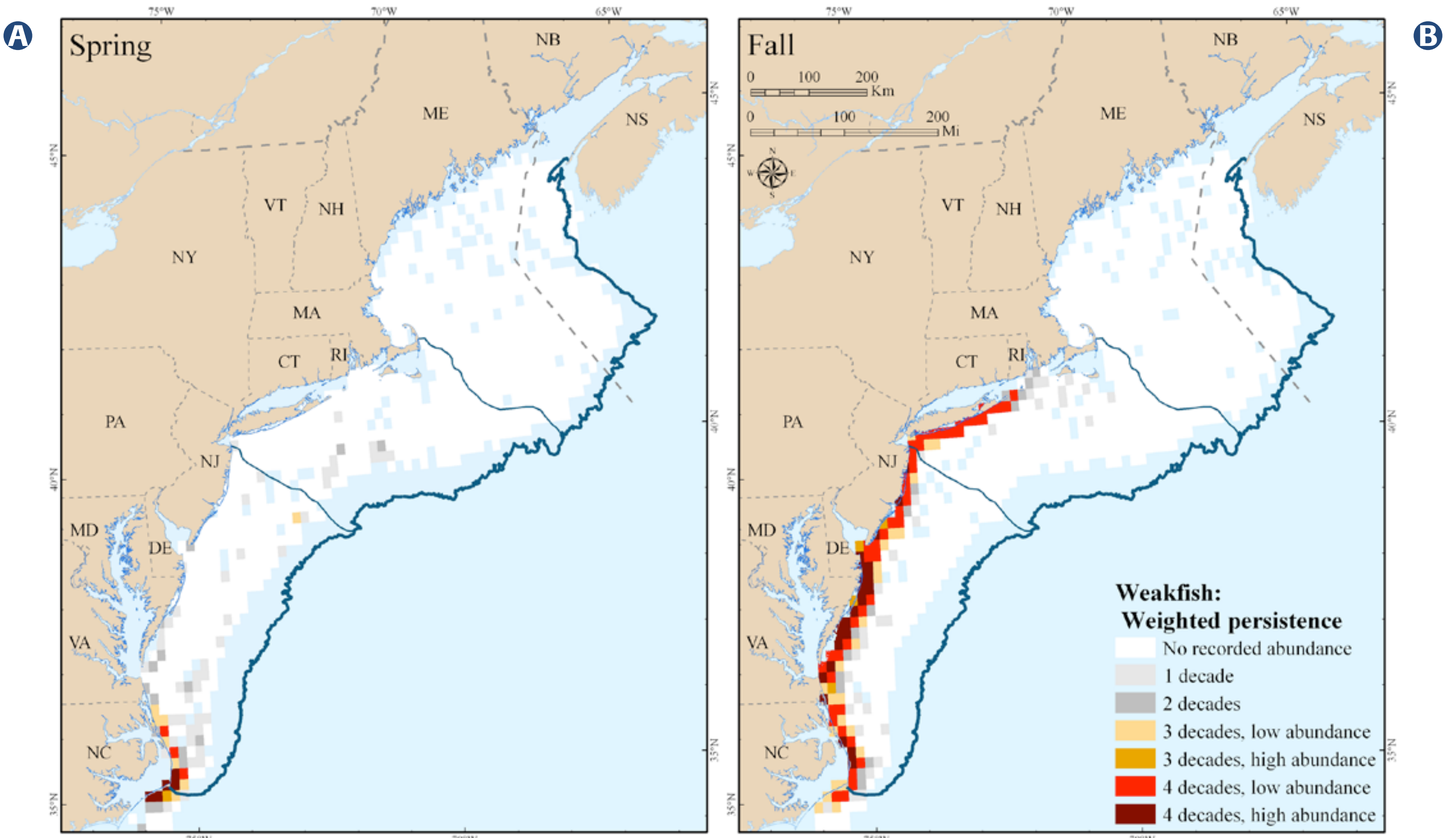


Figure 7-40. Areas with high persistence and abundance over 40 years for weakfish during the spring and fall seasons.

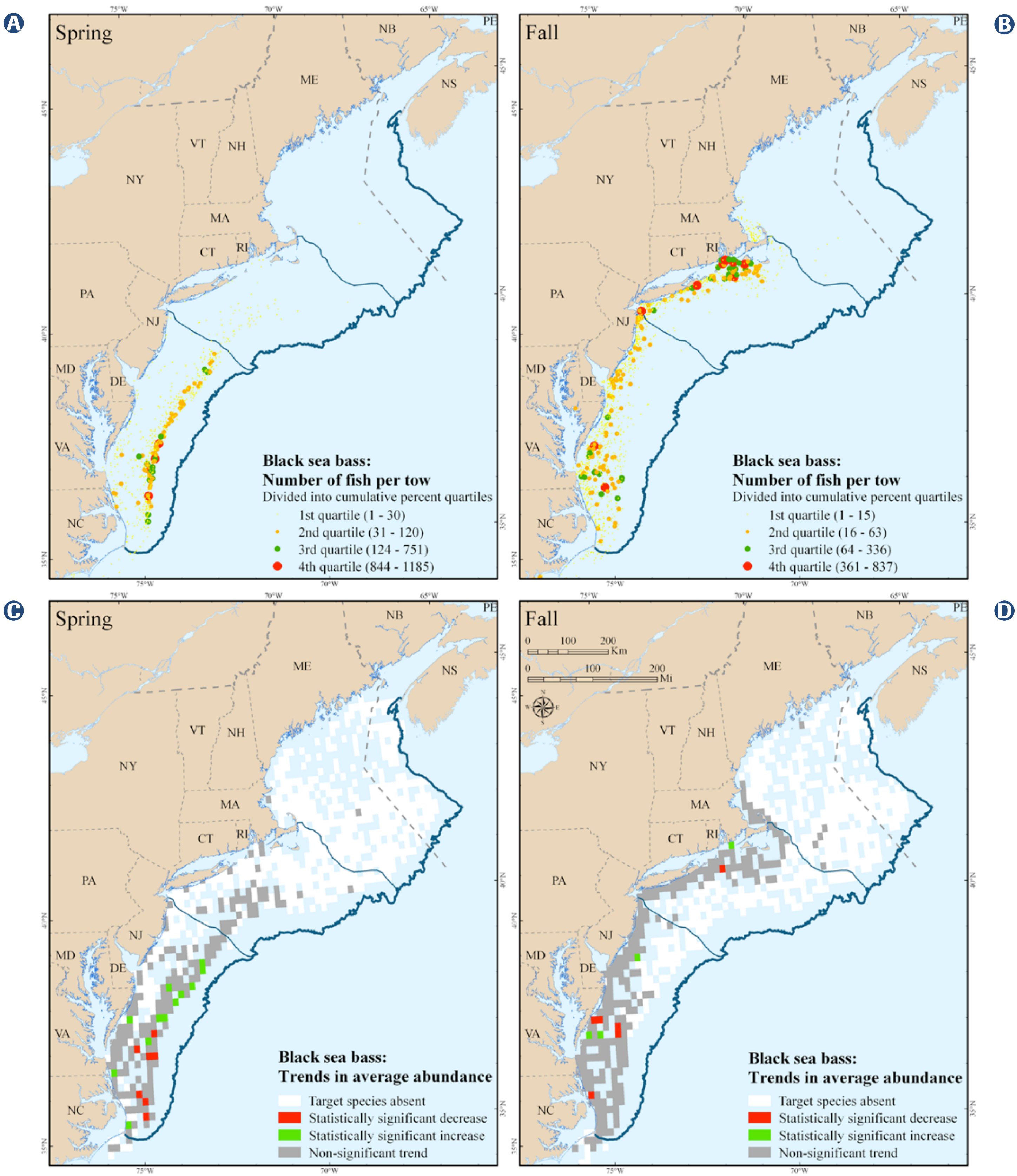


Figure 7-41. Trends in average abundance over 40 years for black sea bass during the spring and fall seasons.

Offshore Wintering Guild

Within the region, the highest numbers of species in this guild were found from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. However, all species also occurred along the 50 fathom curve of Georges Bank and the Great South Channel and in the Gulf of Maine, particularly in and around Massachusetts Bay and the Jeffreys Ledge and Stellwagen Bank area.

Highest numbers of black sea bass were found from Vineyard Sound and Narragansett Bay to the Hudson/Raritan Estuary and Cape Charles, Virginia to Albemarle Sound (Figure 7-41a, b). Distinct seasonal patterns were also observed, with highest numbers found in coastal waters in the fall and along the shelf/slope break in the spring. Statistical analyses did not identify significant trends across much of the species' range, though variable increasing trends were observed along the southern flank of Georges Bank in fall and from Cape May, New Jersey to Chincoteague Bay in the spring, while decreasing trends were observed in offshore waters from Chincoteague Bay to Pamlico Sound in the spring (Figure 7-41c, d). Weighted persistence analyses for black sea bass identified the shelf/slope break from Delaware Bay to Chesapeake Bay as important during the spring and nearshore waters from Martha's Vineyard to Albemarle/Pamlico Sound as important in the fall (Figure 7-42).

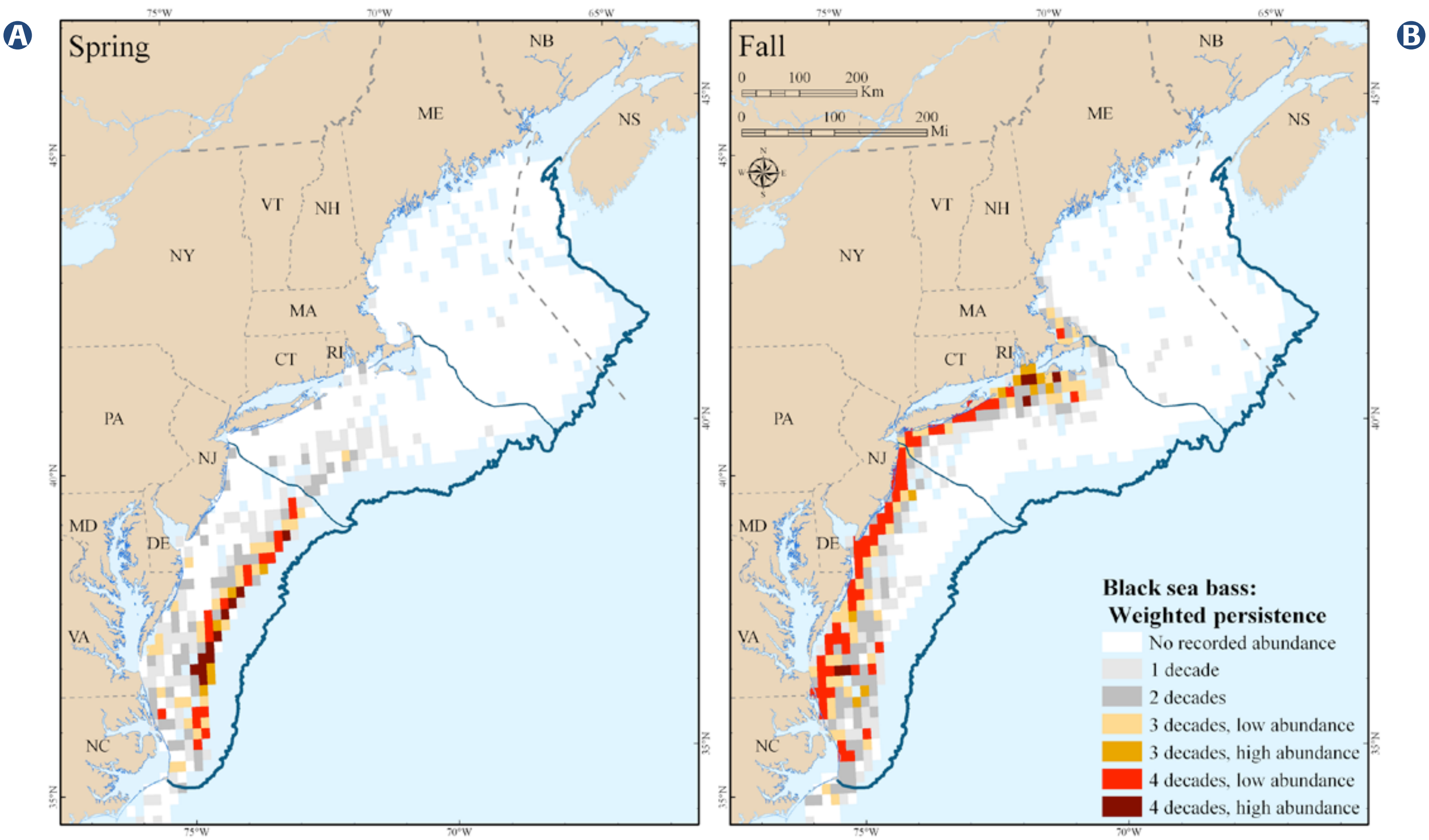


Figure 7-42. Areas with high persistence and abundance over 40 years for black sea bass during the spring and fall seasons.

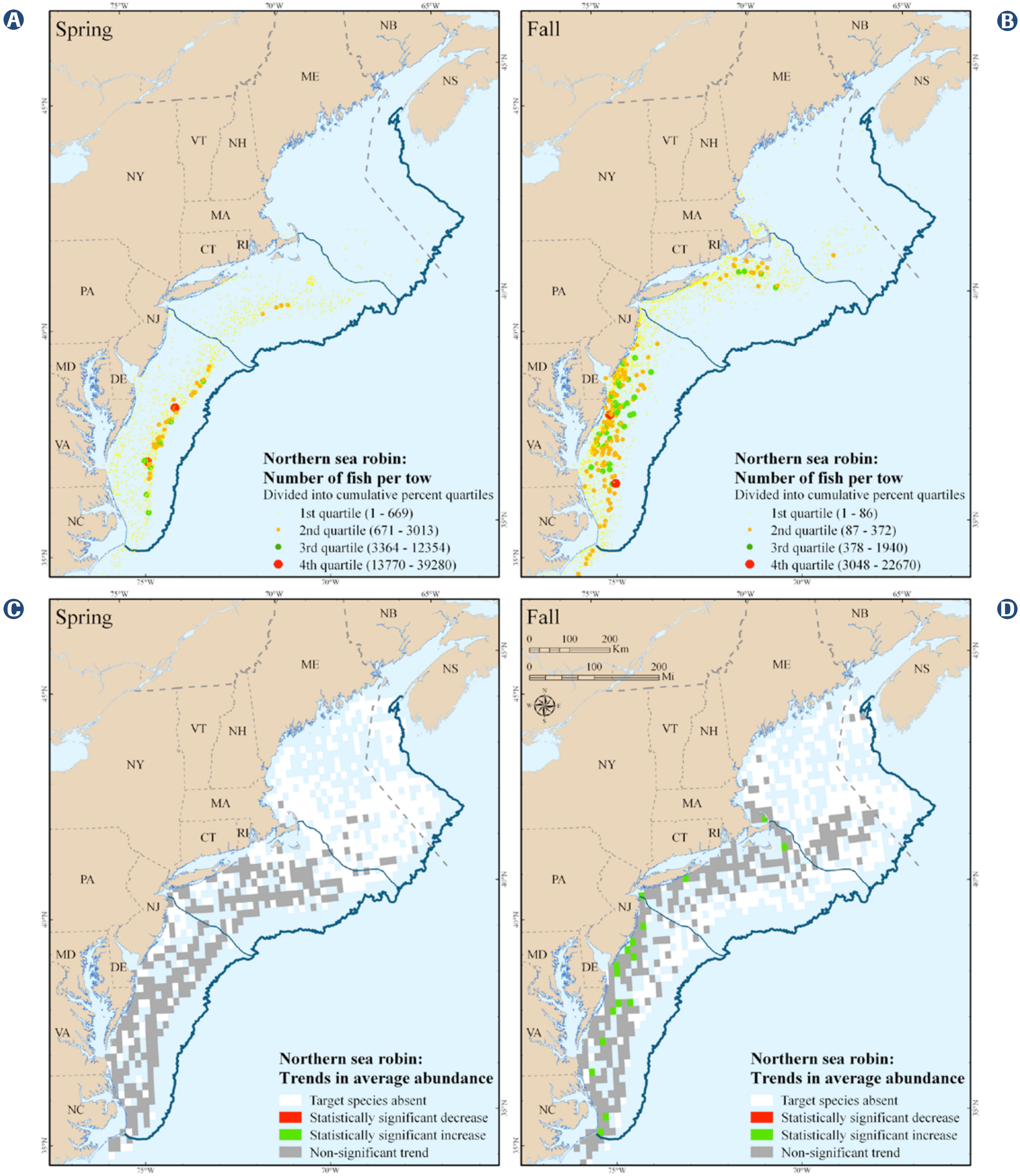


Figure 7-43. Trends in average abundance over 40 years for northern sea robin during the spring and fall seasons.

Highest numbers of northern sea robin were found from Great Bay, New Jersey to Cape Henry, Virginia (Figure 7-43a, b). Distinct seasonal patterns were also observed, with highest numbers found in nearshore coastal waters in the fall and along the shelf/slope break in the spring. Statistical analyses did not identify significant trends across much of the species' range. However, decreasing trends were observed in Southern New England from Long Island Sound to the Great South Channel, while a mix of increasing and decreasing trends were observed at discrete locations in the Mid-Atlantic from Great Bay, New Jersey to Pamlico Sound (Figure 7-43c, d). Weighted persistence analyses for northern sea robin identified offshore waters along the shelf/slope break extending from east of the Hudson /Raritan Estuary to Virginia Beach as important in the spring and nearshore waters from Vineyard Sound to Long Island and from Barnegat Bay, New Jersey to Pamlico Sound as important in the fall (Figure 7-44).

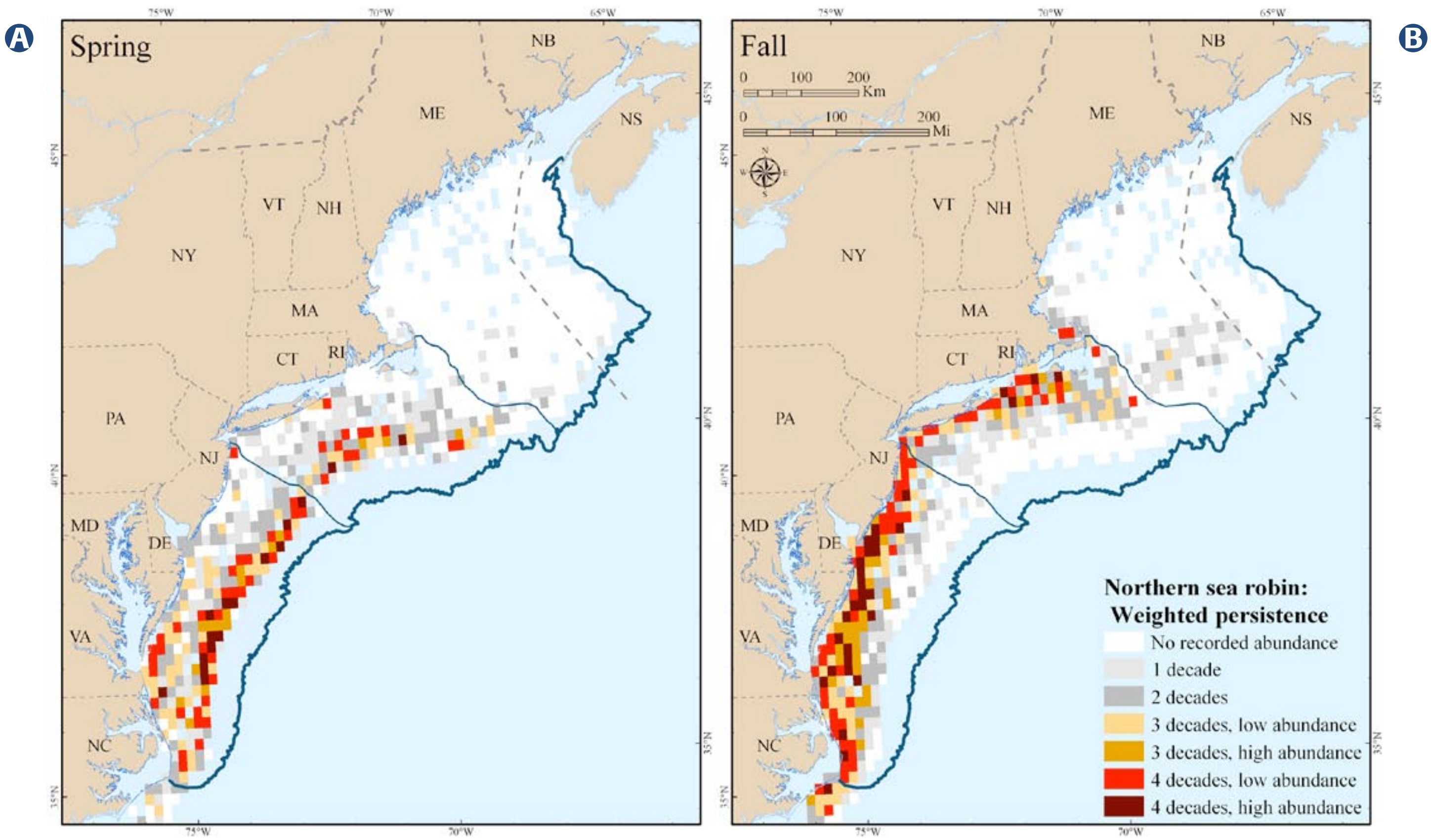


Figure 7-44. Areas with high persistence and abundance over 40 years for northern sea robin during the spring and fall seasons.

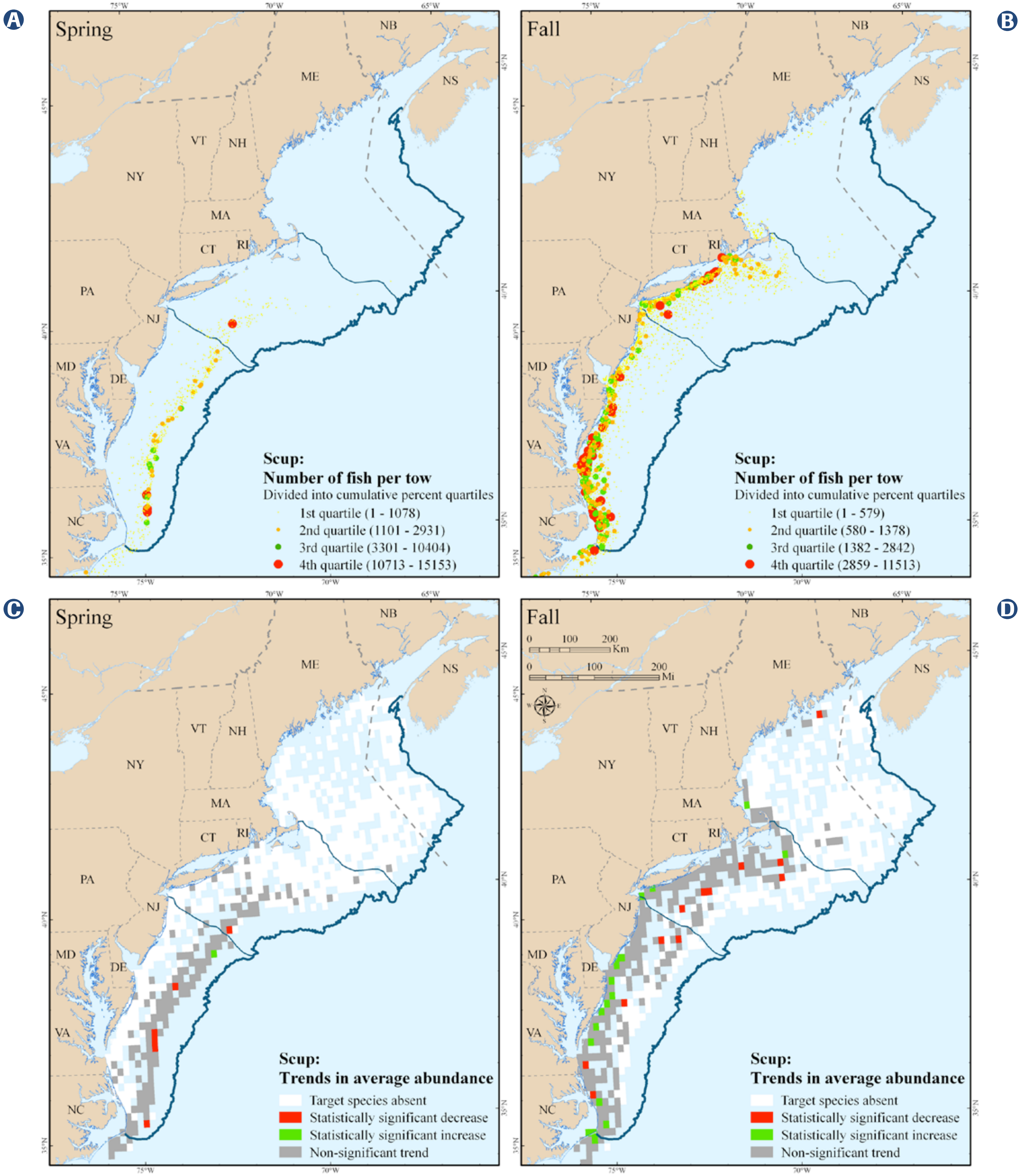


Figure 7-45. Trends in average abundance over 40 years for scup during the spring and fall seasons.

Highest numbers of scup were found in Southern New England and the Mid-Atlantic Bight from Cape Cod, Massachusetts to Pamlico Sound (Figure 7-45a, b). Distinct seasonal patterns were also observed, with highest numbers found in nearshore coastal waters in the fall and along the shelf/slope break in the spring. Statistical analyses did not identify significant trends in abundance across the species' range, though increasing trends were observed in some nearshore waters of Southern New England and the Mid-Atlantic Bight, while decreasing trends were observed further offshore (Figure 7-45c, d).

Weighted persistence analyses for scup identified offshore waters along the shelf/slope break from Cape May, New Jersey to Albemarle/Pamlico Sound as important in the spring and nearshore waters from Vineyard Sound to Sandy Hook, New Jersey, the mouth of Delaware Bay, and Cape Charles, Virginia to Pamlico Sound as important in the fall (Figure 7-46).

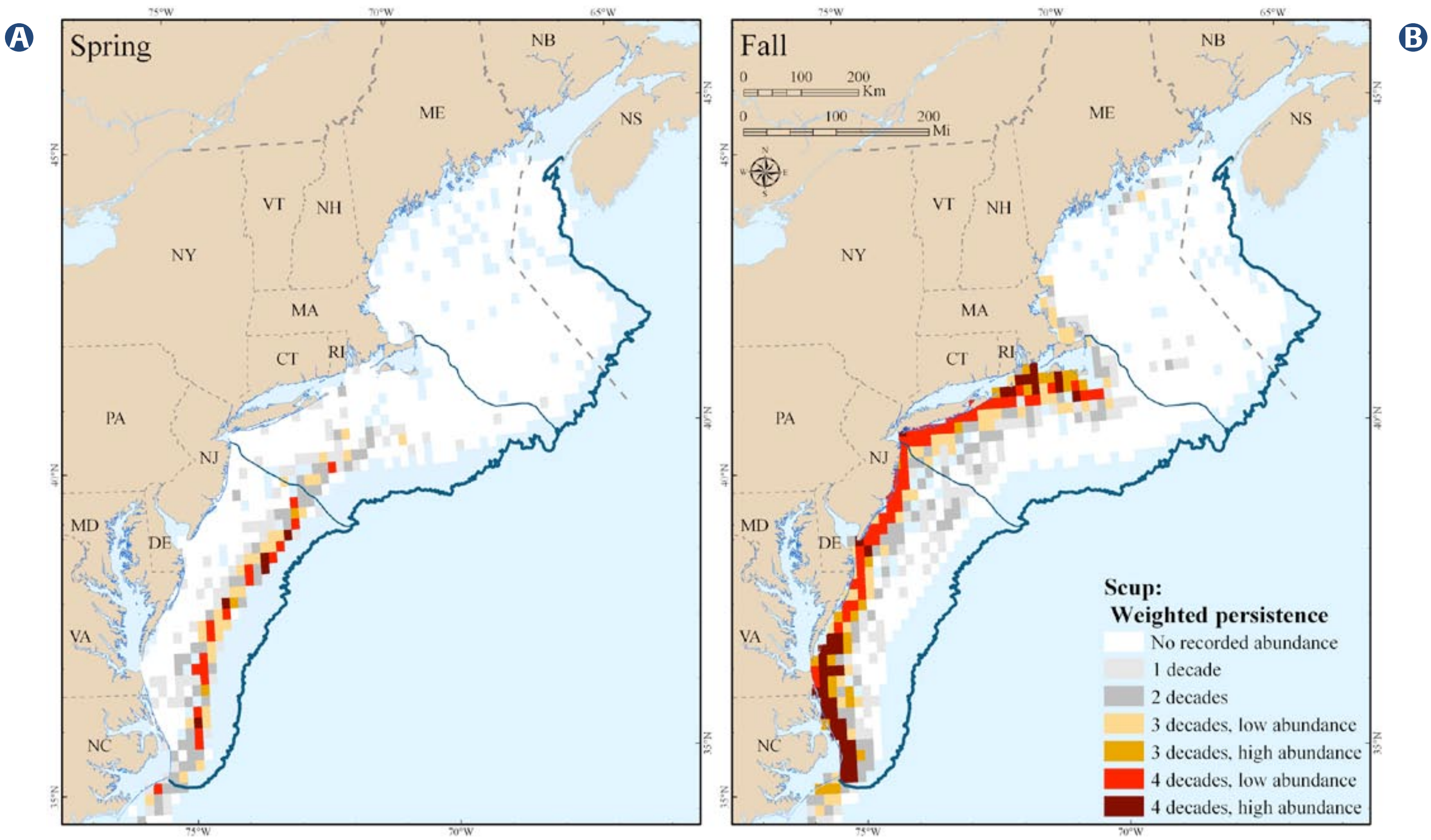


Figure 7-46. Areas with high persistence and abundance over 40 years for scup during the spring and fall seasons.

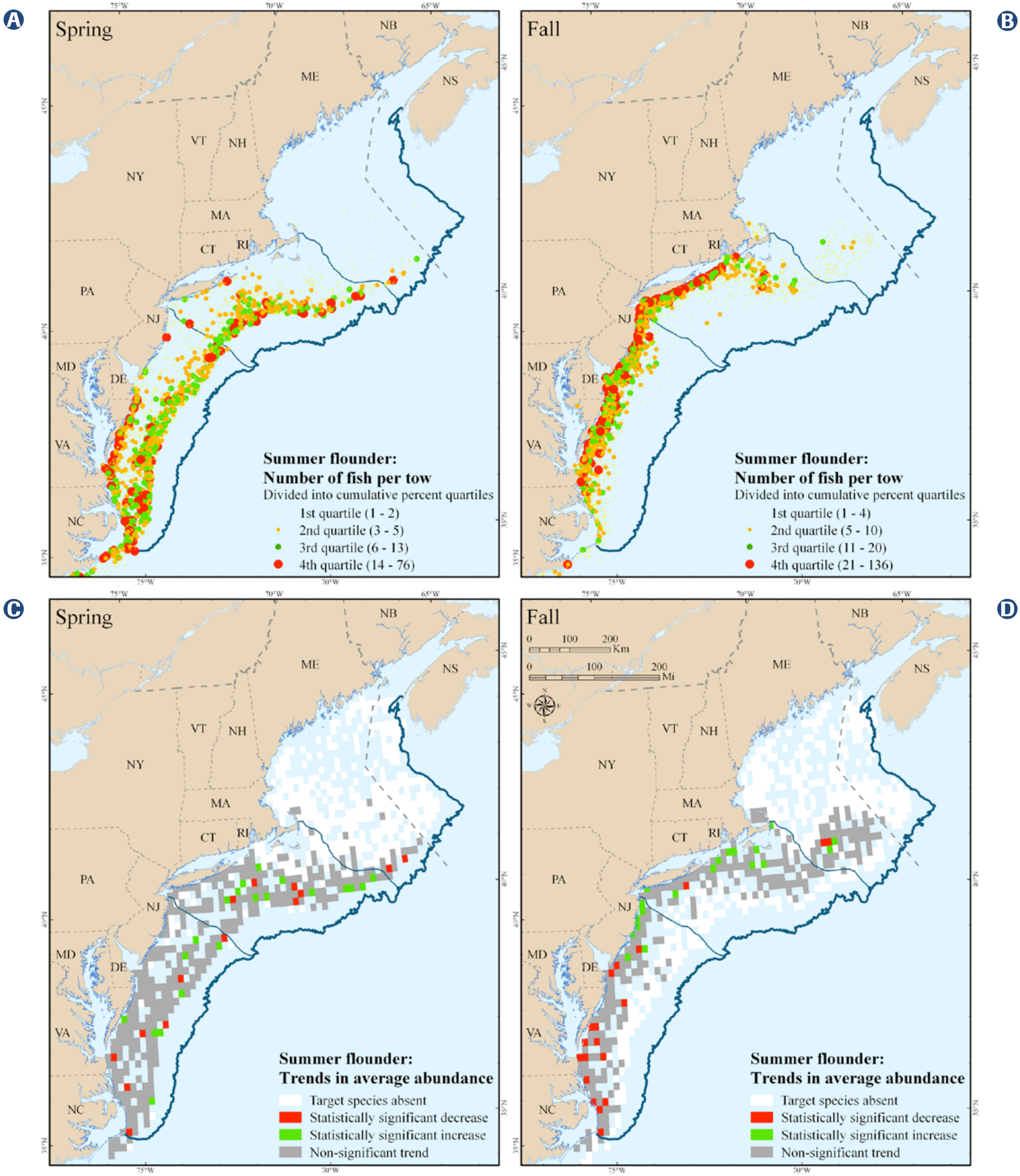


Figure 7-47. Trends in average abundance over 40 years for summer flounder during the spring and fall seasons.

Highest numbers of summer flounder were found from the southern flank of Georges Bank through Southern New England and the Mid-Atlantic as far south as Pamlico Sound (Figure 7-47a, b). Distinct seasonal patterns were also observed, with highest numbers found in nearshore coastal waters in the fall and a broader distribution out to the shelf/slope break in the spring. Statistical analyses did not identify significant trends across the species' range, though decreasing trends were observed across parts of the Mid-Atlantic while increasing trends were observed in portions of Southern New England (Figure 7-47c, d). Weighted persistence analyses for summer flounder identified offshore waters along the shelf/slope break extending from east of the Hudson/Raritan Estuary to Pamlico Sound and nearshore waters from south of Delaware Bay to Pamlico Sound as important in the spring, and nearshore waters from Cape cod, Massachusetts and to Cape Henry, Virginia as important in the fall (Figure 7-48).

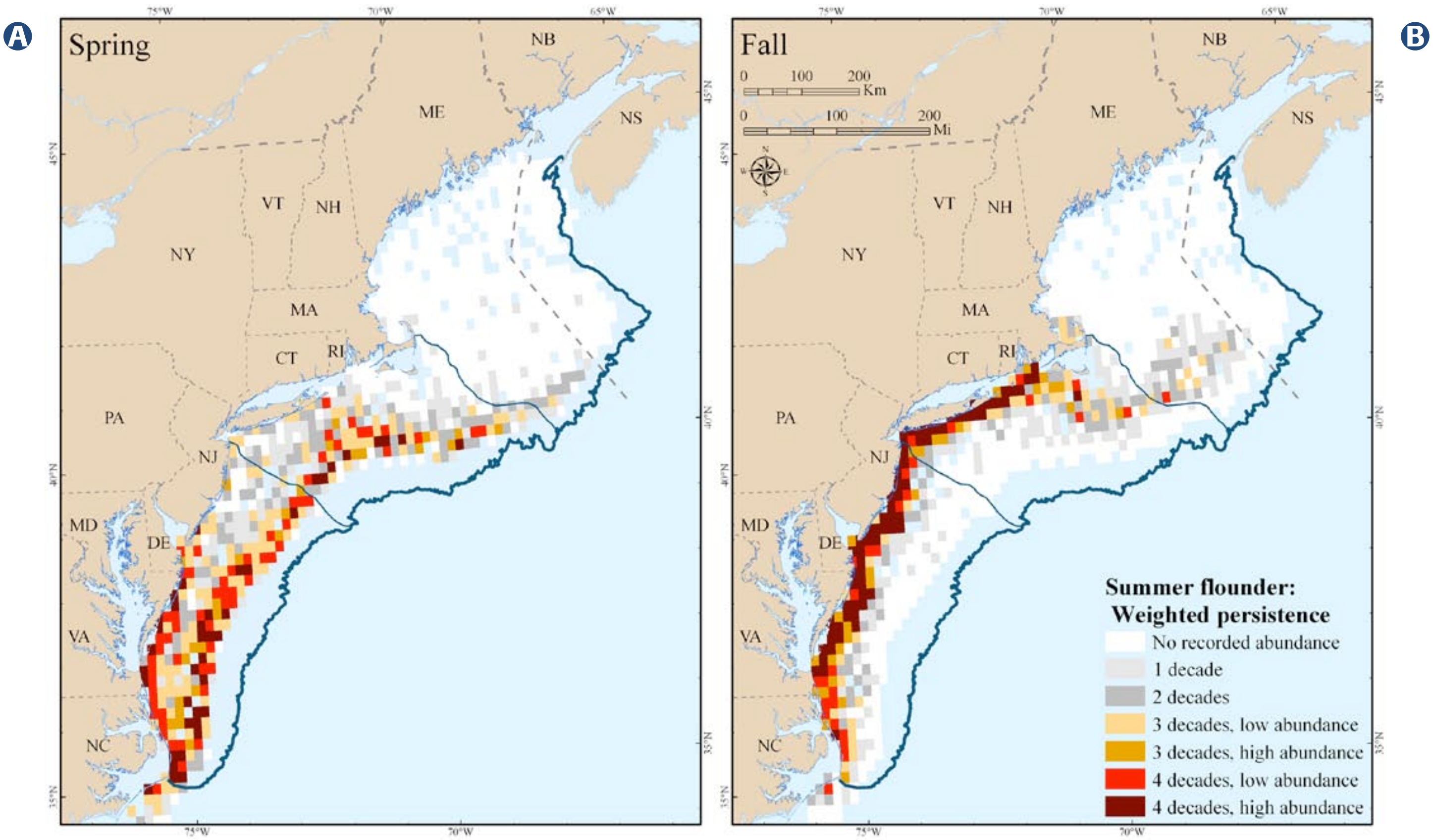


Figure 7-48. Areas with high persistence and abundance over 40 years for summer flounder during the spring and fall seasons.

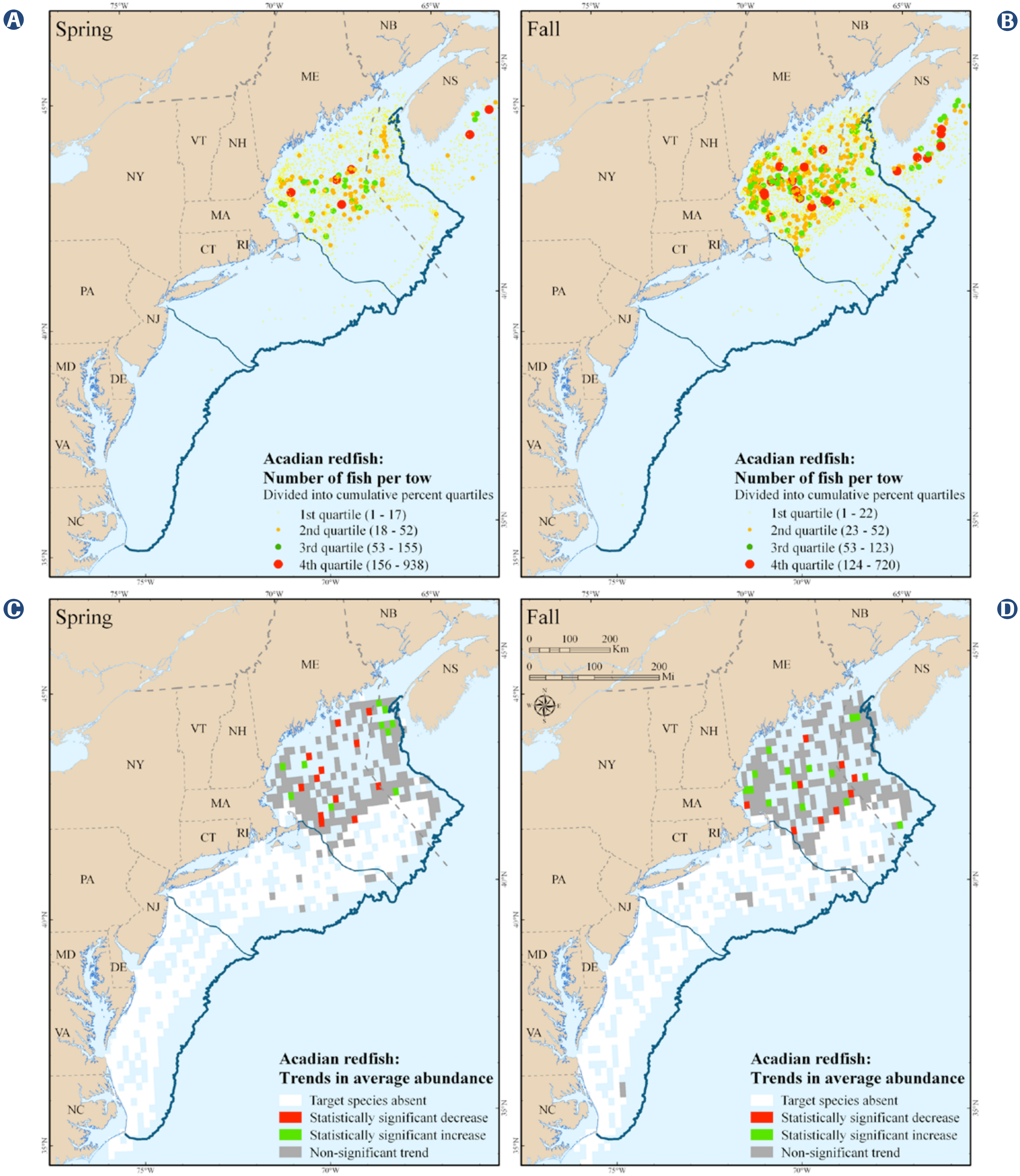


Figure 7-49. Trends in average abundance over 40 years for Acadian redfish during the spring and fall seasons.

Other Species of Interest

Acadian Redfish

Within the region, highest numbers of redfish occurred in the western and central portions of the Gulf of Maine and along the northern perimeter of Georges Bank and the Great South Channel (Figure 7-49a, b). Statistical analyses did not find significant trends across much of the range, though variable increasing and decreasing trends were observed at discrete locations within the Gulf of Maine in both United States and Canadian waters (Figure 7-49c, d). Weighted persistence analyses identified discrete and patchy locations scattered across much of the western and central portions of the Gulf of Maine including Jordan and Georges Basins, waters south of Digby, Nova Scotia, and the northern perimeter of Georges Bank as important (Figure 7-50).

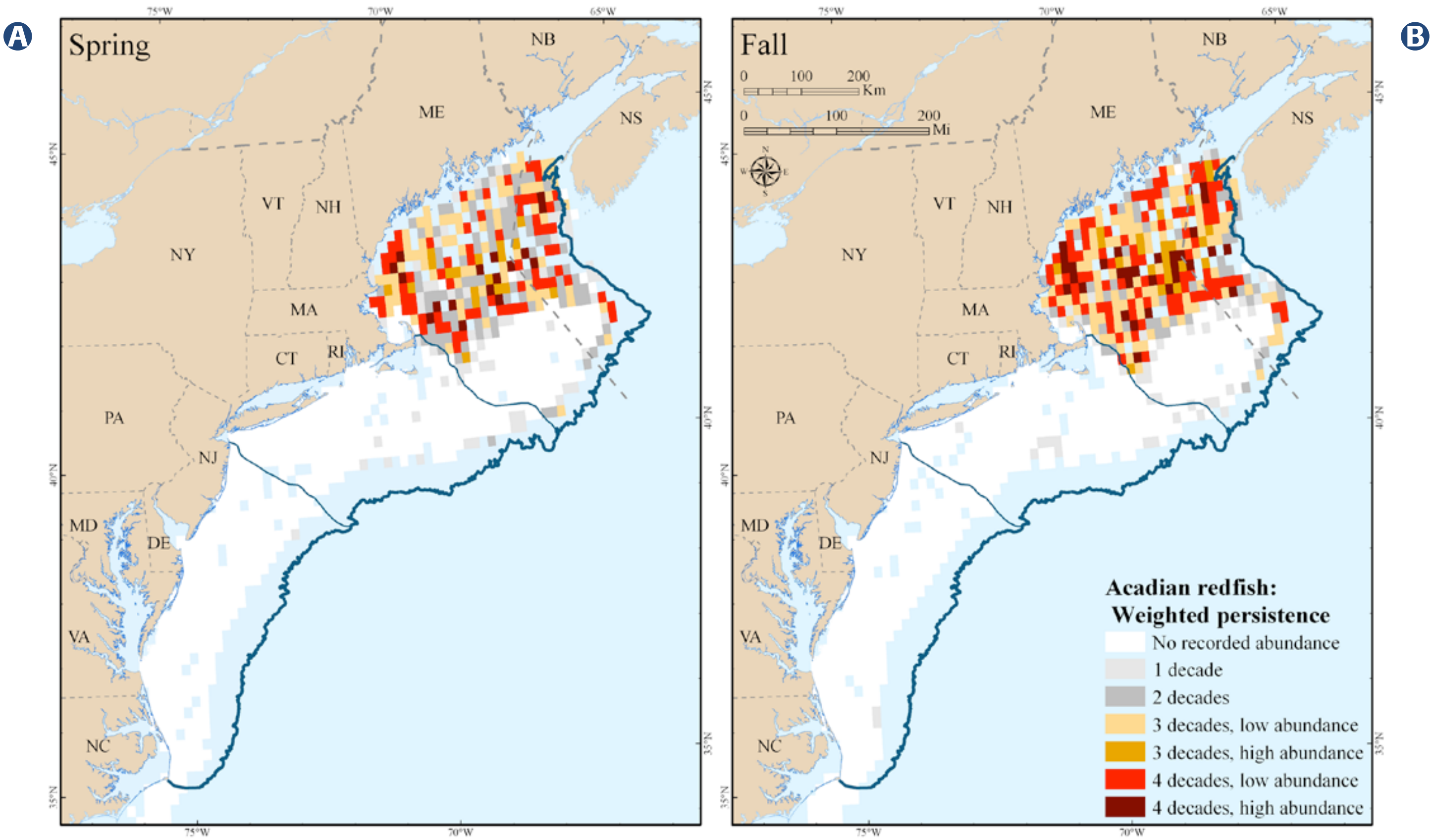


Figure 7-50. Areas with high persistence and abundance over 40 years for Acadian redfish during the spring and fall seasons.

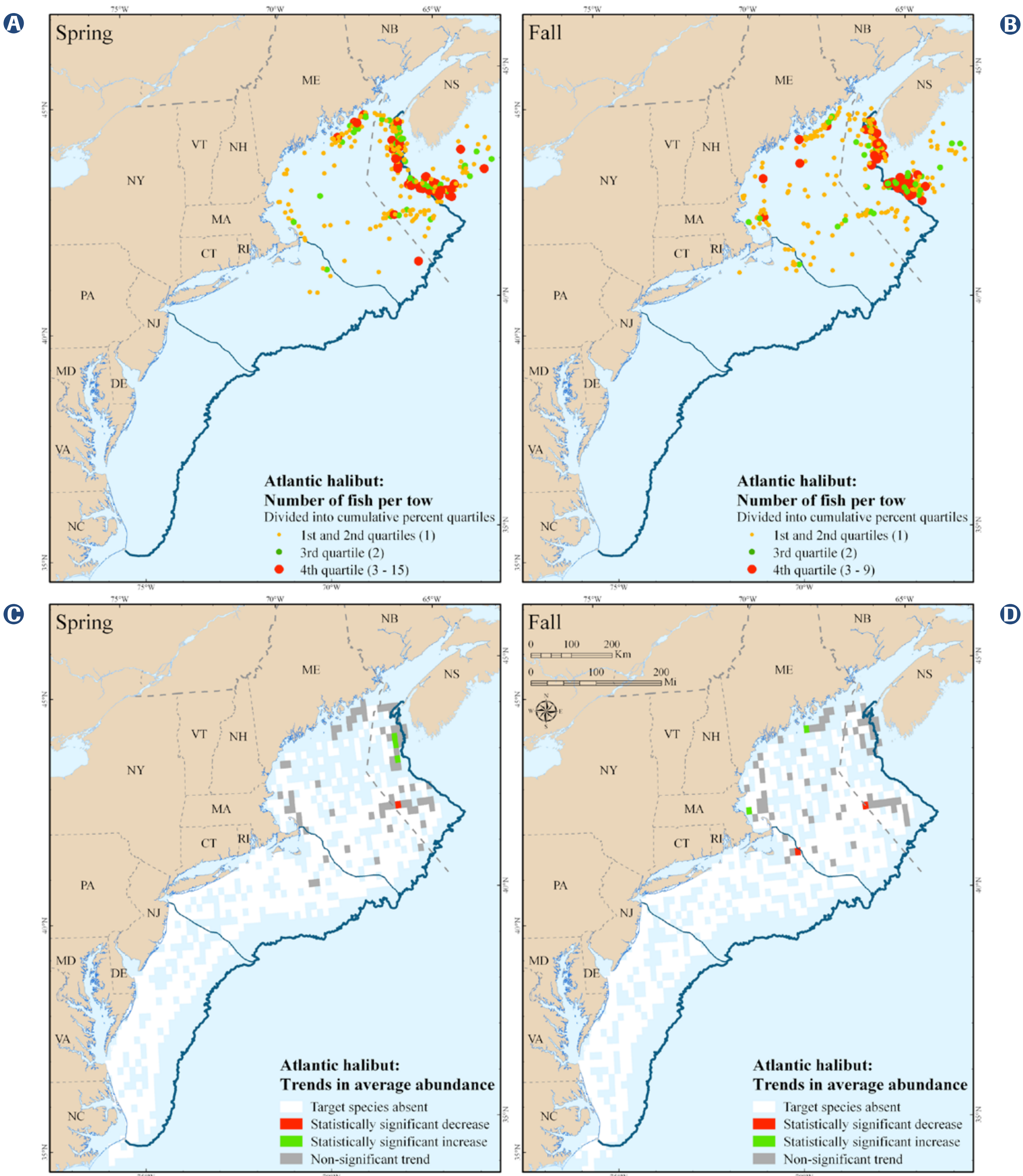


Figure 7-51. Trends in average abundance over 40 years for Atlantic halibut during the spring and fall seasons.

Atlantic Halibut

Within the region, the highest numbers of Atlantic halibut occurred along the coastal shelf in eastern Maine from Penobscot Bay to Grand Manan Banks, in Canadian waters from Digby, Nova Scotia to Browns Bank, and along the northern edge to the Northeast Peak of Georges Bank (Figure 7-51a, b). Statistical analyses did not identify significant trends across the species' range in the Gulf of Maine in either United States or Canadian waters (Figure 7-51c, d). Weighted persistence analyses for halibut identified coastal shelf waters in eastern Maine from Penobscot Bay to Jonesport, and Canadian waters from Digby, Nova Scotia to German Bank as important (Figure 7-52).

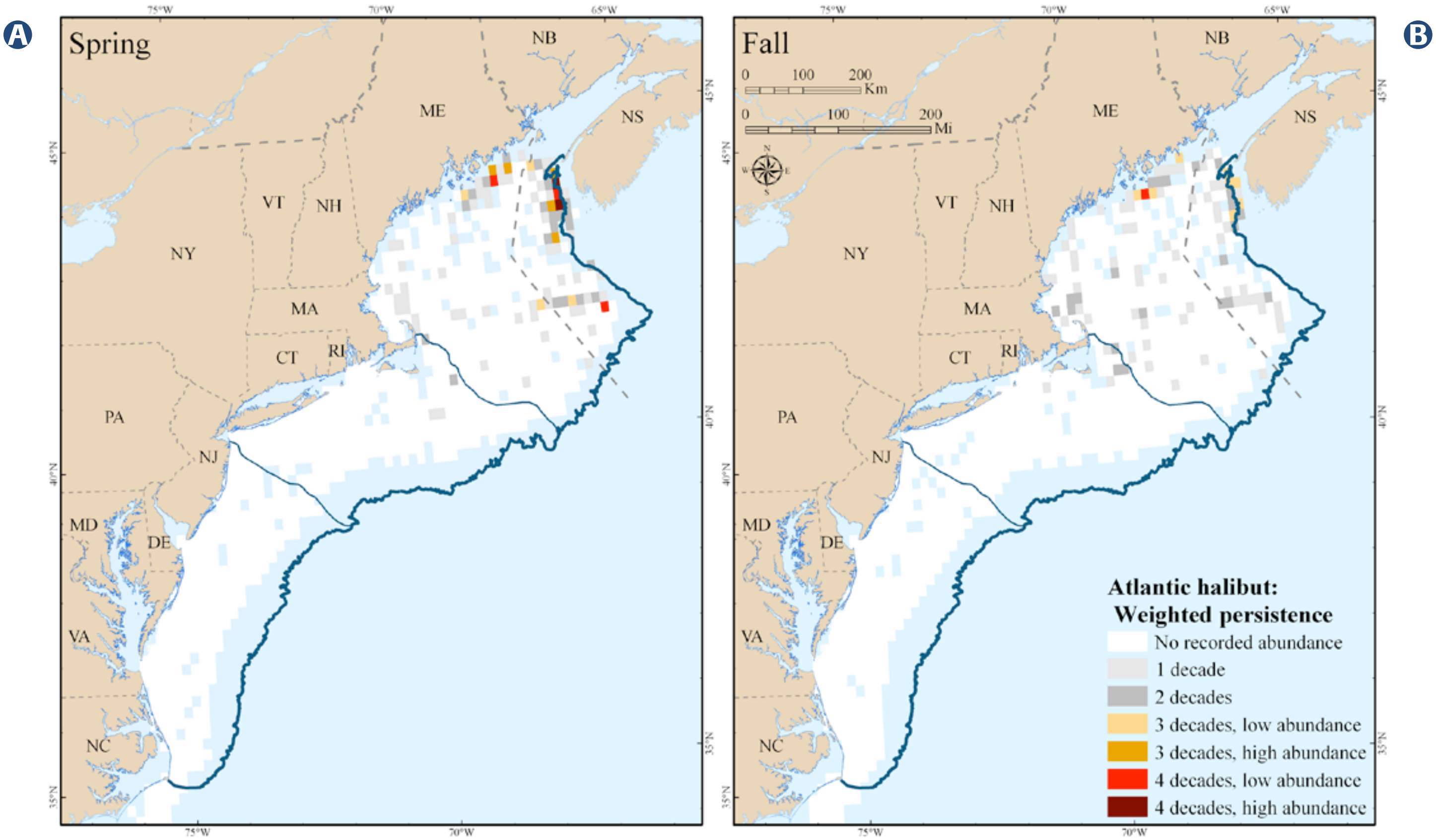


Figure 7-52. Areas with high persistence and abundance over 40 years for Atlantic halibut during the spring and fall seasons.

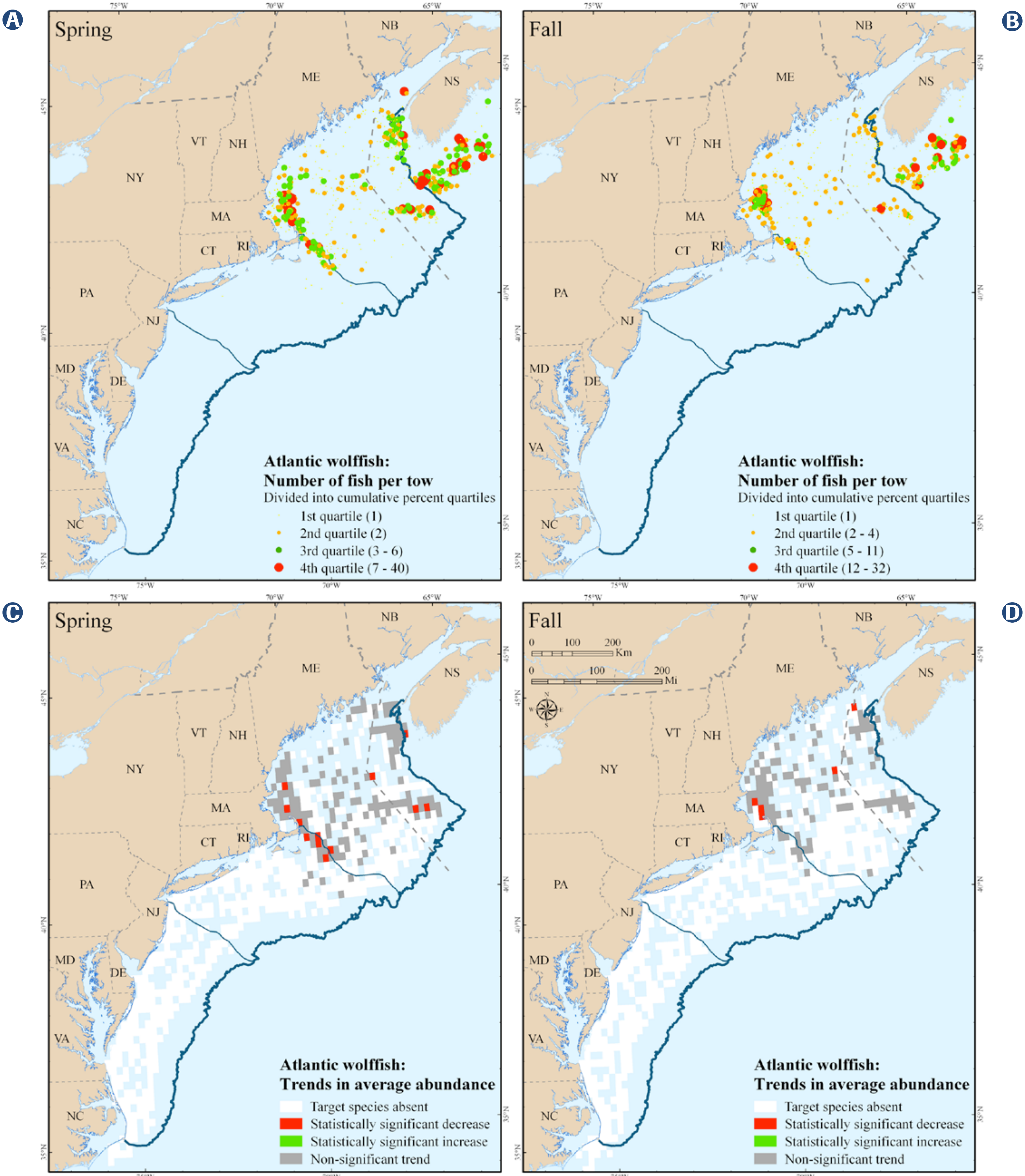


Figure 7-53. Trends in average abundance over 40 years for Atlantic wolffish during the spring and fall seasons.

Atlantic Wolffish

Within the region, highest numbers of Atlantic wolffish were found from the Great South Channel to the Jeffreys Ledge and Stellwagen Bank area, select locations in the central Gulf of Maine, Canadian waters from Digby, Nova Scotia to Browns Bank and along the Scotian Shelf, and the Northeast Peak of Georges Bank (Figure 7-53a, b). Statistical analyses identified declining trends for wolffish in the areas where they are still present in the Gulf of Maine and Georges Bank, most notably from the Great south Channel to the Stellwagen Bank/Jeffreys Ledge area (Figure 7-53c, d). Weighted persistence analyses for wolffish identified the area from Provincetown, Massachusetts to the Jeffreys Ledge and Stellwagen Bank area in the Gulf of Maine, waters off the southern tip of Nova Scotia including German Bank, and along the northern edge and Northeast Peak of Georges Bank as important (Figure 7-54).

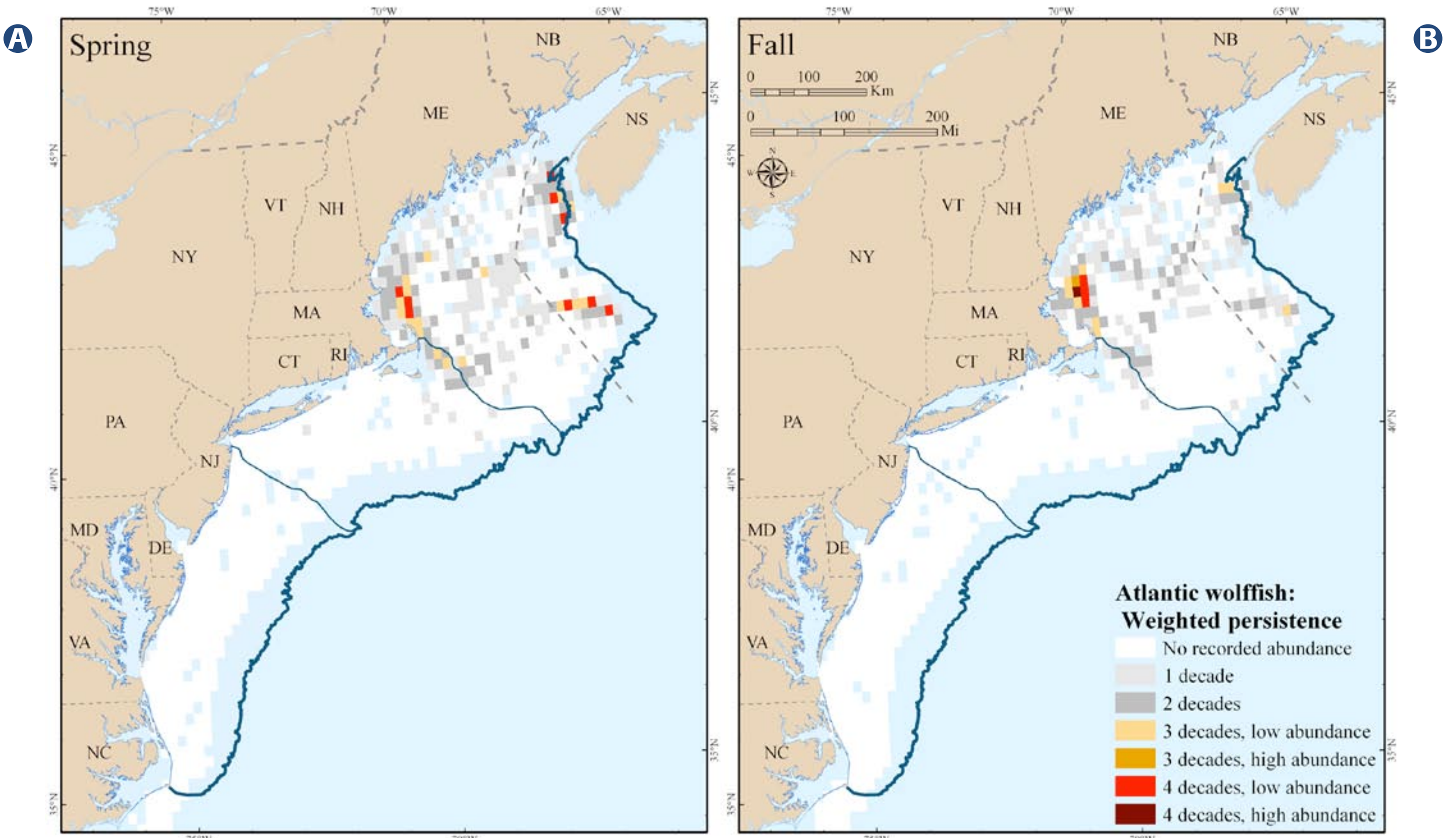


Figure 7-54. Areas with high persistence and abundance over 40 years for Atlantic wolffish during the spring and fall seasons.

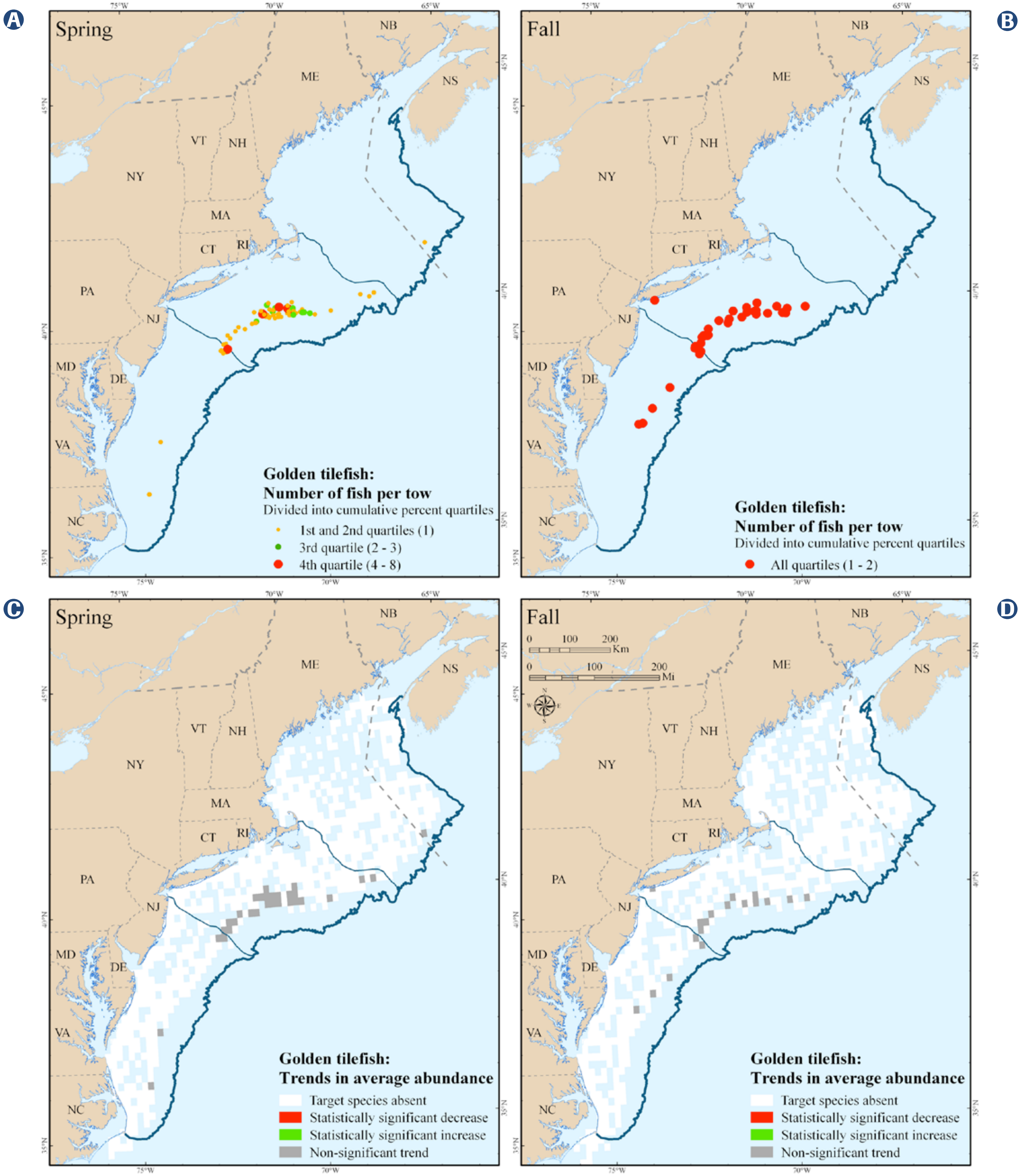


Figure 7-55. Trends in average abundance over 40 years for golden tilefish during the spring and fall seasons.

Golden Tilefish

Within the region, golden tilefish occurred along the Continental Shelf in the Southern New England and mid-Atlantic areas, with highest numbers found in deeper waters along the shelf/slope break off Long Island Sound to Chincoteague Bay, Virginia (Figure 7-55a, b). Statistical analyses did not identify significant trends for tilefish (Figure 7-55c, d). Weighted persistence analyses identified a narrow band of waters along the shelf/slope break from Long Island to the Hudson/Raritan Estuary as important (Figure 7-56). This area is consistent with the location of the tilefish Habitat Area of Particular Concern designated by MAFMC and NMFS.

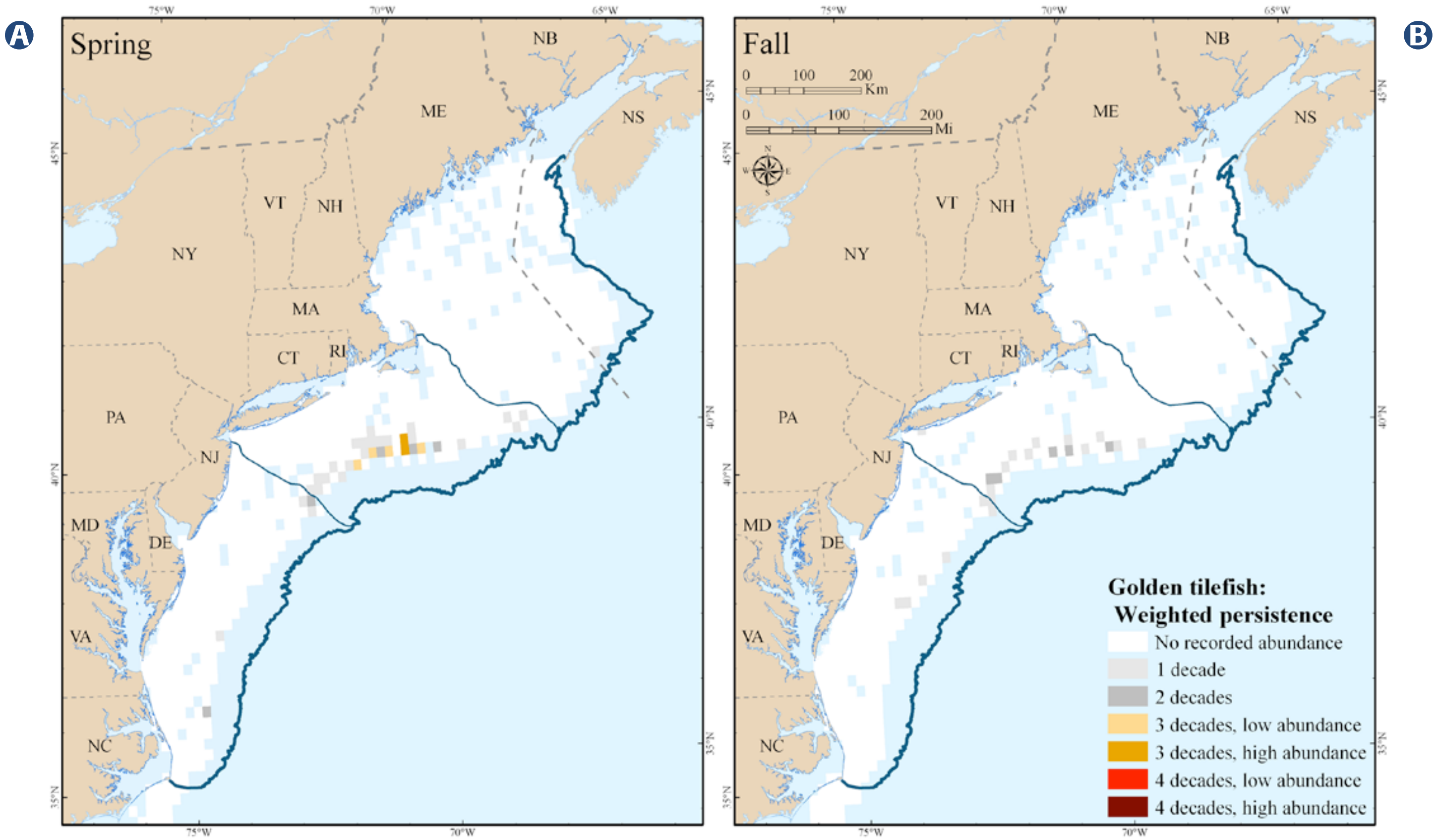


Figure 7-56. Areas with high persistence and abundance over 40 years for golden tilefish during the spring and fall seasons.

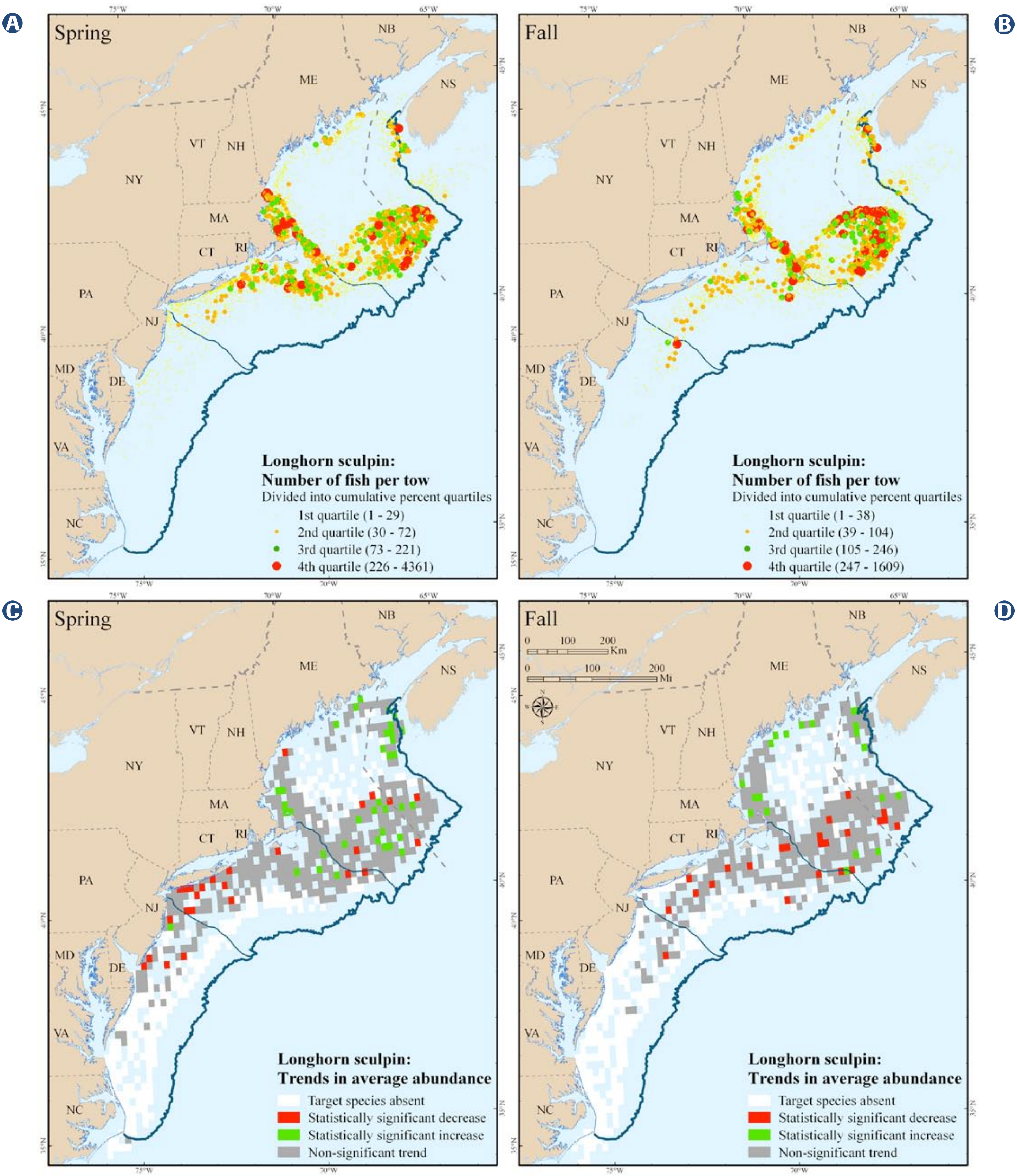


Figure 7-57. Trends in average abundance over 40 years for longhorn sculpin during the spring and fall seasons.

Longhorn Sculpin

Within the region, longhorn sculpin occurred from the Bay of Fundy and off the southern tip of Nova Scotia south to Virginia, with highest numbers found in the western Gulf of Maine, along the flanks of Georges Bank, and south to Barnegat Bay, New Jersey (Figure 7-57a, b). Statistical analyses identified generally increasing trends in the Gulf of Maine, a mix of increasing and decreasing trends on Georges Bank, and decreasing trends across much of the Southern New England/Mid-Atlantic (Figure 7-57c, d). Weighted persistence analyses identified Massachusetts Bay, the Great South Channel and the eastern portions of Georges Bank including the Northeast Peak and Northeast Channel, and waters off the southern tip of Nova Scotia as important (Figure 7-58).

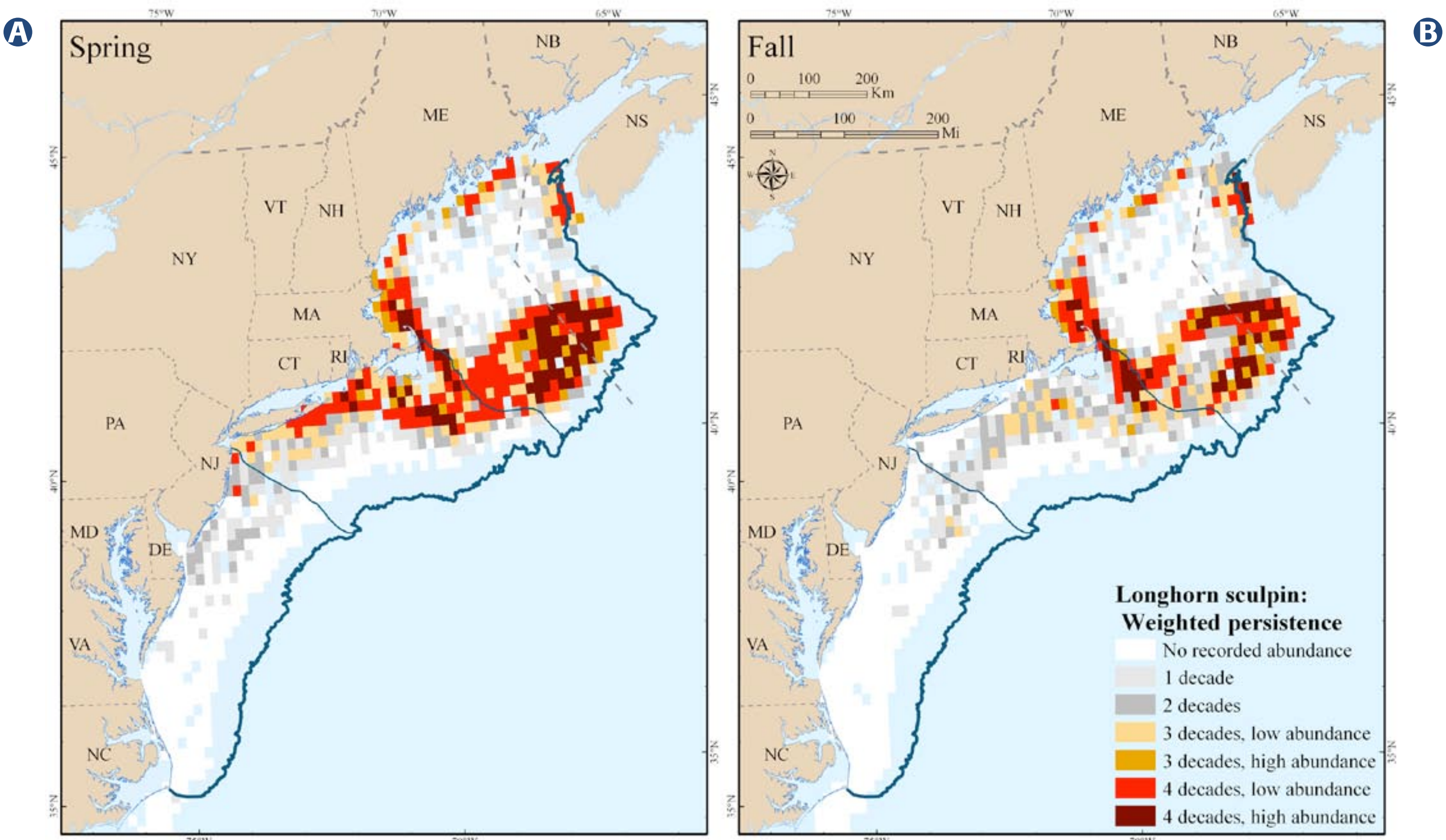


Figure 7-58. Areas with high persistence and abundance over 40 years for longhorn sculpin during the spring and fall seasons.

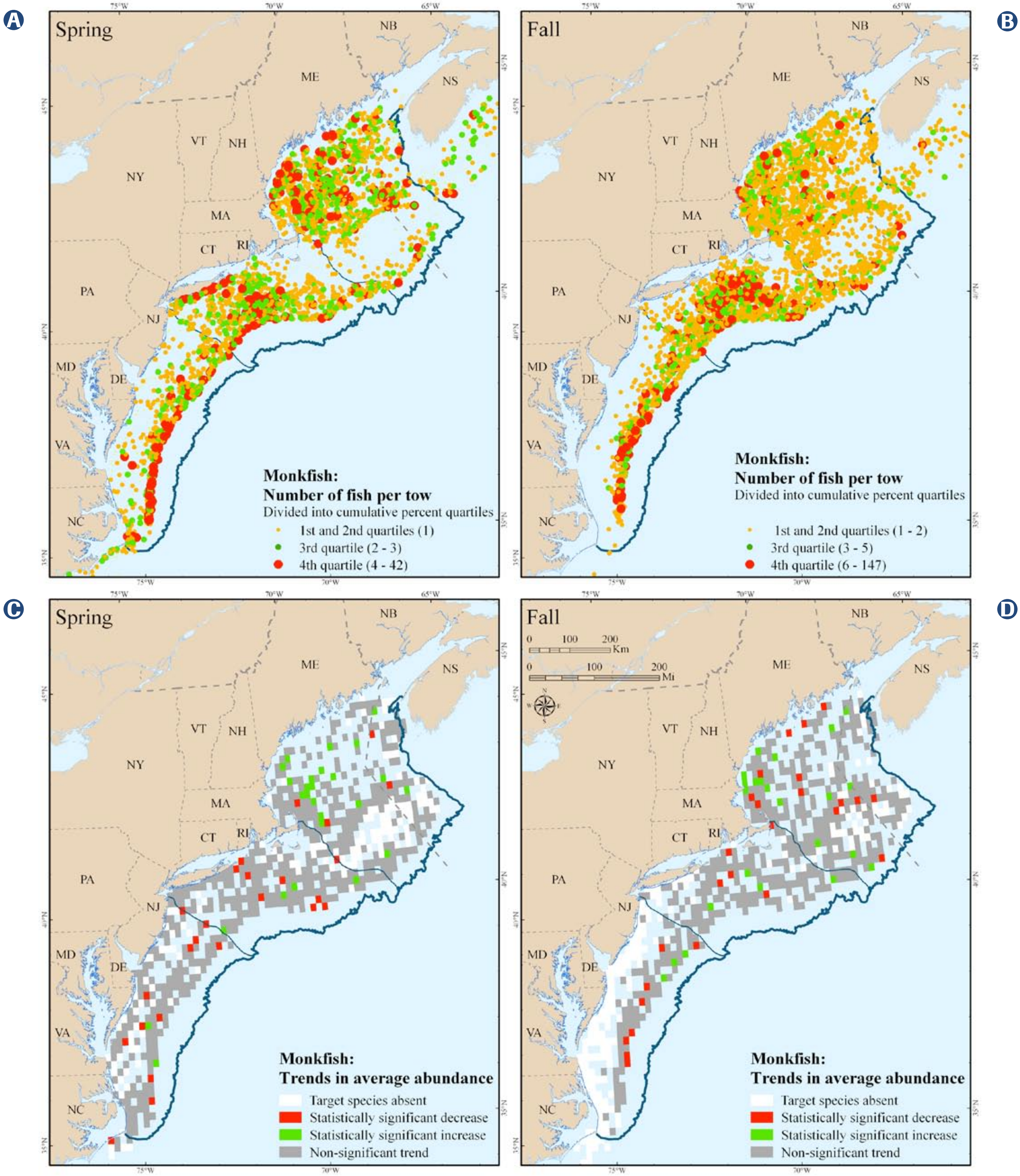


Figure 7-59. Trends in average abundance over 40 years for monkfish during the spring and fall seasons.

Monkfish

Within the region, monkfish was common in both inshore and offshore areas of the Gulf of Maine and ubiquitous across the Continental Shelf in the Mid-Atlantic Bight (Figure 7-59a, b). Highest numbers occurred throughout the Gulf of Maine, off Long Island Sound in Southern New England, and along the shelf/slope break from New Jersey to Pamlico Sound. Statistical analyses identified variable trends for monkfish, with a mix of increasing and decreasing trends observed throughout the range depending on location (Figure 7-59c, d). Weighted persistence analyses identified deeper waters in the Gulf of Maine from Jeffreys Ledge to the Cashes Ledge area extending to Franklin Swell, shelf waters south of Nantucket and east of the Hudson/Raritan Estuary, and waters along the shelf/slope break from Chincoteague Bay to Albemarle Sound as important (Figure 7-60).

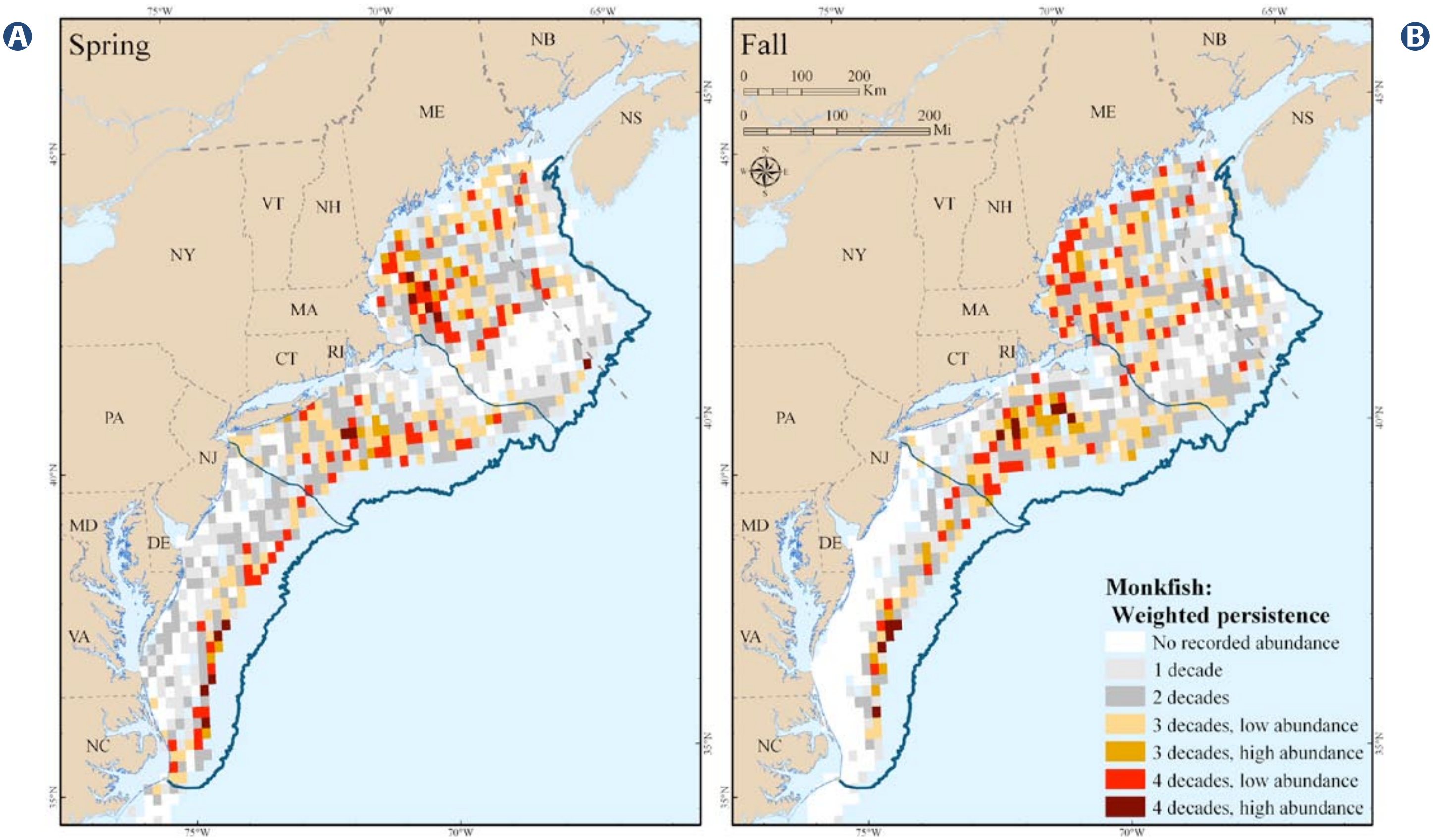


Figure 7-60. Areas with high persistence and abundance over 40 years for monkfish during the spring and fall seasons.

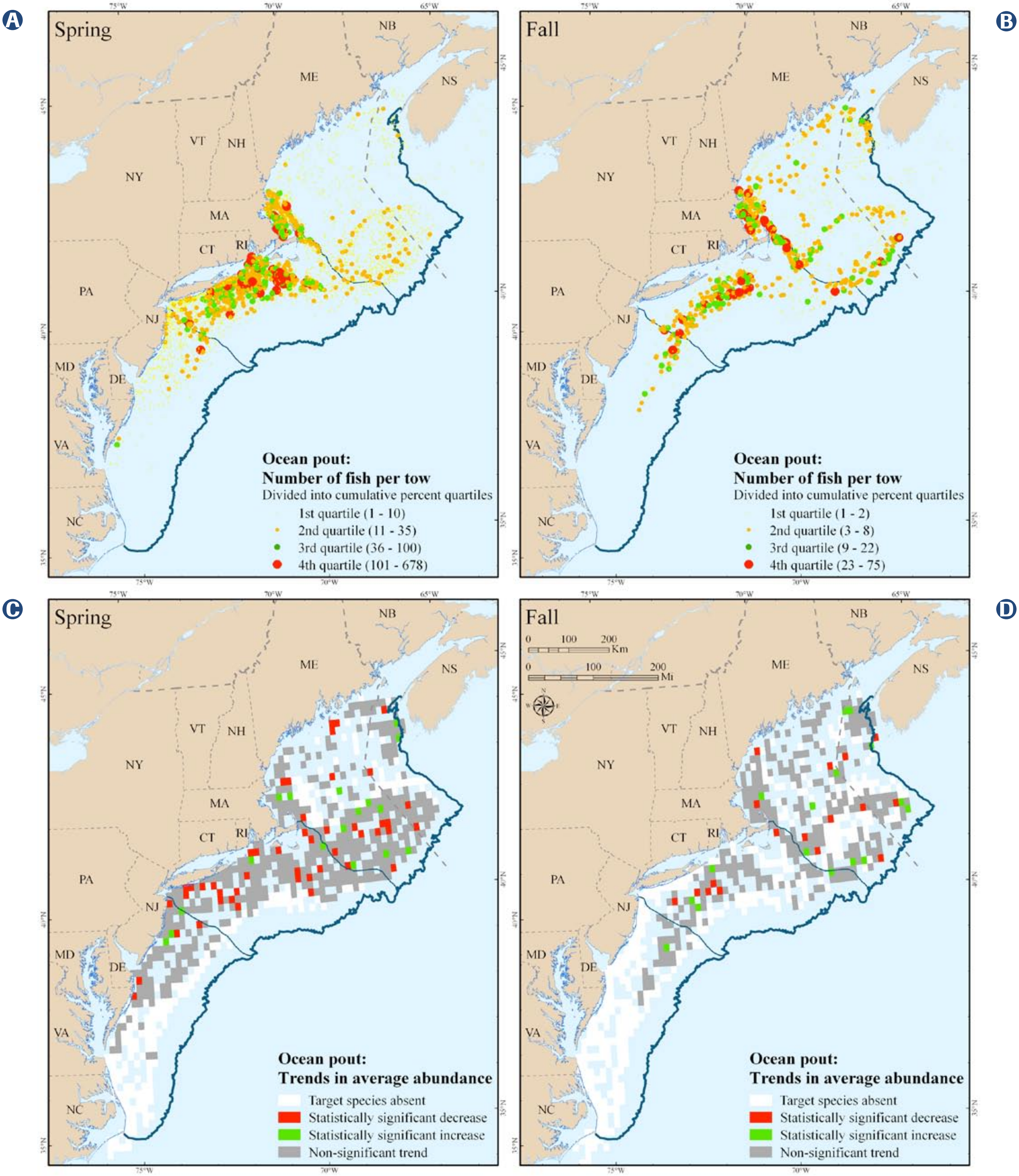


Figure 7-61. Trends in average abundance over 40 years for ocean pout during the spring and fall seasons.

Ocean Pout

Within the region, ocean pout were found in highest numbers along a narrow band from Barnegat Bay, New Jersey through Narragansett Bay to south of Nantucket in Southern New England; in Cape Cod Bay, Massachusetts Bay, and Stellwagen Bank in the western Gulf of Maine; and along the southern flank of Georges Bank (Figure 7-61a, b). Statistical analyses identified variable trends across the species' range, with declining trends generally observed in Southern New England and a mix of declining and increasing trends in the Gulf of Maine and Georges Bank depending on location (Figure 7-61c, d). Weighted persistence analyses identified nearshore waters in Massachusetts Bay from Stellwagen Bank to the Great South Channel and waters south of Narragansett Bay to Sandy Hook, New Jersey as important (Figure 7-62).

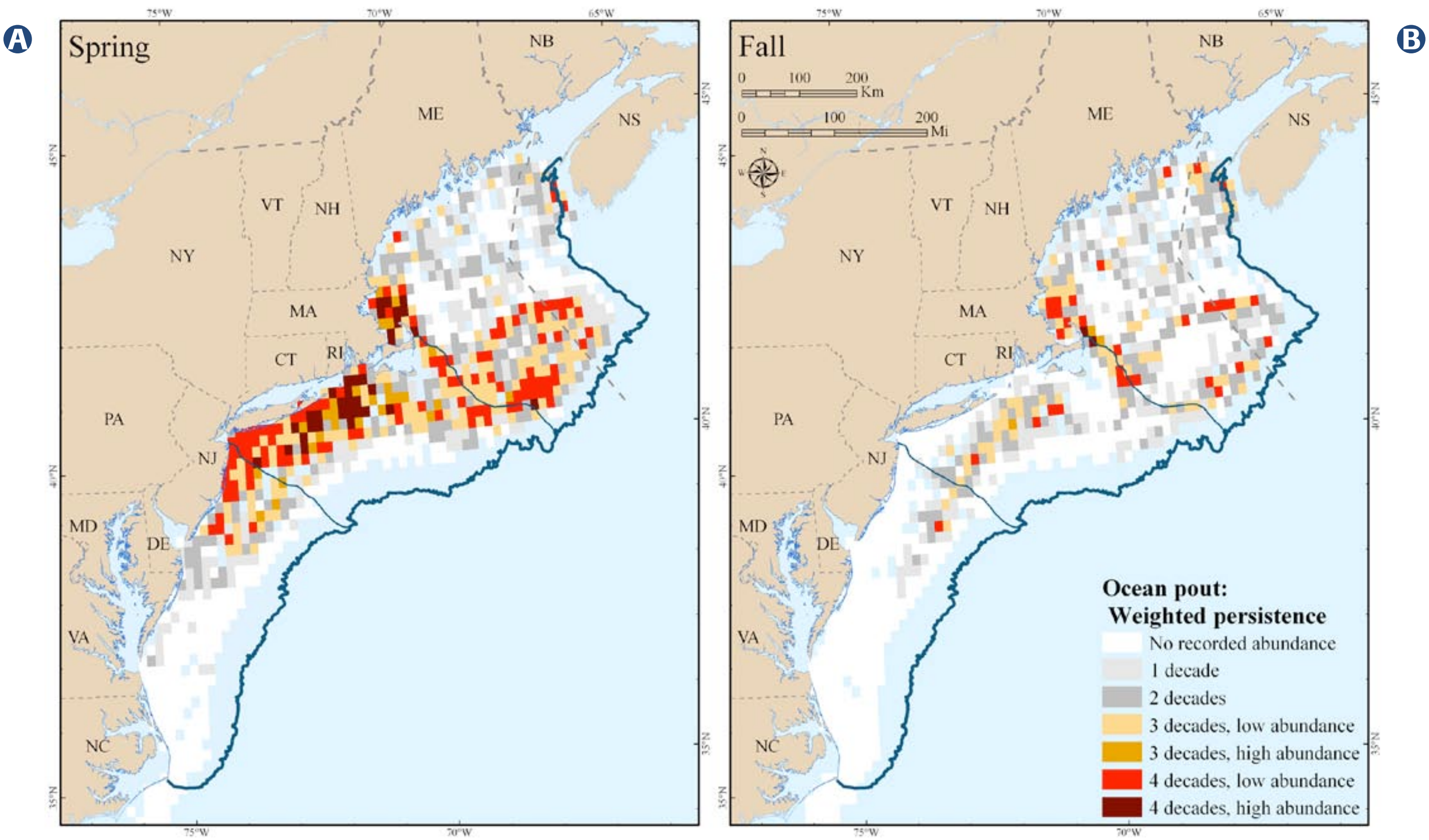


Figure 7-62. Areas with high persistence and abundance over 40 years for ocean pout during the spring and fall seasons.

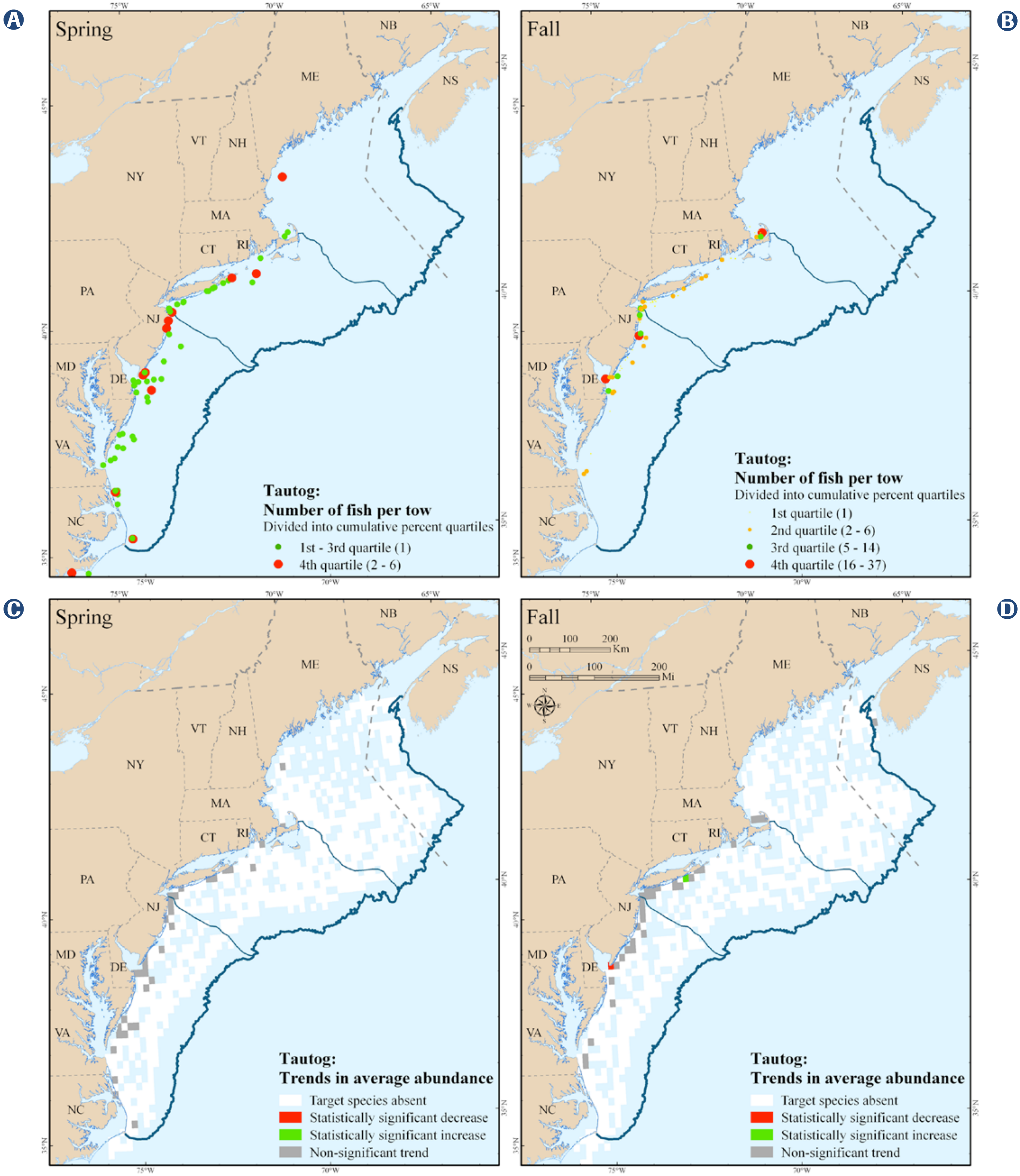


Figure 7-63. Trends in average abundance over 40 years for tautog during the spring and fall seasons.

Tautog

Within the region, highest numbers of tautog were found from Chesapeake Bay to Cape Cod, with lesser numbers observed in the Gulf of Maine in and around Massachusetts Bay and the Jeffreys Ledge/Stellwagen Bank area (Figure 7-63a, b). Statistical analyses did not identify significant trends in abundance over the species' range (Figure 7-63c, d).Weighted persistence analyses for tautog identified nearshore waters from the Hudson/Raritan Estuary to the mouth of Delaware Bay as important (Figure 7-64).

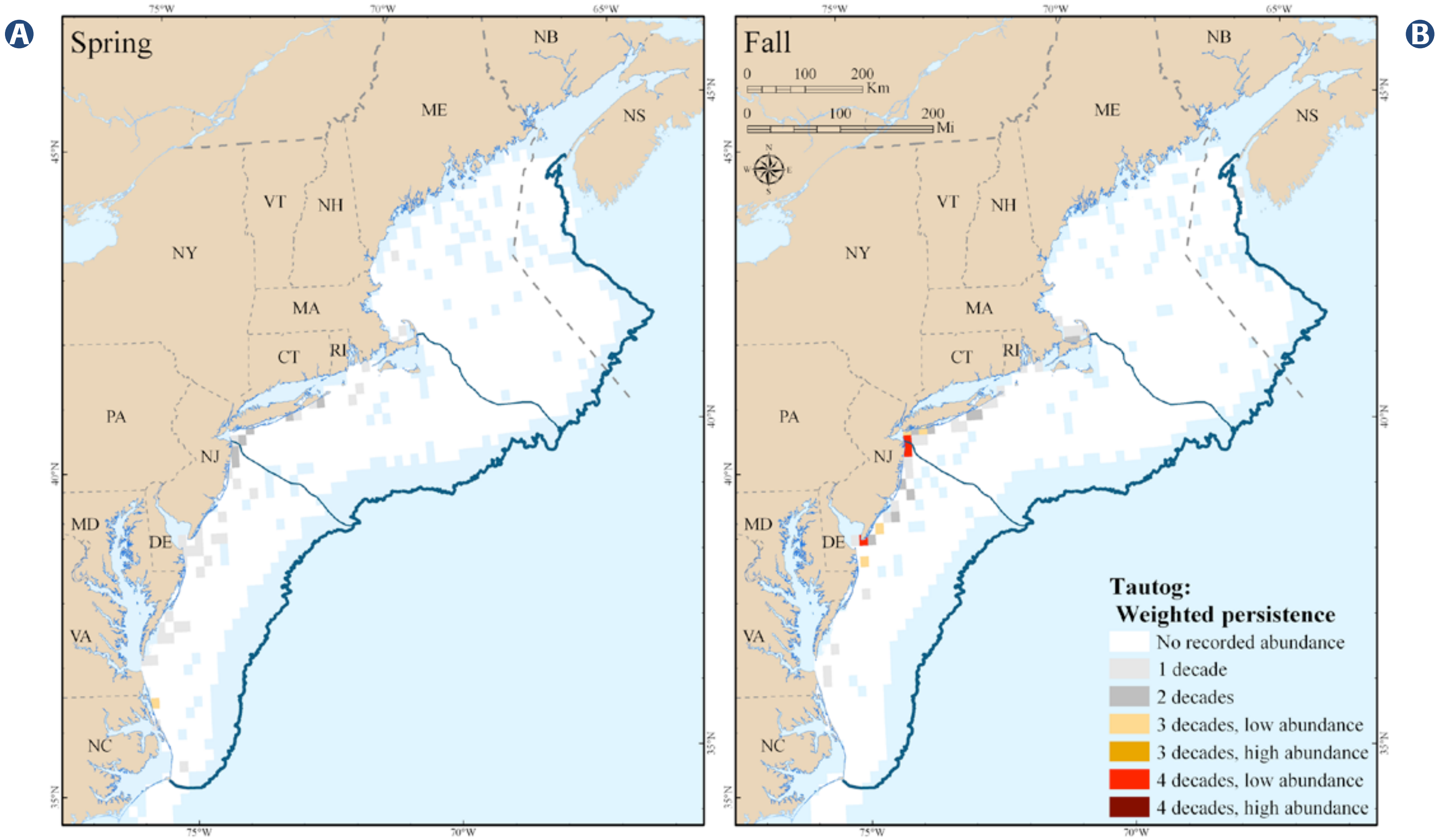


Figure 7-64. Areas with high persistence and abundance over 40 years for tautog during the spring and fall seasons.

Human Interactions

Humans interact with the species included in the demersal fish assemblage in a number of ways that either directly or indirectly influences their relative abundance and distribution within the region. While the degree and intensity of interaction varies significantly depending on species and location, the following human interactions have been identified as important within the region: 1) fisheries-related interactions, 2) climate change, 3) nearshore habitat loss and degradation, 4) energy development, 5) power plants, and 6) invasive species.

Fishing-related interactions

Ecosystem level effects of fishing are well documented in the scientific literature, including changes in food web interactions and fluctuations in ecosystem productivity. Stock biomass and abundance have been reduced by fishing pressure, and the size structure of populations has been altered (NRC 2006). Within the region, species included in the demersal fish assemblage have been directly and indirectly impacted by both commercial and recreational fisheries for well over a century. In fact, many were fished by natives before colonists arrived hundreds of years ago. The most recent peer-reviewed stock assessments identified twelve stocks of demersal species in the assemblage as overfished (population size is less than one half of the current scientific estimate of a "healthy" population) and ten as subject to overfishing (fishing mortality rates are higher than current estimates of "sustainable" levels) (NMFS 2009b). Directed fisheries on a number of demersal fish have resulted in significant changes in overall abundance, distribution, and life history characteristics. Impacts include decreases in overall spawning stock biomass, truncated age structure (removal of the oldest individuals from the population), and changes in age and length at sexual maturity. Truncated age structures in which there are relatively few older fish have been observed for several species, including witch flounder, Georges Bank Atlantic cod, and Georges Bank yellowtail flounder most recently (NEFSC 2008; TRAC 2009a; TRAC 2009b). In addition, significant reductions in age and length at sexual maturity have been observed for many species including Atlantic cod, black sea bass, golden tilefish, pollock, witch flounder (Lough 2005; Cargnelli et al. 1999a; Steimle et al. 1999a; Cargnelli et al. 1999b; Drohan. et al. 2007). Reduction in age and length at sexual maturity is of particular concern in light of the growing body of scientific evidence that larger, older fish produce more eggs and viable offspring than younger smaller fish (Berkeley et al. 2004). Recreational fishing is also a significant source of mortality, comprising a significant portion of the overall take for many of the demersal species, including Atlantic cod in the Gulf of Maine, black sea bass, scup, spot, summer flounder, tautog, weakfish, and winter flounder (NEFSC 2008; ASMFC 2009).

Benthic habitats for many species included in the assessment are known to be vulnerable to impacts from fishing gear, particularly bottom-tending mobile gear such as trawls and dredges. Numerous studies have documented a variety of impacts that trawls and dredges can have on sensitive marine habitats, including loss of physical features, loss of structure-forming organisms, reduction of overall habitat complexity, and alteration of the detailed physical structure of the seafloor (NRC 2002). The New England Fisheries Management Council (NEFSC) found that habitats for juvenile and/or adult life stages of 23 of the demersal fish species included in this assessment are moderately or highly vulnerable to impacts from otter trawls and dredges (NEFMC 2004). In addition, Atlantic States Marine Fisheries Commission (ASMFC) identified trawling and dredging as threats to habitats for tautog, black sea bass, and summer flounder (ASMFC 2009).

Climate change (water temperatures, currents, and primary production)

Another anthropogenic (human-caused) impact of increasing concern is the set of long-term effects resulting from global climate change, including increasing water temperatures, ocean acidification, and changes in currents, circulation patterns, and overall ocean productivity. The geographic distribution of many of the demersal species included in this assessment is heavily influenced by bottom water temperatures. In addition, spawning events, seasonal migrations, transformation from egg to larval phases, and juvenile survival rates are also temperature-dependent (NMFS 2009c). While the degree to which climate change will influence these critical life stages is unclear, the topic is of growing concern in the region and beyond.

Several studies have been conducted which document shifts in species range in response to temperature changes, while others have been undertaken to predict potential future shifts. For example, Mountain and Murawski (1992) observed latitudinal shifts in Gulf of Maine groundfish distributions in response to temperature changes. University of Rhode Island researchers have also observed long-term shifts in species composition (from vertebrates to invertebrates and from benthic to pelagic species) within Narragansett Bay and surrounding waters over the past 50 years (Collie et al. 2008). Smaller warm-water species have increased while cool-water species have decreased; these changes were attributed to a variety of factors, including climate change and increasing water temperatures. Lastly, Fogarty et al. (2008) looked at potential shifts in the range of Atlantic cod and concluded that the probability of catching cod decreases markedly with increasing bottom water temperatures. They also noted that reduced juvenile Atlantic cod survival caused by increasing water temperatures could significantly impact long-term recruitment trends.

Energy development

As interest in alternative and renewable energy production grows in the United States, energy development in marine water, including oil and gas exploration and extraction, wind and tidal energy facilities, and liquefied natural gas (LNG) terminals, are emerging as an important human interaction. Impacts from oil and gas activities include direct habitat disturbance from exploration and development activities and oil spills during production and transportation. Impacts from wind and tidal energy include direct habitat disturbance during construction, alteration of hydrologic regimes, and noise. Impacts from LNG development include direct habitat impacts from the construction of offloading facilities and entrainment in water withdrawals associated with LNG conversion from liquid to a gaseous state (Johnson et al. 2008).

Potential impacts from oil and gas development are most likely to occur on Georges Bank and along the Continental Shelf in the Mid-Atlantic because these areas are richest in these resources, and proposals for extraction have already been made for these areas. Several wind farms and tidal energy facilities have been proposed within the region, though very few facilities have actually been permitted and constructed. Two LNG terminals were recently sited in the waters of Massachusetts Bay near Gloucester.

Power plants

Coastal power plants have the potential to impact demersal fish species in a number of ways, including by increasing water temperatures as a result of discharging cooling water and increasing direct mortality through entrainment and impingement in cooling water intake systems (Johnson et al. 2008). Interactions will be dependent on the location and design of cooling intake and discharge facilities, and the degree to which individual species utilize nearshore coastal waters. The ASMFC has raised concerns about increased water temperatures, and impingement in cooling water intakes has been specifically identified as a problem for a number of species including winter flounder, tautog, and weakfish.

Nearshore habitat degradation

Nearshore habitat degradation is a pervasive problem throughout much of the region, particularly in the central and southern portions. Habitat degradation takes a number of forms, including direct habitat loss due to coastal development and conversion, water quality degradation from point and non-point source pollution, dredging and dredge spoil placement, dredging for beach nourishment projects, and hydrological modifications resulting from ditching and channelization. The ASMFC has identified these types of nearshore habitat degradation as significant threats to many of the species they manage, including spot, weakfish, tautog, scup, black sea bass, summer flounder, and winter flounder (ASMFC 2009).

Invasive species

Introduction and transportation of non-native invasive species is another human impact of growing concern. Invasive species have altered benthic habitats and food web dynamics at a number of locations within the region. Two species of particular recent concern are Codium and Didemnum. Codium is an invasive green alga (commonly known as dead man's fingers) that has taken hold in many nearshore coastal waters within the region from the Gulf of St. Lawrence to North Carolina. Codium is a dominant species in some subtidal zones and can radically alter subtidal community composition, structure, and function (Levin et al. 2002). The rapid growth of this species and its ability to regenerate from broken fragments assist in its ability to outcompete native plant species like kelp beds, the primary shelter for many finfish and invertebrates.

Didemnum is an invasive tunicate that smothers benthic organisms; it has been found in many parts of the region, causing particular concern by its recent spread across a significant portion of prime fishing grounds on Georges Bank. While extensive studies on the effect of *Didemnum* invasion of seafloor habitats have not been completed to date, evidence suggests it can overgrow scallops, mussels, other sessile species, and gravel potentially creating a barrier between demersal fish and prey items including worms and bivalves (Bullard et al. 2007). In addition, mat surfaces may reduce the area of the seabed suitable for settlement of larvae of other benthic species, including sea scallops (Valentine 2007).

Management and Conservation

Regulatory Authorities

Most of the species included in the demersal fish group are formally managed by one of three fishery management entities: the NEFMC, the Mid-Atlantic Fisheries Management Council (MAFMC), or the ASMFC. Regulatory authority for the NEFMC and the MAFMC is provided by the Magnuson Stevens Fishery Conservation and Management Act as amended in 2006. The Magnuson Stevens Act delegates responsibility for developing fishery management plans (FMP) to the regional councils, but those plans must be approved by the NMFS. Prior to approval and promulgation of implementing regulations, NMFS must review the plans submitted by the regional council and ensure they comply with ten National Standards included in the Magnuson Stevens Act. These standards require that regulations achieve optimum yield while preventing overfishing, rebuild overfished populations, minimize adverse impacts to essential fish habitat caused by fishing activities, minimize bycatch and discard of non-target species, and minimize adverse socio-economic impacts on fishing dependent communities consistent with the other requirements mentioned above.

Regulatory authority for the ASMFC is provided by the Atlantic Coast Fisheries Cooperative Management Act as amended in 1993. First created in 1943, the ASMFC includes representatives from the 15 coastal states on the Atlantic seaboard. Each state appoints three commissioners, representing state fisheries management agencies, state legislators and a member of the public. The ASMFC is responsible for developing management plans for fisheries occurring primarily in state waters (from 0-3 miles offshore). The ASMFC focuses on five major areas interest: 1) Interstate Fishery Management Plans, 2) Research and Statistics, 3) Fisheries Science, 4) Habitat Conservation, and 5) Law Enforcement.

Current Conservation Efforts

Eleven of the species included in the demersal fish group are managed by the NEFMC under the Northeast Multispecies Fisheries Management Plan (Acadian redfish, American plaice, Atlantic cod, Atlantic halibut, haddock, ocean pout, pollock, white hake, winter flounder, witch flounder, and yellowtail flounder). In 2004, the NEFMC and NMFS implemented a formal rebuilding program for many of these species through Amendment 13 to the Multispecies FMP. The rebuilding plan includes implementation of target fishing mortality rates, biomass targets, measures to minimize fishing-related impacts to Essential Fish Habitat, and rebuilding schedules. Most species are scheduled to be rebuilt by 2014, though some have longer rebuilding schedules based on stock conditions and biological constraints (NEFMC 2004). The NEFMC and NMFS have implemented a suite of management measures as part of the rebuilding plans, including restrictions on days at sea, closed areas, gear requirements, and trip limits. Major revisions to the groundfish management plan, including a transition away from days at sea management to "catch shares" and community sectors, are scheduled to take effect in May 2010.

NEFMC implemented the Skate Fishery Management Plan in 2003, which includes all five skate species that are part of this assessment. The FMP includes provisions for mandatory reporting by species; possession prohibitions on barndoor, thorny, and smooth skates; trip limits for winter skate; and a suite of measures in other FMPs to aid the recovery of overfished skate species. Barndoor and thorny skate have also been identified as Species of Concern by NMFS. This designation raises the profile of management concerns for the species but does not mandate additional regulations beyond those implemented through the NEFMC management plan.

Commercial and recreational fisheries for summer flounder, scup, and black sea bass have been jointly managed by the ASMFC and the MAFMC since 1997. The FMP contains several major regulatory provisions, including a total annual quota, minimum size limits, bag limits, and quotas for recreational fisheries, and annual quotas, minimum fish size limits, minimum mesh requirements for trawls, and pot and trap specifications for commercial fisheries.

Spot, croaker, weakfish, and tautog are managed under individual fishery management plans administered by the ASMFC. The Atlantic croaker FMP (last amended 2005) includes goals related to spawning stock biomass and habitat protection, fishing mortality targets, and provisions for regional management, but does not include specific measures restricting commercial or recreational harvest. The tautog FMP (last amended 2007) is focused on reducing fishing mortality by both commercial and recreational fisheries and includes minimum fish sizes, possession limits, gear restrictions, and closed seasons.

The weakfish FMP (last amended 2002) includes overfishing definitions, a goal to restore weakfish population age structure, and a goal to expand geographic range of the species. Management measures include size and possession limits for the recreational fishery and a combination of size limits, gear restrictions for bycatch reduction, and possible seasonal and/or year-round closed areas for the commercial fishery. The spot FMP (last amended 2002) seeks to improve the quality of information on species distribution and abundance and does not include mandatory management measures.

Golden tilefish are managed as two distinct stocks in the United States, one encompassing the Mid-Atlantic Bight south to Cape Hatteras, and the other from Cape Hatteras to the Gulf of Mexico. Implemented by the MAFMC in November of 2001, the tilefish FMP includes provisions for limited entry in the commercial fishery and a system for dividing total allowable landings among three categories.

Monkfish are jointly managed by the NEFMC and the MAFMC. Regional differences in prosecution of the monkfish fishery resulted in management of the species as two stocks (northern and southern), with the northern stock encompassing the Gulf of Maine to northern Georges Bank and the southern stock encompassing central Georges Bank to the Mid-Atlantic Bight. The primary goals of the Monkfish FMP are to end and prevent overfishing and to optimize yield and economic benefits to various sectors involved in the fishery. Current regulatory measures vary with permit type, but include limited access, days at sea limits, mesh size restrictions, trip limits, and minimum size limits.

Spiny dogfish in federal waters are jointly managed by the NEFMC and the MAFMC. The spiny dogfish FMP was first adopted in 1998 and currently includes a female spawning biomass rebuilding target, target fishing mortality rate, and annual quotas on overall catch. Spiny dogfish in state waters are managed by the ASFMC.

Red hake and silver hake are managed under the Small Mesh Multispecies FMP administered by NEFMC. Amendment 12 to this FMP established limited access in the fishery and retention limits based on net mesh size, adopted overfishing definitions for northern and southern stocks, identified essential fish habitat for all life stages, and set requirements for fishing gear.

Northern sea robin, longhorn sculpin, Atlantic wolffish, and cusk are not included in any regional fishery management plan, although the NEFMC is currently considering adding wolffish and cusk to the Northeast Multispecies FMP.

Species Accounts

Gadids

Inhabiting circumpolar to temperate waters mainly in the northern hemisphere, gadids are primarily marine fishes, but a few inhabit estuaries and one is restricted to freshwater (Collette and MacPhee 2002). Gadids are characterized by the presence of three dorsal fins and two anal fins and, sometimes, barbels on their chin used in locating food. Gadid species included in this assessment are Atlantic cod (*Gadus morhua*), cusk (*Brosme brosme*), haddock (*Melanogrammus aeglefinus*), pollock (*Pollachius pollachius*), red hake (*Urophycis chuss*), silver hake (*Merluccius bilinearis*), and white hake (*Urophycis tenuis*).

Species included in the gadid group are distributed across much of the North Atlantic, with Atlantic cod, haddock, pollock, and cusk occurring in both the Northeast and Northwest Atlantic, and white, silver, and red hake limited to the Northwest Atlantic. Within the Northwest Atlantic, gadids generally occur from the Gulf of St. Lawrence to the Mid-Atlantic Bight, with highest densities found in the Gulf of Maine and along Georges Bank and the Great South Channel.

A number of the species in the gadid group make distinct inshore/offshore migrations in response to seasonal changes in water temperature. Atlantic cod in the Gulf of Maine typically move into coastal waters during the fall and over-winter for their peak spawning season, then return to deeper waters in the spring. In the Great South Channel area, cod move southwest in the fall, over-winter in Southern New England and along the mid- Atlantic coast and return to the Great South Channel in the spring (Lough 2005). Haddock do not make extensive migrations, however, adults undertake seasonal movements in the western Gulf of Maine, the Great South Channel, and on the Northeast Peak of Georges Bank, spending much of winter in deeper waters and moving to shoaler waters in spring to spawn (Brodziak 2005).

Juvenile and adult white hake distribution patterns indicate a pronounced inshore movement in warmer months, dispersing to deeper water in winter months (Chang et al. 1999). Red and silver hake also migrate seasonally in response to changes in water temperature. During the spring and summer months, they move into shallower, warmer waters where spawning occurs during late spring and early summer. During the winter months, red hake move offshore to deep waters in the Gulf of Maine and the edge of the Continental Shelf along Southern New England and Georges Bank. Silver hake from the northern stock move to deep basins of the Gulf of Maine in the winter months, while fish in the southern stock move to the outer Continental Shelf slope waters (Lock and Packer 2004; Steimle et al. 1999b).

Species included in the gadid group utilize a variety of benthic, pelagic, and nearshore habitats within the region during various stages of their life history. Adult cod are found inshore and offshore on a variety of bottom habitats, especially along rocky slopes, ledges, and other hard bottom substrates (Lough 2005; Stevenson 2008). Adult haddock are found on offshore bottom habitats composed of gravel, pebbles, clay, broken shells, and smooth, hard sand between rocky patches. They are not common on rocks, ledges, kelp, or soft mud (Stevenson 2008). Substantial areas of suitable substrate for haddock are found on Georges Bank while fewer suitable areas are found within the Gulf of Maine (Brodziak 2005). Adult pollock show little strong preference for particular bottom types and are commonly found in a variety of pelagic and benthic habitats, including areas with a substrate of mud, sand, gravel, and rocky bottom (Stevenson 2008). Adults tend to inhabit deeper waters in the spring and summer than in winter (Cargnelli et al. 1999a).

Adult white hake are found in inshore areas, on the coastal shelf, and along the continental slope. They prefer fine-grained substrates composed of mud and sandy mud (Chang et al. 1999; Stevenson 2008). Adult red hake occur on coastal marine and offshore shelf habitats composed of soft sand and mud. They are most common in soft sediments or shell beds in the Gulf of Maine and on hard bottom in the temperate reef areas of Maryland and northern Virginia. They occur in larger estuaries, including Chesapeake Bay, Delaware Bay, and the Hudson-Raritan Estuary, during cooler seasons and along coastal New England into Canadian waters from spring to fall (Steimle et al. 1999a; Stevenson 2008). Adult silver hake are found across a range of pelagic and benthic habitats, including mud, sand, and shell fragments in the Gulf of Maine and Georges Bank and on flat sand, sand waves, and shells/biogenic depressions in the Mid-Atlantic (Lock and Packer 2004; Stevenson 2008).

Spawning for Atlantic cod, haddock, and pollock generally occurs from November to May, with cod and haddock peaking from January to May and pollock peaking from November to February. Cod spawning is most intense along the Northeast Peak on Georges Bank and around the perimeter of the Gulf of Maine, including Massachusetts Bay, north of Cape Ann, and from Cape Elizabeth to Mt. Desert Isle in Maine (Lough 2005; Stevenson 2008). Georges Bank is the primary spawning area for haddock, with most spawning concentrated on the Northeast Peak. However, they do spawn in the Gulf of Maine, primarily on Jeffreys Ledge and Stellwagen Bank (Brodziak 2005; Stevenson 2008). Principal spawning sites for pollock are found in the western Gulf of Maine, the Great South Channel, and on Georges Bank, with spawning concentrated in Massachusetts Bay, Stellwagen Bank, and from Cape Ann to the Isle of Shoals in the Gulf of Maine (Cargnelli et al. 1999a; Stevenson 2008).

Spawning for white, silver, and red hake generally occurs in the summer months. White hake spawning occurs in April and May, generally in deeper waters along the continental slope from Georges Bank to the Mid-Atlantic Bight (Chang et al. 1999; Stevenson 2008). Red hake spawning peaks in May and June on Georges Bank, July and August in the Gulf of Maine, and occurs throughout the summer in the Southern New England/Mid-Atlantic Bight area. Red hake spawn on the southwestern part of Georges Bank and on the Continental Shelf off of Southern New England and Long Island. Spawning adults and eggs are also common in the marine parts of most bays between Narragansett Bay, RI and Massachusetts Bay (Steimle et al. 1999a; Stevenson 2008). Silver hake spawning peaks in May and June for the southern stock and July to August for the northern stock, and generally occurs on southwest Georges Bank and in Southern New England south of Montauk Point, Long Island (Lock and Packer 2004; Stevenson 2008).

Most of the gadids reach sexual maturity between 2 and 4 years, with the hakes reaching sexual maturity slightly earlier than Atlantic cod, haddock, and pollock. Cusk is the exception, reaching sexual maturity much later, as much as 10 years old (NMFS 2009a). Fertilized gadid eggs are pelagic and buoyant. Egg development occurs within the water column, with transition to the larval phase lasting from several days for silver, red, and white hake to several weeks for Atlantic cod, haddock, and pollock. Larval development also occurs in the water column, lasting for several months before juveniles settle to the bottom to begin their demersal life phase.

Young-of-the-year (YOY, or the young spawned in a particular year) cod settle in seagrass and macroalgae beds, on sand, and on structurally complex hard-bottom substrates with emergent epifauna (Stevenson 2008). On Georges Bank, juveniles are present predominantly in the gravel pavement habitat on the northeastern part of the bank, with gravel habitat appearing to favor the survival of recently-settled juveniles through predator avoidance and and/or increased food availability). Recent studies suggest nearshore nurseries, including grass beds, may be significantly more important to survival of juvenile fish than offshore habitats in the Gulf of Maine (Lough 2005). Juvenile haddock are found in similar habitats as adults, but appear to favor slightly shoaler waters (Stevenson 2008). YOY pollock are common in eel grass and macroalgae habitats in marsh creeks. Inshore and subtidal areas provide important nursery areas where juveniles spend much of the first two years of their lives before moving to deeper waters at age 2+ (Stevenson 2008).

Juvenile white hake are found on soft, muddy habitats in coastal estuarine nursery areas as well as on the Continental Shelf. Eel grass provides important habitat for juvenile white hake in nearshore areas, but they are not tied to eel grass, other vegetation, or structured habitats (Chang et al. 1999; Stevenson 2008). Juvenile red hake occur in estuarine, coastal, marine, and Continental Shelf benthic habitats on sand and mud substrates; physical structure for this species is particularly important for survival (Steimle et al. 1999a; Stevenson 2008). Juvenile silver hake are distributed across similar habitats, including mud, sand, and shell fragments in the Gulf of Maine and Georges Bank and on sand, silt, and amphipod tube mats in the Mid-Atlantic (Lock and Packer 2004; Stevenson 2008).

Ecosystem interactions are similar across the gadid species. Primary prey items include crustaceans, mollusks, euphausiids, and a variety of fishes including herring, mackerel, sand lance, and juvenile life stages of other gadid species. Principle predators include fishes, skates, dogfish, sharks, seals, and occasionally sea birds including puffins and terns.

Pleuronectids

Pleuronectids (or flatfish) are a relatively homogenous group, including in their morphology. They are characterized by their flat body shape, unique mouths, single long fins on each side, and eye position on the dorsal side of their flattened bodies. Flatfish can be "left-eyed" or "right-eyed" depending on which eye "migrated" during metamorphosis (Collette and MacPhee 2002). Summer flounder and halibut are flatfish species which are included in this assessment, but not in this particular grouping. Pleuronectids included in this grouping are American plaice (*Hippoglossoides platessoides*), winter flounder (*Pseudopleuronectes americanus*), witch flounder (*Glyptocephalus cynoglossus*), and yellowtail flounder (*Pleuronectes ferruginea*).

Species included in this group are distributed across much of the North Atlantic, with witch flounder and American plaice occurring in both the Northeast and Northwest Atlantic and winter and yellowtail flounder limited to the Northwest Atlantic. Within the Northwest Atlantic, these flounders generally occur from the Gulf of St. Lawrence to the Mid-Atlantic Bight, with highest densities found in the Gulf of Maine, Georges Bank, Southern New England, and the Mid-Atlantic.

Species within the flounder group are relatively sedentary and are not known to make extensive migrations. However, adult winter flounder do make seasonal migrations in response to changes in water temperature, migrating inshore in the fall and early winter to spawn (Periera et al. 1999). Nearshore coastal bays and estuaries are of particular importance during this time of year. Mark and recapture studies on yellowtail flounder reveal that fish in Southern New England travel eastward during the spring and summer and back to the west in fall and winter in response to changes in water temperature (Johnson et al. 1999).

Adult stages of all four flounder species included in the group show a strong preference for finer-grained sediments, including sand, mud, and silts. American plaice generally prefer substrates of sand and sand/mud and inhabit a broad depth range of 1-500 m (Johnson 2004; Stevenson 2008). Adult winter flounder are found in coastal and estuarine benthic habitats comprised primarily of fine-grained sediments including sand, mud, and muddy sand. However, they are also found on sandy and coarser substrates including pebbles and gravels on Georges Bank and Nantucket Shoals (Periera et al. 1999; Stevenson 2008). Adult witch flounder are closely tied to substrate, preferring mud/silt, muddy sand, and clay substrates, and rarely occur on any other bottom type (Cargnelli et al. 1999b; Stevenson 2008). Adult yellowtail prefer sand or sand/mud sediments where they find their demersal prey, and appear to avoid rocks, stony ground, and very soft mud (Collette and MacPhee 2002).

Flounders in the group spawn throughout much of the year. Spawning season varies with species, but tends to occur later in the year along a south-north gradient. Spawning for American plaice occurs from February to June with a peak in April and May. Plaice generally spawn in shoaler waters less than 90 m over benthic habitats comprised of sand and muds. Highest spawning concentrations occur in the western Gulf of Maine on Jeffreys Ledge and Stellwagen Bank and along the Great South Channel and southern flank of Georges Bank (Johnson 2004; Stevenson 2008). Winter flounder spawning occurs during the winter and spring, peaking in February and March, in shoaler waters less than 72 m over benthic habitats. Coastal bays and estuaries are particularly important spawning sites (Periera et al. 1999; Stevenson 2008). Witch flounder spawn from March to November, with a peak occurring in the summer months, in deeper waters over benthic habitats comprised of sand and muds. The most active spawning sites are found in the western and northern portions of the Gulf of Maine (Cargnelli at al. 1999b; Stevenson 2008). Yellowtail flounder spawn from March to August, with a peak between April and June (Johnson et al. 1999; Stevenson 2008).

Most of the flounders reach sexual maturity by age 4; winter flounder reaches sexual maturity slightly earlier (Periera et al. 1999). Fertilized eggs of plaice, witch, and yellowtail flounder are pelagic and buoyant while winter flounder eggs are demersal, forming clusters that adhere to benthic substrates comprised mostly of sands, but also muds and gravel. The larval phase for plaice and yellowtail flounder occurs in the water column and persists for two to four months before settlement to the ocean floor (Johnson 2004; Johnson et al. 1999). Witch flounder demonstrate one of the longest pelagic larval development phases of all flounders, lasting more than 12 months (Cargnelli et al. 1999b). Larval development for winter flounder occurs in the water column and lasts about eight weeks before settling to the ocean floor (Periera et al. 1999). Juvenile life stages of all of these flounders are found predominantly on sandy substrates. Juvenile winter flounders are especially dependent on nearshore coastal bays and estuaries, spending more than a year in these shallow zones before moving off to deeper water as they mature (Periera et al. 1999, Stevenson 2008). Juvenile plaice are also known to utilize bays and estuarine river systems as nursery areas, though they do occur in the Gulf of Maine, along the Great South Channel, and along the northern edge of Georges Bank (Johnson 2004).

Primary prey items include crustaceans, mollusks, amphipods, and polychaete worms. Winter and yellowtail flounder are also known to eat a variety of fishes. Principal predators include fish, skates, dogfish, sharks, and seals.

Elasmobranchs

Elasmobranchs, the sharks, skates, and rays, are represented in this assessment by five skate species from the family Rajidae: barndoor skate (*Dipturus laevis*), clearnose skate (*Raja eglanteria*), little skate (*Raja erinacea*), rosette skate (*Leucoraja garmani*), and thorny skate (*Amblyraja radiata*). The spiny dogfish (*Squalus acanthias*) represents the family Squalidae. All six species are characterized by their relatively slow growth rates, late age at maturation, and internal egg fertilization and development. Given their unique life history, these species are particularly vulnerable to exploitation due to longer mean generation times and the relatively small number of offspring.

Species included in the elasmobranch group are distributed across much of the Northwest Atlantic, with thorny skate occurring in both the Northeast and Northwest Atlantic; barndoor, little, clearnose, and rosette skates limited to the Northwest Atlantic; and spiny dogfish distributed circumglobally. Within the Northwest Atlantic, barndoor, thorny and little skate generally occur from the Gulf of St. Lawrence to Cape Hatteras, while distributions of clearnose and rosette skates occur further south, from Southern New England to Florida. Highest densities are found on the Continental Shelf in the Gulf of Maine, Georges Bank, Southern New England, and the Mid-Atlantic to Cape Hatteras.

Of the elasmobranchs included in this assessment, spiny dogfish and clearnose skate have the most distinct seasonal migration patterns. Spiny dogfish are known to make distinct north and south migrations along the Continental Shelf, as well as moving inshore and offshore seasonally in response to changes in water temperature. They primarily occur north of Cape Cod in summer, move southward to Long Island in the fall, and go as far south as North Carolina in the winter. In the spring, they migrate back north, reaching Georges Bank in March and April (Stehlik 2007). Clearnose skate also make distinct seasonal migrations north of Cape Hatteras, moving inshore and northward along the Continental Shelf during spring and early summer and offshore and southward during autumn and early winter when temperatures drop to 13-16° C (Packer et al 2003b).

Little skate are not known to migrate extensively, but they do make seasonal onshore and offshore migrations cued by temperature changes, generally moving into shallower waters in the spring and deeper waters in the winter. They also move north and south with seasonal temperature changes along the southern fringe of their range (Collette and MacPhee 2002). While several reports indicate that thorny skate undertake seasonal migrations in the summer and winter, others suggest they are a sedentary species. No seasonal migration patterns have been reported for rosette skate, although shoreward migrations during the summer have been suggested.

Adult and juvenile life stages of elasmobranchs included in this assessment generally utilize similar habitats within the region, but habitat preference varies with species. Adult and juvenile barndoor skate generally occupy similar habitats across the range. Adults are widely distributed on benthic habitats composed of soft muds, sand, and gravel. Adult and juvenile clearnose skates are found predominantly on soft bottom substrates along the Continental Shelf at depths less than 30 m. They have also been found on rocky and gravelly substrates (Packer et al. 2003b; Stevenson 2008). Adult and juvenile little skate are widely distributed across benthic habitats in coastal bays and estuaries along the Continental Shelf, generally on sandy or gravelly mud bottoms, but are also found in predominantly mud substrates (Packer et al. 2003c; Stevenson 2008). Adult and juvenile rosette skate occur on the outer Continental Shelf on benthic substrates of mud and sand, and also on substrates of mud and sand mixed with gravel (Packer et al. 2003d; Stevenson 2008). Adult and juvenile thorny skate occur on a variety of benthic substrates across the Continental Shelf and Slope, including sand, gravel, broken shells, pebbles, and soft mud (Packer et al. 2003e; Stevenson 2008). Spiny dogfish distributions are heavily influenced by depth, water temperature, and prey availability (Stehlik 2007).

All of the elasmobranchs included in this assessment share a similar life history, characterized by relatively slow growth rates, late age at maturity, and production of few offspring. The skate species reach sexual maturity at 5-7 years, while spiny dogfish do not reach sexual maturity until 10-12 years. Elasmobranchs mate throughout much of the year, with clearnose, thorny, and rosette skate having highest egg production in the summer, little skate producing eggs twice a year (spring and fall), barndoor skate mating in late-fall and winter, and spiny dogfish mating in the fall. Spiny dogfish are unique in that their egg fertilization and development is oviparous. Fertilized eggs develop within a tough, leathery egg casing which is deposited over a variety of substrates. Egg development is slow, lasting 2-3 years before hatching occurs on the sea floor (Packer et al. 2003 a, b, c, d, and e; Stehlik 2007).

Elasmobranchs are omnivorous, feeding on a variety of benthic prey species including crustaceans, amphipods, and a variety of small fishes. The skate species display similar dietary preferences, feeding primarily on polychaetes, decapods, copepods, bivalves, and shrimp but also on a variety of small fishes. Spiny dogfish are more piscivorous, feeding on a variety of fish species including capelin, cod, haddock, herring, mackerel, sand lance, and several species of flatfish. Elasmobranch eggs are preyed on by a variety of fish species, while adults have relatively few predators.

Predators of adults include large gadids, flounders, monkfish, sharks, seals, and dolphins.

Trophic dynamics within the Gulf of Maine/Georges Bank portion of the region have been fundamentally altered, as the depletion of gadids and flounders have coincided with large increases in skate and spiny dogfish populations. Spiny dogfish are now a major predator within this part of the region, accounting for a significant portion of the overall fish biomass in the system. Many have suggested that their recent population increase and associated predation have confounded efforts to rebuild depleted populations of gadids and flounders (FORDM 2009).

Mid-Atlantic Estuarine

The Mid-Atlantic Estuarine species grouping includes three species from the family Scianidae: Atlantic croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*), and weakfish (*Cynoscion regalis*). The family Labridae is represented by tautog (*Tautoga onitis*). The group was selected based upon the species' relative dependence on estuarine habitats to complete various stages of their life history. Specifically, a recent study on relative degree of estuarine dependence concluded that Atlantic croaker, spot, and tautog are obligate users of estuarine habitats while weakfish are facultative users of these areas (Able 2005).

Global distribution of species in the mid-Atlantic estuarine group is limited to the western Atlantic, from Nova Scotia to Florida. Distributions of croaker may extend as far south as Brazil and Argentina. Within the Northwest Atlantic, these species are predominantly found from Long Island Sound to Cape Hatteras, North Carolina, with highest numbers occurring south of Delaware Bay. However, all species do occur in significant numbers along Georges Bank and the Great South Channel. They are occasionally found in the Gulf of Maine in and around Massachusetts Bay and the Jeffreys Ledge and Stellwagen Bank area.

Species within the mid-Atlantic estuarine group are characterized by distinct seasonal migrations, moving inshore and offshore in response to changes in water temperature. Spot enter bays and estuaries in the spring and remain there until late summer or fall when they move offshore to spawn (ASMFC 2009). Adult croaker generally spend the spring and summer in estuaries, moving offshore and south along the Atlantic coast in the fall as nearshore water temperatures decline (ASMFC 2009). When coastal waters warm in the spring, adult weakfish form large aggregations and undertake inshore and northward migrations to bays, estuaries, and sounds from offshore wintering grounds (ASMFC 2009). Adult tautog make shorter seasonal migrations in the fall when water temperatures fall below 10° C, moving from coastal areas to deeper waters (25-45 m) with rugged topography. They move back inshore to coastal and estuarine waters in the spring when water temperatures warm above 11° C (Steimle et al. 1999c).

Species included in this group are characterized by their utilization of coastal bays and estuaries (ASMFC 2009). Spot, croaker, and tautog are recognized as obligate users of these habitats while weakfish are considered facultative users of these areas. Adult spot and weakfish occur across a variety of substrates within nearshore bays and estuaries; habitat selection for these species is influenced by a number of variables including sediment type, summer water temperatures, salinity, and dissolved oxygen levels. Adult croaker prefer muddy and sandy substrates in waters shallow enough to support submerged aquatic plant growth and are also found on oyster, coral, and sponge reefs as well as man-made structures. Temperature and depth are important factors in determining distribution of adults. Distribution and abundance of adult tautog is heavily influenced by the availability of cover for protection during the night when they are not foraging (Steimle et al. 1999c).

Species included in this group reach sexual maturity at relatively young ages (ASMFC 2009). Croaker and weakfish reach sexual maturity between ages 1 and 2, spot mature between ages 2 and 3, and tautog mature between ages 3 and 4. Croaker, tautog, and weakfish all spawn in nearshore habitats in coastal bays and estuaries while spot spawn in offshore waters along the Continental

Shelf. Spawning season for species in this group occurs throughout much of the year. Croaker spawn from July to December, with a peak in late fall and early winter. Spot spawning begins in the fall and continues through the winter into early spring. Tautog spawning primarily occurs near the mouths of estuaries and inshore waters and follows a northward progression through the summer, beginning in April in the southern part of the Mid-Atlantic Bight and extending to the northern area by May. Peak spawning in the central Mid-Atlantic Bight is reported to occur in June and July and declines by August. Weakfish spawning occurs in nearshore coastal waters after the inshore spring migration from March through September, peaking between April and June.

Fertilized eggs of all four species are buoyant and pelagic (ASMFC 2009). Eggs and larvae remain in the water column and are transported to coastal and estuarine waters by tides, currents, and other oceanographic processes. Juveniles utilize a variety of benthic habitats within nearshore nursery areas depending on species before migrating offshore to the open ocean along the Continental Shelf.

These species eat a variety of benthic prey items including polychaetes, mollusks, mussels, shrimp, and fishes. Tautog prey heavily on blue mussels, while weakfish are much more piscivorous than other species in the group, preying on a variety of fishes including menhaden, shad, river herring, sea herring, and sand lance. Weakfish are recognized as an important top predator in Chesapeake Bay, feeding along the edges of eel grass habitats and along channel edges, rock, and oyster reefs (ASMFC 2009). Species within the group are preyed upon by a variety of fishes, spiny dogfish, skates, sharks, and in the case of juvenile tautog, piscivorous seabirds (Steimle et al. 1999c).

Offshore Wintering Guild

The fishes included in the offshore wintering are characterized by similar movements, habitats, and food habits (Musick and Mercer 1977; Colvocoresses and Musick 1984). In particular, these species generally move into shallow coastal waters in the summer months then move offshore to the Continental Shelf during winter months as nearshore water temperatures decrease. The offshore wintering guild group includes black sea bass (*Centropristis striata*), northern sea robin (*Prionotus carolinus*), scup (*Stenotomus chrysops*), and summer flounder (fluke, *Paralichthys dentatus*).

Global distribution of these species is limited to the western Atlantic, from Nova Scotia to Florida. Within the Northwest Atlantic, highest numbers are found from Narragansett Bay in Southern New England to Cape Hatteras, North Carolina. However, all species occur on portions of Georges Bank and the Great South Channel and in the Gulf of Maine, particularly in and around Massachusetts Bay and the Jeffreys Ledge and Stellwagen Bank area.

Species in this guild undertake distinct season migrations, moving inshore and offshore in response to changes in water temperature. Summer flounder, scup, and black seas bass display strong seasonal movements, occupying shallow coastal and estuarine waters in the spring and summer and moving offshore onto the Continental Shelf during the colder winter months. These annual migrations are apparently triggered when bottom water temperatures approach 7° C (Packer et al. 1999f; Steimle et al. 1999d; Drohan et al. 2007). Northern sea robin found north of Cape Hatteras make similar seasonal migrations, seemingly triggered by a broader temperature range of 4.5 to 15.5° C (Collette and MacPhee 2002).

Species in the offshore wintering guild utilize a variety of coastal and shelf habitats depending on season. Adult summer flounder show a strong preference for coarse, sandy substrates in nearshore coastal waters, generally occurring at depths less than 25 m (Packer et al. 1999f). Adult scup are found in a variety of benthic habitats in the warmer months, including soft, sandy bottoms and on or near structures including rocky ledges, wrecks, artificial reefs, and mussel beds, although they appear to demonstrate a strong preference for mixed sand and mud deposits in Long Island Sound. Specific habitats used by adults during the offshore over-wintering period are poorly defined (Steimle et al. 1999d). Adult black sea bass are strongly associated with structurally complex habitats, including eel grass, rocky reefs, cobble, rock fields, wrecks, and shellfish beds. They occupy nearshore coastal waters during spring and summer months and overwinter along the Continental Shelf (Drohan et al. 2007). Specific habitat preferences of adult northern sea robin are not as well defined, though they have been found to be closely associated with deep flats and channel edges in Chesapeake Bay (Collette and MacPhee 2002).

Spawning habitats for species in the offshore wintering guild vary depending on species. Summer flounder spawn in Southern New England and the Mid-Atlantic Bight during two distinct seasons, the strongest occurring in late fall as they move offshore to overwinter and a lesser one occurring in the spring in the southern part of the Mid-Atlantic (Packer et al. 1999f). Scup spawn once per year during their inshore migration from May through August, with a peak in June and July. Most spawning occurs over weedy or sandy areas in Southern New England from Cape Cod, Massachusetts south to the New York Bight (Steimle et al. 1999b). Black sea bass spawn in April-October, peaking in May to July. Spawning generally occurs between Montauk Point, Long Island and Chesapeake Bay and appears to be concentrated on the nearshore Continental Shelf at 20-50 m (Drohan et al. 2007). Less is known about the spawning habitats of northern sea robin, though they are known to spawn in the summer months from June to September, generally from Block Island to Cape Hatteras (Collette and MacPhee 2002).

All species in the guild reach sexual maturity between ages 2 and 4. However, black sea bass are protogynous hermaphrodites, meaning that fish change sex from female to male as they increase in age and size. Females reach sexual maturity at age 2-4 and most fish change sex to male at age 2-5 (Packer et al. 1999f). The fertilized eggs for all four species are buoyant and pelagic and development to the larval phase occurs within a matter of days to weeks. Juveniles migrate to nearshore coastal waters and descend to the seafloor where they begin their demersal life phase. Important juvenile nurseries for these species occur in many of the coastal bays and estuaries of Southern New England and the Mid-Atlantic Bight, including Buzzards Bay, Narragansett Bay, the Hudson-Raritan Estuary, Long Island Sound, Delaware Bay, and Chesapeake Bay. Habitats with structural complexity, including submerged aquatic vegetation, oyster reefs, and man-made structures, appear to be an essential component influencing juvenile survival for scup and black sea bass, while juvenile summer flounder utilize a variety of coastal habitats including marsh creeks, sea grass beds, mud flats, and open bay areas.

Species included in the offshore wintering guild prey on a variety of benthic organisms including polychaetes, amphipods, crustaceans, and fishes. Black sea bass, scup, and northern sea robin feed primarily on polychaetes, amphipods, crustaceans, and bivalves, though fishes are also a part of their diet (Drohan et al. 2007; Steimle et al. 1999d; Collette and MacPhee 2002). Summer flounder are more piscivorous, feeding on hakes, menhaden, and flounders as well as squids, shrimps, and bivalve mollusks (Packer et al. 1999f). These species are primarily preyed upon by other fishes including flounders, hakes, monkfish, skates, and dogfish.

Other Species of Interest

Other species of interest were included in this assessment because of concerns about their conservation status (Atlantic halibut (*Hippoglossus hippoglossus*), Atlantic wolffish (*Anarhichas lupus*)), unique life history characteristics (Acadian redfish (*Sebastes fasciatus*), Atlantic monkfish (*Lophius americanus*), golden tilefish (*Lopholatilus chamaeleonticeps*), and ocean pout (*Zoarces americanus*)), and non-commercial species (longhorn sculpin (*Myoxocephalus octodecimspinosus*)). The team elected to include these species in this assessment, but chose to present findings on a species by species basis rather than within the groupings used for most species.

Acadian Redfish

Acadian redfish occur on both sides of the Atlantic Ocean. In the Northwest Atlantic, they are common from Nova Scotia to New Jersey and have been observed as far south as Virginia. Areas of highest abundance include the Gulf of St. Lawrence, the Continental Shelf northeast of Newfoundland, the southern edge of the Grand Bank, and the Flemish Cap.

Although redfish are not believed to make extensive migrations, Bigelow and Schroeder (in Collette and MacPhee 2002) reported that redfish do make seasonal migrations. They have been observed in deep waters of the Gulf of Maine during summer and early autumn, then migrate south and east where they concentrate during the winter.

Adult redfish are found primarily in deeper waters over substrates of silt, mud, and hard bottom and are rarely observed in sand substrates. There is also evidence that redfish use boulders, corals, anemones, and other structure-forming epifauna for cover. Redfish are also known to make diurnal vertical migrations following movements of euphuasiids, their primary prey species (Pikanowski et al.1999; Stevenson 2008).

Redfish are a slow-growing, long-lived ovoviparous species with very low natural mortality rates. Redfish greater than 22 cm are considered adults and median age for sexual maturity is 5-6 years, ranging from as young as 2 to as old as 10. Very little is known about redfish breeding behavior, but fertilization is internal and fecundity is relatively low. Mating is believed to occur in October-January, but fertilization is delayed until February-April. Redfish eggs are fertilized internally and develop within the oviduct until they are released near the end of the yolk sac phase. The pelagic larval phase generally lasts about 4-5 months, then they descend to the bottom by the fall of their first year. Upon settling to the bottom, juveniles are found on a variety of substrates including silt, mud, and hard bottoms with emergent epifauna. YOY demonstrate strong associations with boulder reefs (Pikanowski et al. 1999; Stevenson 2008).

Redfish feed on a variety of benthic prey items including copepods, euphausiids, amphipods, pandalid and sand shrimp, and fish and invertebrate eggs. Key predators are piscivorous fishes including Atlantic cod, Atlantic halibut, Atlantic wolffish, little skate, monkfish, pollock, larger redfish, silver hake, and white hake. Of these, cod and white hake appear to be most important (Pikanowski et al. 1999; Stevenson 2008).

Atlantic Halibut

Atlantic halibut is found on both sides of the North Atlantic Ocean and in parts of the Arctic Ocean. In the Northwest Atlantic, they are distributed from north of Labrador to south of Long Island. Areas of highest abundance seem to be along the southern edge of the Grand Banks and on the Scotian Shelf from Browns Bank to Banquereau Bank.

Adult Atlantic halibut are found over sand, gravel, and clay substrates along the Continental Shelf and Slope. They are typically found at depths of 40-1000 m, with the NMFS bottom trawl survey capturing most at 25-200 m.

The largest of all the flatfish in the region, Atlantic halibut can reach over 200 cm in length. Late to mature and long-lived, some reach ages of 50 years, achieving sexual maturity between 5 and 15 years. Atlantic halibut spawn between late winter and early spring, peaking between November and December. Spawning grounds are not well known, but generally occur on hard substrates of sand, gravel, and clay on offshore banks and along the Continental Slope (Cargnelli et al 1999(c); Stevenson 2008).

Atlantic halibut eggs are among the largest planktonic fish eggs. Eggs are bathypelagic and float suspended in the water at depths greater than 50 m rather than at the surface. Incubation is strongly temperature-dependent, lasting from 13-20 days at 4-7° C. Larvae have a long developmental period lasting up to 90 days before metamorphosis to the juvenile stage. Settlement to the bottom occurs after metamorphosis is complete. Juveniles are known to inhabit distinct nursery grounds, including Sable Island Gully on the Scotian Shelf, where they remain for 3-4 years before migrating away (Cargnelli et al. 1999(c); Stevenson 2008).

Atlantic halibut feed on a variety of benthic prey items, including crustaceans, mollusks, squid, and fishes such as Atlantic cod, Atlantic herring, alewife, capelin, cusk, flounder, haddock, mackerel, ocean perch, ocean pout, sand lance, sculpin, skates and silver hake. Given their large size they have relatively few predators, primarily monkfish, spiny dogfish, Greenland sharks, and seals (Cargnelli et al. 1999c).

Atlantic Wolffish

The largest of the blenny-like fishes, Atlantic wolffish are distributed on both sides of the Atlantic Ocean. In the Northwest Atlantic, they occur from the Davis Straits in Greenland to Cape Cod. Relatively little is known about the biology, migration, or seasonal movements of the species, though some evidence suggests a migration from deep to shallower waters in the fall and spring. Wolffish are known to prefer complex bottom habitats including rocky outcrops and seaweed beds (Collette and MacPhee 2002; NMFS 2009a).

Atlantic wolffish are a slow-growing, long-lived species that may live more than 20 years. Age at maturity is influenced by temperature, with most reaching sexual maturity by age 6. Males and females form spawning pairs during the spring and summer prior to spawning. Spawning is believed to occur almost year-round, with peak season occurring from September to October. Eggs are believed to be fertilized internally and are laid in large, tight clusters in nests which are guarded by the parental male. Egg incubation is heavily influenced by water temperature, and takes three to nine months. Larval development is pelagic and lasts 20-60 days depending on water temperature. Juveniles are demersal and begin displaying aggressive, territorial behavior at a young age. Growth rates are relatively rapid until age 5-6 when growth begins to slow as sexual maturity is reached (Collette and MacPhee 2002; NMFS 2009a).

Atlantic wolffish feed on a variety of benthic prey items, including bivalves, gastropods, decapods, urchins, and echinoderms. Predators include Atlantic cod, haddock, red hake, sea raven, spiny dogfish, thorny skate, Greenland shark, and gray seal (Collette and MacPhee 2002).

Golden Tilefish

Golden tilefish are distributed in the Northwest Atlantic along the outer Continental Shelf from Nova Scotia to South Florida, and are relatively abundant in the Southern New England to mid-Atlantic region at depths of 80 to 440 m. Tilefish are believed to be relatively sedentary and closely associated with their burrows and are not known for extensive seasonal migrations. Shorter movements may occur when feeding or when seeking to stay within their preferred temperature range (Steimle et al. 1999a).

Distribution of adult tilefish is heavily influenced by substrate, temperature, and depth. They have a narrow temperature preference of 9° to 14° C (known as the “warm belt”) and generally occur in and around submarine canyons (including Oceanographer, Hudson, and Norfolk Canyons) where they occupy burrows in sedimentary substrates (Steimle et al. 1999a). As important modifiers and creators of habitat on the outer Continental Shelf and along the slopes and walls of submarine canyons, tilefish create elaborate “pueblo villages” of burrows within clay substrates, presumably to avoid predation (Able et al. 1982; Grimes et al. 1986). Tilefish provide habitat for a variety of other species, including crustaceans, lobster, conger eel, ocean pout, cusk, redfish, and hake.

Tilefish are relatively slow-growing and long-lived. Males and females reach sexual maturity between ages 5 and 7. Little is known about their spawning activity, though they are considered serial or fractional spawners, spawning from March to November with peak spawning activity occurring between May and September. Non-adhesive and buoyant eggs are found in temperatures of 8-19° C (Steimle et al. 1999 a). Larvae occur in the water column from July to September over the outer Continental Shelf in the Mid-Atlantic Bight. Juvenile tilefish occupy similar habitats as adults, creating vertical shaft burrows in clay.

They appear to be more tolerant of low temperatures than adults, which could help recruits survive in marginal habitat conditions.

Tilefish feed on a variety of benthic prey items including bivalve mollusks, polychaetes, sea anemones, echinoderms, and other fishes including conger eel, hagfish, squid, small spiny dogfish, mackerel, herring, squid, and silver hake. Major predators on juvenile tilefish include spiny dogfish, conger eels, and mostly larger adult tilefish, while monkfish are believed to be the primary predator on adults.

The Mid Atlantic Fisheries Management Council has designated a Habitat Area of Particular Concern for juvenile and adult tilefish in the Southern New England/mid-Atlantic region, which encompasses the substrate between the 250 and 1,200 ft isobath line extending from the southern flank of Georges Bank to just north of Delaware Bay.

Longhorn sculpin

Longhorn sculpin are distributed across much of the Northwest Atlantic, occurring from Newfoundland to Virginia. They are common along the Nova Scotia coast and extend as far north as the Gulf of St. Lawrence. In the region, they occur from the Bay of Fundy south to Virginia, with highest numbers found in the western Gulf of Maine, along the flanks of Georges Bank, and south to Long Island Sound. Longhorn sculpin are not known for making extensive migrations, although onshore to offshore movements have been observed as they move from shallower to deeper waters as temperatures approach 20° C (Collette and MacPhee 2000).

Monkfish

The monkfish is a solitary, large, slow-growing, bottom-dwelling anglerfish which occurs in the western Atlantic from the southern and eastern parts of the Grand Banks and the northern side of the Gulf of St. Lawrence to the east coast of Florida, but is common only north of Cape Hatteras. Within the region, they are common in both inshore and offshore areas of the Gulf of Maine and ubiquitous across the Continental Shelf in the Mid-Atlantic Bight. Monkfish make seasonal onshore-offshore migrations in response to temperature changes. In the Gulf of Maine they move and stay offshore to avoid cold coastal conditions in the winter-spring and return inshore as coastal waters warm in the summer and fall. In the Mid-Atlantic, monkfish may avoid overly warm inshore summer conditions and take advantage of a residual cool pool that occurs along the mid- to outer Continental Shelf (Steimle et al. 1999e).

Adult monkfish occur on soft bottom sediments including sand, mud, and shell fragments nearshore and on the Continental Shelf. Juveniles occupy similar substrates but were not captured in the NMFS trawl survey at depths <20 m or temperatures greater than 13° C (Steimle et al. 1999e; Stevenson 2008). Monkfish reach sizes of 140 cm and 22 kg in weight; females reach larger sizes than males and live longer (females reach ages of 11 years, males, 9 years). Males and females reach sexual maturity between 4 and 5 years. Spawning occurs from spring through early fall with a peak in May-June. Monkfish spawn in the early spring off the Carolinas, in May-June in the Gulf of Maine, and into September in Canadian waters. Spawning locations are not well known, but are thought to be on inshore shoals to offshore. Relatively large eggs are shed within buoyant, free-floating ribbon-like mucoid veils or rafts that may be 6-12 m long. This manner of egg production is thought to be unique among fishes. Newly hatched eggs remain protected in the open egg chamber within the mucus veil for two to three days after hatching and are pelagic upon release. Adults spend most of their time on the sandy bottoms where they partially bury their body to support their ambush method of predation (Steimle et al. 1999e).

Monkfish feed on a variety of benthic organisms, primarily fishes including Atlantic cod, Atlantic herring, Atlantic menhaden, black sea bass, butterfish, cunner, eels, flounders, haddock, hake, mackerel, pufferfish, sand lance, sculpins, sea raven, sea robins, skates, silver hake, smelt, spiny dogfish, squid, tautog, tomcod, and weakfish. Major predators include Atlantic cod, monkfish, swordfish, smooth and spiny dogfish, and dusky and sandbar sharks (Steimle et al. 1999e).

Ocean Pout

The ocean pout is a bottom-dwelling, temperate species found on the Atlantic Continental Shelf of North America between Labrador and the southern Grand Banks and Virginia. It can also occur south of Cape Hatteras in deeper, cooler waters. They do not undertake extensive migrations, but do move seasonally to different habitats to remain within their preferred temperature range of 2-10° C (Steimle et al. 1999f).

Adult ocean pout are found over a variety of bottom types including shells, rock, algae, sand, mud, and/or gravel. During winter and spring, they feed over sand or sand and gravel substrates and then move to rocky areas in the fall to spawn (Steimle et al. 1999f; Stevenson 2008).

Ocean pout are relatively long-lived species with males reaching maturity at 2-4 years and females maturing at 5-9 years of age. Spawning occurs in the late summer through winter, peaking between August and October. Spawning occurs on hard bottom, sheltered areas including artificial reefs and shipwrecks at depths <50 m and temperatures <10° C. These spawning and nesting areas include the saline parts of New England estuaries. Fecundity is size-dependent and relatively low, with large females producing more eggs than smaller ones. Ocean pout eggs are fertilized internally. Demersal eggs are laid in gelatinous masses in sheltered places on the bottom including rocky crevices. They are guarded by one or both parents until hatching occurs after two to three months depending on water temperature. Juveniles are found on similar substrates as adults, including shallow coastal waters around rocks, attached algae, and bivalve shells. Juvenile growth rates vary depending on temperature, and they can reach lengths of 10-15 cm after the first year. Adults remain demersal and are not known to form schools or aggregations (Steimle et al. 1999f; Stevenson 2008).

Ocean pout feed on a variety of benthic invertebrates including polychaetes, mollusks, crustaceans, and echinoderms, as well as urchins, scallops, crabs, and lobster. Predators include Atlantic cod, bluefish, hakes, sea raven, skates, spiny dogfish, and harbor seals (Steimle et al. 1999f).

Literature Cited

Able, K. W. 2005. A re-examination of fish estuarine dependence: Evidence for connectivity between estuarine and ocean habitats. Estuarine and Coastal Shelf Science 64 (2205): 5-17.

Able, K. W., C. B. Grimes, R. A. Cooper, and J. R. Uzmann. 1982. Burrow construction and behavior of tilefish, *Lopholatilus chamaeleoticeps,* in the Hudson submarine canyon. Environmental Biology of Fishes. 7:199-205

ASMFC (Atlantic States Marine Fisheries Commission). 2009. Atlantic States Marine Fisheries Commission Species Profiles at http://www.asmfc.org. Accessed May 2009

Berkeley, S. A., M. A. Hixon, R. J. Larson, and M. S. Love. 2004. Fisheries sustainability via protection of age structure and spatial distribution of fish populations. Fisheries. 29: 23-32.

Brodziak, J. K. 2005. Essential fish habitat source document: Haddock, *Melanogrammus aeglefinus,* life history and habitat characteristics. NOAA Technical Memorandum. NMFS 196.

Bullard S.G., G. Lambert, M.R. Carman, J. Byrnes, R.B. Whitlatch, G. Ruiz, R.J. Miller, L. Harris, P.C. Valentine, J.S. Collie, J. Pederson, D.C. McNaught, A.N. Cohen, R.G. Asch, J. Dijkstra, and K. Heinonen. 2007. The colonial ascidian Didemnum sp. A: Current distribution, basic biology and potential threat to marine communities of the northeast and west coasts of North America. Journal of Experimental Marine Biology and Ecology. 342(1): 99-108.

Cargnelli L.M., S.J. Griesbach, D.B. Packer, P.L. Berrien, D.L. Johnson, and W.W. Morse. 1999a. Essential fish habitat source document: Pollock, *Pollachius virens*, life history and habitat characteristics. NOAA Technical Memorandum 131.

Cargnelli L.M., S.J. Griesbach, D.B. Packer, P.L. Berrien, W.W. Morse, and D.L. Johnson.1999b. Essential fish habitat source document: Witch flounder, Glyptocephalus cynoglossus, life history and habitat characteristics. NOAA Technical Memorandum. NMFS NE 139.

Cargnelli, L.M., S.J. Griesbach, and W.W. Morse, 1999c. Essential fish habitat source document: Atlantic halibut *Hippoglossus hippoglossus,* life history and habitat characteristics. NOAA Technical Memorandum. NMFS-NE-125.

Chang S., W.W. Morse, and P.L Berrien. 1999. Essential fish habitat source document: White hake, *Urophycis tenuis*, life history and habitat characteristics. NOAA Technical Memorandum. NMFS NE 136.

Collette, B. B. and G. K. MacPhee. 2002. Bigelow and Schroeder's Fishes of the Gulf of Maine. Edited by Bruce B. Collette and Grace Klein MacPhee. 3rd ed. Smithsonian Institution Press.748 pp.

Collie, J. S., A.D. Wood, and H.P. Jeffries. 2008. Long-term shifts in the species composition of a coastal fish community.

Colvocorress, J. A. and J. A. Musick. 1984. Species associations and community composition of Middle Atlantic Bight continental shelf demersal fishes. Fishery Bulletin. 82: 295-313.

Cook, R. R. and P. J. Auster. 2007. A bioregional classification of the continental shelf of northeastern North America for conservation analysis and planning based on representation. Marine Sanctuaries Conservation Series NMSP-07-03. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Sanctuary Program, Silver Spring, MD. 14 pp.

Drohan A.F., J.P. Manderson, and D.B. Packer. 2007. Essential fish habitat source document: Black sea bass, *Centropristis striata*, life history and habitat characteristics, 2nd edition. NOAA Technical Memorandum. NMFS NE 200.

Fogarty, M. J. and S. A. Murawski. 1998. Large-scale disturbance and the structure of marine systems: Fishery impacts on Georges Bank. Supplement: Ecosystem Management for Sustainable Marine Fisheries. Ecological Applications 8(1): S6-S22.

Fogarty, M., L. Incze, K. Hayhoe, D. Mountain, and J. Manning. 2008. Potential climate change impacts on Atlantic cod (*Gadus morhua*) off the northeastern USA. Mitigation and Adaptation Strategies for Global Change. 13:453-466.

FORDM (Fishermen Organized for Responsible Dogfish Management). 2009. Letter to Jane Lubchenco. http://www.fishnet-usa.com/FORDM_Letter.pdf. Accessed August 2009

Grimes, C. B., K. W. Able, and R. S. Jones. 1986. Tilefish *Lopholatilus chamaeleoticeps* habitat, behavior, and community structure in the Mid-Atlantic and southern New England waters. Environmental Biology of Fishes. 15: 273-292.

Johnson D.L., W.W. Morse, P.L. Berrien, and J.J. Vitaliano. 1999. Essential fish habitat source document: Yellowtail flounder, *Limanda ferruginea*, life history and habitat characteristics. NOAA Technical Memorandum. NMFS NE 140.

Johnson, D. 2004. Essential Fish Habitat Source Document: American Plaice, *Hippoglossoides platessoides*, Life History and Habitat Characteristics. NOAA Technical Memorandum. NMFS-NE-187.

Johnson, M.R., C. Boelke, L.A. Chiarella, P.D. Colosi, K. Greene, K. Leslie-Dibble, H. Ludeman, M. Ludwig, S. McDermott, J. Ortiz, D. Rusanowsky, M. Scott, and J. Smith 2008. Impacts to Marine Fisheries Habitat from Non-fishing Activities in the Northeastern United States. NOAA Technical Memorandum. NMFS-NE-209.

Kurlansky, M. 1997. Cod: A biography of the fish that changed the world. Penguin Books Ltd. Registered Offices: 80 Strand, London WC2R 0RL England.

Levin, P. S., J.A. Coyer, R. Petrik, and T. P. Good. 2002. Community-wide effects of nonindigenous species on temperate rocky reefs. Ecology. 83 (11): 3182-3193.

Link, J. S. and L. P. Garrison. 2002. Trophic ecology of Atlantic cod *Gadus morhua* on the northeast continental shelf. Marine Ecology Progress Series. 227: 109-123.

Lock, M.C. and D.B. Packer. 2004. Essential Fish Habitat Source Document: Silver Hake, *Merluccius bilinearis*, Life History and Habitat Characteristics. 2nd ed. August 2004. NOAA Technical Memorandum. NMFS-NE-186.

Lough, R. G. 2005. Essential Fish Habitat Source Document: Atlantic Cod, *Gadus morhua*, Life History and Habitat Characteristics. 2nd ed. August 2005. NOAA Technical Memorandum. NMFS-NE-190.

Mountain, D. G. and S. A. Murawski. 1992. Variation in the distribution of fish stocks on the northeast continental shelf in relation to their environment , 1980-1989. ICES Marine Science Symposium. 195: 424-432.

Musick, J. A. and L. P. Mercer. 1977. Seasonal distribution of black sea bass *Centropristis striate*, in the Mid-Atlantic Bight with comments on the ecology and fisheries of the species. Transactions of the American Fisheries Society. 106: 12-25.

NMFS (National Marine Fisheries Service). 2009a. Proactive Conservation Program: Species of Concern. http://www.nmfs.noaa.gov/pr/species/concern/. Accessed May 2009

NMFS (National Marine Fisheries Service). 2009b. National Marine Fisheries Service: 2009 Status of U.S. Fisheries – Second Quarter Update. http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm. Accessed May 2009

NMFS (National Marine Fisheries Service). 2009c. Essential Fish Habitat Source Documents. http://www.nefsc.noaa.gov/nefsc/habitat/efh/. Accessed May 2009

NMFS (National Marine Fisheries Service). 2009 d. Status of Fisheries Resources at http://www.nefsc.noaa.gov/sos/. Accessed June 2009

NRC (National Research Council). 2002. Effects of Trawling and Dredging on Seafloor Habitat. National Academies Press, Washington D.C. 126 pp.

NRC (National Research Council). 2006. Dynamic changes in marine ecosystems: Fishing, food webs, and future options. National Academies Press, Washington D.C. 153 pp.

NEFMC (New England Fisheries Management Council). 2004. New England Fisheries Management Council – Amendment 13 to the Northeast Multispecies Fisheries Management Plan. Newburyport, Massachusetts. 1659 pp.

NEFSC (Northeast Fisheries Science Center). 2008. Assessment of 19 Northeast Groundfish Stocks through 2007: Report of the 3rd Groundfish Assessment Review Meeting (GARM III), Northeast Fisheries Science Center, Woods Hole, Massachusetts, August 4-8, 2008. US Department of Commerce, NOAA Fisheries, Ref Doc. 08-15; 884 p + xvii.

Packer, D.B., C.A. Zetlin, and J.J. Vitaliano. 2003a. Essential fish habitat source document: barndoor skate, *Dipturus laevis,* life history and habitat characteristics. NOAA Technical Memorandum. NMFS-NE-173.

Packer, D.B., C.A. Zetlin, and J.J. Vitaliano. 2003b. Essential fish habitat source document: clearnose skate, *Raja eglanteria,* life history and habitat characteristics. NOAA Technical Memorandum. NMFS-NE-174.

Packer, D.B., C.A. Zetlin, and J.J. Vitaliano. 2003c. Essential fish habitat source document: little skate, *Leucoraja reinacea,* life history and habitat characteristics. NOAA Technical Memorandum. NMFS-NE-175.

Packer, D.B., C.A. Zetlin, and J.J. Vitaliano 2003d. Essential fish habitat source document: rosette skate, *Leucoraja garmani virginicus,* life history and habitat characteristics. NOAA Technical Memorandum. NMFS-NE-176.

Packer, D.B., C.A. Zetlin, and J.J. Vitaliano 2003e. Essential fish habitat source document: thorny skate, *Amblyraja radiata,* life history and habitat characteristics. NOAA Technical Memorandum. NMFS-NE-178.

Packer, D.B., S.J. Greisbach, P.L. Berrien, C.A. Zetlin, D.L. Johnson, and W.W. Morse 1999(f). Essential fish habitat source document: summer flounder, *Paralichthys dentatus,* life history and habitat characteristics. NOAA Technical Memorandum. NMFS-NE-151, 44 p.

Pereira J.J., R. Goldberg, J.J. Ziskowski, P.L. Berrien, W.W. Morse, and D.L. Johnson. 1999. Essential fish habitat source document: Winter flounder, Pseudopleuronectes americanus, life history and habitat characteristics. NOAA Technical Memorandum. NMFS NE 138.

Pikanowski, R.A., W.W. Morse, P.L. Berrien, D.L. Johnson, and D.G. McMillan. 1999. Essential Fish Habitat Document: Redfish, *Sebastes* spp., Life History and Habitat Characteristics. NOAA Technical Memorandum. NMFS-NE-132.

Sherman, K., M. D. Grosslein, D. Mountain, D. Busch, J. O'Reilly, and R. Theroux. 1996. The Northeast Shelf Ecosystem: An Initial Perspective. In K. Sherman (ed.) The Northeast Shelf Ecosystem: Assessment, Sustainability, and Management. Blackwell Science. 554 pp.

Sissenwine, M. P., B. E. Brown, J. E. Palmer, R. W. Essig, and W. Smith. 1982. Empirical examination of population interactions for the fishery resources off the Northeastern USA. Canadian Special Publication of Fisheries and Aquaculture Sciences. 59:82-94.

Stehlik, L.L. 2007. Essential fish habitat source document: spiny dogfish*, squalus acanthias.* Life history and habitat characteristics, 2nd edition. NOAA Technical Memorandum. NMFS-NE-203.

Steimle, F.W., C.A. Zeitlin, P.L. Berrien, D.L. Johnson, and S. Chang. 1999a. Essential Fish Habitat Source Document: Tilefish, *Lopholatilus chamaeleoticeps*, Life History and Habitat Characteristics. NOAA Technical Memorandum. NMFS-NE-152.

Steimle, F.W., W.W. Morse, P.L. Berrien, and D.L. Johnson, 1999b. Essential Fish Habitat Source Document: Red Hake, *Urophicis chuss*, Life History and Habitat Characteristics. 2nd ed. August 2004. NOAA Technical Memorandum. NMFS-NE-133.

Steimle, F.W. and P.A. Shaheen, 1999c. Tautog *(Tautoga onitis)* life history and habitat requirements. NOAA Technical Memorandum. NMFS-NE-118.

Steimle, F.W., C.A. Zeitlin, P.L. Berrien, D.L. Johnson, and S. Chang 1999d. Essential fish habitat source document: scup, *Stenotomus chrysops,* life history and habitat characteristics. NOAA Technical Memorandum. NMFS-NE-149.

Steimle, F.W., W.W. Morse, P.L. Berrien, and D.L. Johnson, 1999e. Essential fish habitat source document: Goosefish, *Lopphius americanus,* life history and habitat characteristics. NOAA Technical Memorandum. NMFS-NE-127.

Steimle, F.W., W.W. Morse, P.L. Berrien, D.L. Johnson, and C.A. Zeitlin 1999f. Essential fish habitat source document: Ocean pout, *Macrozoarces americanus,* life history and habitat characteristics. NOAA Technical Memorandum. NMFS-NE-129.

Steneck, R. S. 1997. Fisheries-induced changes to structure and function of the Gulf of Maine Ecosystem. In Wallace, G. T., and E. F. Braasch, eds. Proceedings of the Gulf of Maine Ecosystem Dynamics Scientific Symposium and Workshop, RARGOM Report. Pages 151-165.

Stevenson, D. 2008. Personal communication with David Stevenson of Nation Marine Fisheries Service based on review of NMFS Essential Fish Habitat Source documents. August 2008.

Theroux, R. B. and M. D. Grosslein. 1987. Benthic fauna. IN R.H. Backus and D. Bourne (eds.), Georges Bank, p. 283-295. MIT Press, Cambridge, MA.

TRAC (Transboundary Resource Assessment Committee). 2009a. Eastern Georges Bank Cod. TRAC Status Report 2009/01. http://www.mar.dfo-mpo.gc.ca/science/TRAC/TSRs/TSR_2009_01_E.pdf. Accessed August 2009

TRAC (Transboundary Resource Assessment Committee). 2009b Georges Bank Yellowtail Flounder. TRAC Status Report 2009/03. http://www.mar.dfo-mpo.gc.ca/science/TRAC/TSRs/TSR_2009_03_E.pdf. Accessed August 2009

Valentine, P.C., J.S. Collie, R.N. Reid, R.G. Asch, V.G. Guida, and S. Dann. 2007. The occurrence of the colonial ascidian *Didemnum* sp. on Georges Bank gravel habitat - Ecological observations and potential effects on groundfish and scallop fisheries. Journal of Experimental Marine Biology and Ecology. 342 (2007) 179-181.

CHAPTER

8

Small Pelagic Fish

Chris Littlefield

Introduction

© Chris Littlefield, TNC

Small pelagic, or forage, fish species comprise a critical component of the incredibly complex and resilient ecosystem of the Northwest Atlantic (Link et al. 2006). Also known as small pelagics, these species, with a few notable exceptions, are abundant. Because they provide crucial ecological links between plankton and higher level predators, small pelagic species bind the entire system together and can help aid the recovery of depressed populations of benthic and pelagic fish, mammals, and birds. There are several species among the small pelagic group currently of concern to conservation, most notably the Atlantic menhaden. Virtually all marine fish and invertebrate species, from egg to adult stages, are forage for other predators at some stage of their lives and most will not be considered here. Zooplankton, worms, crustaceans and other invertebrates, except for two species of squid, also will not be included in this assessment. In addition to their importance to the ecology of the region as a crucial intermediate component of the food web, small pelagic species are subject to varying degrees of fishing effort and exploitation. Until recently, the ecosystem impacts of fisheries conducted on small pelagic species were seldom taken into account.

Technical Team Members

Mark Bryer, The Nature Conservancy, Maryland
Ted Durbin, Ph.D., University of Rhode Island
Chris Littlefield, The Nature Conservancy, Rhode Island
Jay Odell, The Nature Conservancy, Virginia
William Overholtz, Ph.D., Northeast Fisheries Science Center, National Marine Fisheries Service

Selection of Target Species

The team chose eight important species to include in the assessment, six of which are the objects of commercial fisheries, one subject to only a small regional bait fishery. These species were selected after consultation with numerous experts on the basis of their level of importance to the Northwest Atlantic marine ecosystem, especially with regard to their role as prey for a variety of birds, cetaceans, pinnipeds, and many larger coastal and offshore predatory fish species, including large pelagics. We acknowledge the role of the many other small pelagic species in the ecosystem, but felt it was important to limit the analysis to several important ones. Also, as six of eight are the object of significant fisheries and are managed as such, there is abundant information on them which aids in developing conservation strategies.

The species chosen are:

- Atlantic herring *(Clupea harengus)*
- Atlantic mackerel *(Scomber scombrus)*
- Atlantic menhaden *(Brevoortia tyrannus)*
- Northern sand lance *(Ammodytes dubius)*
- American sand lance *(A. americanus)*
- Longfin inshore squid *(Loligo pealeii)*
- Northern shortfin squid *(Illex illecebrosus)*
- Butterfish *(Peprilus triacanthus)*

Population Status and the Importance of Northwest Atlantic Region

Because of widespread overfishing of more desirable groundfish species and large pelagics, small pelagic species comprise a growing global percentage of fish landings, a phenomenon known as "fishing down the food web (Pauly et al. 1998). In some cases, populations of forage species have increased dramatically due to release from "top down" predation pressure as their predators have been removed from the system, or from reduced fishing pressure, or a combination of factors. In the Northwest Atlantic, there are a number of instances of severe declines in small pelagic populations linked to both overfishing and climate change, which have in turn had adverse impacts on predator populations. In the Northwest Atlantic region and elsewhere, the fish community has undergone a shift from demersal to pelagic (including many small pelagic) species (Wood et al. 2008).

This shift has occurred as groundfish populations have decreased and several key species of small pelagics have recovered from previous overfishing, most notably Atlantic herring and Atlantic mackerel. Atlantic herring have been at or near peak levels of abundance in the past several years, relative to previous highs in the 1960s (Overholz 2006a and 2006b). The majority of these eight species have declined since the 1960s when foreign industrial fleets began depleting both groundfish and small pelagic stocks prior to the creation of the Exclusive Economic Zone (EEZ). Domestic exploitation of Atlantic menhaden in State waters surged around the same time. The Northeast Fisheries Science Center initiated its bottom trawl surveys in the 1960s and they remain the only reliable fishery-independent data set for all the species except Atlantic menhaden. Only Atlantic mackerel and Atlantic herring are at or near 1960s levels. Also, it should be noted that the Georges Bank Atlantic herring stock has recovered completely from collapse over the past two decades, a great success story (Overholz and Friedland 2002).

According to the ASMFC (2008), Atlantic menhaden have not been overfished and overfishing is not currently occurring, yet abundance levels are low compared to the 1950s and 1960s. The geographic range of this species has contracted, young-of-the-year indices have been extremely low for the past several years (Maryland Department of Natural Resources 2008), and there are few larger older fish who can migrate into the Gulf of Maine, i.e., through the full migratory range. Although menhaden can live ten years or more, the population is dominated by very young fish. In addition, approximately sixty percent of the fish taken in the reduction fishery (processed for fish meal and oils) in Virginia are subadult (mostly year 2) and are being removed from a very restricted area near the mouth of Chesapeake Bay (Spear 2008).

Loligo squid have demonstrated a relatively stable biomass since the beginning of the National Marine Fisheries Service (NMFS) trawl data series (Hendrickson and

Jacobson 2006). The lack of recovery of the Illex squid population may be due to extreme overfishing in the 1970s, as well as depressed populations of capelin, a key forage species for Illex at the northern limit of their migratory range (i.e. Nova Scotia and Labrador) (Macy 2008). Finally, butterfish reached historic lows around 2000 and the population is still depressed. Though fishing pressure is low, there is significant bycatch in other fisheries (Overholz 2006c).

Sand lance populations exploded during the early 1980s, a response to release from predation pressure due to overfishing of species which prey on them. As some stocks have recovered, most notably herring and mackerel, sand lance numbers have declined. As the only species among the small pelagic group assessed here that are not subject to significant fisheries, sand lance populations are regulated directly by predation which in turn is influenced by fishery impacts (Weinrich et al. 1997).

Ecosystem Interactions and Ecological Dependencies

Small pelagic species are crucial to the health and functioning of marine ecosystems (Read and Brownstein 2003). On a very broad scale, they capture energy from lower trophic levels (phytoplankton, zooplankton, and small planktivorous fish) and transfer it to higher level carnivores including mammals, birds, and numerous species of pelagic and demersal fish and marine invertebrates. Because of their seasonal migrations and other life history traits, they also provide a significant link between coastal and pelagic systems by transporting energy and biomass seasonally from coastal embayments and nearshore waters to offshore waters (Gottleib 1998).

Herbivorous or omnivorous small pelagic species also are capable of removing significant amounts of phytoplankton from the water column. As a result of the often massive numbers and dense schooling behavior of some of these species, they can significantly alter water chemistry on a localized scale by increasing nutrients and depleting oxygen (Oviatt et al. 1972). On a bay- or estuary-wide scale, small pelagic species serve as net exporters of nitrogen from these systems (Gottleib 1998).

Some species in this group compete with one another and with species outside the group, serving as predator or prey depending on life stage. Atlantic herring and Atlantic mackerel consume sand lance. Sand lance competes for *Calanus finmarchicus* (a zooplankton) with endangered northern right whales (Kenney et al. 1986). Both species of squid are piscivorous, and squid are also cannibalistic. Also of note is the importance of small pelagic species to a host of large pelagic fish, as well as cetaceans and birds.

Northwest Atlantic Distribution and Important Areas

Methods

See methods overview in Chapter 5.

Limitations of Data for Small Pelagic Species

Spatial data for determining distribution and important areas was obtained from NMFS bottom trawl surveys. These surveys represent more than four decades of fishery-independent data collection throughout the Northwest Atlantic region, primarily in federal waters but in some state waters as well (inside three miles). When used for sampling small pelagic species, the survey method has some limitations with regard to fish behavior and ecology. These species tend to be found near the surface and/or can outswim the gear, so these species are not sampled as effectively as many demersal species in the trawl surveys. In addition, these fish can make diurnal vertical migrations or exhibit other behaviors that can cause them to be more difficult to catch at certain times of day. A number of experts have cautioned that there are better methods for sampling populations of small pelagic species, such as acoustics, purse seines, or midwater trawls. There is some likelihood that the trawl surveys have missed some important locations where small pelagic fish tend to be close to the surface, and the data may be biased toward areas where these species can be caught in a bottom trawl. It is unclear the extent to which these issues affect the validity of the maps created for this assessment.

Another important limitation of the data is the relatively short time frame (six weeks) in spring and fall within

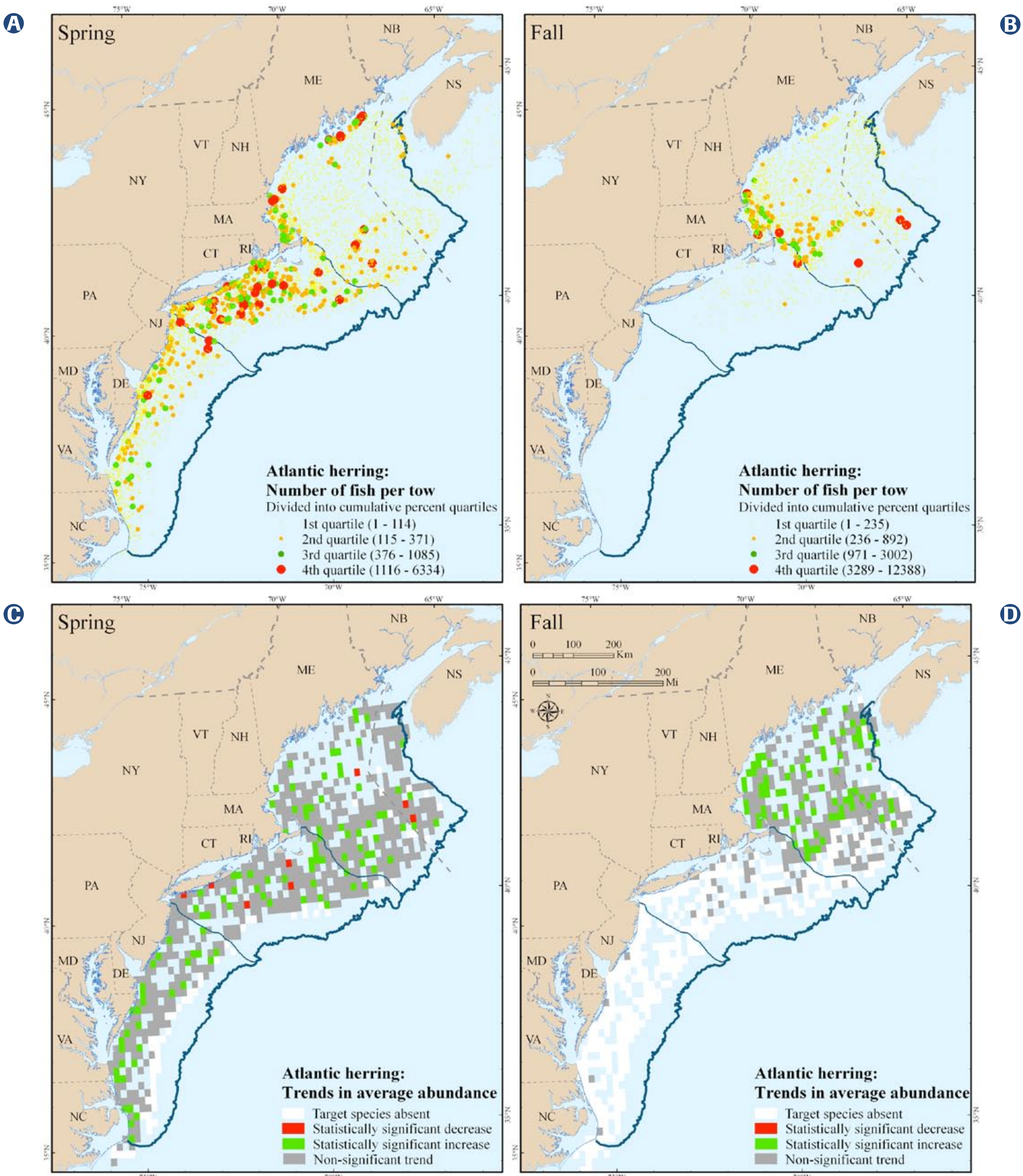


Figure 8-1. Trends in average abundance over 40 years for Atlantic herring during the spring and fall seasons.

which the surveys are conducted. These "snapshots" do not provide information about what is happening the rest of the year. When this aspect of the data is combined with the fact that these species undertake extensive migrations, a question arises as to the overall accuracy of the determination of areas of importance or persistence. As research continues, other sources of data need to be used to corroborate these findings, and would also be useful in verifying observations of spawning aggregations.

Maps, Analysis, and Areas of Importance

American Sand Lance

American sand lance is found mostly inshore of the trawl survey area. As such, American sand lance was not sampled adequately in the NMFS trawl survey.

Important Areas for American Sand Lance:
Not enough data to determine

Atlantic Herring

Distribution maps to correspond to what is known about the species from other studies (Figure 8-1a, b). In the spring, herring are found in high persistence in southern New England waters; other areas of persistence are quite localized, including Georges Bank, the area from Cape Ann to southeast of Nantucket, and very close to shore in Downeast Maine (Figure 8-2a). Less persistent, but significant concentrations are found nearshore from New Jersey to Cape Hatteras. In the fall, the fish appear to congregate in high abundances further north and east, in cooler water of the Gulf of Maine, completely outside of Mid-Atlantic Bight and Southern New England except for the area east of Nantucket near Great South Channel (Figure 8-2b). Significantly increasing trends support other data that demonstrate that this Georges Bank stock has recovered from the collapse of several decades ago (Figure 8-1c, d).

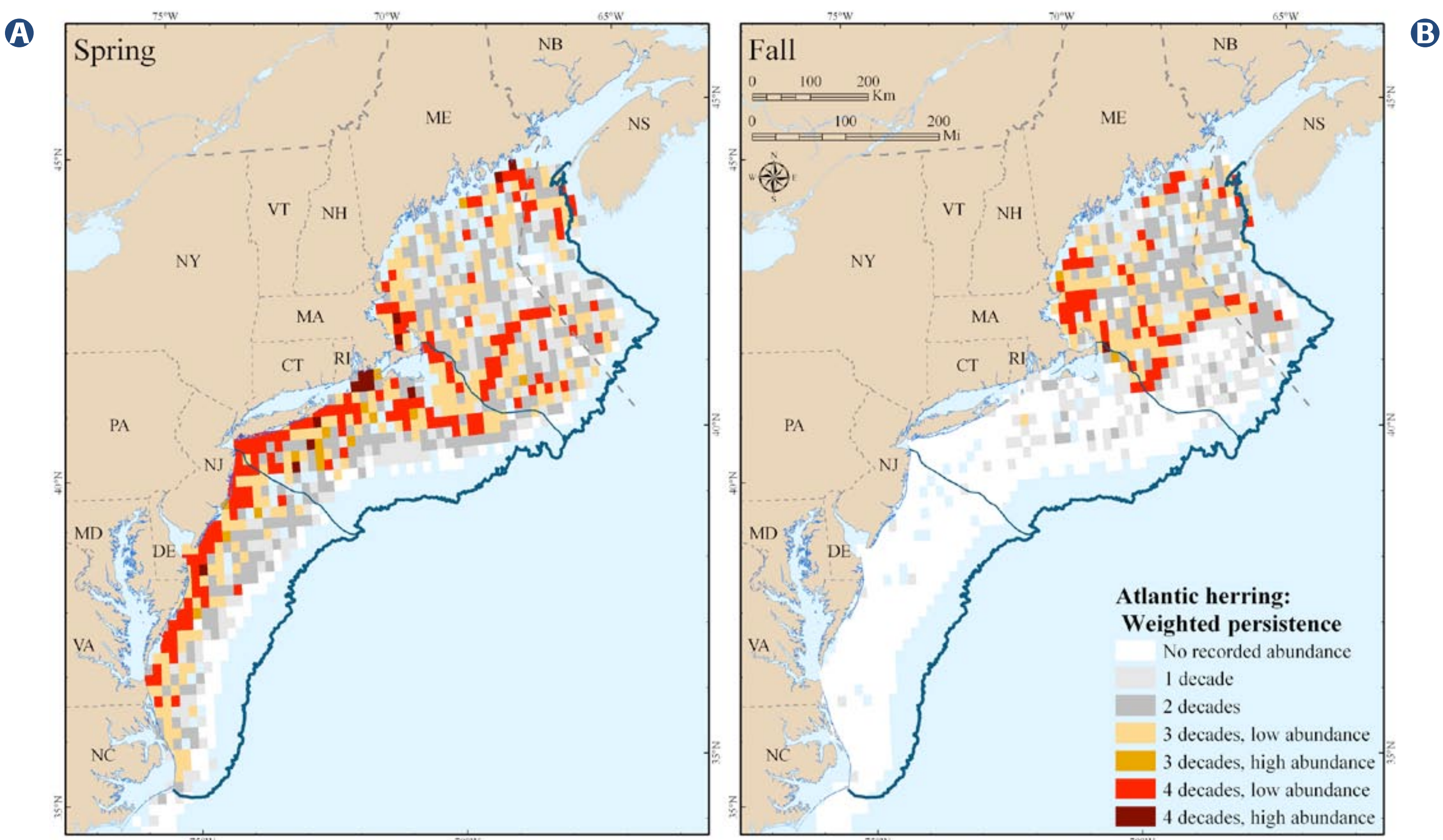


Figure 8-2. Areas with high persistence and abundance over 40 years for Atlantic herring during the spring and fall seasons.

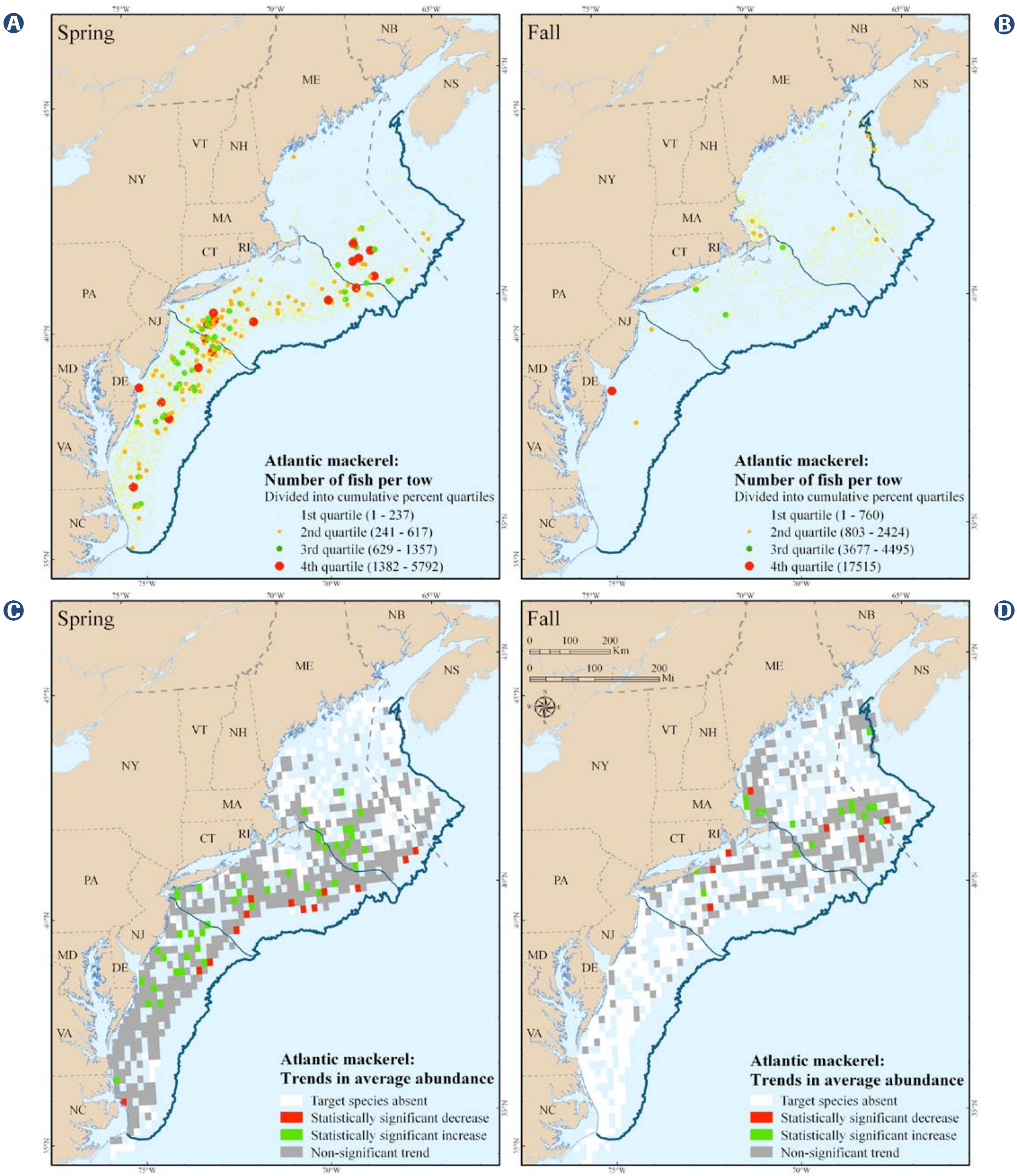


Figure 8-3. Trends in average abundance over 40 years for Atlantic mackerel during the spring and fall seasons.

Important Areas for Atlantic Herring:

Spring: Southern New England shelf waters, Georges Bank, Cape Ann to southeast of Nantucket, inshore eastern Maine

Fall: Gulf of Maine, east of Nantucket

Atlantic Mackerel

Consistent with what is known of this species' life history, in spring (Figure 8-3a), the fish are broadly distributed from Georges Bank to Cape Hatteras along the mid to outer Continental Shelf, as well as closer inshore from Rhode Island to Cape Hatteras. The high persistence/high abundance locations off southern New Jersey are likely associated with a known aggregation/spawning area at around this time of year though the spawn may be later (April/May) than the trawl survey (Figure 8-4a). In the fall, the fish are either scarce in the Northwest Atlantic area, or they are caught in lower numbers because of a change in catchability, or substantial mortality has occurred (Figure 8-4b). The spring and fall trend maps appear to reveal an increase in population size which agrees with the NMFS biomass trend for the species (Figure 8-3c, d). There seems to be a distinct decline in numbers in the spring along the outer shelf off southern New England and the areas immediately adjacent in the Mid-Atlantic Bight and the Gulf of Maine. The fall map shows no distinct pattern in the locations of decrease.

Important Areas for Atlantic Mackerel:

Spring: Shelf waters, mid- to outer Georges Bank to Cape Hatteras, near shore from Rhode Island to Cape Hatteras

Fall: Not enough data to determine

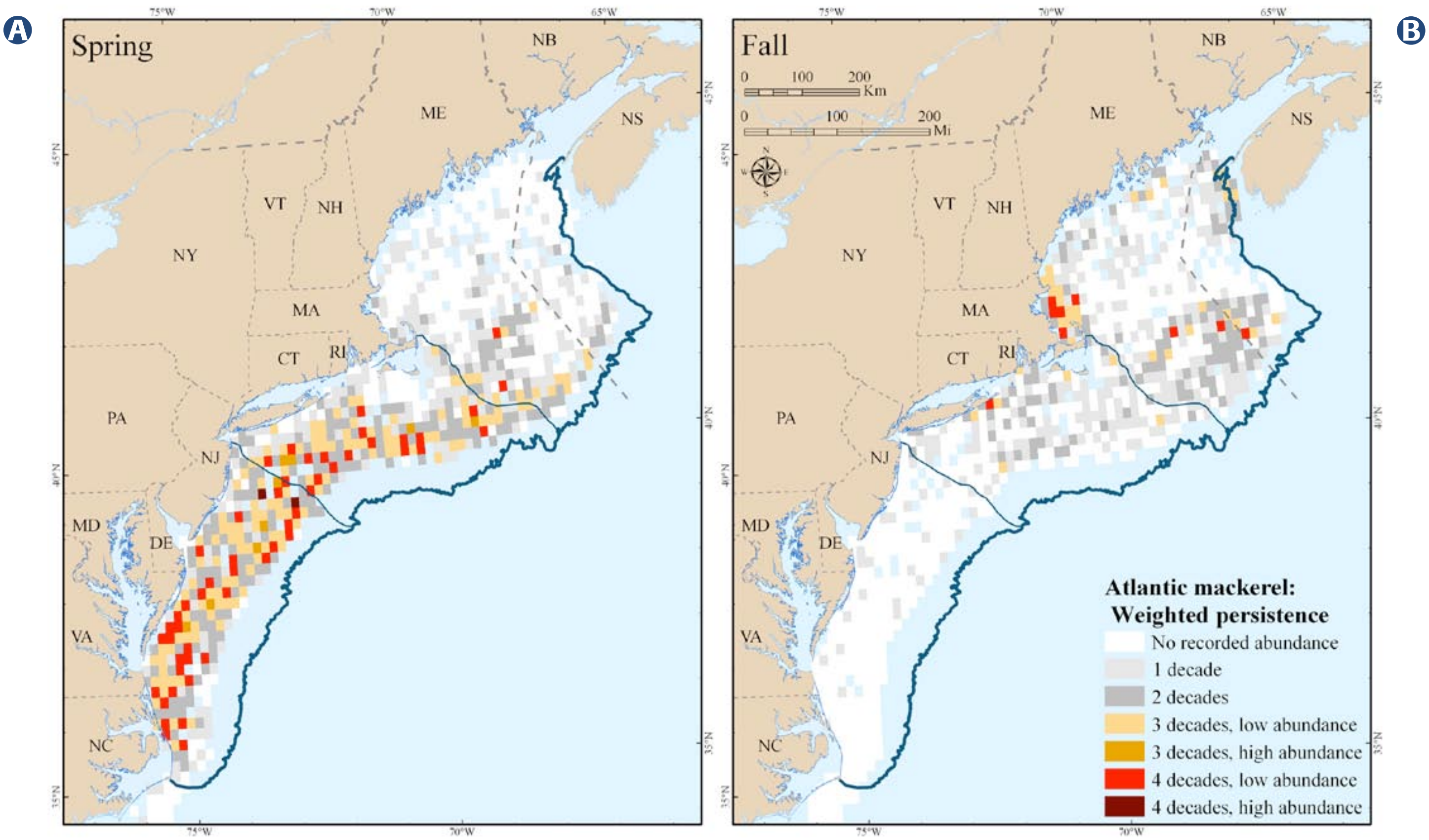


Figure 8-4. Areas with high persistence and abundance over 40 years for Atlantic mackerel during the spring and fall seasons.

A B C D

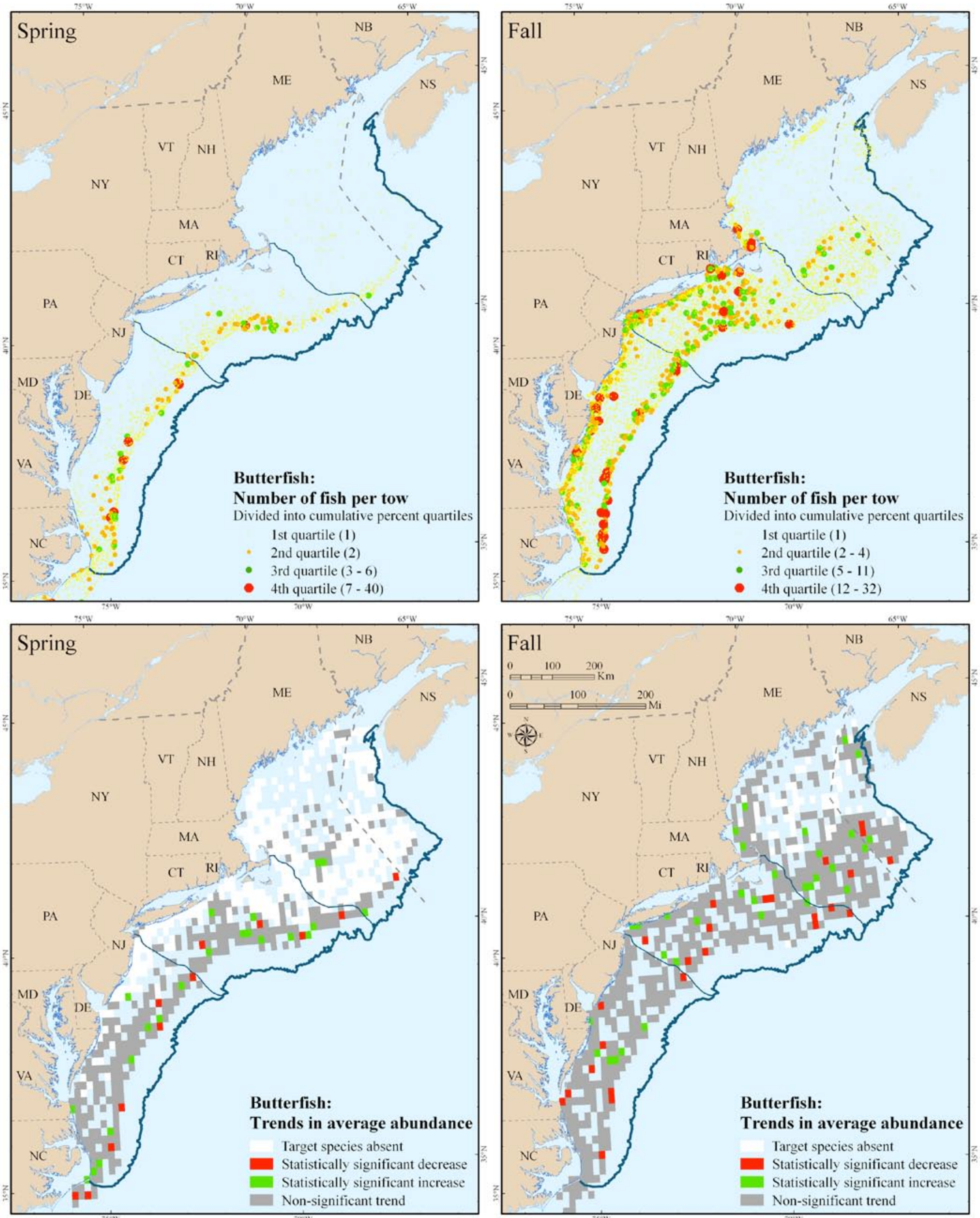


Figure 8-5. Trends in average abundance over 40 years for butterfish during the spring and fall seasons.

Atlantic Menhaden

Because of the small sample size for this species, the maps will not be interpreted. As previously stated, bottom trawls are not the best gear to use for sampling menhaden.

Important Areas for Atlantic Menhaden:

Not enough data to determine

Butterfish

Like several of the other small pelagic species, in spring, butterfish are distributed in a band along the outer Continental Shelf from southern Georges Bank to Cape Hatteras, with a more broadly distributed pattern from inshore to offshore in the fall (Figure 8-5a, b). In the fall, they are very persistent close to shore in the Mid-Atlantic Bight. South of Rhode Island to Georges Bank, they are broadly persistent from inshore to offshore in shelf waters (Figure 8-6b). There seems to be significant, highly localized persistent areas in Cape Cod Bay in the fall. These maps seem to correspond well with what is known about seasonal migration patterns. Southern New England waters seem to be particularly important in both seasons, with the Mid-Atlantic Bight less so except for an area near the northern boundary of the bight (Figure 8-6a). Of particular note is the limited movement of the offshore locations of importance. The large increase in important locations in the fall could be due to catchability or other issues and requires closer investigation. The spring trend map illustrates an immense decline, which is in agreement with NMFS temporal population trends (Figure 8-5c). Curiously, the fall trend analysis does not detect the decline (Figure 8-5d).

Important Areas for Butterfish:

Spring: Outer Continental Shelf from Georges Bank to Cape Hatteras

Fall: Same as spring, plus inshore waters of Mid-Atlantic Bight, all shelf waters from Rhode Island to Georges Bank, Cape Cod Bay

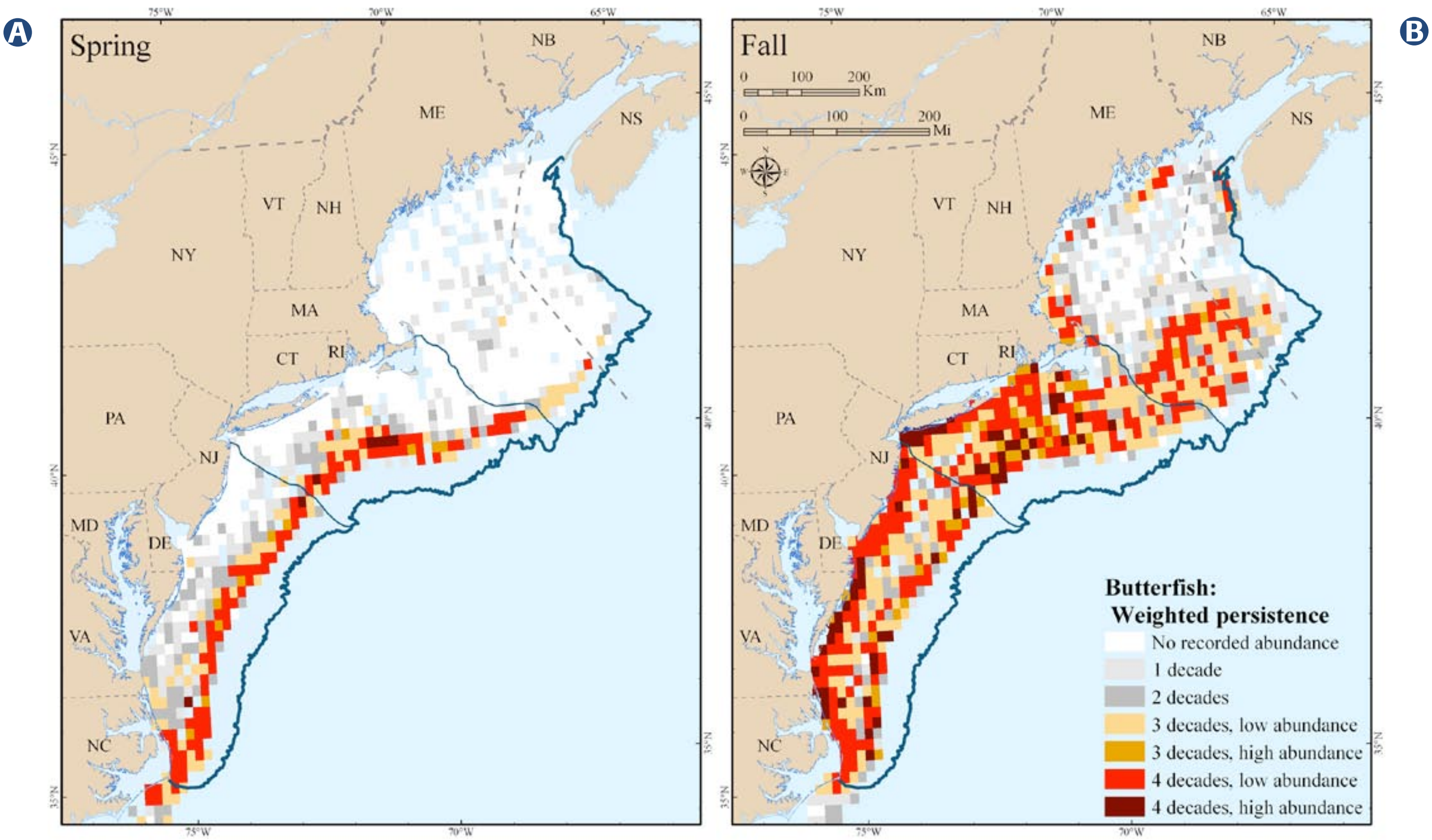


Figure 8-6. Areas with high persistence and abundance over 40 years for butterfish during the spring and fall seasons

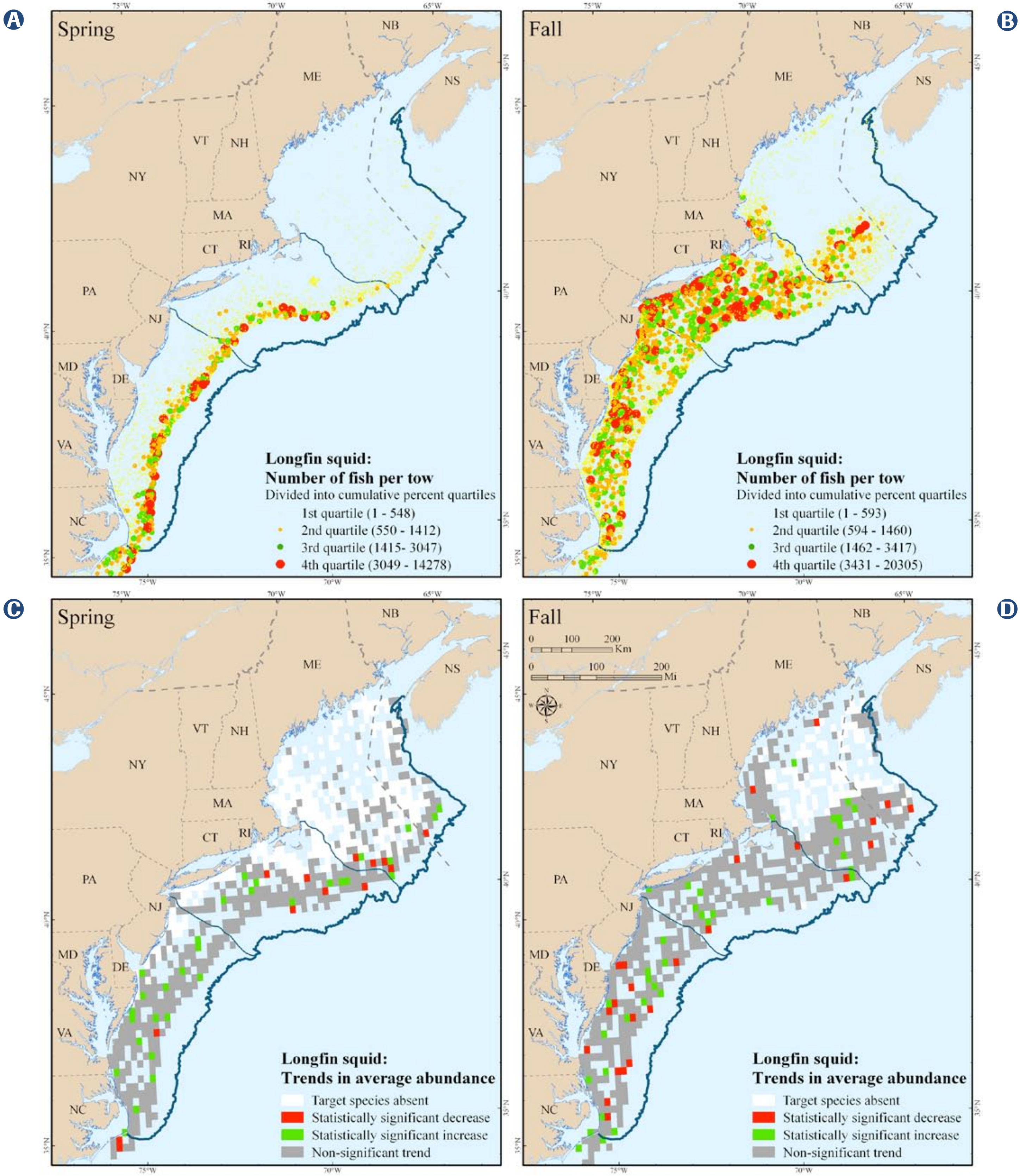


Figure 8-7. Trends in average abundance over 40 years for longfin squid during the spring and fall seasons.

Longfin Inshore Squid

The distribution of this species corresponds well to information on its life history and movements (Figure 8-7a, b). They are persistent near the shelf edge from Cape Hatteras to south of Cape Cod in the spring (Figure 8-8a). In the fall, they are broadly dispersed in shelf waters of southern New England and the Mid-Atlantic Bight, on portions of Georges Bank, Cape Cod Bay, a small area adjacent to the tip of Cape Cod, and inshore (Figure 8-8b). There may be two groups in the fall, possibly representing two main age cohorts, one further inshore than the other. The trend maps seem to indicate a relatively stable population which is in agreement with NMFS biomass trend data (Figures 8-7 c, d).

Important Areas for Longfin Inshore Squid:

Spring: Continental Shelf edge waters, Cape Cod to Cape Hatteras

Fall: Shelf waters, southern New England, Mid-Atlantic Bight, on portions of Georges Bank, Cape Cod Bay, a small area adjacent to the tip of Cape Cod, and inshore

Northern Sand Lance

This species is broadly distributed in the spring from the Chesapeake to Georges Bank, mostly inshore, with a dense concentration in the Cape Ann to Stellwagen Bank area (Figure 8-9a). During the spring, analysis reveals high persistence, but low abundance in an area extend-

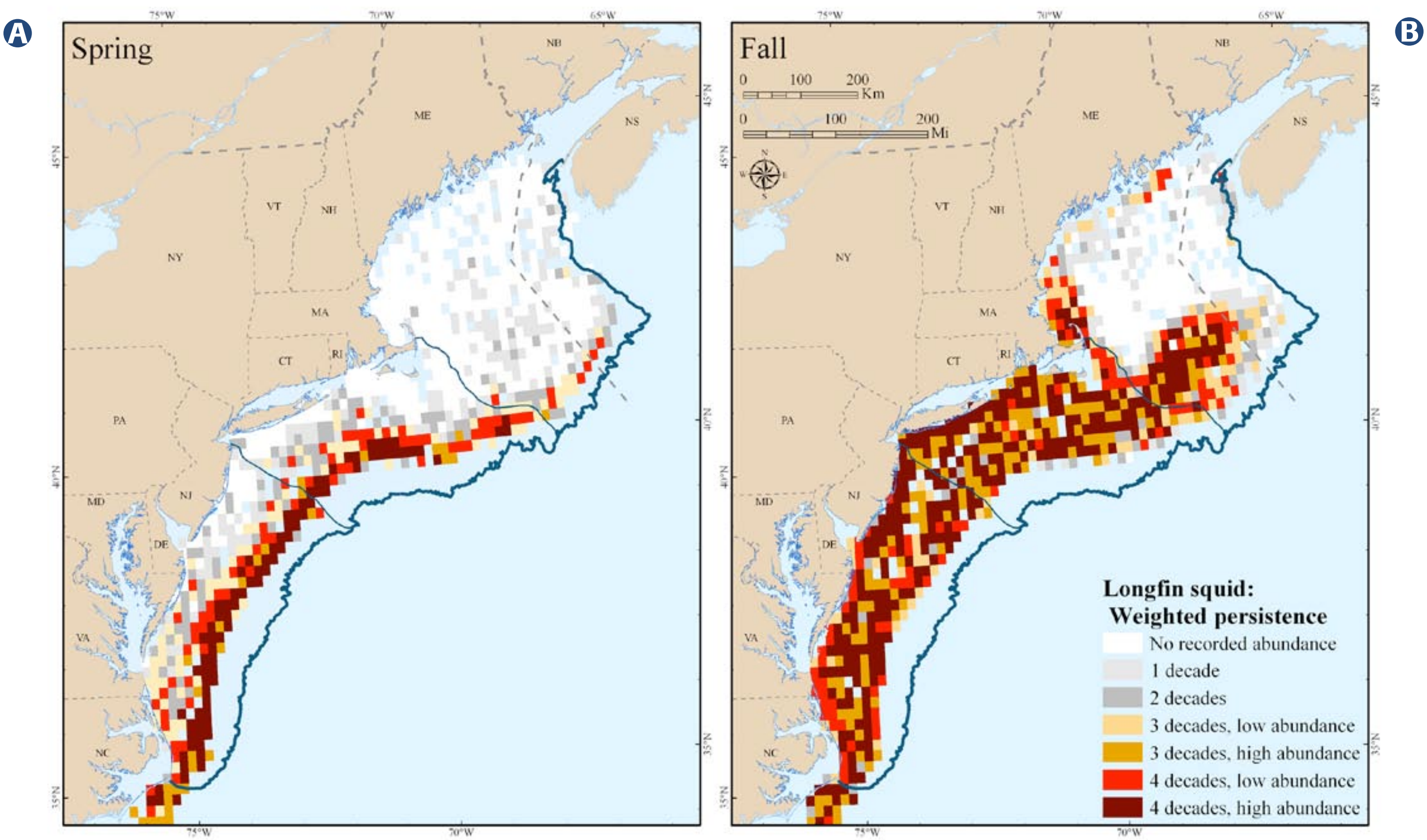


Figure 8-8. Areas with high persistence and abundance over 40 years for longfin squid during the spring and fall seasons.

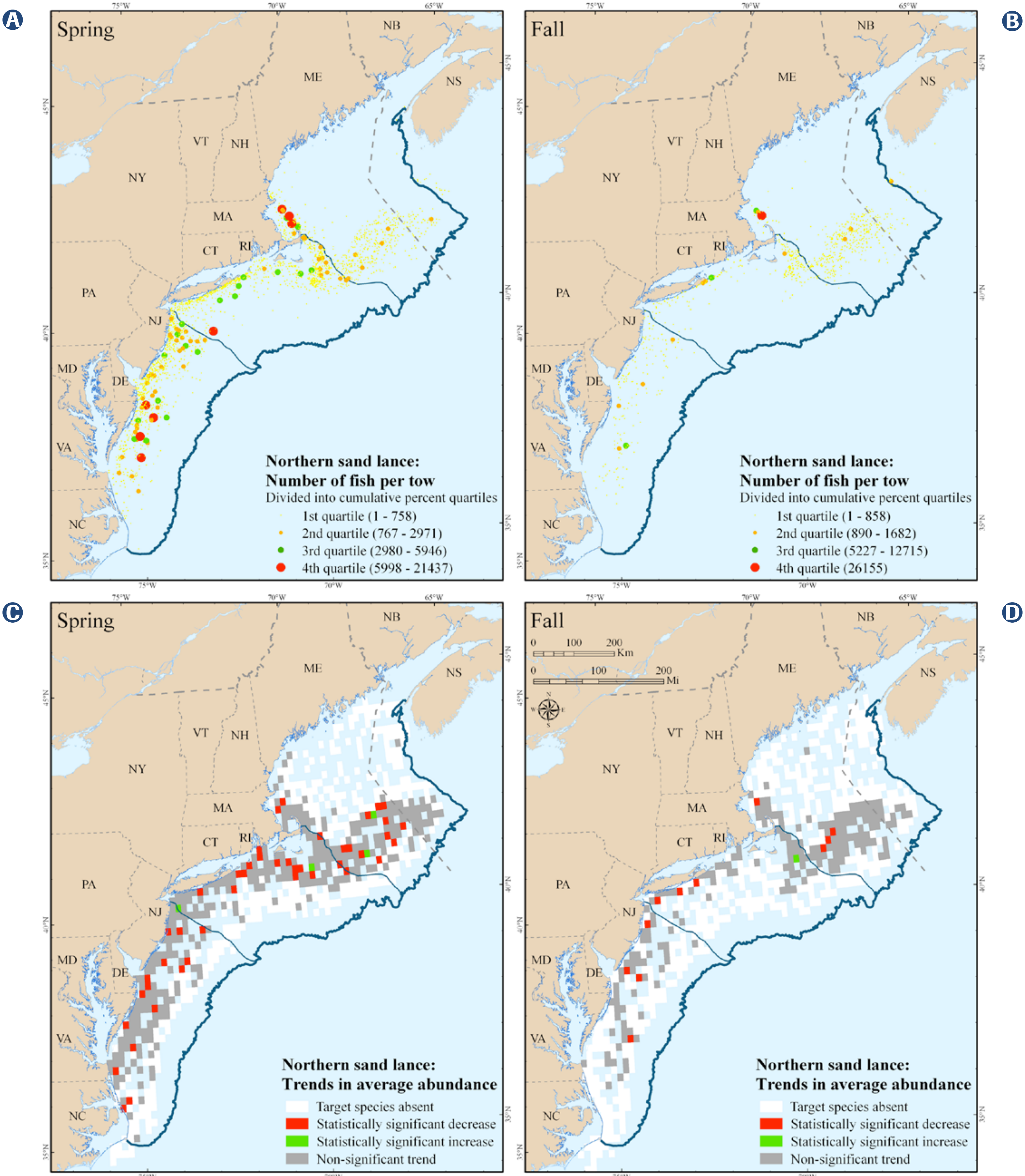


Figure 8-9. Trends in average abundance over 40 years for northern sand lance during the spring and fall seasons.

ing from south of Cape Ann, Massachusetts to southeast of Nantucket, near shore off southern New England and off of Long Island, New Jersey, Delaware, and Virginia, as well as portions of Georges Bank (Figure 8-10a). There are a few scattered high abundance locations that were persistent over three decades, the most noteworthy near Stellwagen Bank. In the fall, areas of high persistence remain in the area from Cape Ann to southeast of Nantucket, and on Georges Bank, as well as a series of isolated sites from Long Island to the shelf off Virginia (Figure 8-10b). The species is much less abundant in the fall, possibly due to predation by fishes, mammals, and birds for the previous half of the year. The spring trend map indicates a broad decline, while the fall map has far fewer points but shows a strong downward trend as well (Figure 8-10a, b). Sand lance populations exploded in the early 1980s when their predator populations were overfished, especially Atlantic mackerel. As predator populations recovered sand lance populations were reduced, the populations have never been as high as in the early 1980s.

Important Areas for Northern Sand Lance:

Spring: Cape Ann, Massachusetts to southeast of Nantucket, Stellwagen Bank

Fall: Cape Ann to Nantucket, Georges Bank, isolated locations from Long Island, New York to Virginia

Northern Shortfin Squid

Distribution maps indicate Illex are fairly persistent and moderately abundant in a narrow band along the edge of the Continental Shelf in the spring from southern Georges Bank to Cape Hatteras, in addition to the recognized spawning area in the Mid-Atlantic Bight (Figures 8-11a, b). They are more persistent in the same area in

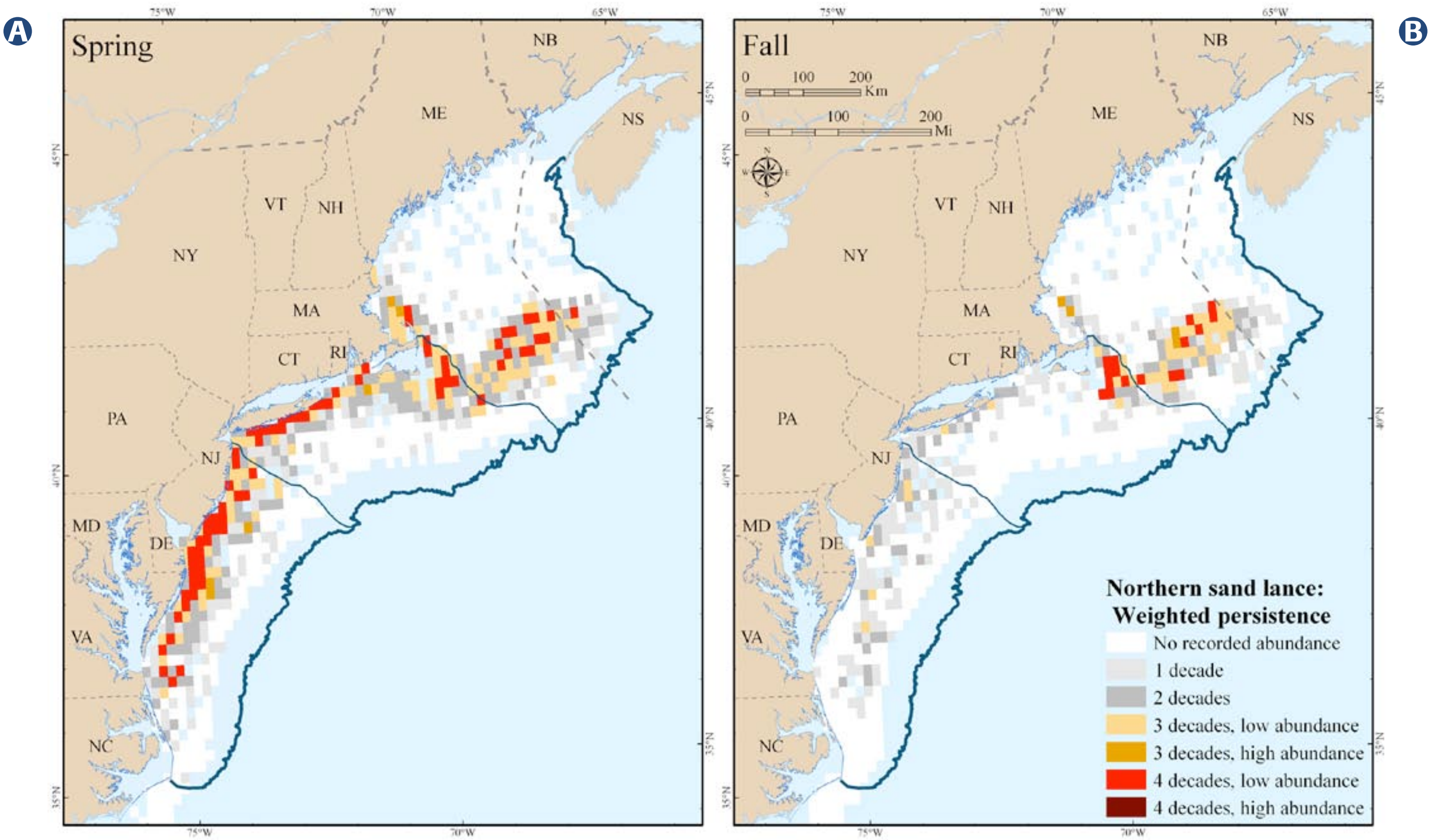


Figure 8-10. Areas with high persistence and abundance over 40 years for northern sand lance during the spring and fall seasons.

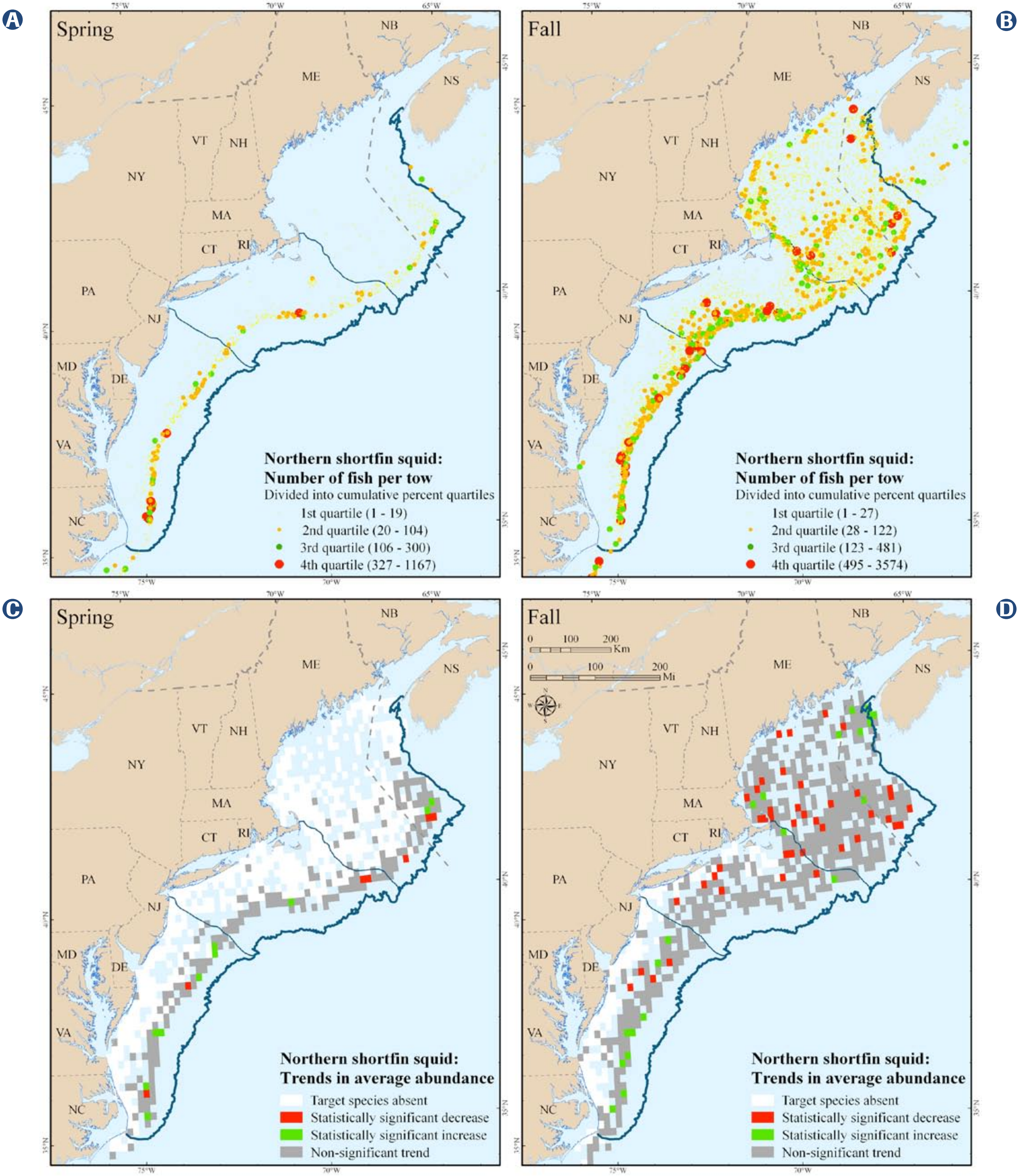


Figure 8-11. Trends in average abundance over 40 years for northern shortfin squid during the spring and fall seasons.

the fall, as well as throughout the Gulf of Maine and on Georges Bank, on the outer portions of the shelf in southern New England and the Mid-Atlantic Bight, and at an isolated spot southeast of Nantucket (Figure 8-12b). Because they are a sub-annual species, it is possible that they are simply more abundant in the fall. There appears to be no strong trend in population size in spring, while the fall map indicates a significant, broad decline mirroring what NMFS has detected in their long-term data set (Figure 8-11c, d).

Important Areas for Northern Shortfin Squid:

Spring: Edge of Continental Shelf, Georges Bank to Cape Hatteras

Fall: Gulf of Maine, outer Continental Shelf waters from Georges Bank to Cape Hatteras

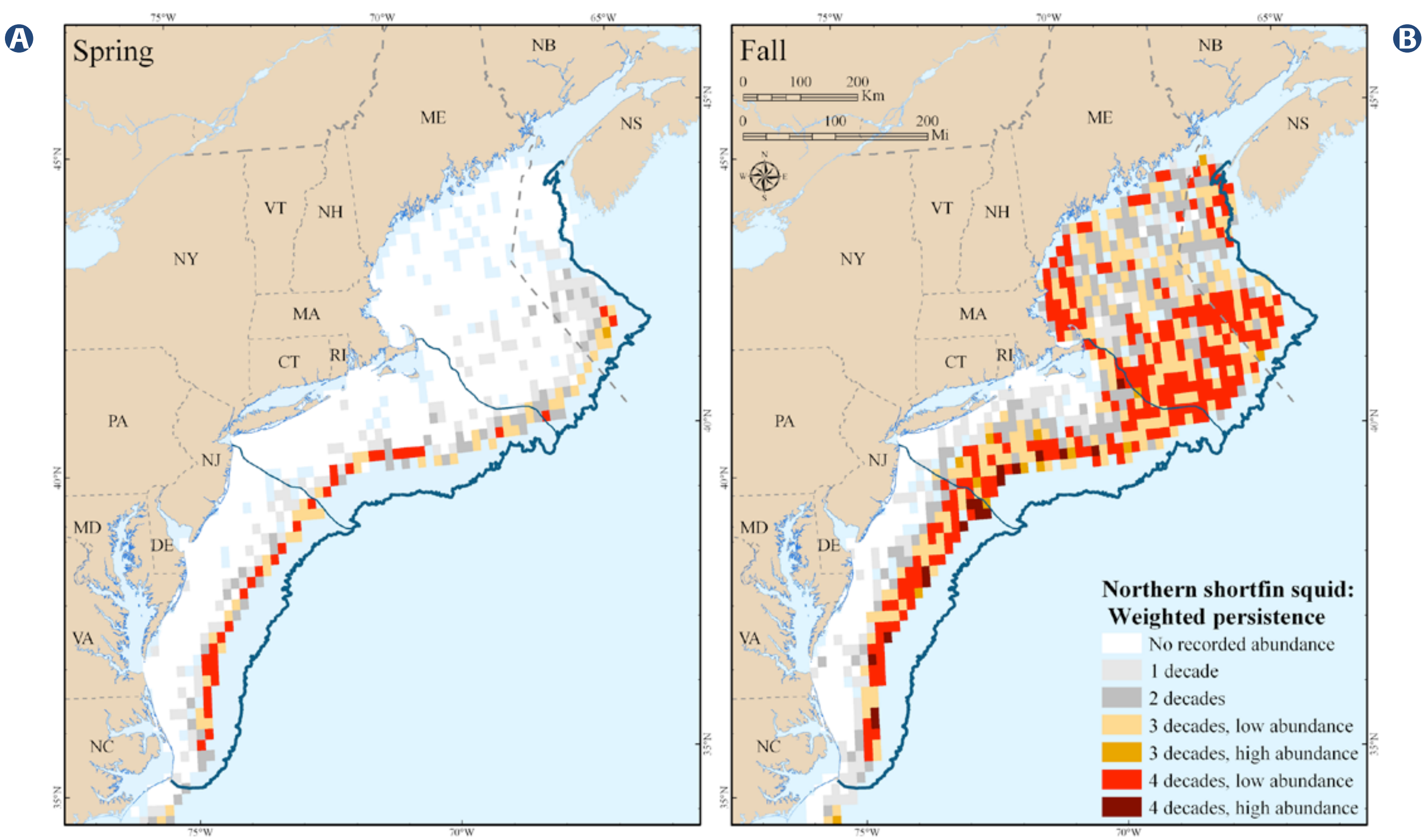


Figure 8-12. Areas with high persistence and abundance over 40 years for northern shortfin squid during the spring and fall seasons.

Human Interactions

Pollution, primarily land-based, is a major threat to these species when they are found in bays and estuaries, especially the estuarine dependent Atlantic menhaden. While some life stages or population segments of some of these species utilize bays and estuaries where they can be impacted by pollution, none are potentially impacted as much as the menhaden. Nitrogen from atmospheric deposition, agriculture, sewage, lawn fertilizers, and from enriched coastal and estuarine sediments, causes excessive plankton and algal growth. As these plankton die, their decomposition can lead to increased frequency of episodes of hypoxia (low oxygen). Such events are widely known to cause episodic mortality and increased disease rates of menhaden. Other pollutants include pesticides and other toxics, estrogen and estrogenic compounds, mutagens, pharmaceuticals, and other substances, many of which can pass through sewage treatment plants unaltered (Kennish 2002).

Climate change is impacting small pelagic species in a number of ways. As is true on land, the increase in average water temperature is affecting the timing of critical ecological events, such as plankton blooms. Such changes can severely impact the most vulnerable life stages which depend on particular conditions or food items to be present at critical times. This is especially true of larvae which cannot travel to find food if it is not locally available. Climate change can alter the timing and location of fish spawning; for example, it has been suggested that the Atlantic menhaden spawning area may be moving northward which does not allow larvae to be transported as effectively into Chesapeake Bay, their single most important nursery system (Griffin et al. 2007).

Fishing impacts on most small pelagic species are significant. The sizeable catch of Atlantic menhaden, taken near the mouth of Chesapeake Bay, is comprised primarily of subadult fish removed from the population before they have spawned (Spear 2008). While some fishery managers believe the stock is not overfished, others disagree. The bulk of the population is composed primarily of these subadult fish, as opposed to a more optimal broad age/size distribution including significant numbers of older, larger, more fecund fish. Another example of significant fishing impacts is the severe downward trend in the butterfish population over the past several years (Overholz 2006c). Although direct fishing effort on the species has been reduced, bycatch mortality of butterfish in other fisheries has been high. Finally, while there is insufficient information to understand the extent of the damage, bottom trawls and dredges have the potential to damage or destroy the demersal eggs of Atlantic herring, longfin squid, and both species of sand lance.

Another source of mortality is entrainment of eggs, larvae and small fish in power plants; mortality can occur from thermal effluents emitted by power plants as well. As many of these plants are located within large estuaries, it is important to gather high-quality data on the magnitude of this threat in order to determine necessary actions (US EPA 2010). Once again, it is likely that Atlantic menhaden is most impacted. Finally, ocean acidification is a looming threat that has the potential to severely alter marine chemistry, food webs, and a host of other critical processes. The full potential impacts of this threat are unknown.

Management and Conservation

Regulatory Authority

Atlantic herring, Atlantic mackerel, short-finned inshore squid, long-finned squid, and butterfish are managed in federal waters by NMFS under the authority of the Magnuson-Stevens Fishery Conservation and Management Act. Atlantic herring are managed by the New England Fishery Management Council (NEFMC), while the two squid species, butterfish, and mackerel are managed together under the Atlantic Mackerel, Squid, and Butterfish Fishery Management Plan by the Mid-Atlantic Fishery Management Council. Atlantic menhaden are managed by the Atlantic States Marine Fisheries Commission (ASMFC), while the two species of sand lance are unmanaged.

Atlantic herring are unique as they are jointly managed by ASMFC and NEFMC because they occur and are fished in both state and federal waters. A variety of tools are used to manage the species, including area management, spawning closures, controls on catch, and a total allowable catch (TAC) for the inshore fishery in the Gulf of Maine. While Atlantic menhaden are managed by ASMFC, they are also under the jurisdiction of the various states throughout their migratory range, each of which has unique rules and regulations regarding harvest.

As all of these species except Atlantic menhaden are transboundary stocks relative to our international maritime border with Canada, they are also subject to the management authority of the Canadian government and the Department of Fisheries and Oceans. Also, several species migrate beyond the limits of the U.S. and Canadian Exclusive Economic Zones.

Current Conservation Efforts

Atlantic herring are being managed by NEFMC in concert with ASMFC. The Georges Bank stock has fully recovered from collapse, biomass is at very high levels, and exploitation rates are moderate (Overholz 2006a). There is a broad age/size distribution and spawning closures in major spawning areas prevent damage to egg beds. A recently enacted NEFMC nearshore Gulf of Maine closure was initiated by the Coalition for the Atlantic Herring Fishery's Orderly, Informed, and Responsible Long-Term Development (CHOIR), a coalition of commercial and recreational fishing interests, whale watch enterprises, and environmentalists, in response to an expansion of the midwater trawl fishery. There was a perception that the large scale capture of Atlantic herring was leading to localized depletion resulting in loss of forage for whales, other wildlife, and species sought by commercial and recreational vessels which prey on herring.

Atlantic mackerel are managed solely by the Mid-Atlantic Fisheries Management Council (MAFMC). Stock levels are high (Overholz 2006b), and there is currently no non-governmental organization (NGO) conservation effort directed toward the species (nor are there such efforts aimed at any of the other federally managed species). Butterfish are at or near historic lows (NEFSC 2008) and NMFS is working on reducing the high bycatch of this species in other fisheries (Overholz 2006c). The Illex squid population, which has not recovered from overfishing that took place in the 1970s, is closely monitored and strict quotas are adhered to in the fishery (W. Macy, Personal communication 2008). There are no conservation efforts directed toward the two unmanaged species of sand lance. In the United States, localized bait fisheries do have the potential to decimate discrete populations of American sand lance as the fish concentrate so heavily in specific locations. In 2008, ASMFC enacted a five year cap on annual harvests of Atlantic menhaden of 109,020 metric tons, in response to pressure from a host of recreational fishing and environmental groups. All states north of Virginia have banned the taking of menhaden for reduction purposes.

Species Accounts

Atlantic Herring *(Clupea harengus)*

Atlantic herring are a common pelagic, planktivorous fish (Bigelow and Schroeder 2002). They are found throughout Northwest Atlantic Continental Shelf waters from Labrador to Cape Hatteras, and in the North and Northeast Atlantic from Greenland to the Straits of Gibraltar, including the North and Baltic Seas. Ranging from shallow inshore waters to offshore, Atlantic herring adults occur predominantly in open water in large schools, while juveniles frequent bays and estuaries from the Chesapeake northward at various times of year, with greater abundance north of Delaware Bay (Bigelow and Schroeder 2002). Atlantic herring spawn in discrete locations from Labrador to Nantucket Shoals, from spring in the more northerly areas to summer and fall in U.S. waters. Juveniles and adults undergo significant migrations during the year in response to temperature, salinity, and food availability. They are relatively long-lived, reaching ages of 15-18 years and lengths of approximately 40 cm.

Atlantic herring deposit adhesive eggs in “beds” on gravel bottom in specific locations both inshore and offshore in the Gulf of Maine, on Georges Bank, and Nantucket shoals (Stevenson and Scott 2005). After hatching, larvae are spread by surface currents, though some larvae are able to remain near their place of hatching for extensive periods. Larvae are found in coastal, estuarine, and offshore waters from the Bay of Fundy to New Jersey. Juveniles are pelagic, found close to shore and in bays and estuaries in their first year of life, and are tolerant of low salinities but avoid estuarine waters south of Long Island Sound during the warmer months. Second-year fish prefer higher salinities when inshore and avoid brackish areas. In the winter, one year olds move to deeper inshore waters while two year old fish can be found offshore from Cape Hatteras to the Bay of Fundy in winter and spring. Food availability, frontal zones and currents can further limit suitable habitat (Bigelow and Schroeder 2002).

During summer and fall, adults are found throughout the Gulf of Maine and in the deeper portions of Georges Bank, with a southerly shift in winter from Cape Hatteras to deeper waters of Georges Bank. During the spring, they are found from the southwest part of the Gulf of Maine to the shelf waters of the mid-Atlantic, again with fish also found in the deeper parts of Georges Bank. They are most abundant where dense plankton concentrations are found, in well-mixed areas and where fronts develop between well-mixed areas and stratified waters (Stevenson and Scott 2005).

Atlantic Mackerel *(Scomber scombrus)*

Atlantic mackerel, a pelagic, fast-swimming species which consumes zooplankton, small fishes and invertebrates, occur on both sides of the North Atlantic as well as in the Baltic, Mediterranean, and Black Seas (Bigelow and Schroeder 2002). In the Northwest Atlantic, they range from Labrador to North Carolina, undergoing extensive seasonal movements. They overwinter along the Continental Shelf edge, and then move inshore then northeast in spring, and in the fall, reverse the movement (Bigelow and Schroeder 2002).

They are sometimes known to enter estuaries and harbors in search of food and to avoid predation, especially when they are young, though occasionally adults can be found in very shallow waters in coastal embayments. Mackerel make significant migrations to and from spawning and wintering areas. During spring they generally are found somewhat closer to shore for spawning off the Mid-Atlantic Bight, and in the southern Gulf of St. Lawrence in midsummer. From spring to fall, they are found in and near surface waters from 46-55 m.

There are two distinct major spawning groups of Atlantic mackerel. The southerly component spawns in spring (April-May) in the Mid-Atlantic Bight, and the northern segment in early summer (June -July) in the southern half of the Gulf of St. Lawrence. Both spawn in waters generally shoreward of the mid-Continental Shelf. Pelagic eggs are found in shelf waters from Cape Hatteras to the Gulf of St. Lawrence, and less than a week transpires before hatching. Larvae are found over the same range, but from May to August, and juveniles begin to appear about two months after hatching. Spawning is also known to occur in Long Island Sound and Cape Cod Bay, as well as near the edge of the Continental Shelf and beyond. Females are serial spawners and lay four to seven batches of eggs (Studholme et al. 1999).

Longfin Inshore Squid *(Loligo pealeii)*

Longfin inshore squid, a pelagic cephalopod mollusk, occur in Continental Shelf and Slope waters from Newfoundland to the Gulf of Venezuela (Bigelow and Schroeder 2002); in the Northwest Atlantic they are most abundant from Georges Bank to Cape Hatteras, moving into the Gulf of Maine in the warmer months. Distribution varies seasonally due to a general inshore migration during the spring and summer. From Cape Hatteras northward, this species migrates offshore during late fall to overwinter along the shelf edge and slope in warmer waters, then returns inshore in the spring, staying until late autumn. Loligo are a subannual species, living less than a year (Jacobson 2005).

During the summer, they are restricted to surface and shallow nearshore waters, but they can be found along the shelf edge and slope in winter. Spawning occurs inshore in areas with rocks and small boulders to which the eggs are attached. Eggs can also be attached to various species of macroalgae and other eggs. Macy (personal communication 2008) has recently discovered that spawning occurs offshore in winter off Chincoteague, Virginia at depths of 50 fathoms (91.4 m), and has also identified the warmer waters near canyon heads as important wintering areas. Spawning occurs throughout the year. Eggs are laid in masses contained within semi-transparent, rubbery capsules. Hatching occurs in days to weeks, incubation time decreasing with increasing water temperature. Distribution of eggs is not well known. After hatching, larvae stay near the surface and move deeper as they grow larger and are broadly distributed.

Northern Shortfin Squid *(Illex illecebrosus)*

The highly migratory northern shortfin squid is found in the Northwest Atlantic from the Florida Straits to Newfoundland (Bigelow and Schroeder 2002). Utilizing both oceanic and shelf habitats, Illex squid undertake long migrations and are short-lived species. It is unclear if the species consists of a single stock or if there are multiple stock components. While spawning is believed to occur throughout the year, and over large areas, the only confirmed spawning location is between Cape Hatteras and southern New Jersey, where spawning occurs during late May. Spawning may also occur south of Cape Hatteras in the Gulf Stream/slope water frontal zone in winter, and near the Blake Plateau off Florida. Females die within days after spawning. It is widely believed the Gulf Stream plays a crucial role in dispersing neutrally-buoyant eggs, paralarvae (a developmental stage unique to cephalopod mollusks), and larvae, transporting them north and east along the shelf/slope waters. Paralarvae are most abundant in the Gulf Stream/slope water convergence zone in February and March, south of Cape Hatteras, though they are found in the same zone all the way to the Grand Banks

© Roger T. Hanlon

later in the year. The high biological productivity of this area is important for larvae and juveniles as well; juveniles begin to migrate onto the shelf in late spring between Cape Hatteras and Nova Scotia. Adults inhabit offshore shelf waters during the summer, except in the Gulf of Maine where they are found quite close to shore. An extensive offshore migration occurs in the fall (Hendrickson and Holmes 2004).

American Sand Lance *(Ammodytes americanus)*

American sand lance are a small, planktivorous, highly abundant fish with both demersal and pelagic traits, having a unique ability (like other species in the genus) to burrow into suitable bottom types (loose sand, sand/shell hash/fine gravel). They are equally noteworthy for aggregating and foraging in dense schools of dozens to thousands of individuals for protection from predators. Closely related to the northern sand lance, the species are often confused. Occurring from Labrador to Cape Hatteras, they are considered by many to be a keystone small pelagic species as they are food for whales, other cetaceans and marine mammals, birds, numerous fish species, squids, and crustaceans (Bigelow and Schroeder 2002).

Generally found in more inshore habitats compared to northern sand lance, they mostly inhabit very shallow coastal waters, inlets, bays, and estuaries, but also occur in shelf waters primarily on offshore banks as well as deeper waters (Auster and Stewart 1986). They are usually found over or near bottoms with substrates which allow them to burrow and seldom occur over rocky bottoms or shores. American sand lance mature in the first or second year of life, and spawn in late fall and early winter. Demersal eggs hatch from sand and fine gravel bottoms as the water temperature cools below 9° C. Exact spawning locations are difficult to determine from the available literature. Widely distributed in shelf waters, larvae consume phytoplankton, fish eggs, and copepod nauplii. Copepods are the primary food for older larvae, juveniles, and adults (Auster and Stewart 1986).

Northern Sand Lance *(Ammodytes dubius)*

Northern sand lance range in Continental Shelf waters from Greenland to North Carolina; in the Northeast Atlantic they are found in the North and Baltic seas (Bigelow and Schroeder 2002). In the Northwest Atlantic, they occur primarily offshore to depths of 108 m, but can be found in very shallow waters on offshore banks and also occur inshore (Winters and Dalley 1988). They require similar, but deeper, habitats as those described above for the American sand lance, with substrate suitable for burrowing. Consequently, they seem to avoid rock and mud bottoms.

They spawn in late fall to winter on sandy bottom habitats, where eggs can adhere to sand grains. Larvae can be extremely long-lived and widely distributed; they are found from February to July in Continental Shelf waters from the Scotian Shelf and Grand Banks to off Chesapeake Bay. Larvae seem to be capable of directed movement offshore, and the transition to juveniles occurs after about three months. Many reach sexual maturity during the first year and most by the second year. Adults have a very broad distribution, and can live as long as 9-10 years, reaching a maximum size of nearly 40 cm, but most are not as large or long-lived (Auster and Stewart 1986). Like American sand lance larvae, *A. dubius* larvae consume phytoplankton, fish eggs, and copepod nauplii. Copepods are the primary food for older larvae, juveniles, and adults. As adults, they tend to forage diurnally, seeking refuge in the bottom during the night (Auster and Stewart 1986).

Butterfish *(Peprilus tricanthus)*

Butterfish are a small, fast growing, short-lived pelagic fish found along the Northwest Atlantic coast and shelf and slope waters from Florida to Nova Scotia. They consume a variety of small invertebrates, and are food for a host of predatory fish (Bigelow and Schroeder 2002). They are most common from Virginia to the Gulf of Maine and occur primarily near the surface but can be found throughout the water column from 0 to nearly 400 m. During summer, the Gulf of Maine, Georges Bank, and Nantucket Shoals are areas of particular abundance (Cross et al. 1999).

Butterfish spawn offshore on shelf waters, and in and around estuaries and bays, between June and August, with the timing of spawning moving northward as the water warms (Overholtz 2006c). In general, they tend to prefer sandy bottoms rather than rocks or mud. Eggs are buoyant and hatch within several days, depending on water temperatures (Bigelow and Schroeder 2002). Larvae inhabit the same waters, and in bays and estuaries are restricted to mixed and saline areas; the same is true for juveniles. Juveniles are often associated with floating seaweed, debris, and jellyfish where they find some protection from predators, but they can survive without such cover. Juveniles and adults move offshore and southward in the fall, wintering along the bottom near the edge of the Continental Shelf off the Mid-Atlantic Bight. During the spring, they begin moving northward and inshore to spawn, and in about a year from hatching at a length of 12 cm, most are sexually mature and begin spawning with the older adults. Most adults live only 2-3 years.

Atlantic Menhaden *(Brevoortia tyrannus)*

Atlantic menhaden are an estuarine-dependent, planktivorous, migratory species, occurring from central Florida to Nova Scotia (Bigelow and Schroeder 2002). They are found from freshwater portions of tidal rivers to the oceanic waters of the Continental Shelf, but are most common in a more restricted range in bays and near-coastal waters from North Carolina to Cape Cod. Feeding habitat is dependent on life stage: larvae feed on the shelf and in bays and estuaries, juveniles (primarily young-of-the-year) in heads of bays and estuaries and into freshwater rivers, and subadults in estuaries and shelf waters primarily from Delaware Bay to Florida. Adults, depending on size, forage in bays, estuaries, and shelf waters from central Florida to Nova Scotia, with the larger, older fish swimming the furthest north (ASMFC 2004). Throughout the post-larval life stages and annual migratory range, feeding areas are generally characterized by high primary productivity, whether in freshwater, bays and estuaries, along shore, or on the shelf.

Spawning occurs on the continental shelf throughout their migratory range in every month of the year (Bigelow and Schroeder 2002). Major spawning habitats are waters off Virginia and North Carolina during September and October and March through May, although spawning does occur in areas north of New Jersey/Long Island (Bigelow and Schroeder 2002). The bulk of recruitment is attributed to the late winter-spring spawn off the Chesapeake and subsequent larval and juvenile development in the bay (ASMFC 2004; Friedland 2007). Eggs hatch in two to three days. Transported by currents on the shelf, most of the larvae move into the Chesapeake, North Carolina coastal waters, and other bays and estuaries along the Northwest Atlantic coast. The transition from the larval to juvenile stage usually occurs in the lower salinity zones of bays and estuaries, and late fall-spawned larvae can overwinter in the estuary. Adults range from the heads of estuaries to well offshore. The fish migrate northward in the spring and summer with the larger fish swimming farther (Griffin et al. 2007). Older, larger menhaden continue to spawn as they move northward along the coast, often outside of large estuaries but also in Long Island Sound, the Peconic Bay system, and Narragansett Bay.

Literature Cited

ASMFC (Atlantic States Marine Fisheries Commission). 2004. Addendum I to amendment I to the Interstate Fishery Management Plan for Atlantic menhaden. http://www.asmfc.org/speciesDocuments/menhaden/fmps/addendum1.pdf.

Auster, P. J. and L. L. Stewart. 1986. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic): Sand lance. U.S. Fish Wildlife Service Biological Reports. 82 (11.66). U.S. Army Corps of Engineers, TR EL-82-4. 11 pp.

Bigelow, H. B. and W. C. Schroeder. 2002. Fishes of the Gulf of Maine. (3rd Ed.) Bruce B. Collette and Grace Klein-MacPhee (Eds.) Smithsonian Institution Press, Washington DC. 748 pp.

Cross, J. N., C. A. Zetlin, P. L. Berrien, D. L. Johnson, and C. McBride. 1999. Essential fish habitat source document: Butterfish, *Peprilus triacanthus,* life history and habitat characteristics. NOAA Technical Memo. NMFS NE 145. 42 pp.

Gottleib, S.J. 1998. Nutrient Removal by Age-0 Atlantic Menhaden (Brevoortia tyrannus) in Chesapeake Bay and Implications for Seasonal Management of the Fishery. Ecological Modeling. 112 (2-3): 111-130.

Hendrickson, L. C. and E. M. Holmes. 2004. Essential fish habitat source document: Northern shortfin squid, Illex illecebrosus, life history and habitat characteristics, Second Edition. NOAA Technical Memo. NMFS-NE-191. 36 p. http://www.nefsc.noaa.gov/nefsc/publications/tm/tm191/index.htm

Hendrickson, L. and L. Jacobson. 2006. Status of Fishery Resources off the Northeastern U.S: Longfin inshore squid *(Loligo pealeii).* www.nefsc.noaa.gov/sos/spsyn/iv/lfsquid/. Accessed 06/16/08

Jacobson, L. 2005. Essential fish habitat source document: longfin inshore squid, Loligo pealeii, life history and habitat characteristics, Second Edition. NOAA Tech. Memo. NMFS-NE-193, 42 p. http://www.nefsc.noaa.gov/nefsc/publications/tm/tm193/.

Kenney, R. D., M. A. M. Hyman, R. E. Owen, G. P. Scott, and H. E. Winn. 1986. Estimation of prey densities required by western North Atlantic right whales. Marine Mammal Science. 2:1-13.

Kennish, M. 2002. Environmental threats and environmental future of estuaries. Environmental Conservation. 29:1:78-107.

Link, J.S., C.A. Griswold, E.T. Methratta, and J. Gunnard, eds. 2006. Documentation for the Energy Modeling and Analysis eXercise (EMAX). US Department of Commerce, Northeast Fisheries Science Center. Ref. Doc. 06 15. 166 p.

Maryland Department of Natural Resources. Striped Bass Seine Survey. Juvenile Index Page. http://www.dnr.state.md.us/fisheries/juvindex/index.html

Overholtz, W.J. and K.D. Friedland. 2002. Recovery of the Gulf of Maine-Georges Bank Atlantic herring *(Clupea harengus)* complex: Perspectives based on bottom trawl survey data. Fishery Bulletin. 100: 593-608.

Overholtz, W. 2006a. Status of Fisheries Resources off the Northeastern U.S.: Atlantic Herring *(Clupea harengus).* http://www.nefsc.noaa.gov/sos/spsyn/pp/herring/. Accessed 06/16/08

Overholtz, W. 2006b. Status of Fisheries Resources off the Northeastern U. S.: Atlantic Mackerel *(Scomber scombrus).* http://www.nefsc.noaa.gov/sos/spsyn/pp/mackerel/. Accessed 06/16/08

Overholtz, W. 2006c. Status of Fishery Resources off the Northeastern US: Butterfish *(Peprilus tricanthus).* http://www.nefsc.noaa.gov/sos/spsyn/op/butter/. Accessed 06/16/08.

Oviatt, Candace, A.L Gall, and S.W. Nixon .1972. Environmental Effects of Atlantic Menhaden on Surrounding Waters. Chesapeake Science. 13 (4): 321-323.

Pauly, D, V.Christensen, J. Dalsgaard, R. Froese, and F. Torres Jr. 1998. Fishing Down Marine Food Webs. Science. 279 (5352) 860-863.

Read, A. J. and C. R. Brownstein. 2003. Considering other consumers: Fisheries, predators, and Atlantic herring in the Gulf of Maine. Conservation Ecology. 7(1): 2.

Castro,K., B. Somers, and N. Lazar, Eds. Compiled by M. Griffin. Rhode Island Sea Grant and Rhode Island Department of Environmental Management. 2007. Proceedings of the Menhaden Science and Policy Symposium. Rhode Island Sea Grant and Rhode Island Department of Environmental Management. NOAA Grant No. NA40AR4170062. 42 pp.

Spear, B. 2008. Atlantic States Marine Fisheries Commission (ASMFC 2008). Unpublished Data.

Stevenson, D. K. and M. L. Scott. 2005. Essential fish habitat source document: Atlantic herring, *Clupea harengus,* life history and habitat characteristics (2nd edition). NOAA Technical Memo NMFS NE 192. 84 pp.

Studholme, A. L., D. B. Packer, P. L. Berrien, D. L. Johnson, C. A. Zetlin, and W. W. Morse. 1999. Essential fish habitat source document: Atlantic mackerel, *Scomber scombrus,* life history and habitat characteristics. NOAA Technical Memo NMFS NE 141. 35 p.

Weinrich, M., M. Martin, R. Griffiths. J. Save, and M. Schilling 1997. A shift in distribution of humpback whales, *Megaptera novaeangliae,* in response to prey in the southern Gulf of Maine. Fishery Bulletin. 95:826-836.

Winters, G. H. and E. L. Dalley. 1988. Meristic composition of sand lance (Ammodytes spp.) in Newfoundland waters with a review of species designations in the Northwest Atlantic. Canadian Journal of Fisheries and Aquatic Sciences. 45:516-529.

Wood, A., H. P. Jeffries, and J.S. Collie. 2008. Long-term shifts in the species composition of a coastal fish community. Canadian Journal of Fisheries and Aquatic Sciences. 65 (7): 1352-1365.

CHAPTER

9

Large Pelagic Fish

Jennifer Greene, Caroly Shumway, Mark Anderson, Jay Odell, and Kevin Ruddock

Introduction

© Terry Goss, Marine Photobank

Pelagic fish include highly migratory species such as tuna, swordfish, billfish and various species of sharks. The wide ranging distribution of these species across diverse habitat types, their roles as apex predators, and their threatened population status make them prime candidates for inclusion in this assessment. Conservation of large pelagic fishes like tuna, marlin, swordfish and sharks is a high priority because these species represent a particularly threatened group within the characteristic biodiversity of the Northwest Atlantic. Moreover, conservation of these species is especially critical because of their ecological function as apex predators that can substantially control the abundance of other species through direct and indirect food web interactions. In some cases, the presence or absence of top-down control provided by apex predators may have a strong influence at the scale of whole ecosystems (Kitchell et al. 2006; Baum and Worm 2009). However, this influence varies by time and place as mediated by several factors including competition with other predators, trophic complexity, prey preferences, primary productivity, and fishery effects (Pace et al. 1999; Dowd et al. 2006).

Effective conservation and management of pelagic fishes is difficult due to their wide ranging distribution (basin-wide to circumglobal), their natural vulnerability to overfishing and their high value as harvest species. However, in recent years increased concern and attention by stakeholders, researchers and management agencies have begun to lay the groundwork for additional actions needed to promote recovery for these species. Many of the products of historic and current efforts to better understand the conservation needs for large pelagics within the Northwest Atlantic region are described below.

Technical Team Members

Vera Agostini, Ph.D., The Nature Conservancy, Global Maine Initiative
Mark Anderson, Ph.D., The Nature Conservancy, Eastern Division
Richard Brill, Ph.D., Virginia Institute of Marine Science
Jennifer Greene, The Nature Conservancy, Eastern Division
Jay Odell, The Nature Conservancy, Virginia
Kevin Ruddock, The Nature Conservancy, Rhode Island
Caroly Shumway, Ph. D., Boston University

Selection of Target Species

Target species were selected based on the following criteria: (1) level of threat as assessed by the 2008 IUCN Red List, (2) intrinsic vulnerability (Cheung et al. 2005; 2007), and (3) current population status. All of the sharks in this have been assessed under the IUCN Red List, but the commercially valuable teleost fish have either not been evaluated or are considered 'data deficient', thus not able to undergo an evaluation. The dusky shark for example is a National Marine Fisheries Service (NMFS) Species of Concern, and was considered for Endangered Species Act Listing, but was not listed due to incomplete data (NMFS 2004). The Canadian government considered listing of the porbeagle under their Species at Risk Act, but rejected the listing based on the impact to the commercial fishing industry and the governmental cost of monitoring (NMFS 2008).

In consideration of the criteria outlined above, along with input from expert reviewers, the following species were selected for inclusion in this assessment:

- Atlantic bluefin tuna *(Thunnus thynnus)*
- Albacore tuna *(Thunnus alalunga)*
- Bigeye thresher *(Alopius superciliosus)*
- Blue marlin *(Makaira nigricans)*
- Dusky shark *(Carcharhinus obscurus)*
- Great hammerhead *(Sphyrna mokarran)*
- Porbeagle *(Lamna nasus)*
- Sand tiger *(Carcharia taurus)*
- Sandbar shark *(Carcharhinus plumbeus)*
- Scalloped hammerhead *(Sphyrna lewini)*
- Shortfin mako *(Isurus oxyrinchus)*
- Swordfish *(Xiphias gladius)*
- Thresher shark *(Alopius vulpinus)*
- White marlin *(Tetrapturus albidus)*

Population Status and Importance of the Northwest Atlantic Region

The species included in this assessment have wide geographic distributions and travel significant distances throughout their life to feed and breed, and are consequently labeled as highly migratory species. These species use the Northwest Atlantic for both feeding and breeding purposes.

According to the NMFS Highly Migratory Species Division (HMS) 2009 Stock Assessment and Fishery Evaluation (SAFE) for Atlantic HMS, seven of the target species are overfished; and seven are experiencing overfishing. The International Commission for the Conservation of Atlantic Tunas Stock Assessments suggests that bluefin and albacore tuna are overfished (ICCAT 2004). Globally, bluefin tuna spawning stock sharply declined between 1970 and1993, began increasing until 1998, and then continued to decline to the present. Based on these biomass estimates, International Commission for the Conservation of Atlantic Tuna (ICCAT 2004) determined that there was a 50% probability of rebuilding the stocks (albacore and bluefin) by 2023 only if implementation and enforcement of current regulations worked perfectly, including a severe reduction in fishing effort by 2023, and if future recruitment stayed at about the 1990s level and was unaffected by recent spawning biomass level. Catch per unit effort (CPUE) for bluefin tuna, blue marlin, and white marlin plummeted in the 1990s; but began to recover in 2000 (ICCAT 2004). CPUE began declining again since 2002 for both white and blue marlin. This conclusion is supported by other assessments. For example, Safina and Klinger (2008) report a 92% decline in bluefin tuna landings over a forty-year time period, from 1964 to 2005. ICCAT considers blue marlin, white marlin, and shortfin mako "possibly overfished." Albacore at age 5 yrs appeared to peak in 1979 and then declined through 2008.

Swordfish biomass projections indicate a short term increase in spawning stock biomass starting in 2005, with a 50% probability of the stock rebuilding by 2009 (ICCAT 2008). Within United States populations, ICCAT catch per unit effort (CPUE) data for swordfish has dropped by about fifty percent since the 1980s, but is currently rebuilding. IUCN's (2007) Review of Chondrichthyan Fishes indicates that all of the sharks listed here are a "harvest threat." Porbeagle population size is estimated to be 10-20% of the 1961 population (Campana et al. 2003).

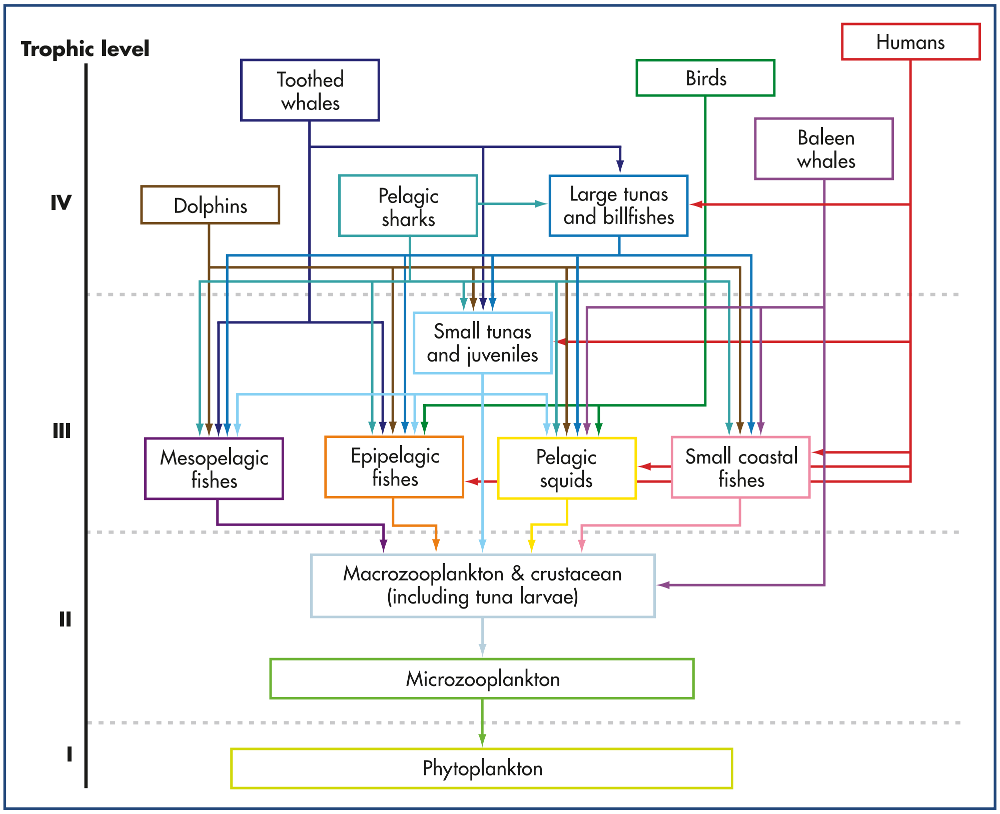


Figure 9-1. An example of the complex food web that large pelagic species occupy in the ecosystem (FAO 2010).

In sum, most large pelagic species are in trouble. Substantial additional detail on population status and current management strategies for the fourteen target species and several other large pelagics is contained within the documents reviewed for this section (SAFE for Atlantic Highly Migratory Species; IUCN Shark Specialist Group 2000; White Marlin Status Review Team 2002; Mahon and McConney 2004; NMFS Final Consolidated HMS Fishery Management Plan 2006; IUCN Red List 2008). Additionally, ICCAT provides catch per unit effort statistics, size statistics, observer data, and nominal catch statistics. The Northwest Atlantic Fisheries Organization (NAFO) also provides catch statistics. A global atlas of tuna and billfish catch, from 1950 onward, is available through the Food and Agriculture Organization website.

Ecosystem Interactions and Ecological Dependencies

Large pelagic fish are an essential component of the Northwest Atlantic pelagic food web, thus play a key role in the ecosystem. Many of the selected target species feed broadly and opportunistically across the food chain. However, regionally and at certain times, a given age class may focus their feeding on just a few species (Cayré et al. 1988). Tunas and billfishes prey on squid, smaller fish, and crustaceans (Logan et al. 2006). The larger individuals feed on pelagic fishes, and are at the top of the trophic web (Figure 1). Smaller individuals (e.g., juvenile tunas and billfishes) prey on zooplankton (mainly crustaceans). Smaller individuals of all fourteen target species are preyed upon by sharks, cetaceans or larger fish like mackerels, tunas, and swordfishes.

Adults of all of the fourteen target species function as apex predators - large animals at the top of complex food webs without significant predators except humans. Consequently, they play a critical role in energy flow through marine food webs (NOAA 2009) and are sometimes considered to be keystone species with disproportionate influence on ecosystem structure. Their presence (or absence) can affect ecosystem patterns and processes at multiple trophic levels and potentially lead to fundamentally altered ecosystem state conditions (Baum and Worm 2009).

Northwest Atlantic Distribution and Important Areas

Methods

To understand the distribution of pelagic fish target species relative to the Northwest Atlantic and identify critical sites, the following questions were addressed:

- Where are the greatest areas of co-occurrence? *(richness of target species)*
- Where are the most important areas for *essential fish habitat?*
- Where has the species been found consistently over time? *(persistence)*

Observation data were provided by NMFS. This data is compiled from numerous sources, including cooperative tagging programs, mandatory logbook reporting for some fisheries, recreational surveys, and published literature. Approximately 96% of the data points originated from two fisheries-dependent tagging programs: the Cooperative Tagging System run by Southeast Fisheries Science Center, and the Cooperative Shark Tagging Program run by Northeast Fisheries Science Center, the two most comprehensive long-term data sets available. The data provides tagging, and recapture information when available, from tagged individuals, and is given as point locations, with year information associated. A detailed description of the data sources is provided on pg. 10-3 of the HMS document, 2006 Final Consolidated Atlantic Highly Migratory Species Fishery Management Plan. Data were provided in a summarized form by ten minute squares (TMS), where each square contained multiple survey points by life stage and was binned by decade (1965-1974; 1975-1984; 1985-1994; and 1995-2004). Because this assessment explores ecologically important areas within a set boundary, we analyzed gridded points within the study area or within a buffer, extending out to 1500m depth, to 4000m. In the southern area of the Northwest Atlantic, we extended a circular buffer of equivalent spatial scale. At the surface, this equated to 110 km.

Essential fish habitat (EFH) polygons were obtained from the NMFS website, while the sandbar shark EFH was provided by HMS upon request. Source data for EFH polygons (currently being updated by NOAA) were compiled and mapped for the 1999 HMS FMP by NOAA Fisheries, Office of Habitat Conservation and the Highly Migratory Species Division. EFH polygons were available for juvenile and adult life stages for all target species, with the exception of the sand tiger (adult only). Neonate polygons were only available for dusky shark, porbeagle, sand tiger, sandbar shark, shortfin mako, swordfish (larvae), and thresher.

Data limitations

Comprehensive fishery-independent surveys of the studied species are not currently available. The data used in this analysis is derived primarily from fisheries-dependent tagging data, and fishing effort varies considerably throughout the region and likely through time. As we were not able to correct for the bias imposed by variable fishing efforts, true abundances could not be determined from this data, and consequently, we focused on metrics that are less sensitive to fishery bias.

Data Analysis

Richness of target species: To outline the diversity of target species at particular points in space, the number of target species observed within a TMS was summed and mapped based on all available data (1965-2004). Maps were created for total number of targets and by age class (where data was available). The darkest colors on the map indicate the areas with greater numbers of target species or target species within an age class

Persistence: The persistence score refers to the consistency with which a target species was observed in the same general area (TMS) over time. For this calculation, we combined juvenile and adult observations as an indicator that the species was present. The persistence score was calculated by summing the number of decades that a given target species was recorded (e.g. one decade = 1, four decades = 4). The darkest colors indicate areas where target species were consistently observed over all decades.

Areas identified as essential fish habitat: To understand how much of the region is considered EFH, the number of target species whose EFH overlapped each TMS was determined and summarized by total target species and by age class.

Maps, Analysis, and Areas of Importance

Aggregated pelagic distributions (as described by the indicators outlined above) are described below in relation to broad scale bathymetry patterns (Figure 2).

Richness of target species

Across all target species, areas with the highest number of species being observed in these fishery-dependent datasets include: the shelf-slope break for the entire region; south of Block Island Sound along the 50 m isobath for the Southern New England subregion; and the Cape Hatteras area, the area between Washington and Norfolk canyons, and isolated TMS along the coast for the Mid-Atlantic Bight subregion (Figure 3a). For neonates, the majority of observations were located in the Southern New England subregion, just south of Block Island Sound extending from the coast to beyond the 50 m isobath and along the Hudson canyon, as well as a thin strip along the coast in the Mid-Atlantic Bight subregion, particularly by Delaware Bay, Chesapeake Bay, and Cape Hatteras (Figure 3b). In addition, some TMS are located along the shelf-slope break. For juveniles, the majority of observations were located along the 50 m isobath in the Southern New England subregion, and coastal areas outside of the Delaware and Chesapeake Bays, as well as along the shelf-slope break between the 200-1000m isobaths for both subregions (Figure 3c). For adults, the majority of observations were located along the shelf-slope break between the 200-1000 m isobaths, with isolated TMS largely along the 50 m isobath (Figure 3d).

Persistence

The areas where many target species were consistently observed in these fishery-dependent datasets over four decades in the Southern New England and Mid-Atlantic regions, included mouths of major bays and rivers and the region from the Hudson canyon to Block Island sound along the 50 m isobath (Figures 4-17). The dusky shark shows the highest persistence at the Hudson canyon and south of Long Island. The sandbar shark is highly persistent at the mouth of Narragansett Bay, the Hudson River, Delaware Bay and Chesapeake Bay. The sand tiger shows medium levels of persistence in Delaware Bay and Chesapeake Bay; and outside of both Pamlico and Albemarle Sounds. The shortfin mako shows spatial persistence at the Hudson canyon and south of Long Island, along a 50 m band, as well along a band from 200-2000 m in all subregions. Blue marlin persist just outside the study area, south of Cape Hatteras; around Norfolk canyon and Baltimore canyons, and out to 1000 m. White marlin shows high persistence along the shelf slope break in the Mid-Atlantic Bight and Southern New England subregion. Swordfish shows high levels of persistence along the shelf-slope break for all subregions. Atlantic bluefin tuna show the highest levels of persistence in the Block Island Delta, and Hudson canyon, around Cape Ann and Cape Cod Bay, Gulf of Maine. Albacore tuna, porbeagle, scalloped hammerhead, great hammerhead, bigeye thresher, and thresher shark show limited spatial persistence. This suggests that the use of the region by large pelagic species may not be geographically fixed.

Areas identified as essential fish habitat

EFH has been identified for these federally managed fish species by NOAA's Office of Habitat Conservation, Habitat Protection Division. Each EFH designation consists of areas of habitat essential to the long-term survival and health of fisheries and includes waters and substrate necessary for spawning, breeding, feeding, or growth to maturity for all life stages of fish.

Overall, the patterns of target species richness we identified are similar to the patterns identified by overlaying the EFH. Figure 18a shows the cumulative EFH for all fourteen target species within the Northwest Atlantic. For neonates, the area with the greatest EFH concurrence is in the SNE subregion, offshore to Long Island, with a slight 'hot spot' in the 200 m isobath in the Block Island Delta region; and in the Mid-Atlantic Bight subregion, off Delaware Bay and Albemarle Sound (Figure 18b). For

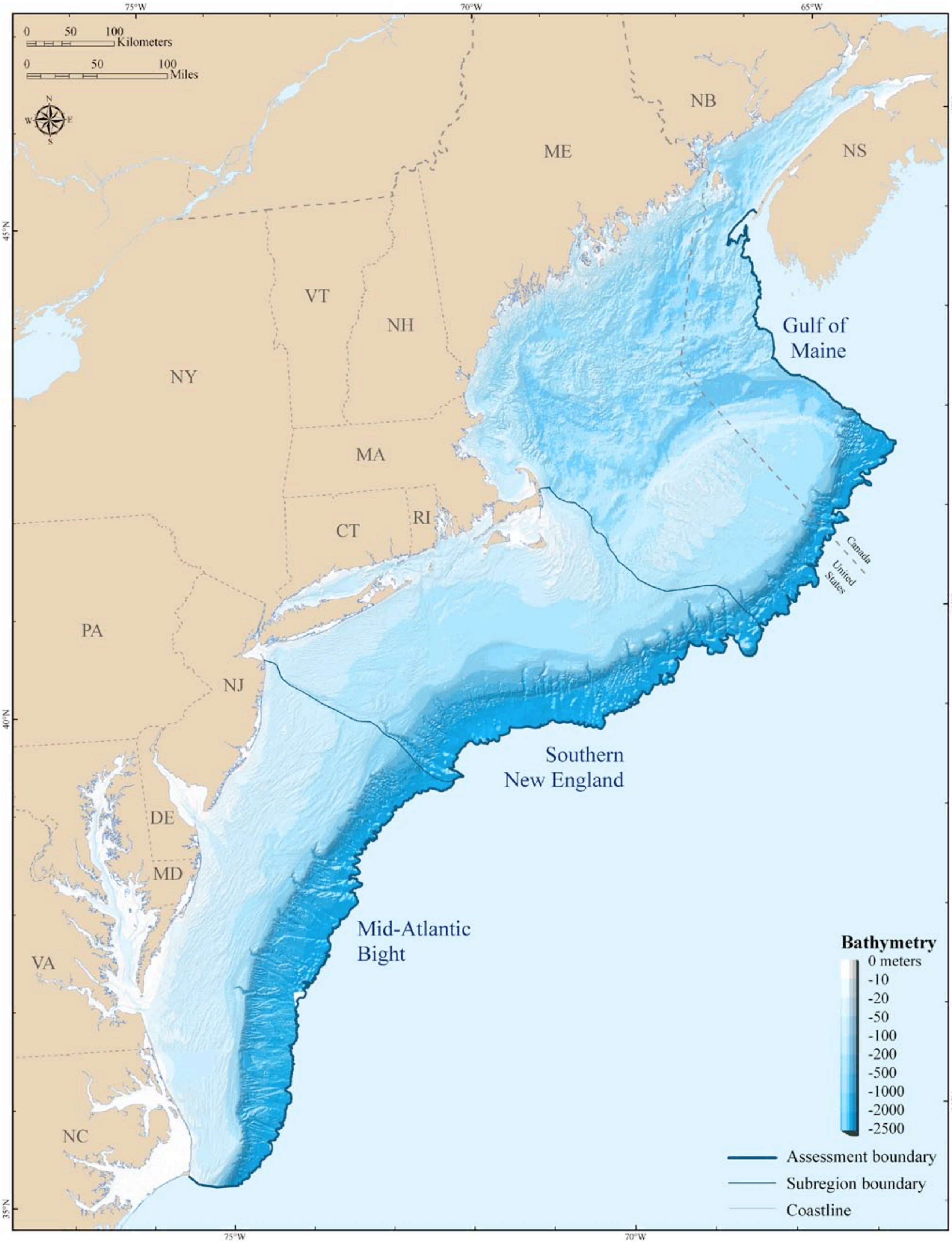


Figure 9-2. Bathymetry of the Northwest Atlantic region.

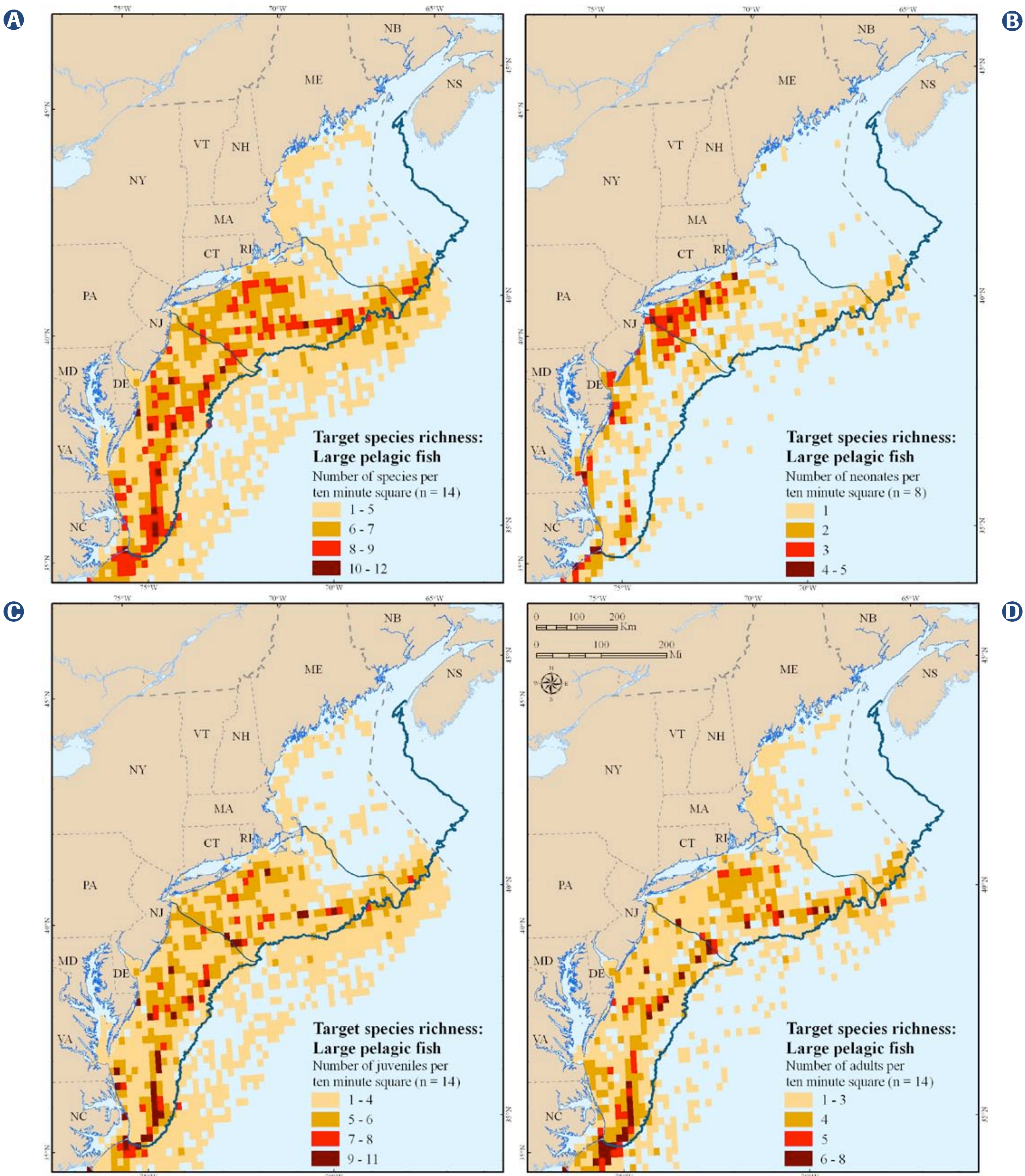


Figure 9-3. Richness of large pelagic target species in the region.

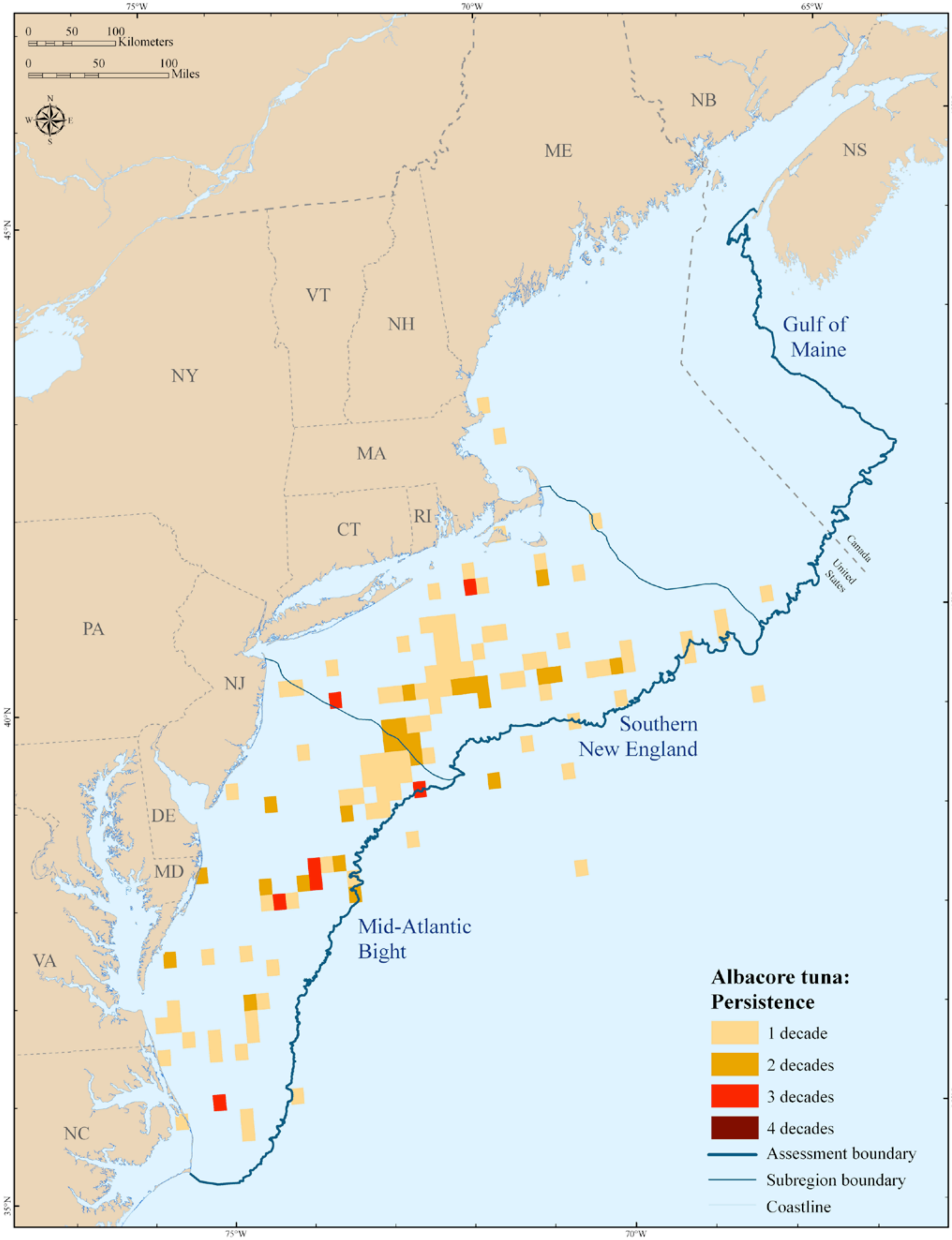


Figure 9-4. The persistence of Albacore tuna by TMS over time.

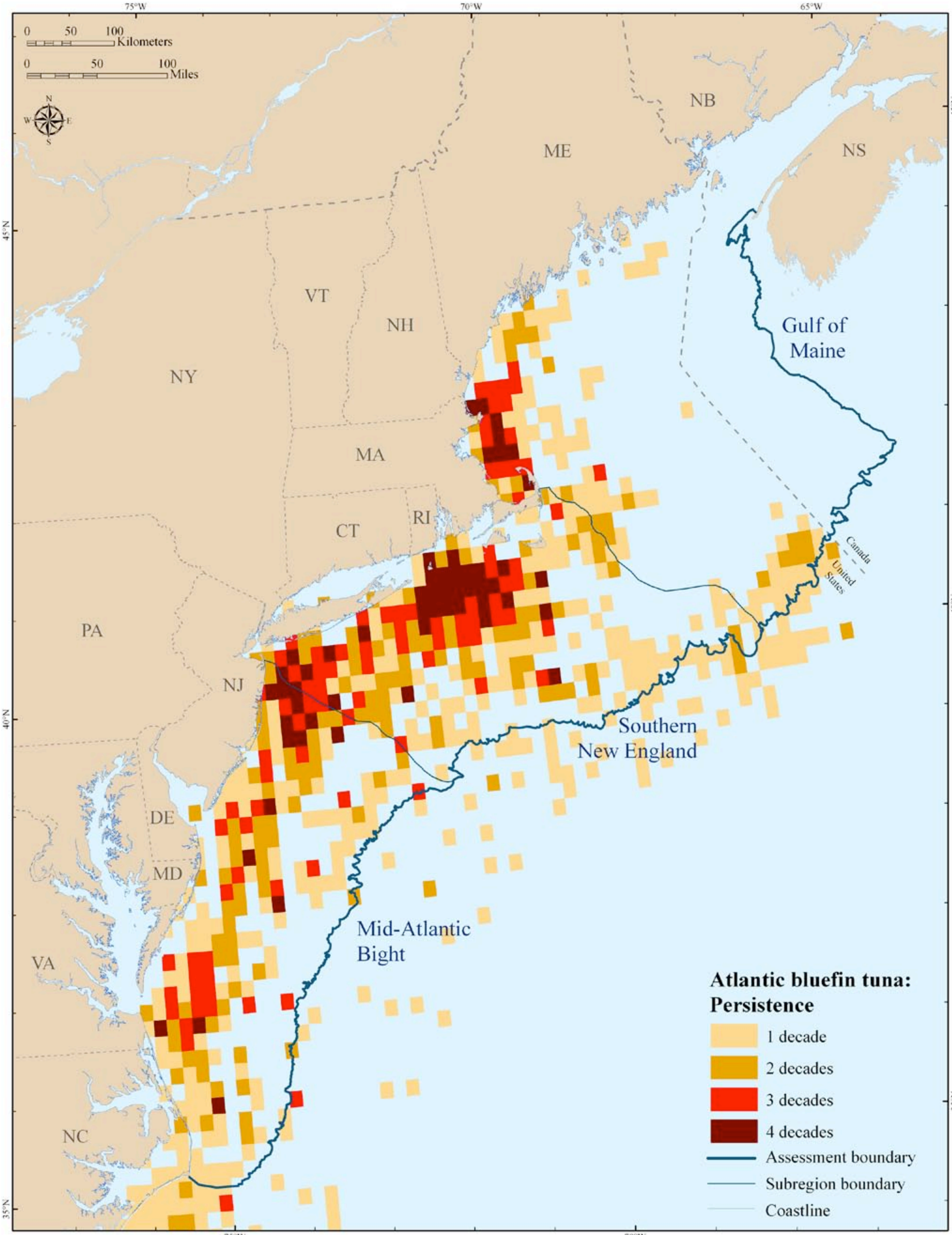


Figure 9-5. The persistence of Atlantic bluefin tuna by TMS over time.

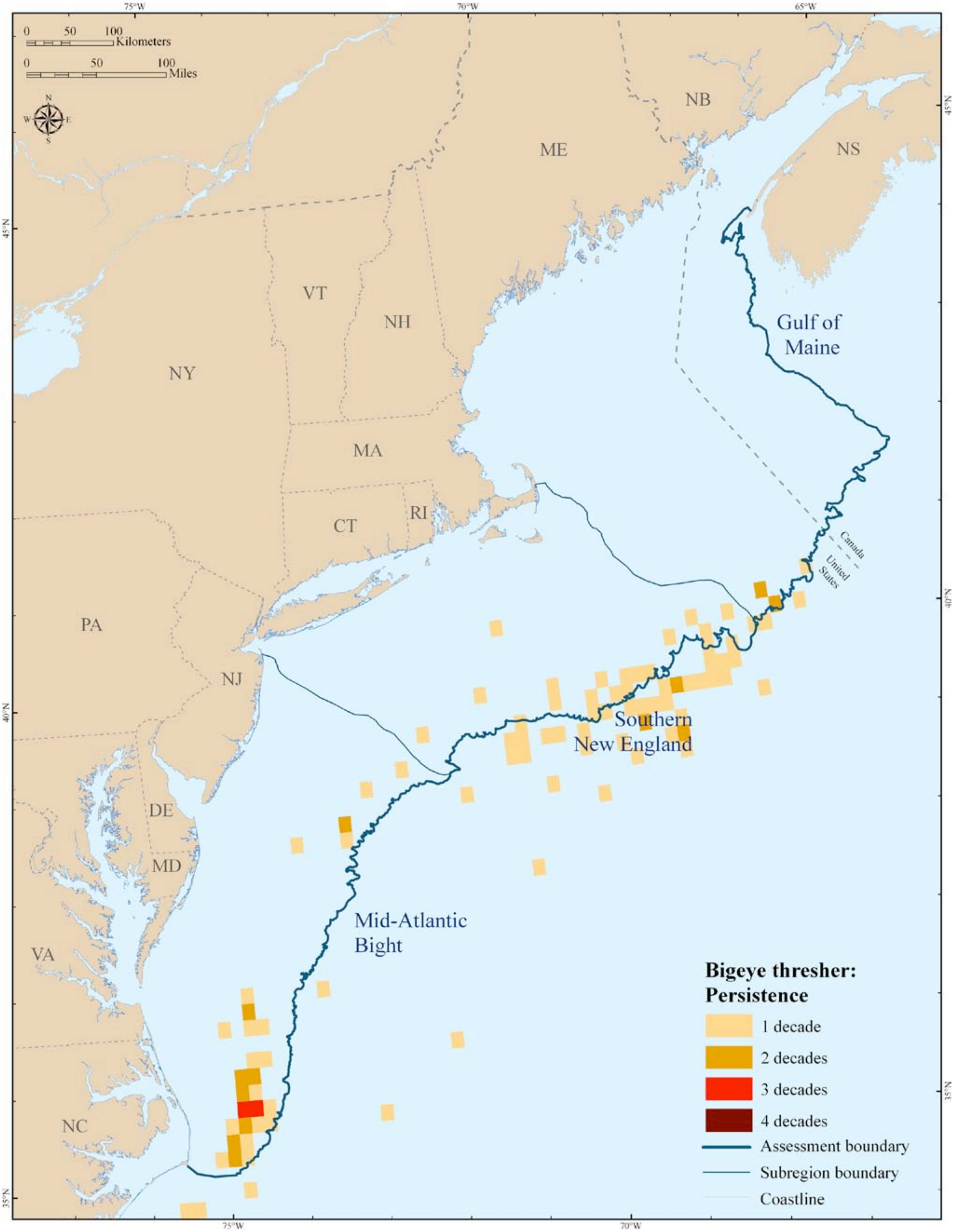


Figure 9-6. The persistence of bigeye thresher by TMS over time.

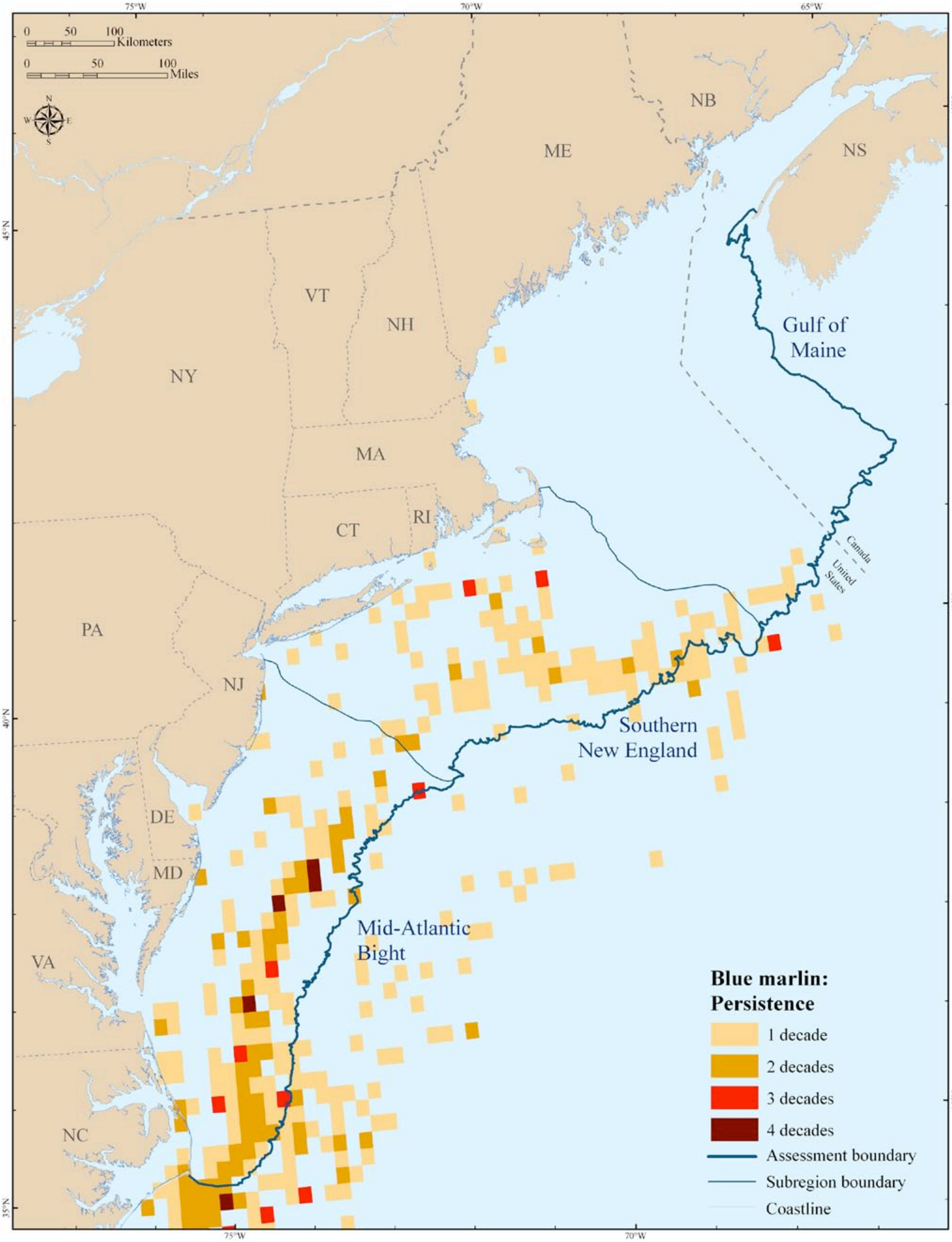


Figure 9-7. The persistence of blue marlin by TMS over time.

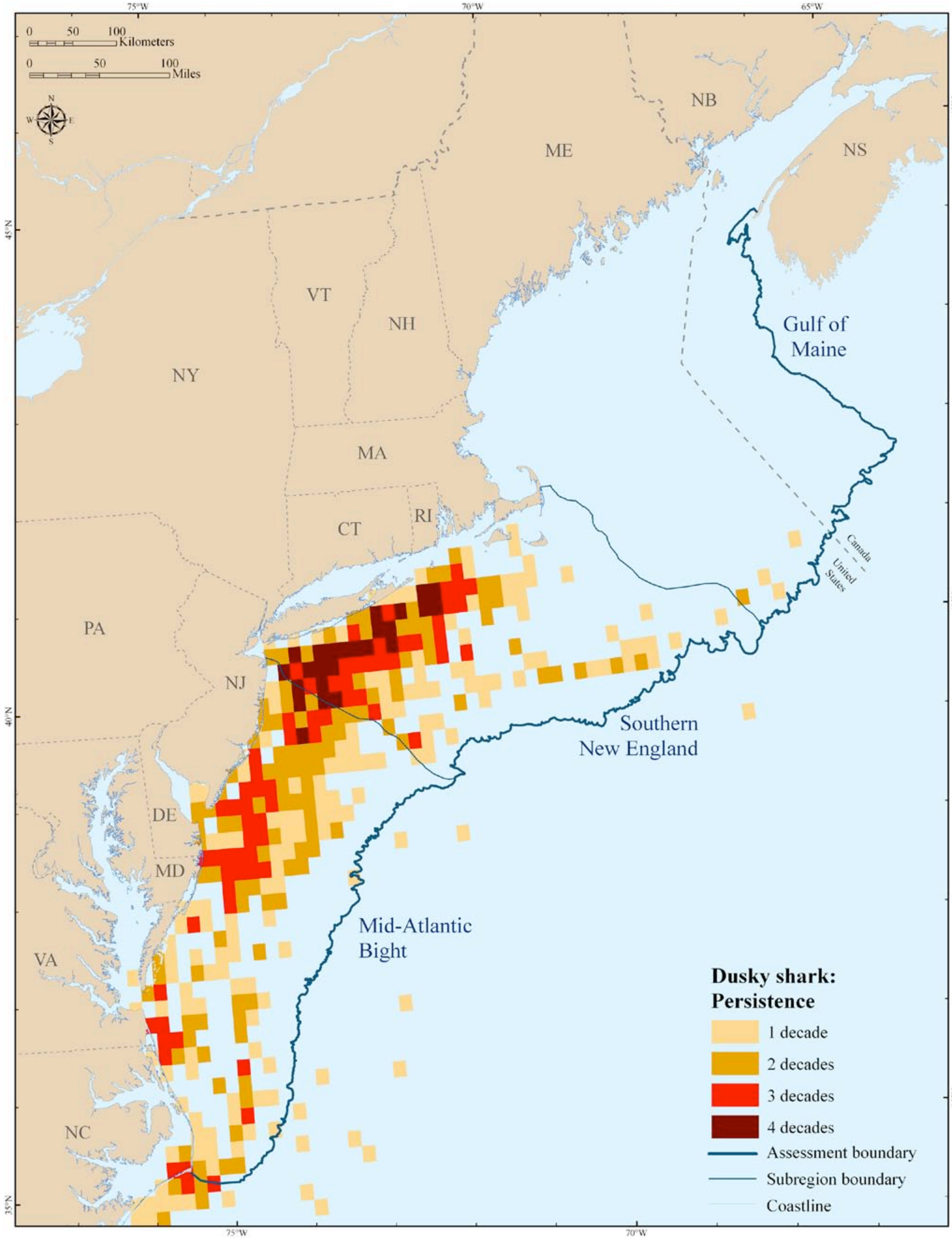


Figure 9-8. The persistence of dusky shark by TMS over time.

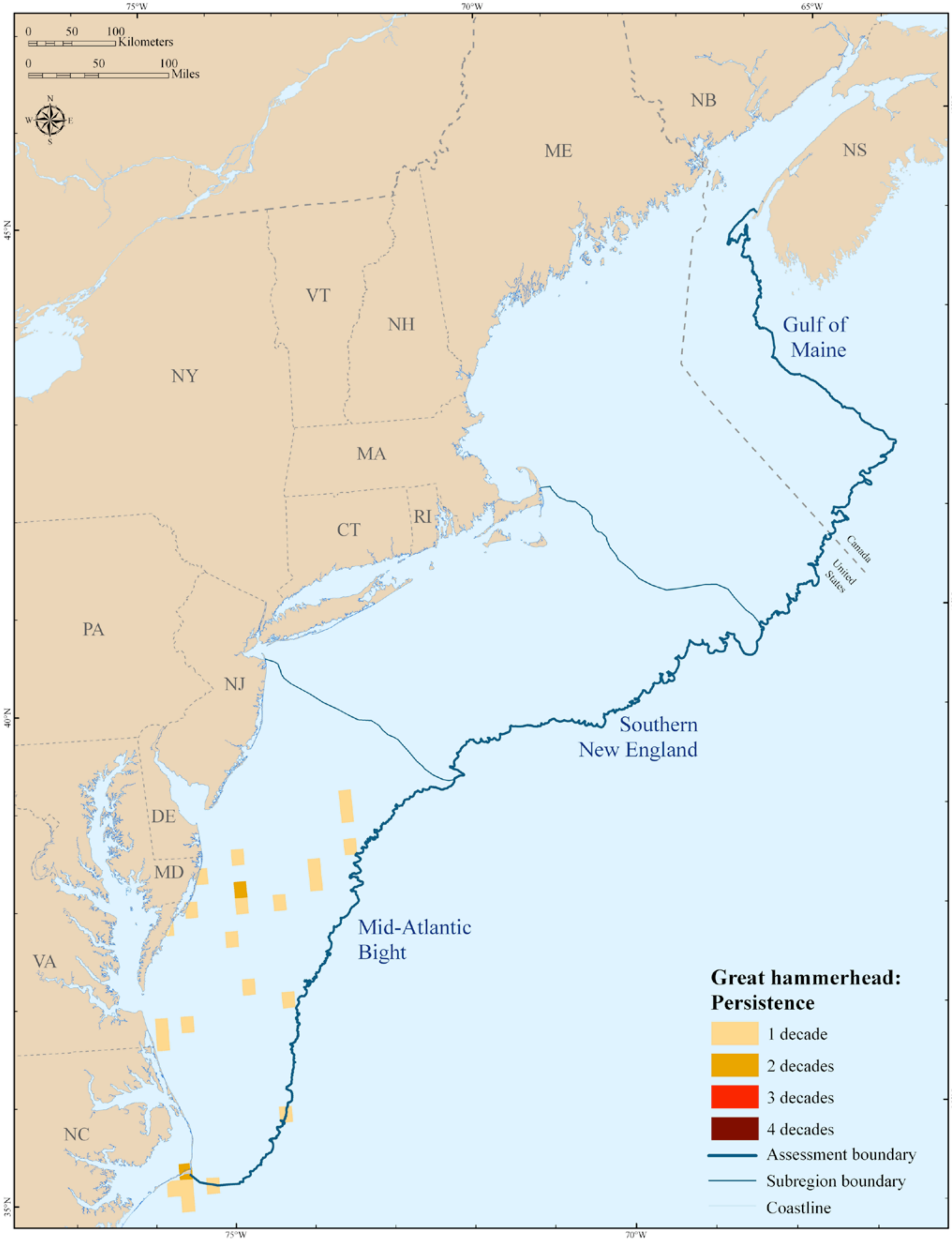


Figure 9-9. The persistence of great hammerhead by TMS over time.

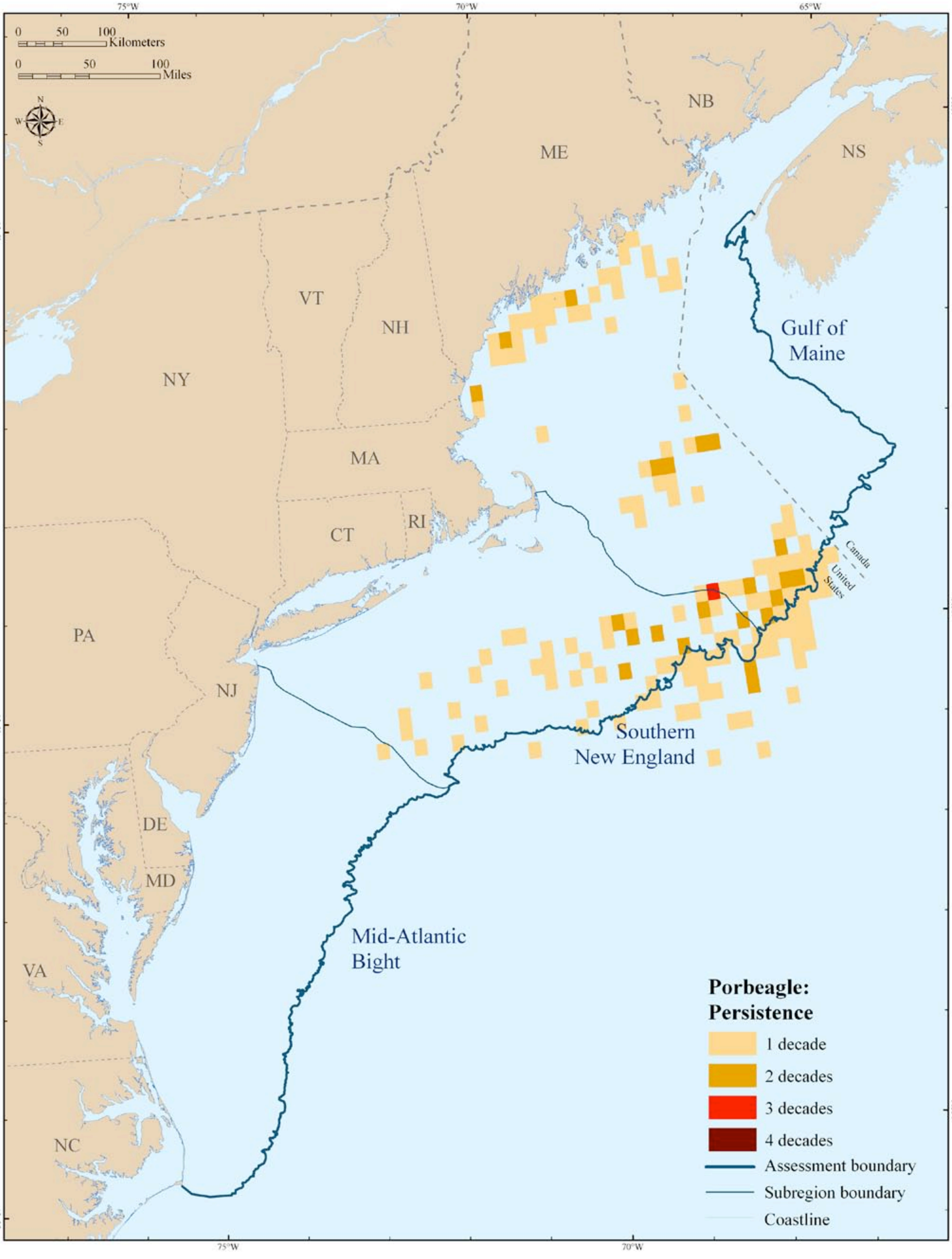


Figure 9-10. The persistence of porbeagle by TMS over time.

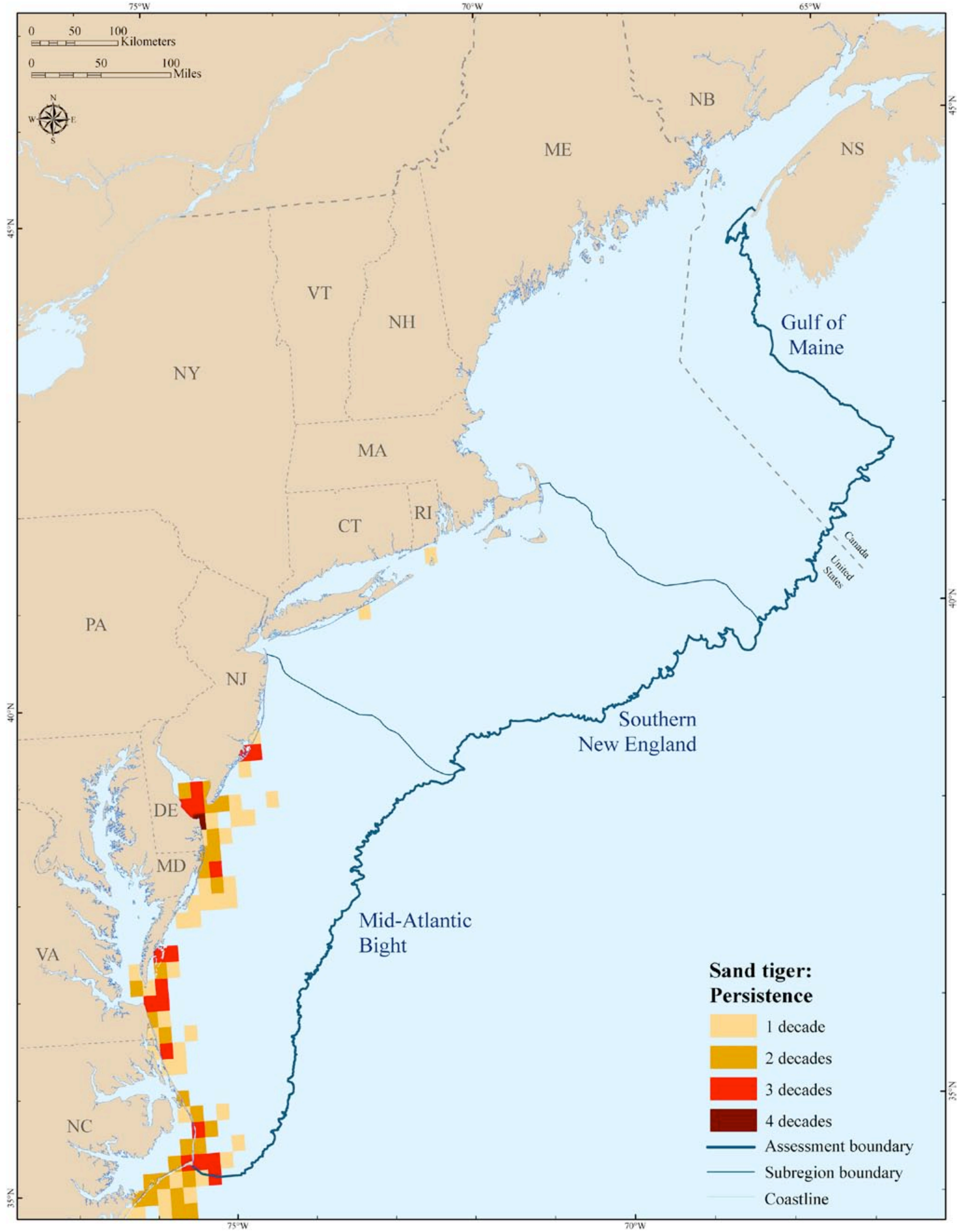


Figure 9-11. The persistence of sand tiger by TMS over time.

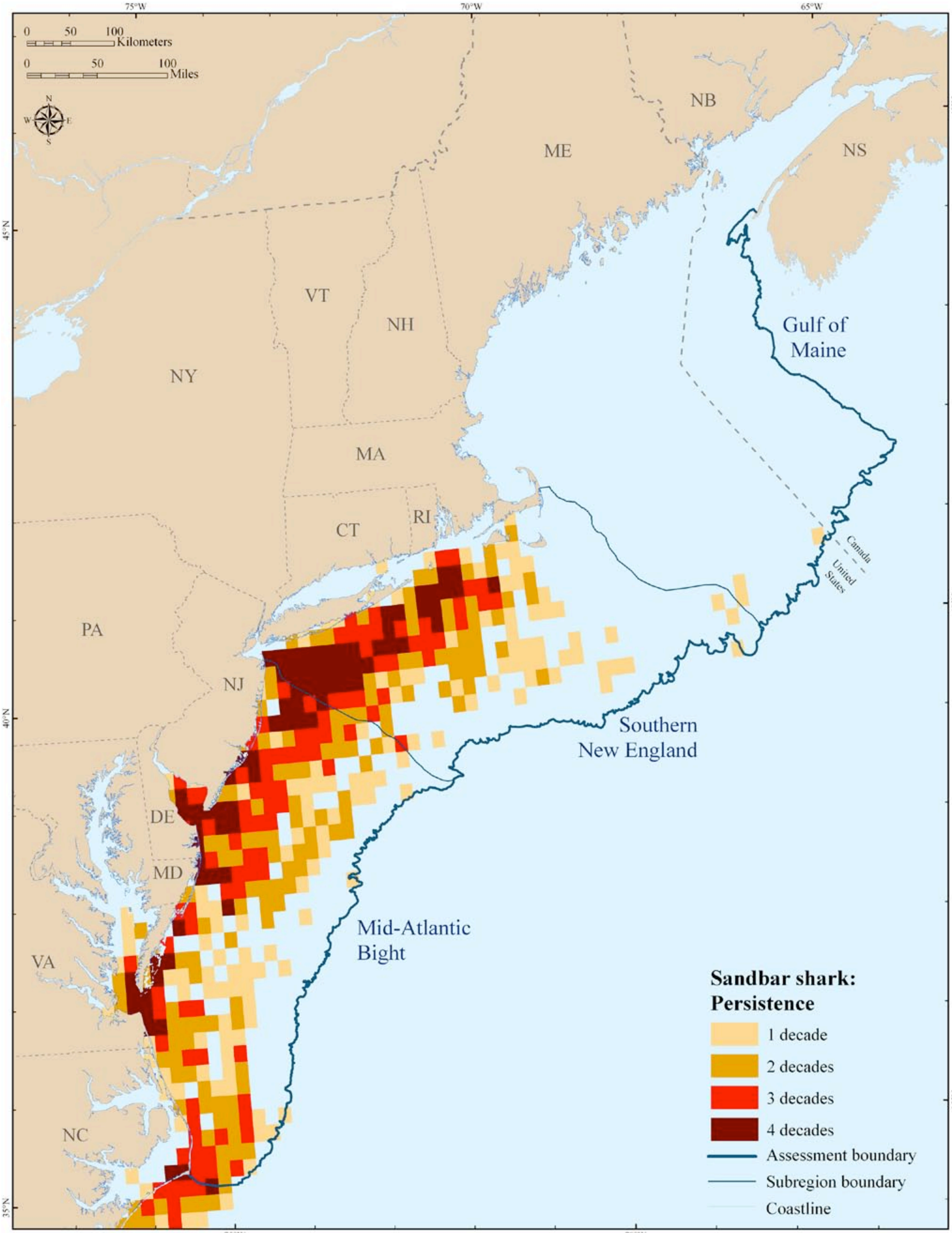


Figure 9-12. The persistence of sandbar shark by TMS over time.

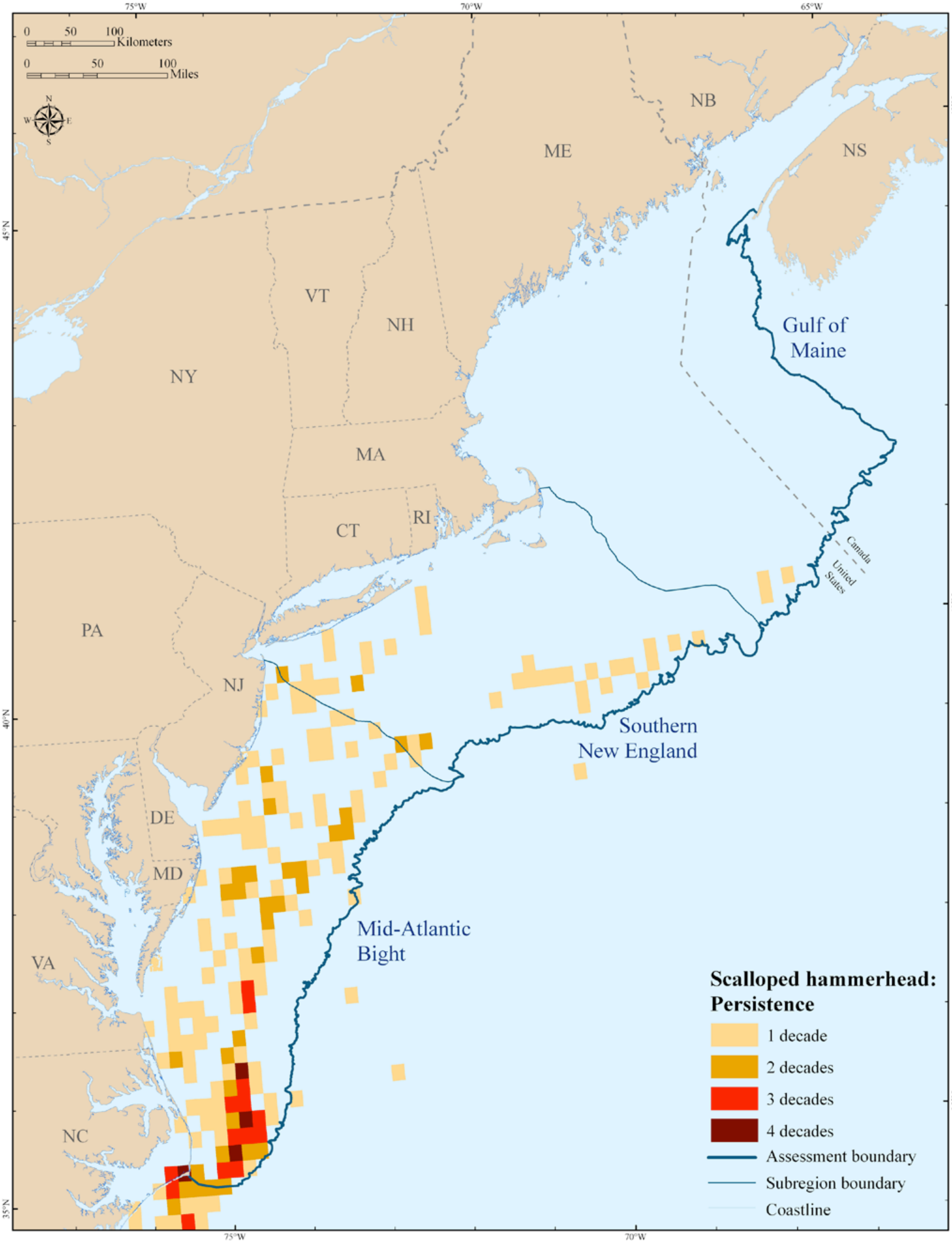


Figure 9-13. The persistence of scalloped hammerhead by TMS over time.

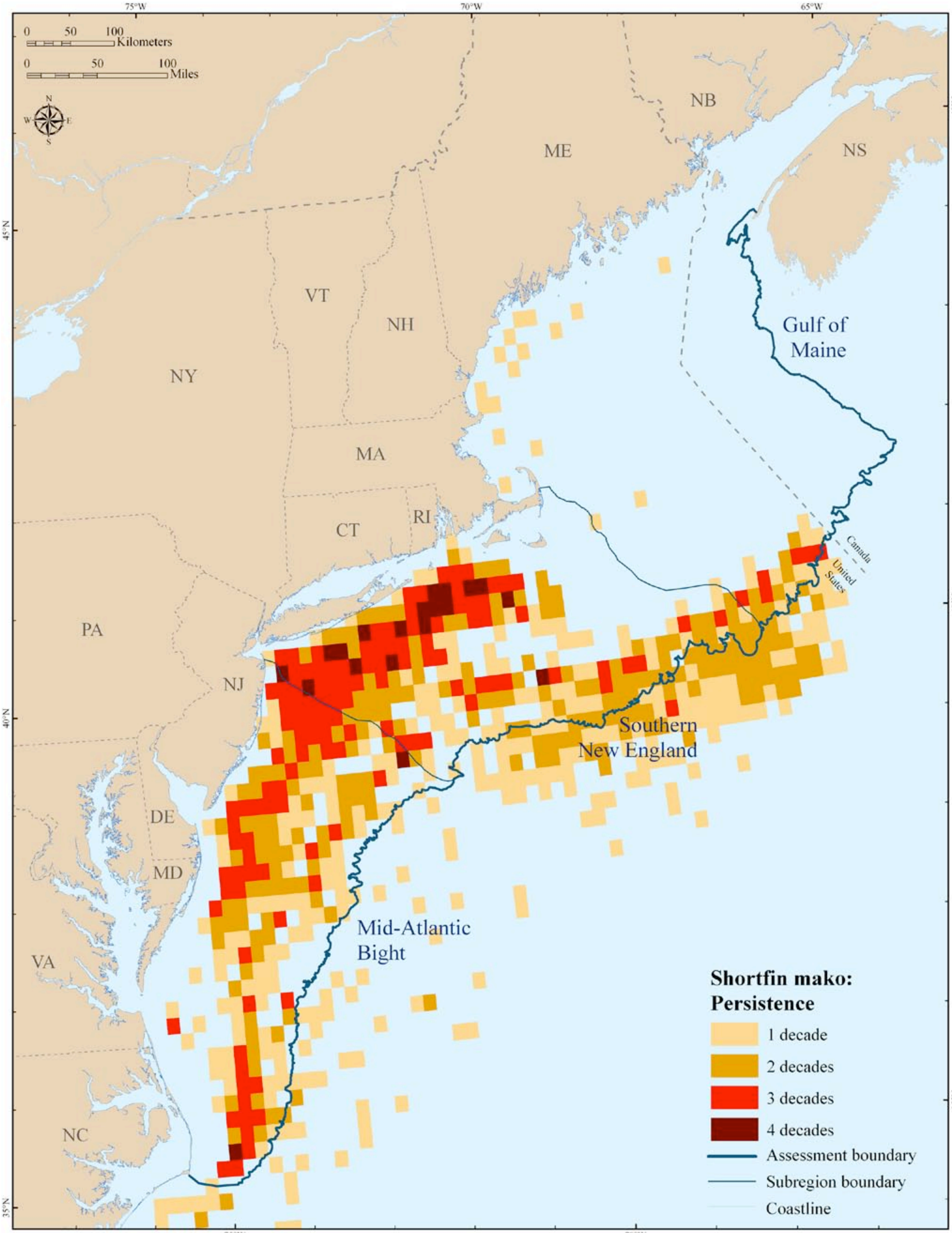


Figure 9-14. The persistence of shortfin mako by TMS over time.

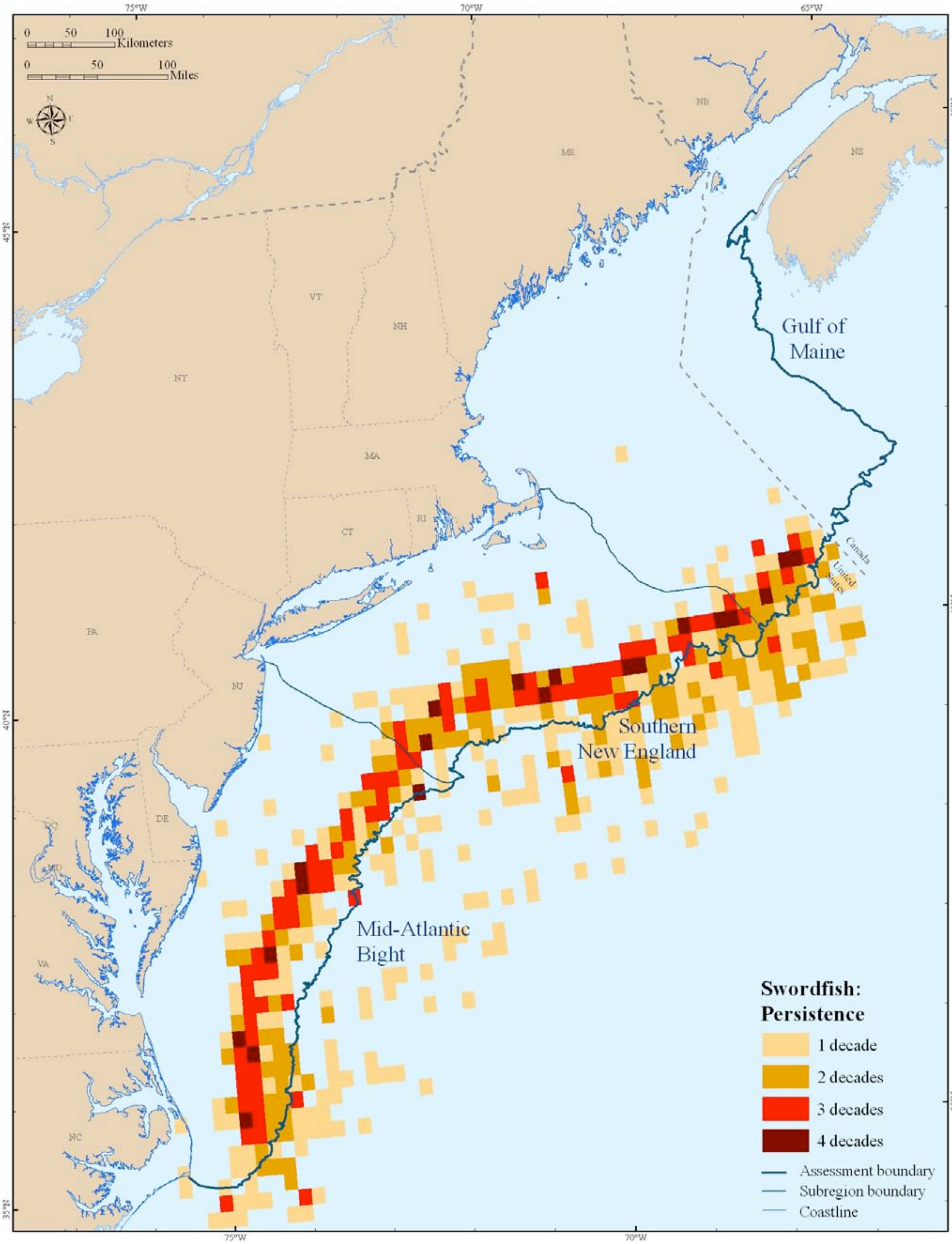


Figure 9-15. The persistence of swordfish by TMS over time.

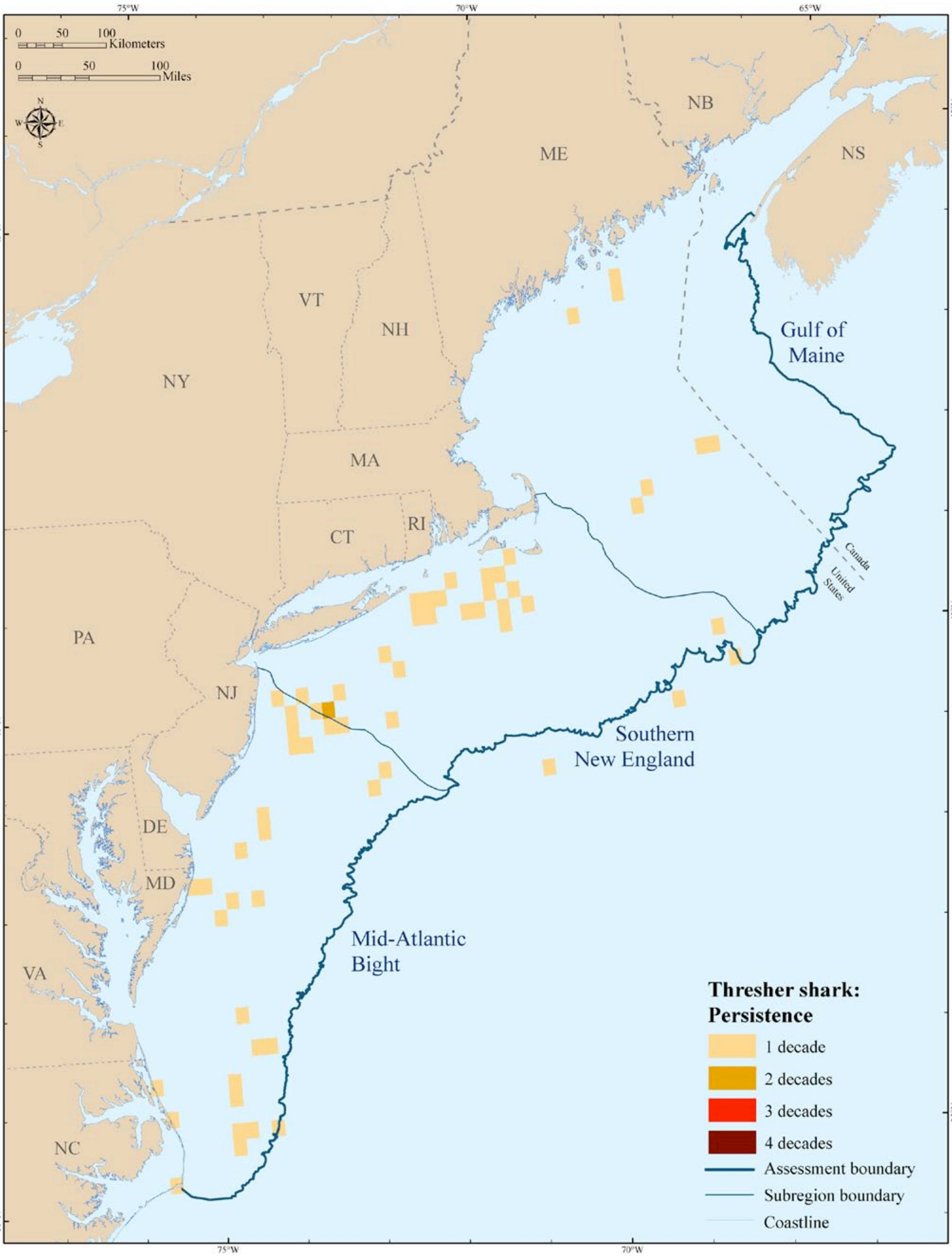


Figure 9-16. The persistence of thresher shark by TMS over time.

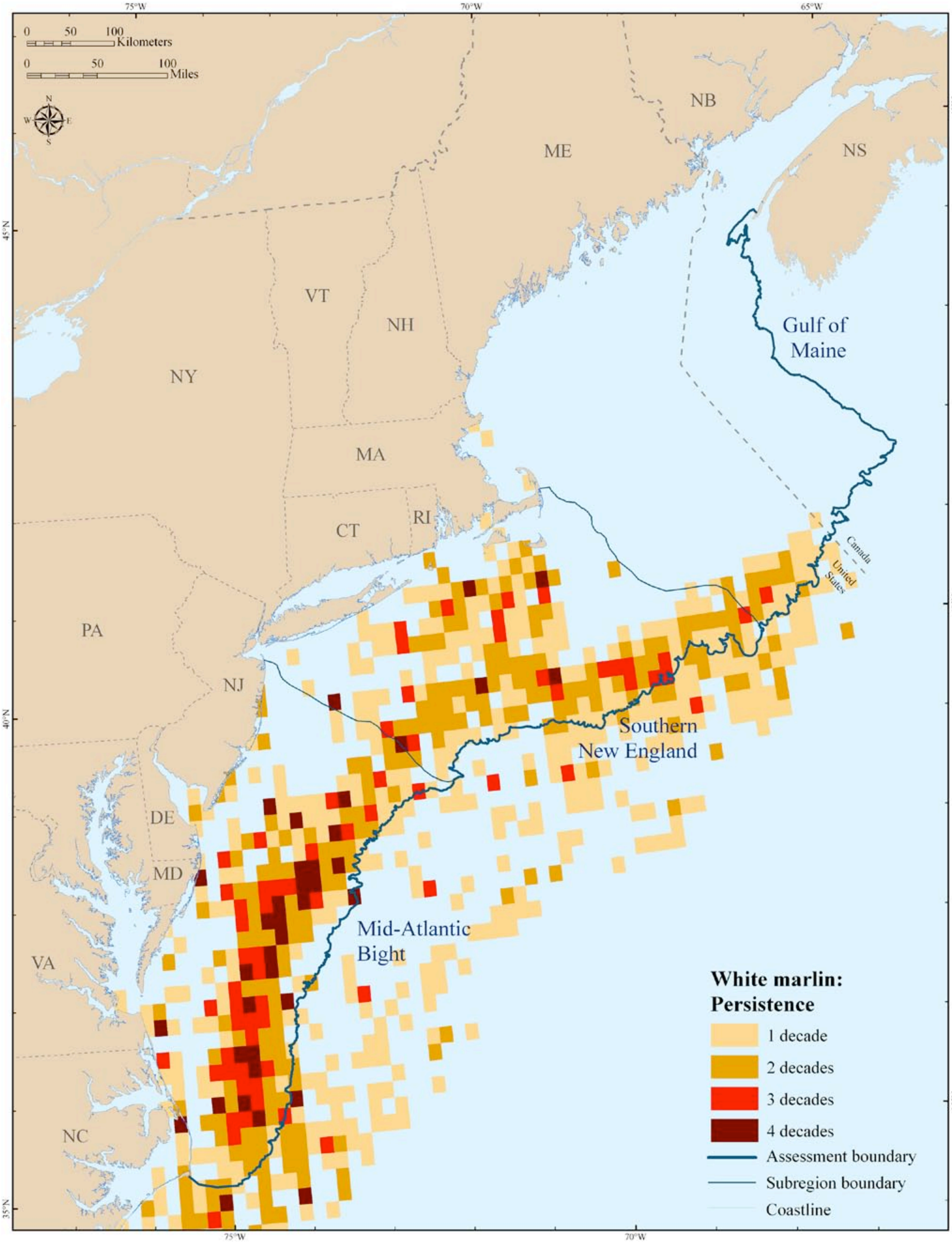


Figure 9-17. The persistence of white marlin by TMS over time.

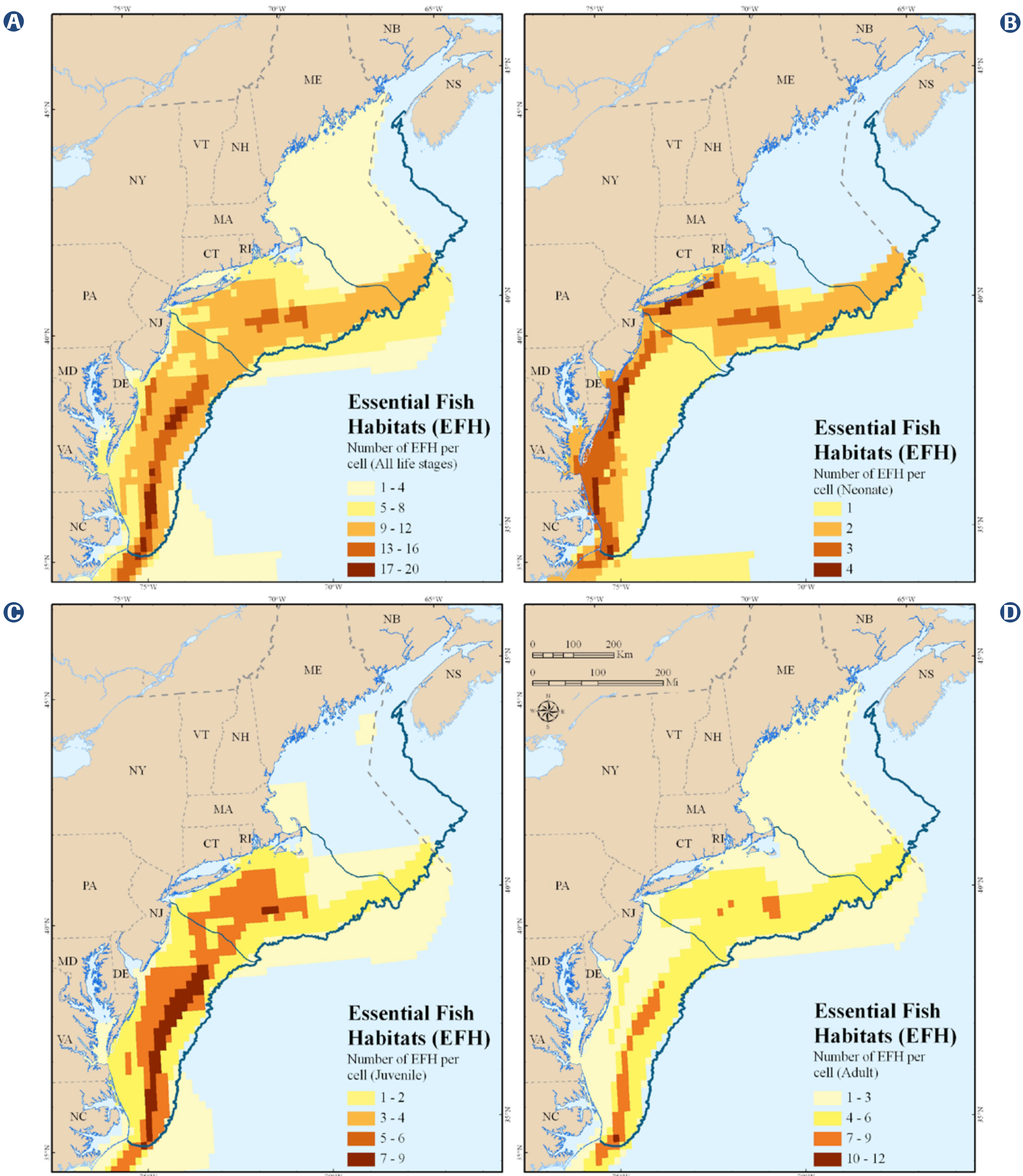


Figure 9-18. Areas designated as essential fish habitat for target species and life stages.

juveniles, the area with the greatest EFH concurrence is the SNE subregion, offshore to Long Island, between Hudson and Veech Canyons, including the Block Island Delta; the Mid-Atlantic Bight, to the 1000 m isobath, primarily between Baltimore and Wilmington Canyons, but extending south to Cape Hatteras; and a pathway along the Hudson canyon (Figure 18c). For adults, the area with the greatest concurrence is along the entire shelf-slope break out to 2000 m (Figure 18d).

Human Interactions and Threats

Threats to large pelagic species include overfishing (direct mortality of targeted species); bycatch (indirect mortality, largely by longline and gillnets, including accidental catches by recreational fisherman, and incidental catches by commercial fisherman (IUCN 2008); and climate change. Secondary threats are impacts to habitat: in particular, habitat loss and degradation of estuaries and shallow bays used by the two species of sharks in our region. Effective conservation of sharks will require attention to both habitat restoration and fishery conservation challenges.

Overfishing

Seven of the species are considered overfished (albacore tuna, blue marlin, bluefin tuna, dusky shark, sandbar shark, shortfin mako, and white marlin) and seven are threatened by overfishing (bigeye thresher, dusky shark, great hammerhead, porbeagle, sand tiger, scalloped hammerhead, thresher shark). Among the shark target species, the most commonly caught species is the shortfin mako, with an estimated annual catch of 6,000-8,000 tons (ICCAT 2005). Outside of the Exclusive Economic Zones, illegal, unreported unregulated fishing continues to occur (Dulvy et al. 2008). Globally, the fishing of pelagic sharks is increasing due to the sharkfin trade as well as the increasing value of shark meat (Simpfendorfer et al. 2008). According to Simpfendorfer et al. (2008), fin trade data suggest that the bigeye thresher and thresher shark may be caught at similar levels as the shortfin mako.

Bycatch

Sharks comprise the highest percentage of bycatch (25% of catch from 1992-2003) in the United States Atlantic pelagic longline fishery for tuna and swordfish (Mandelman and Werner 2007), and include bigeye thresher, thresher shark, white marlin, great hammerhead and dusky shark. Schindler et al. (2002) suggest that longline fisheries will have very different effects on slow-growing species, such as the pelagic sharks, in contrast to the teleosts. Hoey and Moore (1999) reported the order of bycatch in pelagic longlines as follows, with highest number of the target species caught first: mako, dusky shark, hammerheads, thresher shark, sandbar shark, and porbeagle.

To understand the distribution of these types of fishing within the region, the spatial locations of fishing trips for the gillnet fishing, pelagic longline, and bottom longline industry for the years 2001-2006 are shown in Figure 19-21 (source: Fishing Vessel Trip Reports (FVTR) data, provided by NOAA). It should be noted that the FVTR data does not show various state-licensed inshore fisheries that may have bycatch implications for these target species. For gillnet fishing, the Gulf of Maine/Georges Bank and Southern New England subregion show the greatest number of days fished. The highest intensity of fishing occurs within and north of Stellwagen Bank, as well as Jeffreys Bank, the Great South Channel, and Block Island Sound, with isolated high use of gillnets in the Hudson outflow/canyon area. Pelagic longlining occurs along the shelf/slope break in the Southern New England and Mid-Atlantic Bight subregions. For bottom longline fishing, the greatest and spatially broadest intensity is in the Gulf of Maine subregion, northeast of Stellwagen Bank; in the Southern New England subregion, along the Great South Channel, and roughly along the 100 m isobath between the Block Island Delta and Veech Canyon, and, with the Mid-Atlantic Bight subregion, along the Hudson canyon.

Climate Change

In general, any change in physical characteristics of the ocean could affect the distribution of pelagic species, and factors that can influence these changes include temperature, wind patterns, and pH. Currently, only a few cases

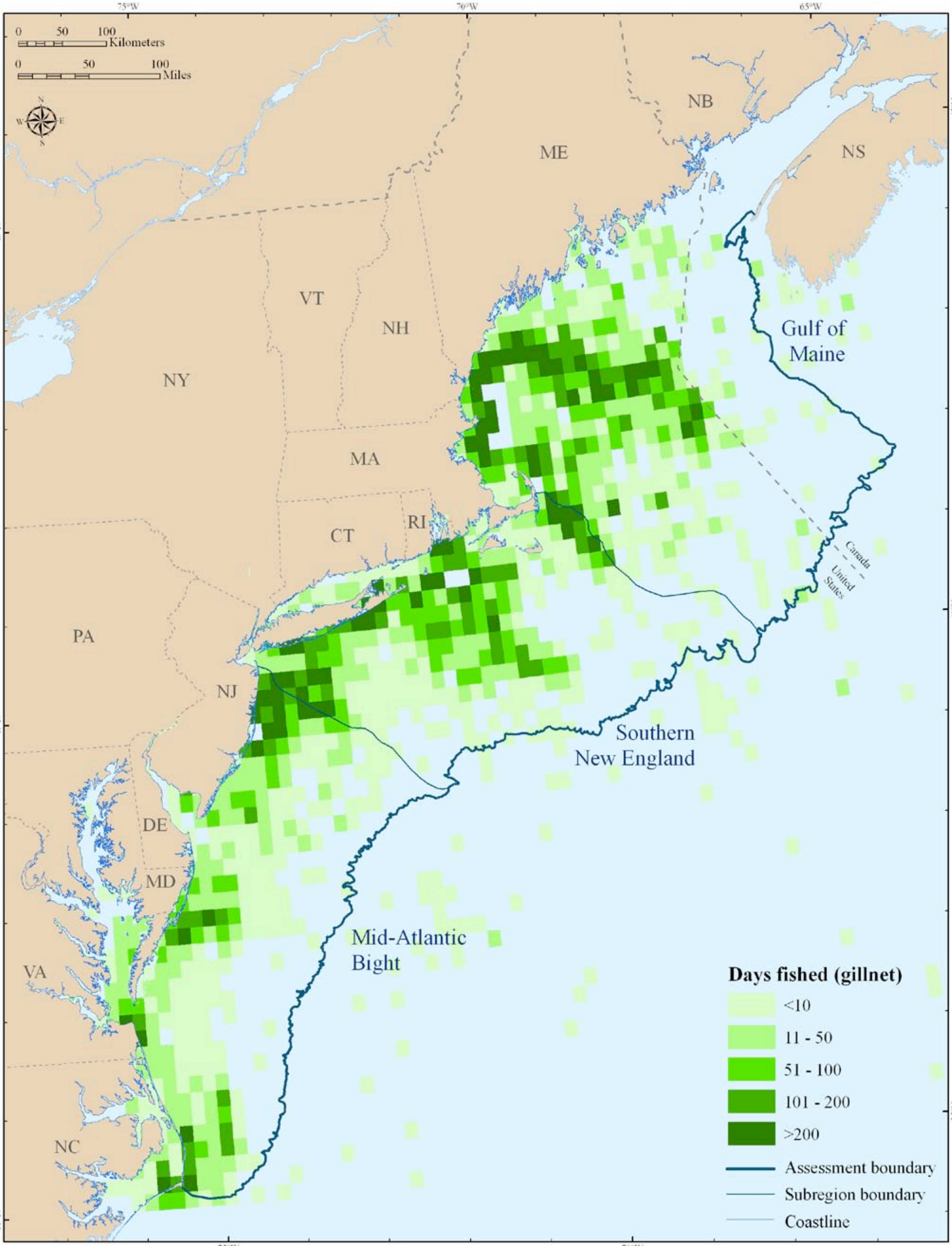


Figure 9-19. Number of days fished by gillnet.

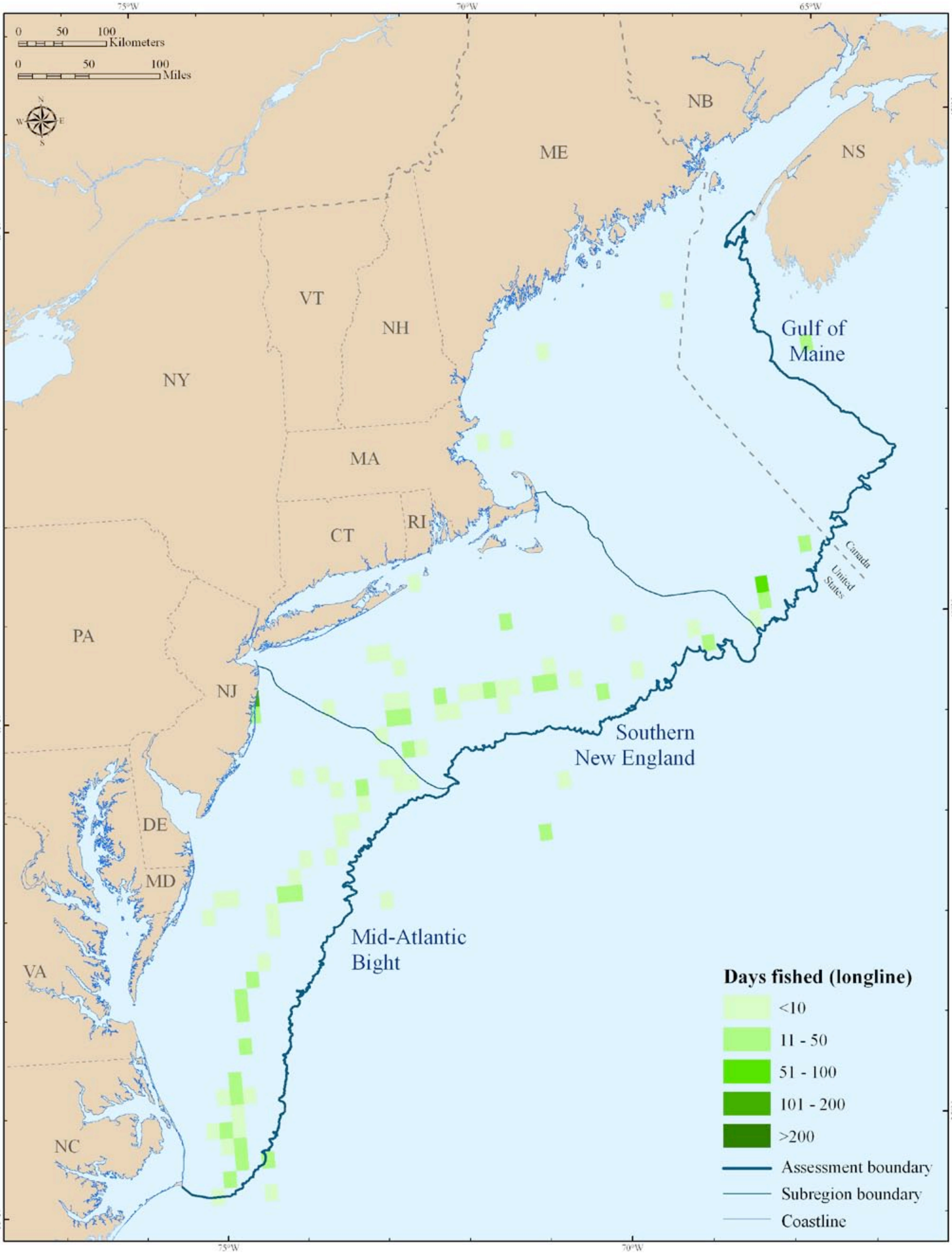


Figure 9-20. Number of days fished by pelagic longline.

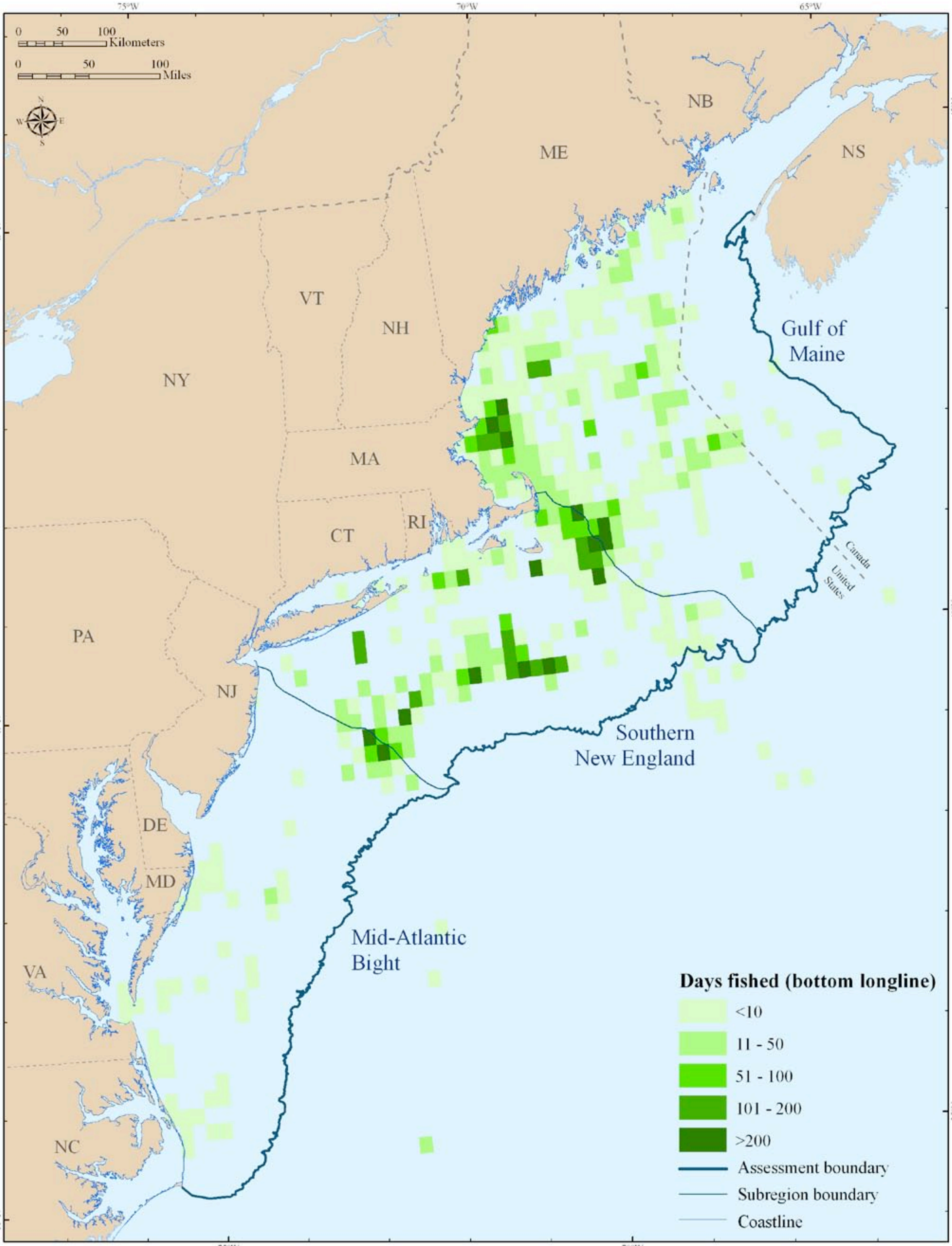


Figure 9-21. Number of days fished by bottom longline.

have documented climate change impacts (see reviews in UNEP/CMS 2006; Hobday et al. 2006), but there are several programs currently collecting information on climate change, including GLOBEC's Climate Impacts on Oceanic Top Predators (CLIOTOP) program (Maury and Lehodey 2005). Likely impacts include sea surface temperature changes and corresponding changes in the food web, wind forcing changes, acidification, changes in prey populations, and increased pollution at the sea surface.

Changes in ocean temperature in time and position could affect the distribution of pelagic species. On the United States east and west coast, sea surface temperature has increased, causing shifts in timing of zooplankton, which affects the entire food web (see Moran 2008; Scripps Institute of Oceanography 1995). Wind also indirectly impacts pelagic species by mixing the surface waters (Cury and Roy 1989). If significant changes to wind forcing do occur, this could impact coastal pelagic systems (Bakun and Weeks 2004). The productivity of pelagic systems could change, depending on the relative balance of nutrients, light, and timing of phytoplankton production.

There is notable concern about the pH changes occurring in the open ocean. While it is expected to be small compared to benthic habitats, acidification could impact lower trophic levels. The scalloped hammerhead, sand tiger, and sandbar shark – all of whom feed to some degree on benthic invertebrates - could be impacted. Other, fast-swimming, high metabolic species such as the tuna and billfish could be affected by changes to their metabolism (Pörtner and Farrell 2008). These animals are at the edge of physiologic extremes in their energy and oxygen needs. Change in prey populations will also potentially affect these species. CLIOTOP is analyzing the role of climate change on loligo squid, a key prey item for tunas and billfishes (Pecl and Jackson 2006). Squid are expected to be very sensitive to climate change, particularly increased temperature. They are expected to respond extremely rapidly, and may be good indicators for climatic impacts.

In summary, the individual and combined threats of global climate change described above could have both subtle and dramatic impacts to pelagic fish populations. While the science regarding the nature and likelihood of these impacts is advancing rapidly, substantial uncertainty remains. In the face of such uncertainty, an extra precautionary approach is indicated when managers must make key decisions regarding abatement of known threats such as overfishing, bycatch, and nearshore habitat loss and degradation. Conservation measures that abate non-climate change related impacts will help to increase resiliency of populations while explicit climate change adaptive management strategies are still being developed and tested.

Management and Conservation

Regulatory Authorities

Unlike the other fish species, these animals are not regulated by the regional fisheries management councils. Since 1992, within the United States Exclusive Economic Zone (EEZ), Atlantic highly migratory species, including tuna, swordfish, billfish (the two marlin species) and sharks are managed by NMFS HMS, under the dual authority of the Magnuson-Stevens Fishery Conservation and Management Act and the Atlantic Tunas Convention Act. NAFO is a regional, non-regulatory body. Its objective is regional cooperation and consultation on fisheries of the NAFO Convention Area of the Northwest Atlantic, including swordfish, porbeagle, shortfin mako, and large sharks; the NAFO Convention does not apply to tunas or marlin.

Because of the circumglobal distribution of many of the species and the fact that the species are often found outside of exclusive economic zones, management requires international cooperation through ICCAT. Note that ICCAT only regulates Atlantic tunas, swordfish and billfish; it does not regulate Atlantic sharks. If ICCAT makes a management recommendation, the United States must implement it, under the Atlantic Tunas Convention Act. All fourteen of the selected species for this chapter are included in Annex 1 of the UN 1982 Convention of the Law of the Sea (UNCLOS) as highly migratory species. Under UNCLOS, the UN held a 1993 Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks. As a result of this Conference, the Fish Stock Agreement (FSA) was created relating to the conservation and management of straddling fish stocks and highly migratory stocks. The FSA entered into force in 2001.

Current Conservation Efforts

Federal

HMS has developed a range of fishery management regulations, ranging from gear restrictions to spatial closures (some are year-round; others are closed for certain periods). Fishing is prohibited for the following four shark species: bigeye thresher, dusky shark, sandbar shark (except fisherman participating in research), and sand tiger. For the teleost fishes, see 50 CFR part 635. Commercial fishermen are restricted by quotas, trip limits, and limited access permits; recreational fishermen are restricted by minimum size as well as bag limits. In 2002, the U.S. banned shark finning in U.S. waters. The United States and Australia are the only two shark fishing nations (out of 87) to develop a National Plan of Action for the Conservation and Management of Sharks.

A summary of recent (2006-2007) NMFS Atlantic HMS Management actions with respect to fisheries is provided in Table 1.2 of the Stock Assessment and Fishery Evaluation Report for Atlantic Highly Migratory Species (NMFS 2009). The 2006 consolidated HMS FMP summarizes state management.

Within United States waters, HMS has designated some temporally closed areas to fishing, including in our region: the Northeastern U.S. Closure is closed in June (effective since 1999), and partially, the Mid-Atlantic closure is closed for 6 months, from Jan. to July (effective since 2005). Outside of the Northwest Atlantic, the Charlestown Bump is closed 3 months, from Feb. to April (effective since 2001), the Florida East Coast is closed all year (effective since 2001), and the De Soto Canyon in the Gulf of Mexico is closed all year (effective since 2000).

Non-Governmental Organizations (NGO)

Several NGOs are working towards protecting pelagic fish within the Northwest Atlantic, primarily focusing on federal and international fisheries policy (including marine protected areas, both year-round and seasonal, depending on the species and efforts to reduce total allowable catch and bycatch), and market-based approaches to encourage sustainable fisheries. The Natural Resources Defense Council has identified North Atlantic swordfish as one of their key fish species to protect. They promote the continued closure of more than 6,500 square miles of the Georges Bank seafloor to fishing and the creation of a marine reserve within the Gulf of Mexico, a key spawning area for bluefin tuna. In April 2008, Blue Ocean Institute called for a five-year moratorium on possession of bluefin tuna throughout the western Atlantic and the closer of Gulf of Mexico spawning areas to all gear capable of catching bluefin tuna during this fish's spawning season. Also, Blue Ocean Institute produces a "Guide to Ocean Friendly Seafood" accessible online or through their new "fishphone" system. World Wildlife Fund is working at a global level, mainly in Europe, to address population declines in Atlantic bluefin tuna and porbeagle. Environmental Defense Fund works within New England, the tri-state area (NY, NJ and CT) and Long Island Sound to protect and restore coastal estuaries, bays, wetlands and cod and to reduce nitrogen loading. They promote sustainable fisheries by advocating catch share policies in New England that gives fishermen a financial stake in fisheries. IUCN recommends listing for all shark species studied in this assessment under the Convention on Migratory Species, to provide additional regulatory mechanisms. Currently, only the shortfin mako, porbeagle, whale shark, great white, and basking shark are listed.

Species Accounts

Atlantic bluefin tuna *(Thunnus thynnus)*

Atlantic bluefin tuna are found throughout the western Atlantic, from Florida to Newfoundland and are considered apex predators (Collette and Nauan 1983; Lutcavage and Kraus 1995). In what is thought to be a single stock, bluefin tuna move seasonally from mid-April to June, from spawning grounds outside the Northwest Atlantic region (Gulf of Mexico and in the FL Straits) to feeding grounds along the Northwest Atlantic region (Mather et al. 1995; Block et al. 2005). Recent tagging studies have shown that they can swim thousands of miles across the Atlantic, with a maximum distance traveled of 5820 km in less than a year (304 days) (Rooker et al. 2007). Bluefin tuna are a thermoconserving species and are found in water temperatures from 6-27°C (Collette and Klein-MacPhee 2002). They usually remain in oceanic waters, but are seen across the continental shelf and are often found in coastal embayments during summer when food resources are in abundance (Collette and Nauen 1983).

© NOAA

Growth rate is slow and maturity is late and occurs about age 8 for the Western Atlantic population (Turner et al. 1991). This species is relatively long-lived and can live up to 30 years (Collette and Klein-MacPhee 2002). Spawning occurs every year, but individuals appear to spawn only every 2-3 years; timing appears to be linked to temperature (Fromentin and Powers 2005). Genetic studies of young of year animals show that the Western Atlantic and Juveniles and adults do overlap, however, in central and eastern North Atlantic foraging grounds and in mid-Atlantic/transatlantic migrations (Block et al. 2005; Lutcavage et al. 1999; Rooker et al. 2007). Adult bluefin are large (up to a TL of 458 cm and wt of 684 g) and feed opportunistically on fish (sand lance, Atlantic herring, mackerel and bluefish), squid and crustaceans (Chase 2002; Estrada et al. 2005). A study of diet across five different feeding grounds in New England shows spatial differences; for example, 50% of the diet in Cape Cod Bay consisted of demersal fish (Chase 2002). In the Gulf of Maine, their preferred prey is herring (Golet et al. 2007). Their distribution in this subregion has been shown to be significantly correlated with the distribution of the herring, which is also correlated to SST (Schick and Lutcavage 2009). Predators of adult bluefin tuna include other large pelagic species like toothed whales, swordfish, and sharks (Tiews 1963).

Albacore Tuna *(Thunnus alalunga)*

North Atlantic albacore are found throughout the Atlantic Ocean and Mediterranean Sea (Collette and Nauan 1983). Throughout its range, albacore migrate over great distances and move in groups that may include different kinds of tuna like skipjack and bluefin tuna. There are two separate stocks of albacore (North and South Atlantic) and there appears to be no mixing between the stocks (Collette and Nauan 1983). Albacore tuna typically feed in the upper layers of the ocean, but have been documented diving to a depth of 500 m in search of prey (Consoli et al. 2008).

North Atlantic albacore are presumed to spawn in the Sargasso Sea and surrounding waters during the boreal summer and their larvae live in the upper 100 m of water at a temperature range of 15 to 20°C (Pusineri et al. 2005). Juvenile fish range from 40 to 90 cm long and are constrained to the same range and temperature. Albacore become sexually mature when they reach 90 cm in length and an age of about 5 years (Collette and Nauan 1983).

© Maria Honig, Marine Photobank

Maximum reported age is 12 years and albacore can reach a maximum fork length of 140 cm and weight of 60.3 kg. Like bluefin tuna, albacore are opportunistic feeders. Their main prey is fish (60% of biomass) and cephalopods (39%) (Pusineri et al. 2005). Studies of feeding behavior in the central Mediterranean Sea have shown preference to other pelagic species like medium sized fish, cephalopods, and crustaceans (Consoli et al. 2008; Dragovich 1969).

Swordfish *(Xiphias gladius)*

Swordfish range throughout the tropical, temperate, and cold-water areas (Collette and Klein-MacPhee 2002). Adult swordfish are found in coastal waters, but are primarily oceanic and concentrations are seen between water masses associated with boundary currents like the Gulf Stream (Govoni et al. 2003). Swordfish are found in the upper layers of the ocean, but feed throughout the water column. This population is genetically different from that found in the Mediterranean Sea, and mixes only slightly with the Mediterranean population west of Gibraltar and south of the NW African coast (Bremer et al. 2005a, b). Atlantic swordfish have two distinct populations, North Atlantic and South Atlantic, as demonstrated by mitochondrial and nuclear DNA studies (Bremer et al. 2005a). They annually migrate thousands of miles along the eastern seaboard of the United States and Canada, moving toward temperate or colder waters during the summer for feeding and back to warmer waters in fall for spawning and overwintering (HMS FMP 2002). In swordfish, the brain and eyes are warmer than the water in which they live, which protects the species on deep foraging dives (Collette and Klein-MacPhee 2002).

In the Northwest Atlantic, swordfish segregate by size and sex; the larger individuals, primarily females, can be found in colder, higher-latitude waters, but the females, along with the males, are eventually found in the warmer breeding areas (Palko et al. 1981). Spawning occurs throughout the year in several warm-water locations (e.g. south of the Sargasso Sea/upper Caribbean Sea, Southeast coast of United States) (Collette and Klein-MacPhee 2002). Larvae are most often found at temperatures greater than 24°C and are often found in nursery areas in the Gulf of Mexico and Florida (NMFS 2009). These regions to the south of the Northwest Atlantic may also serve as juvenile fish nursery areas (NMFS 2009). Swordfish are opportunistic feeders, eating at different depths and at different trophic levels during the diurnal vertical migration (Stillwell and Kohler 1985). The main prey items in the Northwest Atlantic region are predominantly squid, followed by gadids, scombrids, butterfish, bluefish, and sand lance (Stillwell and Kohler 1985).

Blue Marlin *(Makaira nigricans)*

Blue marlins are found throughout the Atlantic Ocean in offshore areas mostly between 45°N and 35°S (Nakamura 1985). They are highly migratory and seasonal movements are correlated to changes in sea surface temperature (especially the 24° C isotherm). Blue marlin are solitary and do not typically school (Nakamura 1985). ICCAT (2001) considers there to be a single Atlantic stock of blue marlin.

Blue marlins spawn outside the Northwest Atlantic region in marine habitats (Nakamura 1985). Female blue marlin mature when they reach 104 to 134 lbs, while males mature at smaller weights, from 77 to 97 lbs (NMFS 1999). Pelagic eggs and fast-growing larvae are found in the same habitat as the spawning region. Larvae are found in marine waters with a temperature of >24°C and are generally bounded by 100-2000m isobath or to the EEZ (NMFS 1999). Pelagic juveniles are obligate marine and found within temperatures ranging between 22 and 31°C. From Jan-April adult blue marlins are found in the SW Atlantic (5-30° N) and from June-Oct. in NW Atlantic (10-35° N). Maximum total length recorded for both males and females is 500 cm (NMFS 1999). Maximum weight of males is 170-175 kg, while females grow larger and faster than males, and can reach a maximum weight of over 900kg (NMFS 1999). Blue marlin feed at a wide variety of depths and their diet consists of other medium sized oceanic organisms like tuna and squid (Collette and Klein-MacPhee 2002).

White Marlin *(Tetrapturus albidus)*

Atlantic white marlin are distributed widely in the Atlantic Ocean, in coastal and offshore areas, mostly ranging from 45°N to 45°S (NMFS 2009). Animals are generally found alone, but can be found in small schools grouped by size or sex (Nakamura 1985). This species follows the thermocline and is usually found in the upper 20 to 30 m of the water column, but may dive to depths of 200 to 250 m in warmer areas. White marlin are only found at the higher latitudes of their range in the warmer months. Tagging data has shown that white marlin undergo extensive migrations; maximum movement has been 6523 km, with a mean displacement of 719 km (Orbesen et al. 2008).

Spawning occurs outside the Northwest Atlantic in marine waters of the Caribbean during early summer at water temperatures greater than 68° F (NMFS 2008). Known spawning areas include the area northeast of Little Bahama Bank, northwest of Grand Bahama Island, and southwest of Bermuda (NMFS 1999). Spawning activity occurs during the spring (March through June) in northwestern Atlantic tropical and sub-tropical waters marked by relatively high surface temperatures (20° to 29°C) and salinities (> 35 ppt). When female white marlin reach 20 kg and 130 cm in length, they become sexually mature (NMFS 2009). Females spawn by releasing eggs and may do so up to four times a year (NMFS 2009). Both larvae and juveniles are oceanic and pelagic. Adult white marlin can grow larger than 300 cm and weight 82 kg (Nakamura 1985). Females grow larger than males. White marlin are known to stun or kill their prey with their bill, but also consume prey whole (Nakamura 1985). The majority of their prey consists of fishes, crustaceans, and cephalopods.

Bigeye Thresher *(Alopias superciliosus)*

Bigeye thresher sharks are coastal and oceanic and found throughout the world in tropical and temperate seas (NMFS 2009). Within the Western Atlantic, bigeye threshers range from New York to Florida (Compagno 2001). They are found in waters over the entire continental shelf, in both shallow and deep waters (Gruber and Compagno 1981). Recent studies have determined that bigeye threshers may not have the thermoconserving mechanisms, the ability to maintain a body temperature above ambient water temperature, that the thresher shark has (Sepulveda et al. 2005).

Male bigeye thresher males mature at about 279 to 300 cm in length when they reach between 9 and 10 years of age and live up to about 19 years (Compagno 2001). Females mature at approximately 294 to 355 cm in length when they reach between 12 and 13 years of age and live for 20 years (Compagno 2001). The exact location of breeding grounds has not yet been identified for these sharks (NMFS 2009). These sharks are ovoviviparous and births may occur through the year, although in the eastern Atlantic births may occur more frequently in the fall and winter (Compagno 2001). Gestation period is thought to be about 12 months long, and females give birth to two fully developed pups per litter that are 100 to 140 cm long (Gruber and Compagno 1981; Compagno 2001). Juveniles of this species are both coastal and oceanic and most are found along the eastern Atlantic coast and Gulf of Mexico just outside 200m depth contour (Kohler et al. 1998). Adults are marine and can range from inshore shallow depths of 1 m to the high seas at depths of 500 m, but mostly below 100 m (Compagno 2001). Maximum published total length for females is 422 cm; males 357 cm (Compagno 2001); and weight is 363.8 kg. These animals feed on squid and pelagic fishes (e.g. herring and mackerel), small billfishes and bottom fishes (e.g. hake) (Compagno 2001; NMFS 2009). Many scientists believe that they stun or kill their prey with their large, elongated tail fin; bigeye thresher caught by their tails on longlines and sport fishing supports this theory (Compagno 2001).

Thresher Shark *(Alopius vulpinus)*

Thresher sharks are circumglobal in tropical to cold-temperate seas (Compagno 2001). They are found in coastal waters over continental shelves and around islands, where they are abundant inshore, but have been found up to 366 m (Strasburg 1958; Compagno 2001). These sharks throughout the Northwest Atlantic, mostly along or within the 200 m depth contour (Kohler et al. 1998; NMFS 2009). The thresher shark has a thermoconservation mechanism, meaning that they are able to maintain a body temperature above ambient water temperature (Sepulveda et al. 2005).

At this time, there is limited information on thresher shark breeding grounds within Northwest Atlantic. The size at which they reach sexual maturity at about 330 cm in males and 260-450 cm in females, which may vary by region (Collette and Klein-MacPhee 2002). These sharks are ovoviviparous and female sharks have an average litter size of 2-4 pups per litter (Collette and Klein-MacPhee 2002). Juveniles are marine and often found inshore and in warm shallow bays (Compagno 2001). These animals show spatial and depth segregation by sex (IUCN 2007a). Adult thresher sharks are apex predators at the highest trophic level of Atlantic sharks (Estrada et al. 2003). These sharks may cooperate with each other to hunt and, like the bigeye thresher, stun their prey using their large tail fin. Thresher sharks may grow to a total length of 600 cm (Collette and Klein-MacPhee 2002). This species feeds on schooling fishes, including squid, herring, mackerels, bluefishes, clupeids, and occasionally seabirds (Compagno 2001).

Porbeagle *(Lamna nasus)*

The porbeagle shark is commonly found in deep, cold temperate waters of the North Atlantic, South Atlantic, and South Pacific Oceans (Castro 1983). This species is common in pelagic waters (from coastal waters up to 300 m), and is most abundant on the continental shelf, but has occasionally been found far from land (Castro 1983; Compagno 2001; Collette and Klein-MacPhee 2002). Porbeagles are thermoconserving and can maintain body temperatures that are 7-10°C warmer than ambient water temperatures (Carey and Teal 1969). The porbeagle generally prefers waters colder than 18°C (Collette and Klein-MacPhee 2002). Porbeagle may occur singly as well as in schools and feeding aggregations (IUCN 2007a). Tagging data suggest maximum travel of 1000km (Campana et al. 2003). Porbeagle populations of the Northwest Atlantic are mostly separate from those of the northeast, and populations in the northern hemisphere are most likely separate from those in the southern hemisphere (Francis et al. 2008). They tend to come inshore and to the surface during summer months, but stay at depth in offshore waters during winter (Collette and Klein-MacPhee 2002).

In the Northwest Atlantic, porbeagle sharks breed between New Jersey to Newfoundland from fall to winter and pregnant individuals are caught from Massachusetts to Maine year-round (Campana et al. 2003). Gestation lasts between 8 and 9 months (Francis et al. 2008). These sharks are ovoviviparous and oophagus during late stage of development (Collette and Klein-MacPhee 2002). The pelagic, obligate marine juveniles are born in spring to summer and there are approximately 4 pups per litter with each between 60-70 cm in total length (Collette and Klein-MacPhee 2002). Males mature at a length between 155-177 cm and females are mature by 208 cm, at ages 6-10 and 12-16, respectively (Francis et al. 2008). Maximum total length is 302 cm (females); 250 cm (males), and the maximum weight recorded is 251 kg and age is 26 years (Francis et al. 2008). Pelagic fish and squid dominate the porbeagle diet in deep water, while demersal and pelagic fish dominate their diet in shallower water (Francis et al. 2008). Gastropods and crabs have also been documented in stomach samples.

Shortfin Mako *(Isurus oxyrinchus)*

Adult shortfin makos are found circumglobally in temperate and tropical seas (Collette and Klein-MacPhee 2002). In western Atlantic, these sharks range from the Gulf of Maine to southern Brazil and Argentina. Shortfin makos are usually solitary and found in littoral and epipelagic zones from surface waters down to about 500 m (Compango 2001). These sharks prefer clear water and are commonly found from 17-22°C (Compango 2001). Shortfin makos are strong-swimming, active species, and like the porbeagle, are thermoconserving and can maintain body temperatures 1-10°C above ambient (Carey and Teal 1969). North Atlantic populations are geographically distinct from other areas, but there is no evidence of multiple sub-species (Heist et al. 1996).

Shortfin makos reproduce approximately every three years and gestation is approximately 15-18 months (Collette and Klein-MacPhee 2002). Shortfin makos are ovoviviparous and oophagous at later stages of development (Collette and Klein-MacPhee 2002). Mothers give birth from late spring to early summer to 10-20 pups per litter (Collette and and Klein-MacPhee 2002). Both males and females grow at the same rate until 11 years old; females continue to grow (Bishop et al. 2006). Maximum size of males and females, respectively, in the North Atlantic Ocean, is 260-298 cm and 340-275 cm (Natanson et al. 2006). Life span estimates and have been recorded as 25 years for females and 29 and 28 years for males and females, respectively (Cailliet and Mollet 1997; Bishop et al. 2006). They feed primarily on schools of fish and consume both pelagic and bony fishes (Collette and Klein-MacPhee 2002). Shortfin makos are also known eat cephalopods and take larger prey such as swordfish and other sharks. They are reported to be one of the fastest sharks and are known to jump out of the water when in pursuit of prey (Compagno 2001; IUCN 2007a).

Great Hammerhead *(Sphyrna mokarran)*

Great hammerheads are solitary, circumtropical sharks and are found in both shallow and oceanic waters (Castro 1983). In the North Atlantic, this species is only found in the waters off North Carolina and southward and are commonly found there during the summer months. The great hammerhead utilizes shallow inshore waters along the Gulf Coast of Florida as nursery areas throughout the warm months, but the location of their pupping grounds in this area is not known (Hueter and Tyminski 2007).

These sharks are viviparous with a yolk-sac placenta and gestation is at least 7 months long (Compagno 1984). Females carry a litter of 13-42 pups that range between 56 and 70 cm in length, where births occur in the summer. Great hammerheads are the largest species of hammerhead and the maximum published total length is 610 cm (Compagno 1984). The species prefers to feed on stingrays, bony fishes, and other sharks.

Scalloped Hammerhead *(Sphyrna lewini)*

Scalloped hammerheads are a circumtropical species, from coastal areas near continents to oceanic islands far offshore (Piercy et al. 2007). The most abundant hammerhead species, the scalloped hammerhead ranges from the shallow depths to at least 275 m (Castro 1983; Compagno 1984). In the Northwest Atlantic, this shark occurs from New Jersey southward and may be the most abundant shark off the Carolinas in the summer months (Castro 1983).These sharks forms large, true schools at different stages of its life, though solitary individuals of both young and adults also occur (Castro 1983). Recent research suggests there is a cryptic species of scalloped hammerhead found in the northwestern Atlantic from coastal North Carolina to Florida (Quattro et al. 2006).

Similar to the great hammerhead, scalloped hammerheads are viviparous and have large litters consists of 15-31 pups that are 38-45 cm in size (Castro 1983). Their gestation period lasts at least 9 months. Females move inshore to shallow waters to give birth during the summer months in SC, GA and FL. Several studies have found nurseries in the shallow coastal waters of South Carolina and have identified the importance of coastal South Carolina waters as primary and secondary nursery areas (Castro 1993; Abel et al. 2007; Ulrich et al. 2007). Juveniles utilize this nursery habitat for at least one year (Duncan et al. 2006). Studies by Klimley (1985; 1993) on schooling behavior show how these sharks use complex body cues to establish social rank during daylight hours, and geomagnetic cues to navigate between seamounts at night, when the schools break up to hunt for prey. Male scalloped hammerheads reach sexual maturity at 140 to 165 cm and reaching at least 295 cm in length (Compagno 1984). Females reach sexual maturity around 212 cm and reaching at least 309 cm. Maximum published total length is 430 cm, weight is 152.4 kg and age is 35 years (Branstetter 1987). Scalloped hammerheads feed on fish, crustaceans, stingrays and small sharks (Compagno 1984).

Dusky Shark *(Carcharhinus obscurus)*

Dusky sharks are common in warm-temperate and tropical waters worldwide and are found from the surf zone to offshore waters (Collette and Klein-MacPhee 2002). They are commonly found at the surface to 400 m in depth (Compagno 1984). They avoid estuaries and areas of low salinity. Within the region, the dusky shark does not usually come north of Cape Cod, but an occasional sighting may occur in the Gulf of Maine (Collette and Klein-MacPhee 2002).

Dusky sharks are viviparous and females give birth to approximately 10 pups per litter ranging in size between 90 and 100 cm (Collette and Klein-MacPhee 2002). Females apparently mate during the spring in alternate years and gestation is thought to be 16 months or more (Castro 1983; Compagno 1984). Females move inshore to shallow bays and estuaries to drop their pups, and then depart the nursery area (Compagno 1984). This birthing may occur over a span of several months in a given region and has been reported as occurring from late winter to summer. Nursery areas within the region extend from the NJ to south of Cape Hatteras (Collette and Klein-MacPhee 2002). Males mature at about 290 cm and females mature at about 300 cm (Castro 1983). Adults are highly migratory in temperate and subtropical areas of western north Atlantic and move north during the warmer summer months and retreat south when the water cools (Compagno 1984). Maximum total length can reach over 400 cm. Dusky sharks primarily eat fish, along with small elasmobranchs and crustaceans (Gelsleichter et al. 1999).

Sandbar Shark *(Carcharhinus plumbeus)*

The sandbar shark occurs throughout the world and is a cosmopolitan species (Castro 1983). This species is abundant, both inshore and offshore, in temperate and tropical waters (Compagno 1984). In the western Atlantic, sandbar sharks range from southern Massachusetts to Argentina and are also found in the Gulf of Mexico, Bahamas, Cuba and south and west Caribbean. They are a bottom-dwelling species that is commonly found at river and bay mouths, in harbors, in shallow muddy or sandy bays (Compagno 1984). They tend to avoid sandy beaches and the surf zone, coral reefs and rough bottom, and are rarely seen at the surface, with the exception of nursery zones (Castro 1983; Compagno 1984). They range in depths from extremely shallow water to 280 m depth.

Sandbar sharks are viviparous and gestation ranges from 11 to 12 months, with a 1-year resting stage between pregnancies (Collette and Klein-MacPhee 2002). Litters range from 6-10 pups and size at birth is 50-60 cm. In the western Atlantic, sandbar shark nursery areas are typically in shallow coastal waters from Massachusetts to Florida, including primary and secondary nurseries in the this region in Martha's Vineyard, Delaware Bay, Chesapeake Bay, Great Bay (NJ), and the waters off Cape Hatteras, North Carolina (Springer 1960; Jensen et al. 2002; Merson and Pratt 2001; Conrath and Muskick 2007; Grubbs and Musick 2007; McCandless et al. 2007; Merson and Pratt 2007). There is some evidence of natal philopatry, sharks that return to the same nursery area, in juveniles

(Hueter et al. 2004). Maturity appears to reach maturity at total length 170 cm and females at 180 cm (Collette and Klein-MacPhee 2002). Sandbar sharks tend to school and are usually segregated by sex, except during the mating season. Maximum published total length is 250 cm is this slow-growing species (Collette and Klein-MacPhee 2002). They primarily eat small bottom fishes, some sharks and rays, and occasionally mollusks and crustaceans (Compagno 1984).

Sand Tiger *(Carcharias taurus)*

The sand tiger is a common warm temperate and tropical in all areas except the east Pacific (Compagno 2001). In the Northwest Atlantic, this species has been found throughout the entire region, but are higher in abundance from Delaware Bay to North and South Carolina in the warmer months (Carlson et al. 2009). Restricted to coastal waters, the species is found in areas ranging from the surf zone, in shallow bays where they sometimes enter mouths of streams and around coral and rocky reefs to a depth of at least 190 m to the outer continental shelves (Compagno 2001). A strong but slow swimmer, sand tiger sharks are more active at night. They are able to maintain near-neutral buoyancy and hover motionless in the water column by gulping air at the surface and holding it in the stomach. These sharks are found near or on the bottom, but also occur in midwater or near the surface, usually at depths < 20m (Compagno 2001).

These sharks are ovoviviparous and usually only two pups are born per litter due to intrauterine cannibalism (Carlson et al. 2009). Gestation is 9-12 months and it is believed this species gives birth between March and April in winter in the southern portions of its range, and the neonates migrate northward to summer nurseries (Compagno 2001). Nursery areas in this region include Narragansett Bay, Delaware Bay, Sandy Hook estuary and Chesapeake Bay, as well as coastal sounds (NMFS 2009). In the Northwest Atlantic, mature males and juveniles occur between Cape Cod and Cape Hatteras, while mature females (including pregnant females) inhabit waters between Cape Hatteras and Florida (Gilmore 1983). Males maturing at about 190 to 195 cm, while females mature at


© Brandon Puckett, Marine Photobank

220 cm, and maximum total length is 320 cm (Compagno 2001). These sharks catch schooling prey by systematically surrounding and concentrating them before feeding. Sand tiger sharks have a diverse diet, feeding on bony fishes, sharks (including juvenile sandbar sharks), stingrays, squid, and crustaceans (Gelsleichter et al. 1999).

Literature Cited

Abel, D.C., R.F. Young, J.A. Garwood, M.J. Travaline, and B.K. Yednock. 2007. Survey of shark fauna in two South Carolina estuaries and the impact of salinity structure. American Fisheries Society Symposium. 50:109-124.

Bakun A., and S.J. Weeks. 2004. Greenhouse gas buildup, sardines, submarine eruptions and the possibility of abrupt degradation of intense marine upwelling ecosystems. Ecology Letters. 7: 1015-1023.

Baum, J.K. and B. Worm. 2009. Cascading top-down effects of changing oceanic predator abundances. Journal of Animal Ecology. 78: 699-714.

Bishop, S.D.H., M.P. Francis, C. Duffy, and J.C. Montgomery. 2006. Age, growth, maturity, longevity and natural mortality of the shortfin mako shark *(Isurus oxyrinchus)* in New Zealand waters. Marine and Freshwater Research. 57:143-154.

Block, B.A., S.L.H. Teo, A. Walli, A. Boustany, M.J.W. Stokesbury, C.J. Farwell, K.C. Weng, H. Dewar, and T.D. Williams. 2005. Electronic tagging and population structure of Atlantic bluefin tuna. Nature. 434: 1121-1127.

Branstetter, S. 1987. Age, growth and reproductive biology of the silky shark, *Carcharhinusfalciformis,* and the scalloped hammerhead, *Sphyrna lewini*, from the northwestern Gulf of Mexico. Environmental Biology of Fishes 19: 161–173.

Bremer, A., J.R. Mejuto, J. Gomez-Marquez, F. Boan, P. Capintero, J.M. Rodriquez, J. Vinas, T.W. Greig, and B. Ely. 2005a. Hierarchical analyses of genetic variation of samples from breeding and feeding grounds confirm the genetic partitioning of northwest Atlantic and South Atlantic populations of swordfish (*Xiphias gladius*). Journal of Experimental Marine Biology and Ecology. 327: 167-182.

Bremer, A., J.R. Vinas, J. Mejuto, B. Ely, and C. Pla. 2005b. Comparative phylogeography of Atlantic bluefin tuna and swordfish: the combined effects of vicariance, secondary contact, introgression, and population expansion on the regional phylogenies of two highly migratory pelagic fishes. Molecular Phylogenetics and Evolution. 36: 169-187.

Cailliet, G.M. and H. M. Mollet. 1997. Preliminary demographic analysis of the shortfin mako, *Isurus oxyrinchus*. American Society of Ichthyologists and Herpetologists. 77th Annual Meeting, June 26-July 2, 1997. University of Washington, Seattle.

Campana, S., W. Joyce, and L. Marks. 2003. Status of the porbeagle shark (*Lamna nasus*) population in the Northwest Atlantic in the context of species at risk. CSAS Research Document 2003/007. 1-27.

Carey, F.G. and J.M. Teal.1969. Mako and porbeagle: Warm-bodied sharks. Comparative Biochemistry and Physiology. 28 (1): 199–204.

Carlson, J.K., C.T. McCandless, E. Cortés, R.D. Grubbs, K.I. Andrews, M. A. MacNeil, and J.A. Musick. 2009. An Update on the Status of the Sand Tiger Shark, *Carcharias taurus*, in the northwest Atlantic Ocean. NOAA Technical Memorandum. NMFS SEFSC-585, 23 p.

Castro, J.I. 1983. The sharks of North American waters. Texas A&M Univ. Press, College Station. 180pp.

Castro, J.I. 1993. The shark nursery of Bulls Bay, South Carolina, with a review of the shark nurseries of the southeastern coast of the United States. Environmental Biology of Fishes. 38(1): 37-48.

Cayre, P., J.B. Amon Kothias, T. Diouf, and J.M. Stretta. 1988. Biology of tuna. In: A. Fonteneau and J. Marcille, eds. Resources, fishing and biology of the tropical tunas of the Eastern Central Atlantic. FAO Fisheries Technical Paper, no. 292. p. 157–268.

Chase, B.C. 2002. Differences in diet of Atlantic bluefin tuna at five seasonal grounds on the New England continental shelf- Thunnus tynnus. Fishery Bulletin 100:168-180.

Cheung, W.W.L., T.J. Pitcher, and D. Pauly. 2005. A fuzzy logic expert system to estimate intrinsic extinction vulnerabilities of marine fishes to fishing. Biological Conservation. 124: 97-111.

Cheung, W.W.L., R. Watson, T. Morato, T.J. Pitcher, and D. Pauly. 2007. Intrinsic vulnerability in the global fish catch. Marine Ecology Progress Series. 333:1-12.

Collette, B. B. and G. Klein_MacPhee. 2002. Bigelow and Schroeder's Fishes of the Gulf of Maine. 3rd Edition. Smithsonian Institution Press, Washington, DC. 748 p.

Collette, B.B and C.E. Nauen. 1983. FAO species catalogue Vol. 2. Scombrids of the world. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date. FAO Fisheries Synopsis. (125) Vol. 2. 137 p.

Compagno, L.J.V. 1984. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Volume 4. Part 2 – Carcharhiniformes. FAO Fisheries Synopsis No. 125, pp. 251-655.

Compagno, L.J.V. 2001. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Vol. 2. Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). FAO Special Catalogue Fisheries Purposes 1: 1-269.

Conrath, C.L. and J.A. Musick. 2008. Investigations into depth and temperature habitat utilization and overwintering grounds of juvenile sandbar sharks, *Carcharinus plumbeus*: the importance of near shore North Carolina waters. Environmental Biology of Fishes. 82 (2): 123-131.

Consoli, P., T. Romero, P.Battaglia, L. Castriota, V. Esposito, and F. Andaloro. 2008. Feeding habits of the albacore tuna *Thunnus alaunga* (Perciformes, Scombridae) from central Mediterranean Sea. Marine Biology. 155(1): 113-120.

Cury, P. and C. Roy, 1989. Optimal environmental window and pelagic fish recruitment success in upwelling areas. Canadian Journal of Fisheries and Aquatic Sciences. 46 (4): 670-680

Dowd, W. W., R. W. Brill, P. G. Bushnell, and J. A. Musick. 2006. Standard and routine metabolic rates for juvenile sandbar sharks (*Carcharhinus plumbeus*), including the effects of body mass and acute temperature change. Fishery Bulletin. 104: 323–331.

Dragovich, A. 1969. Review of studies of tuna food in the Atlantic Ocean. U. S. Fish Wildlife Service Special Scientific Report Fisheries 593. 21 p.

Duncan, K.M., A.P. Martin, B.W. Bowen, and H.G. De Couet. 2006. Global phylogeography of the scalloped hammerhead shark (*Sphyrna lewini*). Molecular Ecology 15: 2239-2251.

Dulvy, N.K., J.K. Baum, S. Clark, L.J.V. Compagno, E.Cortes, A. Domingo, S. Fordham, S. Fowler, M.P. Francis, Cl. Gibson, J. Martinez, J.A. Musick, A. Soldo, J.D. Stevens, and S. Valenti. 2008. You can swim but you can't hide: the global status and conservation of oceanic pelagic sharks and rays. Aquatic Conservation: Marine and Freshwater Ecosystems 2008.

Estrada, J.A., A.N. Rice, M.E. Lutcavage, and G.B. Skomal. 2003. Predicting trophic position in sharks of the north-west Atlantic Ocean using stable isotope analysis. Journal of the Marine Biological Association of the United Kingdom. 83: 1347-1350.

Estrada, J.A., M. Lutcavage, and S.R. Thorrold. 2005. Diet and trophic position of Atlantic bluefin tuna (*Thunnus thynnus*) inferred from stable carbon and nitrogen isotope analysis. Marine Biology 147(1):37-45.

Francis, M.P., L.J. Natanson, and S.E. Campana. 2008. The Biology and Ecology of the Porbeagle Shark, *Lamna nasus*. In: M.D. Camhi, E.K. Pikitch and E.A. Babcock, eds. Sharks of the Open Ocean: Biology, Fisheries and Conservation. pp. 105–113.

Fromentin, J.M. and J.E. Powers. 2005. Atlantic bluefin tuna: population dynamics, ecology, fisheries and management. Fish and Fisheries. 6:281-306.

Gelsleichter, J., J.A. Musick, and S. Nichols. 1999. Food habits of the smooth dogfish, *Mustelus cani*, dusky shark, *Caracharhinus obscurus*, Atlantic sharpnose shark, *Rhizoprionodon terraenovae*, and the sand tiger, *Carcharias taurus*, from the northwest Atlantic Ocean. Environmental Biology of Fishes. 54:205-217.

Gilmore, R.G. 1983. Reproduction and embryonic development of the sand tiger shark, *Odontaspis taurus* (Rafinesque). U.S. Wildlife Service Fisheries Bulletin. 192: 201-225.

Golet, W.J., A.B. Cooper, B. Campbell, and M. Lutcavage. 2007. Decline in condition of northern bluefin tuna (*Thunnus thynnus*) in the Gulf of Maine. Fishery Bulletin. 105: 390–395.

Govoni, J.J., E.H. Laban, and J.A. Hare. 2003. The early life history of swordfish (*Xiphias gladius*) in the western North Atlantic. Fishery Bulletin. 101(4): 778-789.

Grubbs, R.D., and J.A. Musick. 2007. Spatial delineation of summer nursery areas for juvenile sandbar sharks in Chesapeake Bay, Virginia. Pages 63-86 In: C.T. McCandless, N.E. Kohler, and H.L. Pratt, Jr., eds. Shark nursery grounds of the Gulf of Mexico and the east coast waters of the United States. American Fisheries Society Symposium 50, Bethesda, Maryland.

Gruber, S.H. and L.J.V. Compagno. 1981. Taxonomic status and biology of the bigeye thresher, *Alopias superciliosus*. Fishery Bulletin. 79(4): 617-632.

Heist, E.J., J.A. Musick, and J.E. Graves. 1996. Genetic population structure of the shortfin mako (*Isurus oxyrinchus*) inferred from restriction fragment length polymorphism analysis of mitochondrial DNA. Canadian Journal of Fisheries and Aquatic Science. 53: 583-588.

Hobday, A.J, J.A. Okey, E.S. Poloczanska, T.J.Kunz, and A.J. Richardon. 2006. Impacts of climate change on Australian Marine life. CSIRO Marine and Atmospheric Research, Australia.

Hoey, J. J. and N. Moore. 1999. Captain's Report: Multi-species catch characteristics for the US Atlantic pelagic longline fishery. Silver Spring, MD and Arlington, VA, NMFS and the National Fisheries Institute, Inc. 78 p.

Hueter, R.E., M.R. Heupel, E.J. Heist, and D.B. Keeney. 2004. Evidence of philopatry in sharks and implications for the management of shark fisheries. Journal Northwest Atlantic Fisheries Science 35: 239-247.

Hueter, R. and J. Tyminski. 2007. Species-specific distribution and habitat characteristics of shark nurseries in Gulf of Mexico waters off peninsular Florida and Texas. American Fisheries Society Symposium 50:193-223.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2001. Report of the fourth ICCAT billfish workshop. ICCAT Col. Vol. Sci. Pap. 53:1-130.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2004. 2003 ICCAT Albacore Stock Assessment Session. Col Vol Sci Pap ICCAT 56(4):1223-1311.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2005. Report of the 2004 Inter-sessional meeting of the ICCAT Subcommittee on bycatches: shark stock assessment. Col. Vol. Sci. Pap. ICCAT.

ICCAT (The International Commission for the Conservation of Atlantic Tunas). 2008. Report for Biennial Period, 2006-07, Part II, 2008. (Vols. 1-3).

IUCN (International Union for Conservation of Nature). 2008. 2008 IUCN Red List of Threatened Species. www.iucnredlist.org. Downloaded on 03 December 2008.

Jensen, C.F., T.A. Thorpe, M.L. Moser, J.J. Francesconi, G.A. Hopkins, and D. Bersoff. 2002. Shark nursery areas in North Carolina state waters. In: C.T. McCandless, N.E. Kohler, and H.L. Pratt, Jr., eds. Shark nursery grounds of the Gulf of Mexico and the East Coast waters of the United States: an overview. 286 pp.

Kitchell, J.F., S.J.D. Martell, C.J. Walters, O.P Jensen, I.C. Kaplan, J. Watters, T.E. Essington, and C.H. Boggs. 2006. Billfishes in an ecosystem context. Bulletin of Marine Science. 79(3): 669-682.

Klimley, A.P. 1985. Schooling in *Sphyrna lewini*, a species with low risk of predation: a non-egalitarian state. Z. Tierpsychology. 70: 297-319.

Klimley, A.P. 1993. Highly directional swimming by scalloped hammerhead sharks, (*Sphyrna lewini*), and subsurface irradiance, temperature, bathymetry, and geomagnetic field. Marine Biology. 117: 1-22.

Kohler, N.E., J.G. Casey, and P.A. Turner. 1998. NMFS cooperative shark tagging program, 1962-93: an atlas of shark tag and recapture data. Marine Fisheries Review 60(2):1-87.

Logan, J., R. Toppin, S. Smith, J. Porter, and M. Lutcavage. 2006. Contribution of cephalopod prey to large pelagic fish diet in the central North Atlantic Ocean. Pp. 42-44. In: Olsen, R.J. and J.W. Young, eds. The role of squid in open ocean ecosystems. GLOBEC Report No. 24.

Lutcavage, M. and S. Kraus. 1995. The feasibility of direct photographic assessment of giant bluefin tuna in New England waters. USA Fish Bull 93: 495-503.

Lutcavage, M.E., R.W. Brill, G.B. Skomal, B.C. Chase, and P.W. Howey. 1999. Results of pop-up satellite tagging of spawning size class fish in the Gulf of Maine: do North Atlantic bluefin tuna spawn in the mid-Atlantic? Canadian Journal of Fish and Aquatic Science. 56: 173-177.

Mahon, R. and P.A. McConney, eds. 2004. Management of larger pelagic fisheries in CARICOM countries. FAO Fisheries Technical Paper No. 464. Rome. 149 pp.

Mandelman, J.W., and T.B. Werner. 2007. USA Atlantic, Gulf of Mexico and Caribbean pelagic longline swordfish and tuna fisheries: Industry practices and attitudes towards shark depredation and unwanted bycatch. In: E. Gilman, S. Clarke, N. Brothers, J. Alfaro-Shigueto, J. Mandelman, J. Mangel, S. Petersen, S. Piovano, N. Thomson, P. Dalzell, M. Donoso, M. Goren, and T. Werner. Shark depredation and unwanted bycatch in pelagic longline fisheries: Industry practices and attitudes, and shark avoidance strategies. Western Pacific Regional Fishery Management Council, Honolulu, Hawaii. 145 pp.

Mather, F.J., J.M. Mason, and A.C. Jones. 1995. Historical document: life history and fisheries of Atlantic bluefin tuna. NOAA Technical Memorandum NMFS-SEFSC – 370. 165 p.

Maury, O. and P. Lehodey, eds. 2005. Climate Impacts on Oceanic Top predators (CLIOTOP). Science Plan and Implementation Strategy. GLOBEC Report No. 18.

McCandless, C.T., H.L. Pratt, Jr., N.E. Kohler, R.R. Merson, and C.W. Recksiek. 2007. Distribution, localized abundance, movements, and migrations of juvenile sandbar sharks tagged in Delaware Bay. Pages 45-62 In: C.T. McCandless, N.E. Kohler, and H.L. Pratt, Jr., eds. Shark nursery grounds of the Gulf of Mexico and the east coast waters of the United States. American Fisheries Society Symposium 50, Bethesda, Maryland.

Merson, R. and H.L. Pratt, Jr. 2001. Distribution, movements and growth of young sandbar sharks, *Carcharhinus plumbeus*, in the nursery grounds of Delaware Bay. Environmental Biology of Fishes. 61: 13– 24.

Merson, R.R. and H.L. Pratt, Jr. 2007. Sandbar shark nurseries in New Jersey and New York: Evidence of northern pupping grounds along the United States east coast. Pages 35-43 In: C.T. McCandless, N.E. Kohler, and H.L. Pratt, Jr., eds. Shark nursery grounds of the Gulf of Mexico and the east coast waters of the United States. American Fisheries Society Symposium 50, Bethesda, Maryland.

Nakamura, I. 1985. Billfishes of the world. An annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. FAO Species Catalogue Vol. 5. FAO Fisheries Synoposis, (125) Vol. 5. 65 p.

Natanson, L.J., N.E. Kohler, D. Ardizzone, G.M. Cailliet, S.P. Winter, and H.F. Mollet. 2006. Validated age and growth estimates for the shortfin mako, *Isurus oxyrinchus*, in the North Atlantic Ocean. Environmental Biology of Fishes 77(3-4): 367-383.

NMFS (National Marine Fisheries Service). 1999. Amendment 1 to the Atlantic Billfish Fishery Management Plan. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Sustainable Fisheries, Highly Migratory Species Management Division, Silver Spring, MD. http://www.nmfs.noaa.gov/sfa/hms/FMP/AM1_Billfish_FMP.htm

NMFS (National Marine Fisheries Service). 2004. Federal Register Notices. Vol. 69, No. 73, p. 19977.

NMFS (National Marine Fisheries Service). 2006. Final Consolidated Atlantic Highly Migratory Species Fishery Management Plan. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Sustainable Fisheries, Highly Migratory Species Management Division, Silver Spring, MD. Public Document. 1600 pp. http://www.nmfs.noaa.gov/sfa/hms/FMP/Consolidated_FMP.htm

NMFS (National Marine Fisheries Service). 2008. Amendment 2 to the Consolidated Atlantic Highly Migratory Species Fishery Management Plan. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Sustainable Fisheries, Highly Migratory Species Management Division, Silver Spring, MD. http://www.nmfs.noaa.gov/sfa/hms/FMP/AM2.htm

NMFS (National Marine Fisheries Service). 2009. Stock Assessment and Fishery Evaluation Report for Atlantic Highly Migratory Species. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Sustainable Fisheries, Highly Migratory Species Management Division, Silver Spring, MD. http://www.nmfs.noaa.gov/sfa/hms/Safe_Report/2009/HMS_SAFE_Report_2009_FINAL_FULL_DOCUMENT.pdf

NOAA. 2009. Food Habits. Apex Predators Investigation, NOAA Fisheries Narragansett Laboratory. http://na.nefsc.noaa.gov/sharks/fooha.html Accessed May 15, 2009.

Orbesen, E.S., J.P. Hoolihan, J.E. Serafy, D. Snodgrass, E.M. Peel, and E.D. Prince. 2008. Transboundary movement of Atlantic istiophoroid billfishes among international and U.S. domestic management areas inferred from mark-recapture studies. Marine Fisheries Review 70(1): 14-23.

Pace, M., J. Cole, S.R. Carpenter, and J.F. Kitchell. 1999. Trophic cascades revealed in diverse ecosystems. TREE. 14(12): 483–488.

Palko, B.J, G.L. Beardsley, and W.J. Richards. 1981. Synopsis of the biology of the swordfish, *Xiphias gladius* Linnaeus. NOAA Technical Report. NMFS CIRC 441, 2-15.

Pecl , G.T. and G.D. Jackson. 2006. Climate impacts: how climate change may influence loliginid squid populations. Pp. 28-30. In: Olsen, R.J. and J.W. Young, eds. The role of squid in open ocean ecosystems. GLOBEC Report No. 24.

Piercy, A.N., J.K. Carlson, J.A. Sulikowski, and G.H. Burgess. 2007. Age and growth of the scalloped hammerhead shark, *Sphyrna lewini*, in the northwest Atlantic Ocean and Gulf of Mexico. Marine and Freshwater Research. 58(1):34-40.

Pörtner, H.O., A.P. and Farrell. 2008. Ecology: Physiology and Climate Change. Science. 322(5902): 690-692

Pusineri, C., Y. Vasseur, S. Hassani, L. Meynier, J. Spitz, and V. Ridoux. 2005. Food and feeding ecology of juvenile albacore, *Thunnus alalunga*, off the Bay of Biscay: a case study. ICES Journal of Marine Science. 62:116-122.

Quattro, J.M., D.S. Stoner, W.B. Driggers, C.A. Anderson, K.A. Priede, E.C. Hoppmann, N.H. Campbell, K.M. Duncan, and J.M. Grady. 2006. Genetic evidence of cryptic speciation within hammerhead sharks (Genus Sphyrna). Marine Biology. 148(5): 1143-1155.

Rooker, J.R., J.R. Alvarado Bremer, B.A. Block, H. Dewar, G. De Metrio, A. Corriero, R.T. Kraus, E.D. Prince, E. Rodriguez-Marin, and D.H. Secor. 2007. Life History and Stock Structure of Atlantic Bluefin Tuna (*Thunnus thynnus*). Reviews in Fisheries Science. 15: 265-310.

Safina, C. and D.H. Klinger. 2008. Collapse of Bluefin Tuna in the Western Atlantic. Conservation Biology. 22(2):243-246.

Schick, R.S. and M.E. Lutcavage. 2009. Inclusion of prey data improves prediction of bluefin tuna (*Thunnus thynnus*) distribution. Fisheries Oceanography. 18(1): 77-81.

Schindler, D.E., T.E. Essington, J.F. Kitchell, C. Boggs, and R. Hilborn. 2002. Sharks and tunas: fisheries impacts on predators with contrasting life histories. Ecological Applications. 12(3): 735-748.

Sepulveda, C.A., N.C. Wegner, D. Bernal, and J.B. Graham. 2005. The red muscle morphology of the thresher sharks (family Alopiidae). The Journal of Experimental Biology. 208: 4255-4261.

Simpfendorfer, C., E. Cortés, M. Huepel, E. Brooks, E. Babcock, J. Baum, R. McAuley, S. Dudley, J.D. Stevens, S. Fordham, and A. Soldo. 2008. An integrated approach to determining the risk of overexploitation for data-poor pelagic Atlantic sharks. An expert working group report. An Expert Working Group Report, Lenfest Ocean Program, Washington, D.C. 22 p.

Springer, S. 1960. Natural history of the sandbar shark, *Eulamia milberti*. U.S. Fisheries and Wildlife Service Fishery Bulletin. 61(178): 1-38.

Stillwell, C.E., and N.E. Kohler. 1985. Food and feeding ecology of the swordfish *Xiphias gladius* in the western North Atlantic Ocean with estimates of daily ration. Marine Ecology Progress Series. 22: 239-247.

Strasburg, D.W. 1958. Distribution, abundance, and habits of pelagic sharks in the central Pacific Ocean. U.S. Fisheries and Wildlife Service Fishery Bulletin. 138(58): 335-361.

Tiews, K. 1963. Synopsis of biological data on the bluefin tuna *Thunnus thynnus* (Linnaeus) 1758 (Atlantic and Mediterranean). Pages 422- 481 In: H. Rosa Jr., ed. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species. FAO Fisheries Reports No. 6 (2).

Turner, S.C., V.R. Restrepo, and A.M. Edlund. 1991. A review of the growth rate of Atlantic bluefin tuna, *Thunnus thynnus*. Col. Vol. Sci. Pap. ICCAT 35 (2): 271-293.

Ulrich, G.F., C.M. Jones, W.B. Driggers, J.M. Drymon, D.O. Oakley, and C. Riley. 2007. Habitat utilization, relative abundance, and seasonality of sharks in the estuarine and nearshore waters of South Carolina. American Fisheries Society Symposium. 50:125-139.

UNEP/CMS (United Nations Environment Programme/Convention on Migratory Species). 2006. Migratory species and climate change: Impacts of a changing environment on wild animals. United Nations Environment Programme and the Secretariat of the Convention on the Conservation of Migratory Species of Wild Animals. Bonn, Germany. 68 pp.

CHAPTER

10

Cetaceans

Jennifer Greene, Sally Yozell, and Melissa Clark

Introduction

© Henry Lynch/NOAA

Cetaceans are the sub-group of marine mammals that includes whales, dolphins, and porpoises. Because of their extensive migrations, they have very large geographic ranges often encompassing hundreds of thousands of miles in an individual's lifetime. One consequence of these large geographic ranges is frequent opportunity to interact with humans. These interactions, including exposure to shipping traffic, fishing gear, pollution, underwater noise, and the effects of climate change on them and their food sources, can pose serious threats to marine mammal populations. Species chosen for inclusion in this assessment represent the diversity of cetaceans in the Northwest Atlantic. Some of the target whales are considered threatened or endangered, and the porpoise and dolphin species selected represent a range of species that inhabit the region.

Technical Team Members

Kevin Chu, Ph.D., National Marine Fisheries Service (serving in a personal capacity)
Melissa Clark, The Nature Conservancy, Eastern Division
Lindsey Feldman, Duke University
Jennifer Greene, The Nature Conservancy, Eastern Division
Leila Hatch, Ph.D., Stellwagen Bank National Marine Sanctuary
Robert Kenney, Ph.D., University of Rhode Island
Scott Kraus, Ph. D., New England Aquarium
William McLellan, University of North Carolina, Wilmington
Jooke Robbins, Ph.D., Provincetown Center for Coastal Studies
Kevin Ruddock, The Nature Conservancy, Rhode Island
Caroly Shumway, Ph.D., Boston University, Visiting Professor
Mark Swingle, Virginia Aquarium & Marine Science Center
David Wiley, Ph.D., Stellwagen Bank National Marine Sanctuary
Sally Yozell, The Nature Conservancy, Eastern Division

Selection of Target Species

Technical team members and external experts identified the target species for this group as well as the most appropriate data sources and approaches for documentation and analysis. Several factors were considered when selecting the target cetacean species, including population status and distribution in the region. The home ranges of the species included in this assessment extend through part or all of the region (and beyond), from inshore to offshore and north to south. The selected set of species also was chosen to represent the diversity of cetacean species that occur in the region. The final list of targets is:

Baleen Whales

- Fin whale *(Balaenoptera physalus)*
- Humpback whale *(Megaptera novaeangliae)*
- Minke whale *(Balaenoptera acutorostrata)*
- North Atlantic right whale *(Eubalaena glacialis)*
- Sei whale *(Balaenoptera borealis)*

Toothed Whales

- Atlantic white-sided dolphin *(Lagenorhynchus acutus)*
- Bottlenose dolphin *(Tursiops truncatus)*
- Harbor porpoise *(Phocoena phocoena)*
- Sperm whale *(Physeter macrocephalus)*
- Striped dolphin *(Stenella coeruleoalba)*

Population Status and Importance of the Northwest Atlantic Region

Cetaceans targeted by this assessment primarily use the Northwest Atlantic for feeding, nursing, and migration. For most baleen species, breeding occurs outside of the region or the location is unknown, while some small toothed whales may use the region for breeding. The fin, humpback, North Atlantic right, sei, and sperm whales are listed as Endangered by the Endangered Species Act. The IUCN Red List documents the fin, sei, and North Atlantic right whales as "endangered," sperm whales as "vulnerable," and minke and humpback whales and Atlantic white-sided, bottlenose, and striped dolphins as species of "least concern" (IUCN 2008). Unfortunately, there are limited data to determine the population status of most target species at this time. The majority of existing data are derived from marine mammal aerial and ship surveys, and a large portion of the information consists of individual sightings. Survey effort is higher in the summer and generally occurs when researchers know cetaceans will be sighted. Researchers and observers are often hindered by weather, and have varying missions and research goals, usually dictated by funding sources.

A species of particular concern in this region is the North Atlantic right whale, which is considered to be one of the most critically endangered large whales in the world and could be facing extinction (Clapham and Mead 1999; Kenney 2002). The right whale population is currently estimated to be approximately 438 individuals (North Atlantic Right Whale Consortium 2009.) Calculations based on demographic data through 1999 indicate that their current mortality rate would reduce population growth by approximately 10% per year (Fujiwara and Caswell 2001; Kraus et al. 2005; NMFS 2007a). However, minimum population counts (photo-identifications) suggest a small level (<2%) of growth in recent years (North Atlantic Right Whale Consortium 2009).

Ecosystem Interactions and Ecological Dependencies

Relationships between cetaceans and their environment are complex and can vary by ecosystem. While the exact ecological function of cetaceans is not fully known, insights into their role in the marine ecosystem have emerged through large-scale studies of species-ecosystem interactions and community structure (Bowen 1997). Katona and Whitehead (1988) hypothesized that marine mammals could play a major role in determining the behavior and life history traits of their prey species, affecting nutrient storage and cycling, and altering benthic habitats.

For example, as predators, cetaceans are major consumers of production at most trophic levels, specifically feeding on organisms like zooplankton, invertebrates, and forage fish in the region. Cetaceans studied in this assessment are split into two suborders based on morphological structure used in feeding: Mysticeti and Odontoceti (baleen and toothed whales). Mysticetes, including fin, humpback, minke, right, and sei whales, use baleen, a highly structured filtration system made of plates of keratin (similar to human fingernails), to separate prey from water. They typically forage for pelagic prey, consuming large quantities of prey at one time, including zooplankton (e.g., copepods), euphausiids (e.g., krill), and small fish (e.g., sand lance, herring, mackerel) (Nemoto 1959; Jonsgard 1966; Mitchell 1975c; Kawamura 1982; Mizroch et al. 1984; Kenney et al. 1985; Haug et al. 1995; Flinn et al. 2002; Perrin and Brownell 2002). Some baleen species like sei and right whales are dependent on euphausiids and copepods when feeding in the North Atlantic, while other species are less selective in their diet (Nemoto 1959; Kraus et al. 1988).

Odontocetes possess teeth and include the Atlantic white-sided dolphin, bottlenose dolphin, striped dolphin, and sperm whale. Typically, toothed whales prefer larger prey than baleen whales and consume individual organisms. Primary food sources for toothed whales are cephalopods (e.g., small and large squid), small fish (e.g., smelt, herring, mackerel), and demersal fish (e.g., cod, skate) (Smith and Whitehead 2000; Archer 2002; Sergeant et al. 1980; Katona et al. 1978). Within the boundaries of the study area both baleen and toothed whales have two other potential predators besides humans, the killer whale, *Orcinus orca,* and large sharks (Hancock 1965; Dolphin 1987; Perry et al. 1999; Heithaus 2001; Pitman et al. 2001; Perrin and Brownell 2002; Horwood 2002).

Northwest Atlantic Distribution and Important Areas

Methods

Geospatial analyses for cetaceans were obtained from the United States Navy (see Department of Navy 2005). These analyses were completed for the Navy's Marine Resource Assessments (MRA), a program used to develop comprehensive data and literature concerning protected and managed marine resources found in their operating areas for use in environmental and biological assessments prepared in accordance with various federal laws (e.g., Marine Mammal Protection Act, National Environmental Policy Act). Data were from the Navy's Northeast MRA study region, which covers the entire Northwest Atlantic study area except for the mouth of the Chesapeake Bay west of 75.67°W longitude. This gap was filled with data from the Navy's Southeast MRA study region, shown in pink in Figure 10-1. The initial sightings used in the Navy's analysis were taken from National Marine Fisheries Service-Northeast Fisheries Science Center (NMFS-NEFSC) Aerial Surveys, NMFS-NEFSC Shipboard Surveys, and the North Atlantic Right Whale Consortium Database. Data used in these analyses were primarily collected via aerial and shipboard surveys during daylight hours, weather permitting. Each MRA used different dates to determine their seasons. The seasons used in the Northeast were winter: Jan - March, spring: April - June, summer: July - August, and fall: Oct - Dec. The dates used in the Southeast were winter: Dec 6 - April 5, spring: April 6 - July 13, summer: Jul 14 - Sept 16, and fall: Sept 17 - Dec 5. Because of the different season dates, data were processed independently, but displayed together on the map.

One issue with interpreting marine mammal data is the bias introduced by uneven survey coverage or "effort." For example, an area may have few sightings because of the absence of cetaceans or there just may be little survey effort in that location. A standard approach to overcoming this bias is using effort-corrected sightings data (Kenney and Winn 1986; Shoop and Kenney 1992). Calculating sightings per unit effort or SPUE, an index of relative density, allows for comparison of data spatially and temporally within a study area (Shoop and Kenney 1992). SPUE is calculated as:

$$\text{SPUE} = 1000^{*}(\text{number of animals sighted})/\text{effort}$$

Geospatial analysis obtained from the United States Navy included shapefiles of valid sightings for cetaceans studied in this assessment and pre-calculated effort grids for each

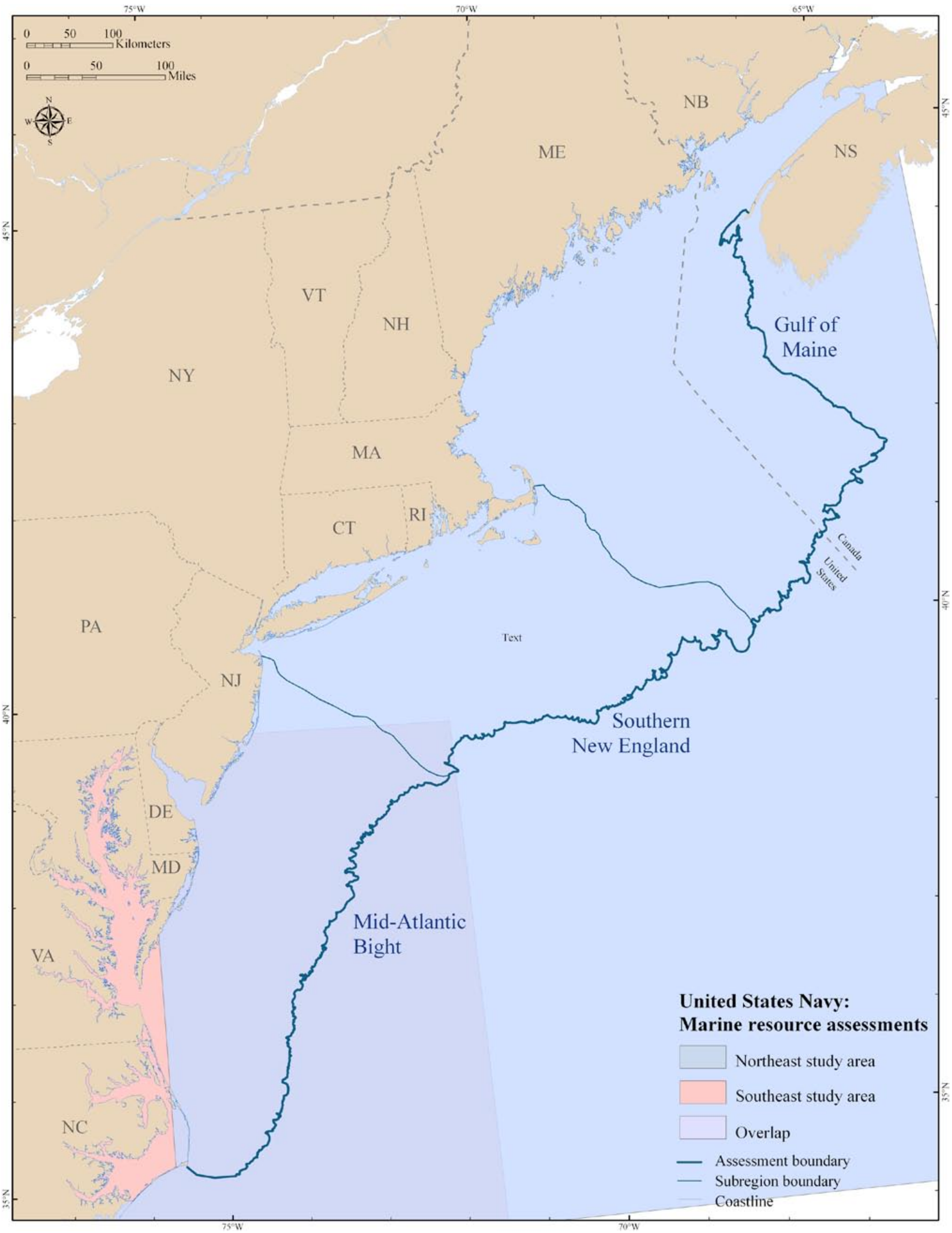


Figure 10-1. United States Navy Marine Resource Assessment study boundaries.

season. The validity of sightings was carefully screened and verified by Navy contractors before inclusion in the model. Invalid records were not included in the analysis. Using the formula above, SPUE was calculated for each target species, for each season, and for each ten minute square.

Maps, Analysis, and Areas of Importance

Baleen Whales

Fin Whale

Fin whales appeared to move throughout the region, both inshore and offshore, and aggregate in some spots. As with other baleen whales, they typically used the southern part of the region for migration and the northern parts for feeding during months with large abundances of prey species. Distribution maps indicated the presence of some fin whales along the southeast portion of the region during the winter months (Figure 10-2a). Data also indicated larger aggregations of fin whales in the highly productive waters of the Gulf of Maine and Bay of Fundy in the spring and summer inshore of the Continental Shelf break, with a significant congregation at the 100 m isobath around Georges Bank in the spring (Figures 10-2b and 10-2c). Other studies have presented similar findings, reporting that the most important northern areas for fin whales appeared to be the Great South Channel, along the 50 m isobath past Cape Cod, Stellwagen Bank, and Cape Ann to Jeffreys Ledge (Hain et al. 1992).

Important Marine Areas for Fin Whale

Gulf of Maine (Cape Cod Bay, Jeffreys Ledge, Stellwagen Bank, Georges Bank and Great South Channel), Bay of Fundy

Humpback Whale

The humpback whale population included in this study travels annually between winter breeding grounds in the Caribbean and summer feeding areas in the Gulf of Maine, Georges Bank and the Bay of Fundy (Figure 10-3a). This species is therefore largely absent from those feeding areas in winter, but it has been sighted off the Mid-Atlantic states and the southeast United States (Swingle et al. 1993; Barco et al. 2002). In spring, the greatest concentrations of humpback whales occurred in the southwestern Gulf of Maine and Massachusetts Bay (Figure 10-3b). This species was more broadly distributed in summer and fall, with areas of concentration in the southern Gulf of Maine and the Bay of Fundy (Figure 10-3c and 10-3d).

These results are largely consistent with the results of prior studies using older datasets (CeTAP 1982). Prior work has also shown that humpback whale distribution across the northern study range depends on physical factors such as bottom depth and slope (CeTAP 1982; Hamazaki 2002) as well as the abundance and distribution of herring and sand lance (Payne et al. 1986; Payne et al. 1990; Weinrich et al. 1997). Prey fish distribution can also result in significant temporal variation in distribution patterns, even from one year to the next (Payne et al. 1986; Payne et al. 1990; Weinrich et al. 1997). On an individual level, humpback whales are known to return preferentially to one or more areas within their feeding range, but also to move among available feeding sites within and between years (Robbins 2007). In addition, although all ages and sexes can be found across the feeding range of this species, the southern Gulf of Maine is more frequently used by mature females and juveniles as compared to northern Gulf of Maine and Bay of Fundy areas (Robbins 2007). This distribution suggests that there may be other demographic factors to consider when evaluating habitat importance, in addition to observed densities. However, such information is rarely available for the other species under investigation.

Important Marine Areas for Humpback Whale

Gulf of Maine (Massachusetts Bay, Jeffreys Ledge, Stellwagen Bank, Great South Channel, northern edge of Georges Bank), Bay of Fundy

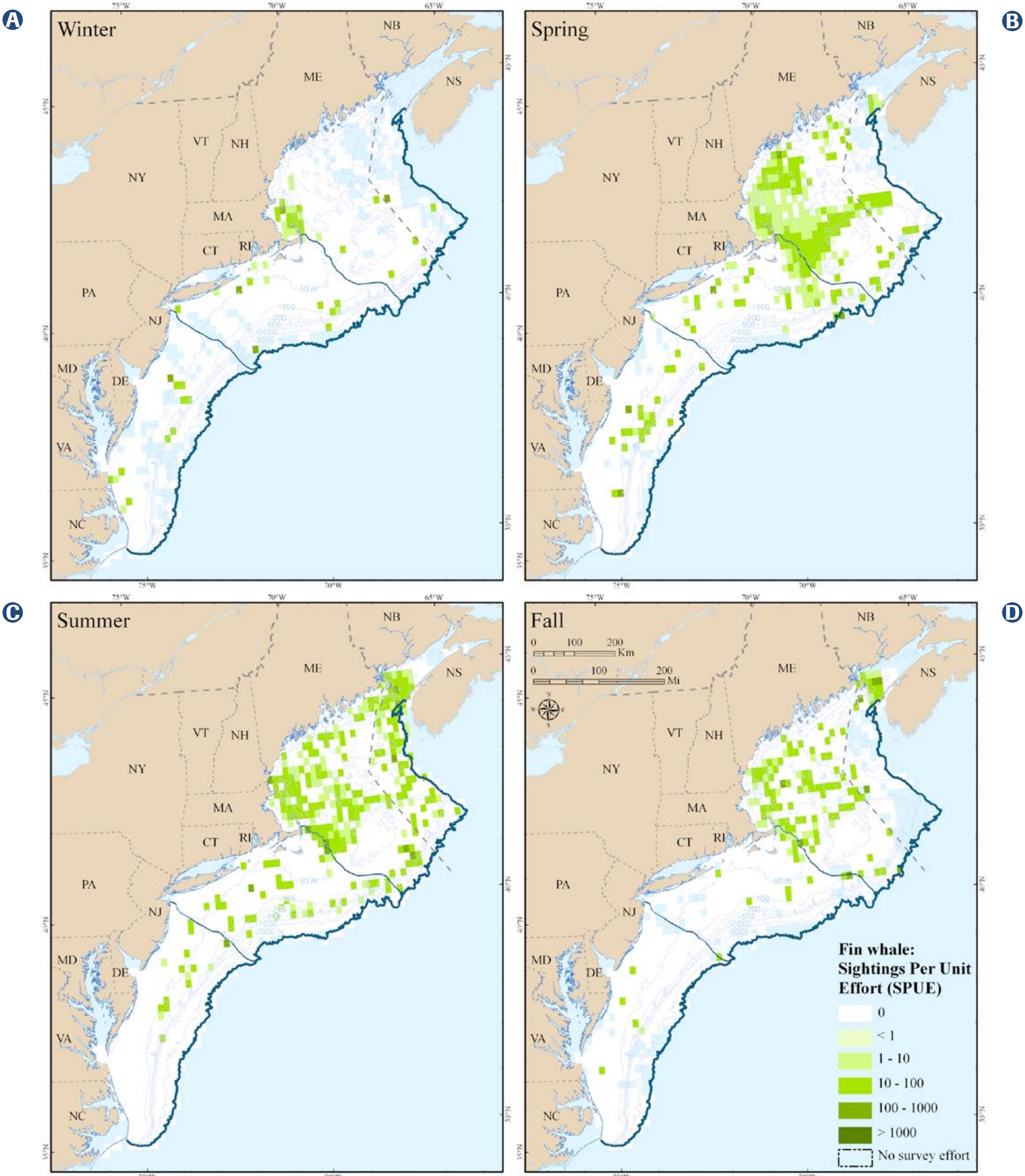


Figure 10-2. Fin whale sightings per unit effort (SPUE) by season.

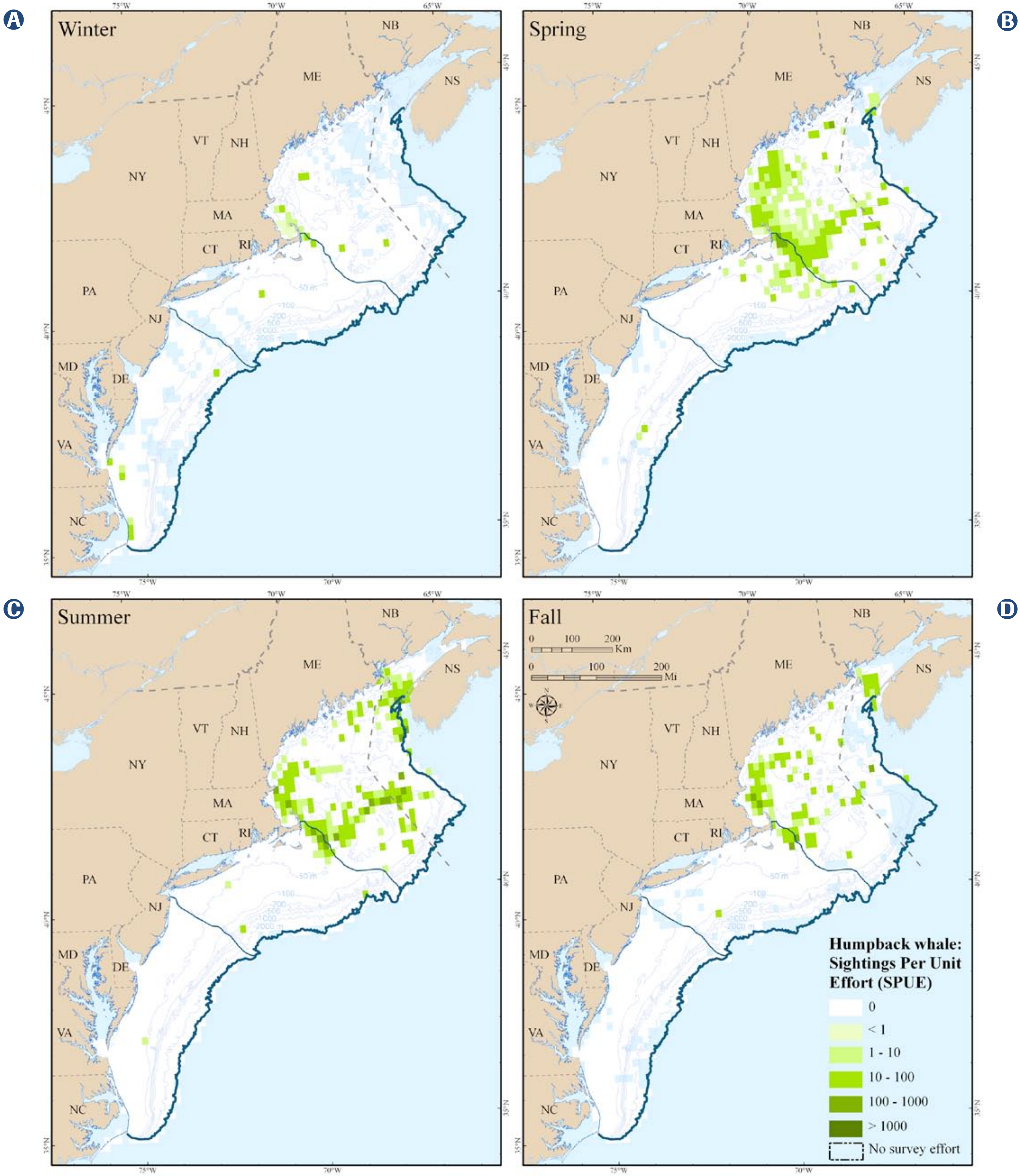


Figure 10-3. Humpback whale sightings per unit effort (SPUE) by season.

Minke Whale

Following patterns similar to fin and humpback whales, minke whales migrated to the productive areas of the Gulf of Maine and were sighted there in the spring and summer months (Figure 10-4b and 10-4c). In studies in the northern Atlantic, they have been found to be positively correlated with gravel/sand seabed types as well as the distribution of sand eel and herring populations in the summer in New England waters (Naud et al. 2003; Macleod et al. 2004). There were limited sightings in the fall and winter (Figure 10-4a and 10-4d).

Important Marine Areas for Minke Whale

Gulf of Maine (Cape Cod Bay, Jeffreys Ledge, Stellwagen Bank, and Great South Channel)

North Atlantic Right Whale

North Atlantic right whales are known to migrate seasonally and spend time in the Northwest Atlantic region in spring through early summer. They are found on feeding grounds off the northeastern United States and eastern Canada. In the spring, feeding aggregations of right whales have been found in the Gulf of Maine especially in Cape Cod Bay and along the Great South Channel into deeper basins in the north (Kenney and Winn 1986, Mitchell et al. 1986, Kenney et al. 1995). The Bay of Fundy is a well known feeding site for right whales during the summer and early fall and aggregations of whales have been seen there every year (Figure 10-5a, 10-5b, 10-5c, 10-5d). Standardized visual survey effort in the Stellwagen Bank National Marine Sanctuary (SBNMS) (Wiley et al. 2003) and increasing passive acoustic monitoring efforts over the winter months on Jeffreys Ledge and in the Stellwagen Bank Marine Sanctuary (Mussoline et al. in review) have detected the presence of right whales in the northeastern portion of the sanctuary and on Jeffreys Ledge beginning in late December through March. These data indicated that some fraction of the right whale population overwinters in this region.

Important Marine Areas for North Atlantic Right Whale

Gulf of Maine (Cape Cod Bay, Jeffreys Ledge, Stellwagen Bank and Great South Channel), Bay of Fundy

Sei Whale

In the Northwest Atlantic, sei whales were sighted predominantly in the deep waters off the Continental Shelf edge in areas like the eastern edge of Georges Bank, the Northeast Channel and Hydrographer Canyon (CeTAP 1982; Hain et al. 1985; NOAA 2008c); however, they have been known to sporadically move into shallower, inshore waters like Stellwagen Bank and Great South Channel as they switch prey species. Assessment data indicated the same general pattern (Figure 10-6a, 10-6b, 10-6c, 10-6d). Whales were reported in more inshore locations, such as the Great South Channel in 1987 and 1989 and Stellwagen Bank in 1986 (Payne et al. 1990). In the past five years, sei whales have been sighted more frequently inshore than in previous years and this has been linked to prey availability (Waring et al. 2008).

Important Marine Areas for Sei Whale

Gulf of Maine (Georges Bank, Northeast Channel, Canyons); Inshore (Cape Cod Bay, Jeffreys Ledge, Stellwagen Bank, Great South Channel)

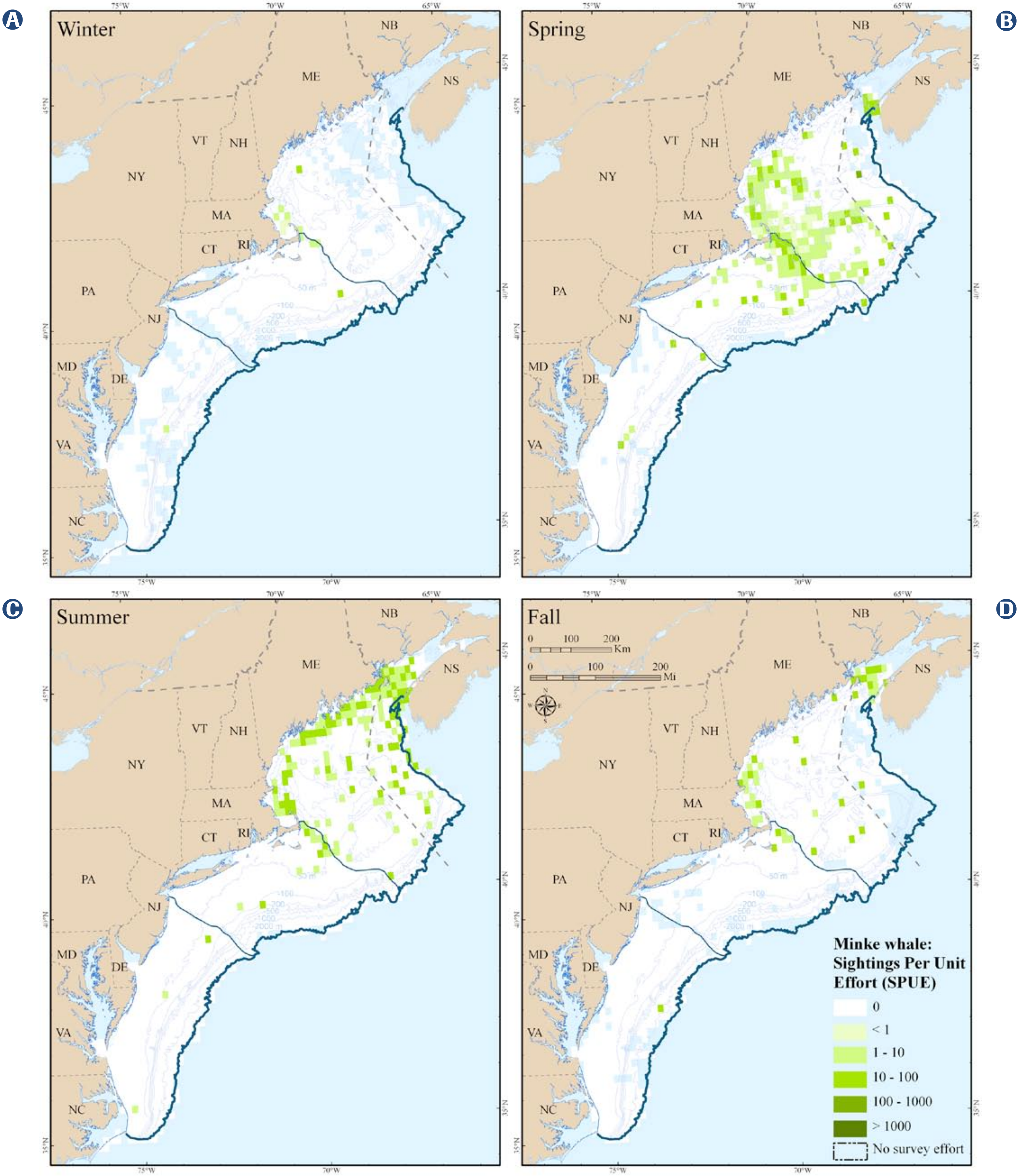


Figure 10-4. Minke whale sightings per unit effort (SPUE) by season.

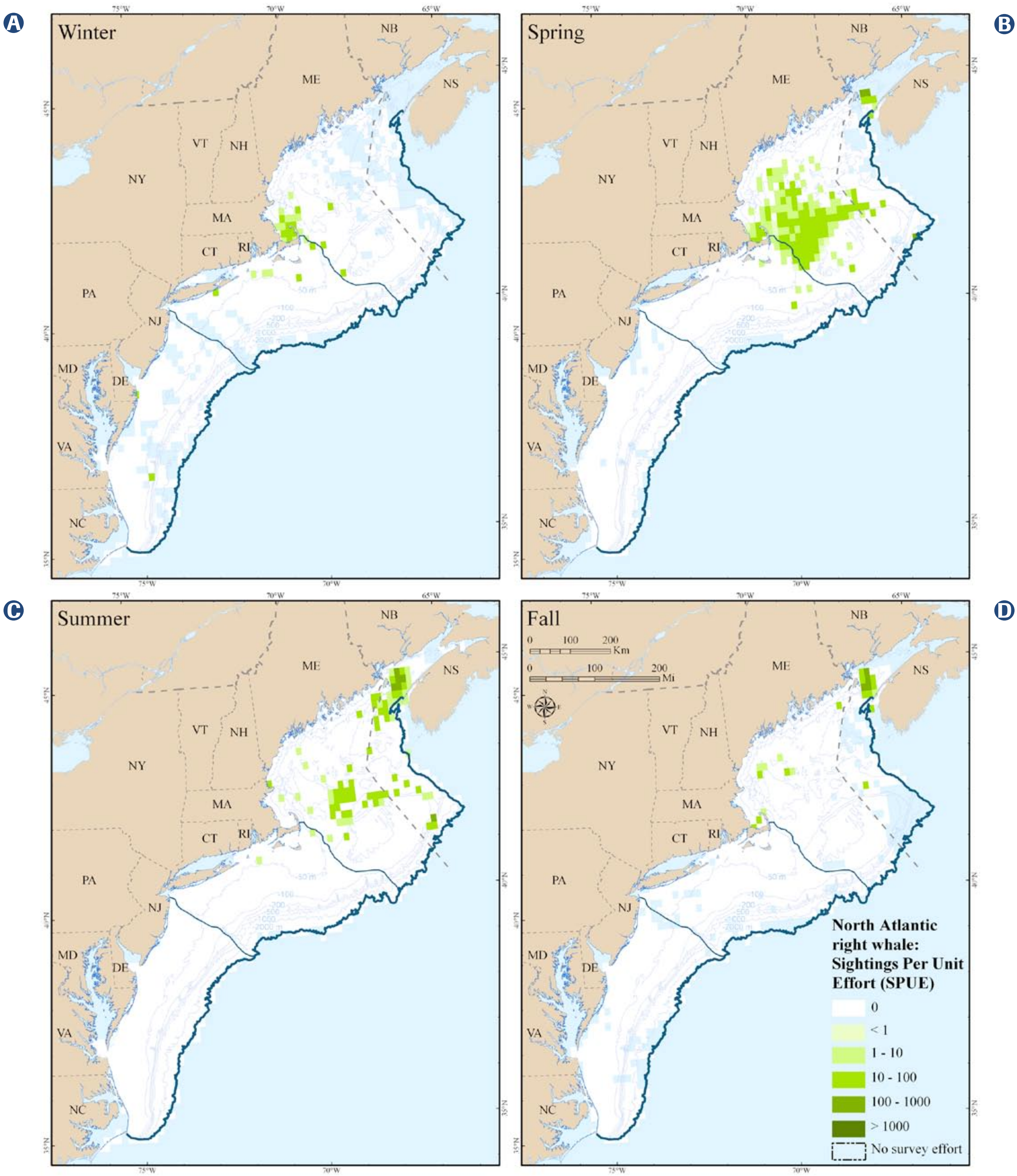


Figure 10-5. North Atlantic right whale sightings per unit effort (SPUE) by season.

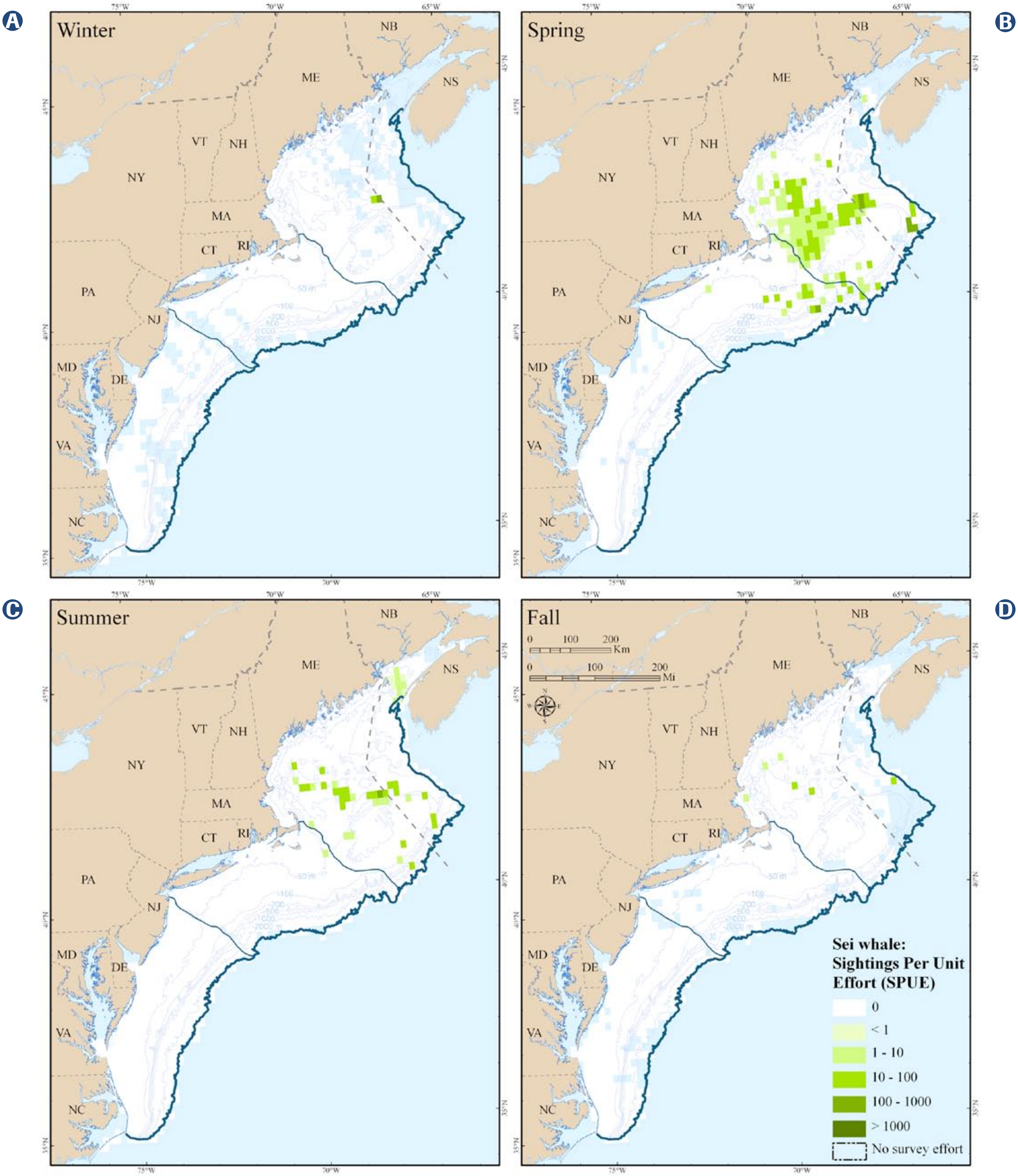


Figure 10-6. Sei whale sightings per unit effort (SPUE) by season.

Toothed Whales

Atlantic white-sided dolphin

Atlantic white-sided dolphins display movement patterns that appeared to vary greatly by season. Although white-sided dolphins were sighted in the Gulf of Maine, they migrated south in the winter months. Bycatch records show presence of this species in the Mid-Atlantic Bight, but the species distribution in these areas was not well reflected in this analysis because of the limited survey data (Figure 10-7a). In the spring and summer, Atlantic white-sided dolphins were located throughout the Gulf of Maine, east of Long Island, and east of Cape Cod to the eastern edge of the assessment boundary in high abundances (Figure 10-7b and 10-7c). Fall patterns showed sparsely distributed sightings throughout the Gulf of Maine (Figure 10-7d).

Important Marine Areas for Atlantic White-sided Dolphin

Gulf of Maine to the edge of Georges Bank, east of Long Island; Not enough data to determine areas in the Mid-Atlantic Bight

© Claire Fackler/NOAA National Marine Sanctuaries

Bottlenose Dolphin

The data indicated that bottlenose dolphins are found mostly offshore in the region, from the 100 m contour to the Continental Shelf edge. In the winter, bottlenose dolphins were present in the southern portion of the region and along the Continental Shelf edge (Figure 10-8a). In the spring, summer, and fall, bottlenose dolphins were found in high abundances along the shelf-slope break, with a clear area of mid- to high abundance at the mouth of Chesapeake Bay in the summer (Figure 10-8b, 10-8c, 10-8d). Mid-Atlantic surveys have indicated that bottlenose are also abundant in coastal areas of Virginia and North Carolina, especially in the winter when more than half of the sightings were between the shoreline and 3 km from shore (Barco et al. 1999; Torres et al. 2005).

Important Marine Areas for Bottlenose Dolphin

Throughout the region from 100 m to the Continental Shelf edge, coastal and estuarine environments including the Chesapeake Bay

Harbor porpoise

Distinct distribution patterns vary greatly by season in harbor porpoise populations in the Northwest Atlantic. Similar to the Atlantic white-sided dolphin, harbor porpoises migrated south in the winter months (Figure 10-9a). Current survey effort does not capture their true distribution in the southern portion of our region, but bycatch records have indicated the species is present. In the spring, harbor porpoises were distributed throughout the Gulf of Maine and east and south of Long Island. During the summer, harbor porpoises were concentrated in the northern part of the Gulf of Maine and the Bay of Fundy in high abundances. Fall patterns for harbor porpoises showed a coastal distribution in the Gulf of Maine with high abundances in the Bay of Fundy.

Important Marine Areas for Harbor Porpoise

Gulf of Maine to the edge of Georges Bank, east and south of Long Island; Not enough data to determine areas in the Mid-Atlantic Bight

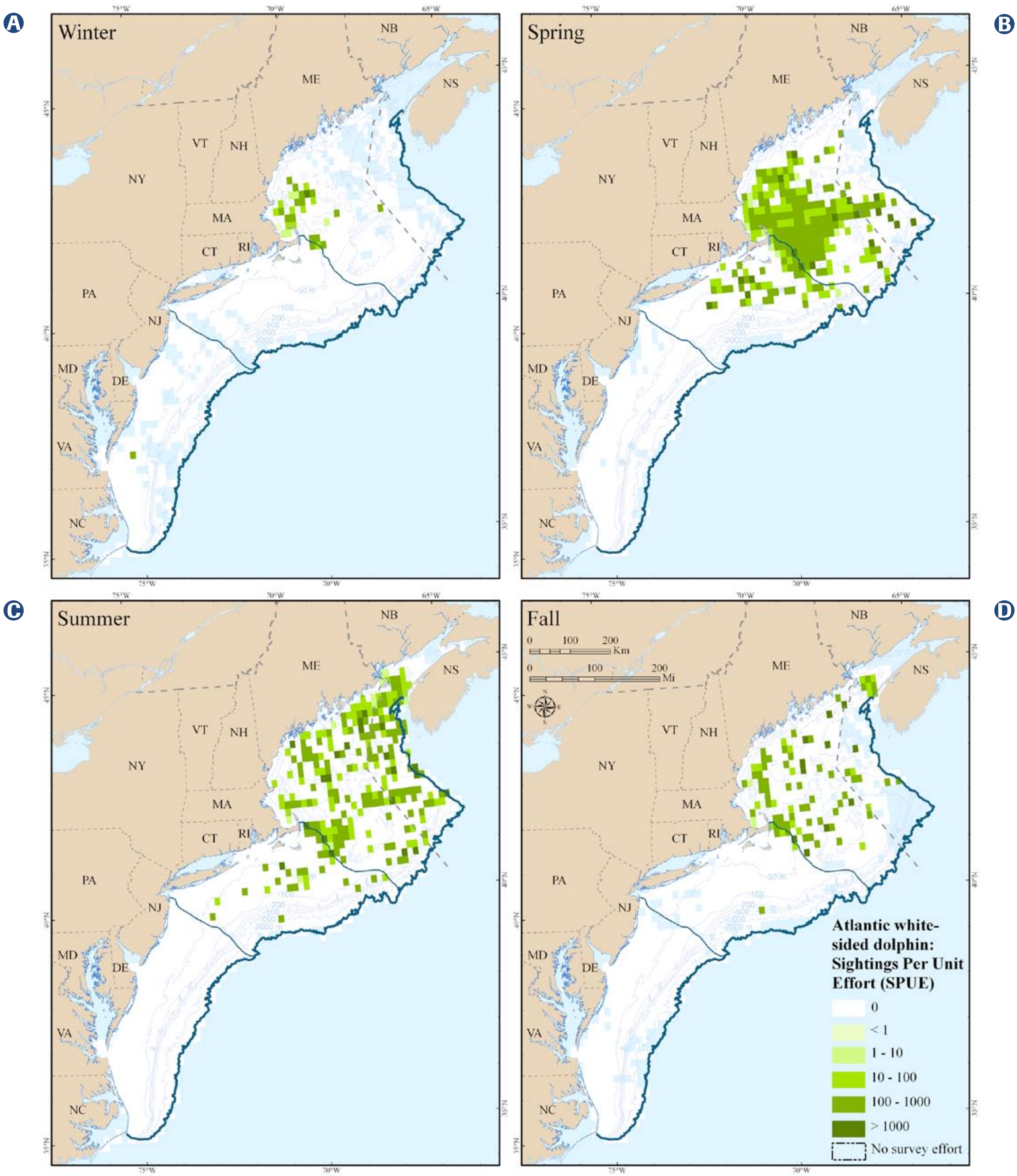


Figure 10-7. Atlantic white-sided dolphin sightings per unit effort (SPUE) by season.

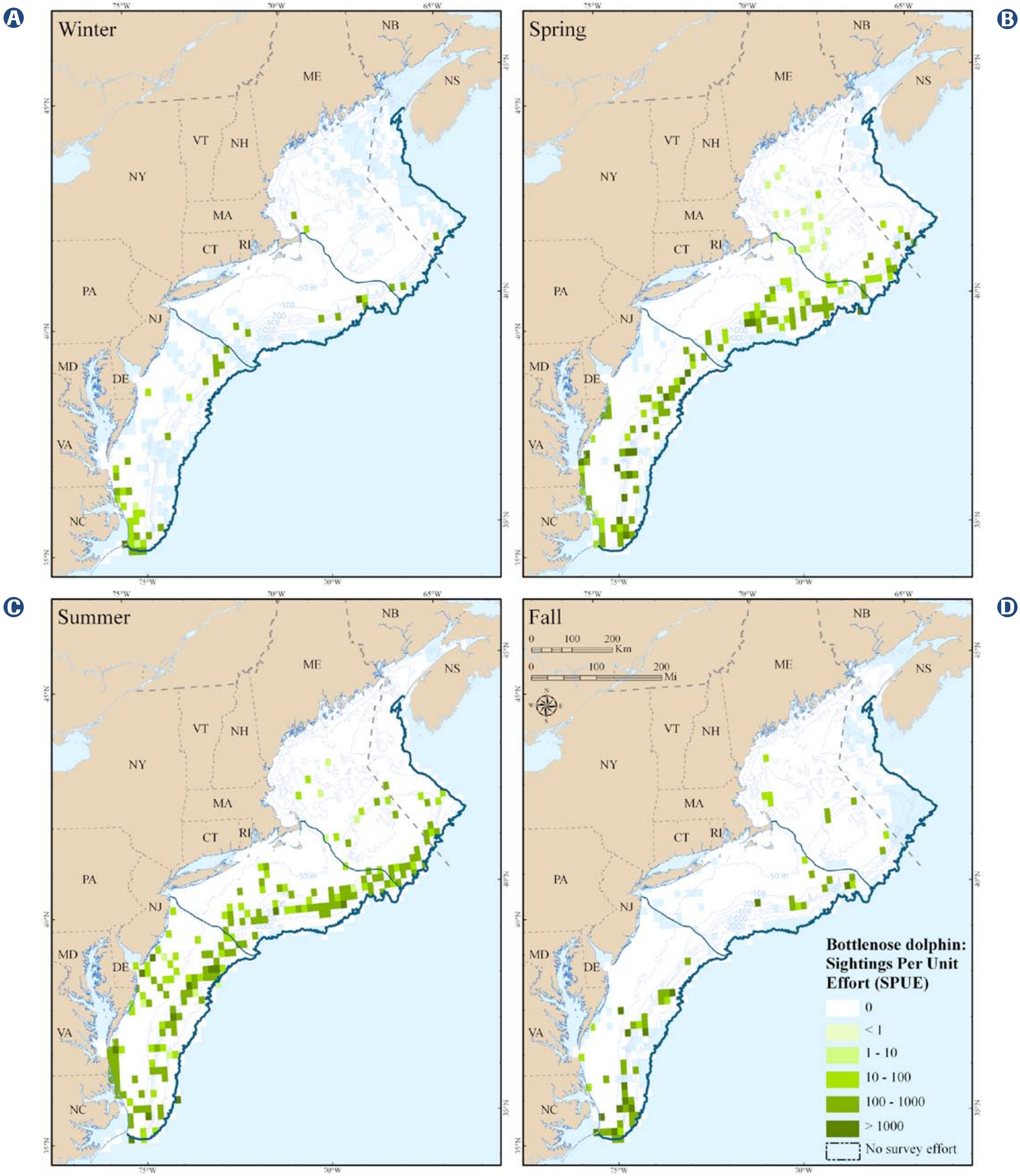


Figure 10-8. Bottlenose dolphin sightings per unit effort (SPUE) by season.

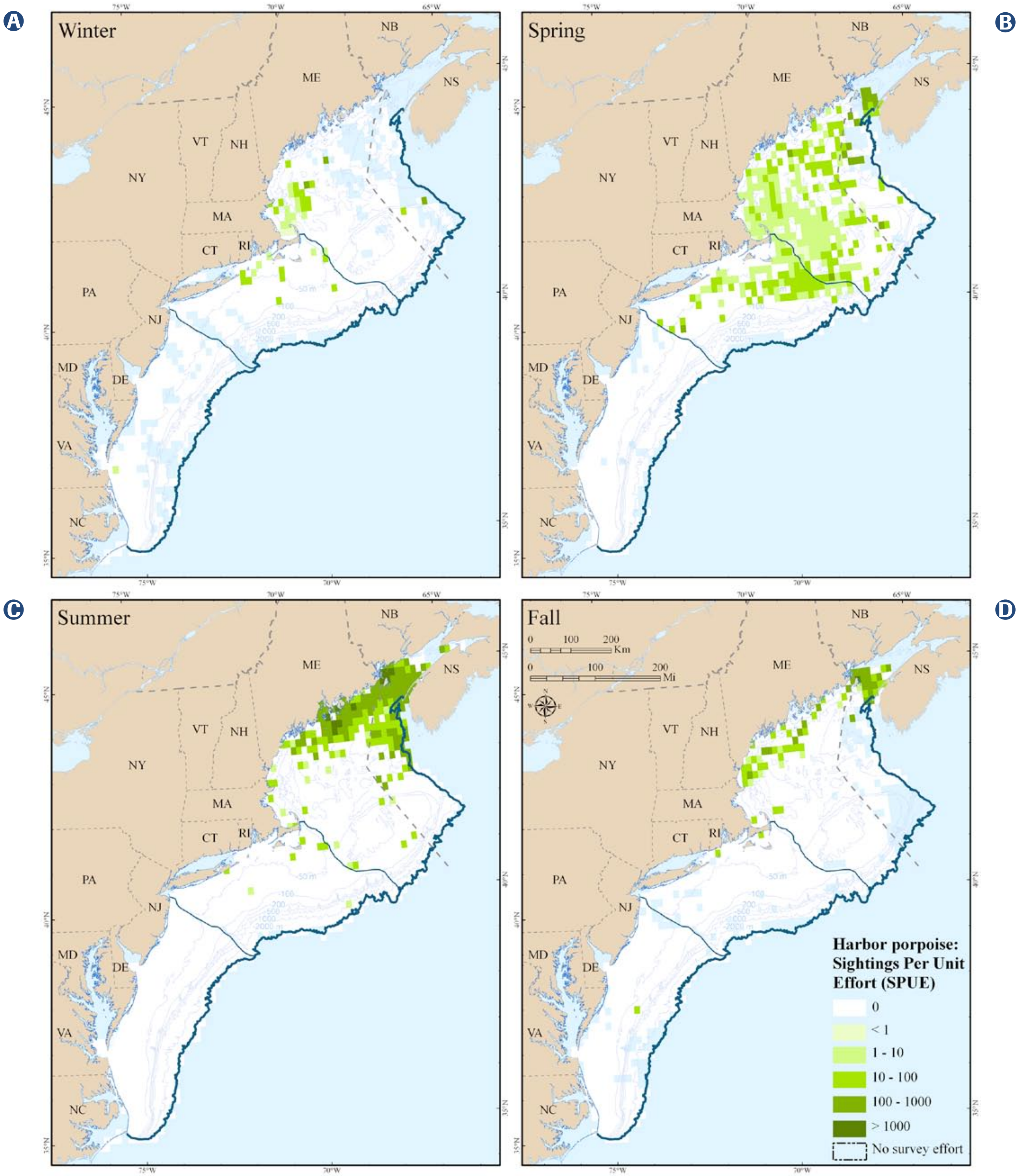


Figure 10-9. Harbor porpoise sightings per unit effort (SPUE) by season.

Sperm Whale

Data indicated that sperm whales were present along the shelf-slope break, primarily between 200-2000 m, in the Mid-Atlantic portion of the region, with most sightings occurring in the summer months (Figure 10-10a). Other studies have indicated similar patterns in sperm whale distribution, reporting that sightings are centered along the Continental Shelf break and over the Continental Slope from 100 to 2000 m deep and in submarine canyons and edges of banks (Mitchell 1975b; Waring et al. 2008).

Important Marine Areas for Sperm Whale

Continental Shelf edge and canyons throughout the region

Striped Dolphin

Based on data used in this assessment, striped dolphins were distributed in low numbers offshore along the shelf-slope break throughout the region (Figure 10-11a). Current survey effort may not capture the full pattern of distribution in the region. CeTAP (1982) reported that striped dolphins are known to range along the Continental Shelf and out to the slope from Cape Hatteras to the southern edge of Georges Bank.

Important Marine Areas for Striped Dolphin

Continental Shelf edge, canyons and Continental Slope throughout the region

Human Interactions

Cetaceans are vulnerable to pressures caused by direct and indirect interactions with humans for many reasons, including their longevity, low fecundity, high position in the food chain, and highly migratory nature. Threats to Northwest Atlantic marine mammal populations include bycatch and entanglement in fishing gear; collisions with vessels at sea; depletion of prey resources; disturbance caused by ship noise, drilling on the sea floor, and other acoustic inputs to the marine environment; and high levels of marine contaminants (Reeves et al. 2003). The full effects of these interactions throughout the region are not fully known. However, intensive research on the interactions between cetacean and humans is taking place in the SBNMS (Clark et al. 2009; Hatch et al. 2008; Hatch et al. 2008; Scheifele and Darre 2005; SBNMS 2009; Wiley et al. 2003; Wiley et al. 2008). This is an area with a particularly strong overlap between humans and cetaceans, and frequent reports of entanglement and vessel strikes (Jensen and Silber 2003; Wiley et al. 2003; SBNMS 2008).

All large whale species in the region are known to be vulnerable to vessel strikes, but the frequency and sites of those interactions are also poorly understood. Ship strikes accounted for 53% of the resolved deaths in necropsied right whales (Campbell-Malone et al. 2008). There is little evidence that right whales avoid vessels, and whales may even become tolerant to vessel noise and ignore it (Nowacek et al. 2004). In the absence of better data, shipping lanes have already been shifted within several high density cetacean habitats, such as the SBNMS and the Bay of Fundy, to reduce the probability of a strike. It is not yet clear to what degree the higher frequency of reports of interactions is due to a greater number of possible observers. Cetaceans in the North Atlantic are also the target of a large commercial whale watching industry. Although the effects of whale watching are not well understood, recent research in the Stellwagen Bank area has failed to detect an impact on juvenile survival or calving rates (Weinrich and Corbelli 2009).

Interaction between the fishing industry and cetaceans in United States waters has been documented by federal monitoring programs. Entanglement is a documented source of injury and death for a wide range of cetacean species in the region (Waring et al. 2009). Small toothed whales, such as Atlantic white-sided and bottlenose dolphins, have been observed as bycatch in a variety of fisheries, including those utilizing sink gillnets, bottom trawls, mid-water trawls, and herring trawls (NMFS 2006b; ATGTRT 2007). Large whales have also been shown to interact with fishing gear. For example, minke whales are prone to entanglement in fishing gear and collision with vessels due to their predominantly coastal distribution in spring and summer (NMFS 2007b). Incidental capture of minke whales has been observed in the northeast bottom

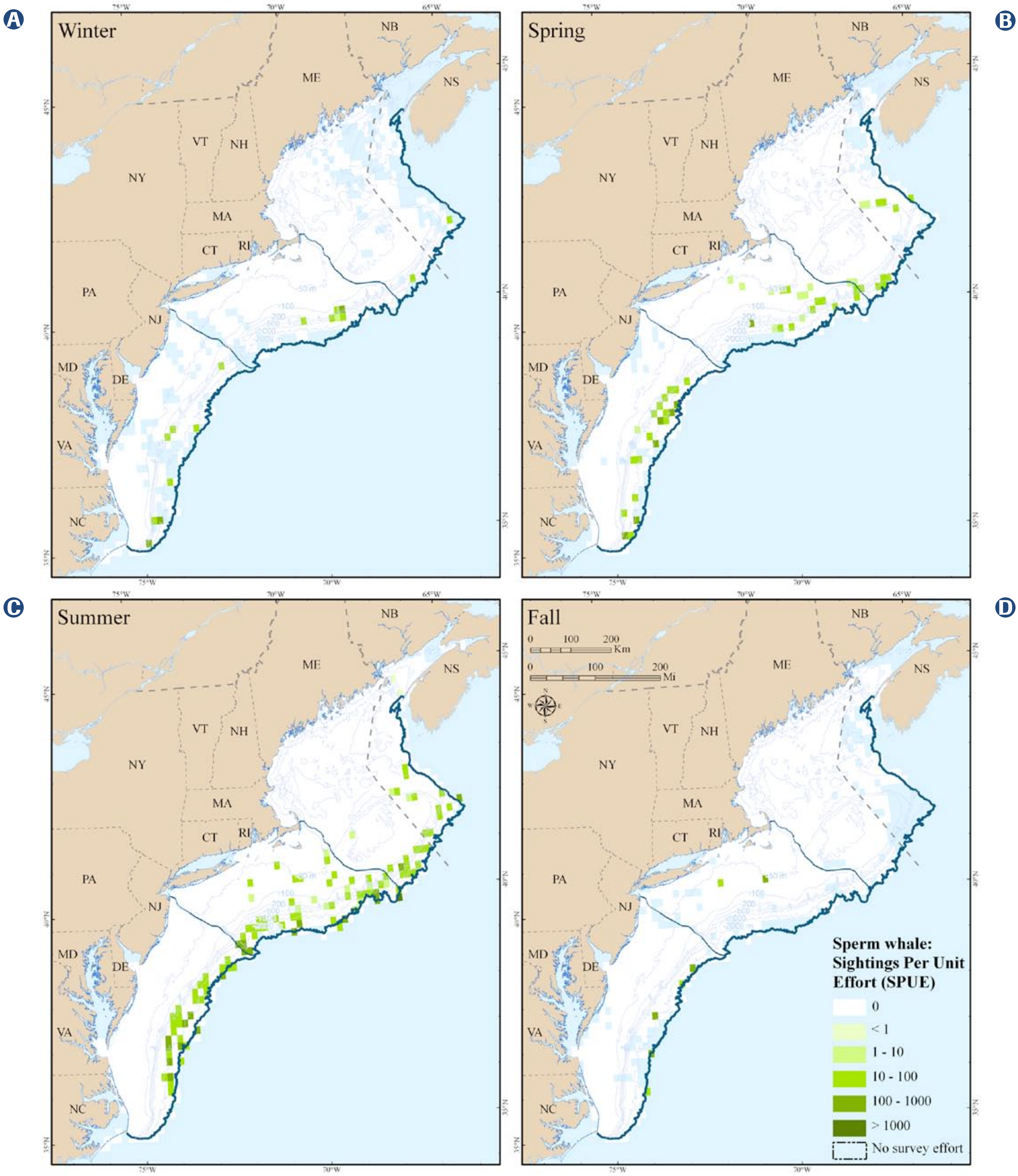


Figure 10-10. Sperm whale sightings per unit effort (SPUE) by season.

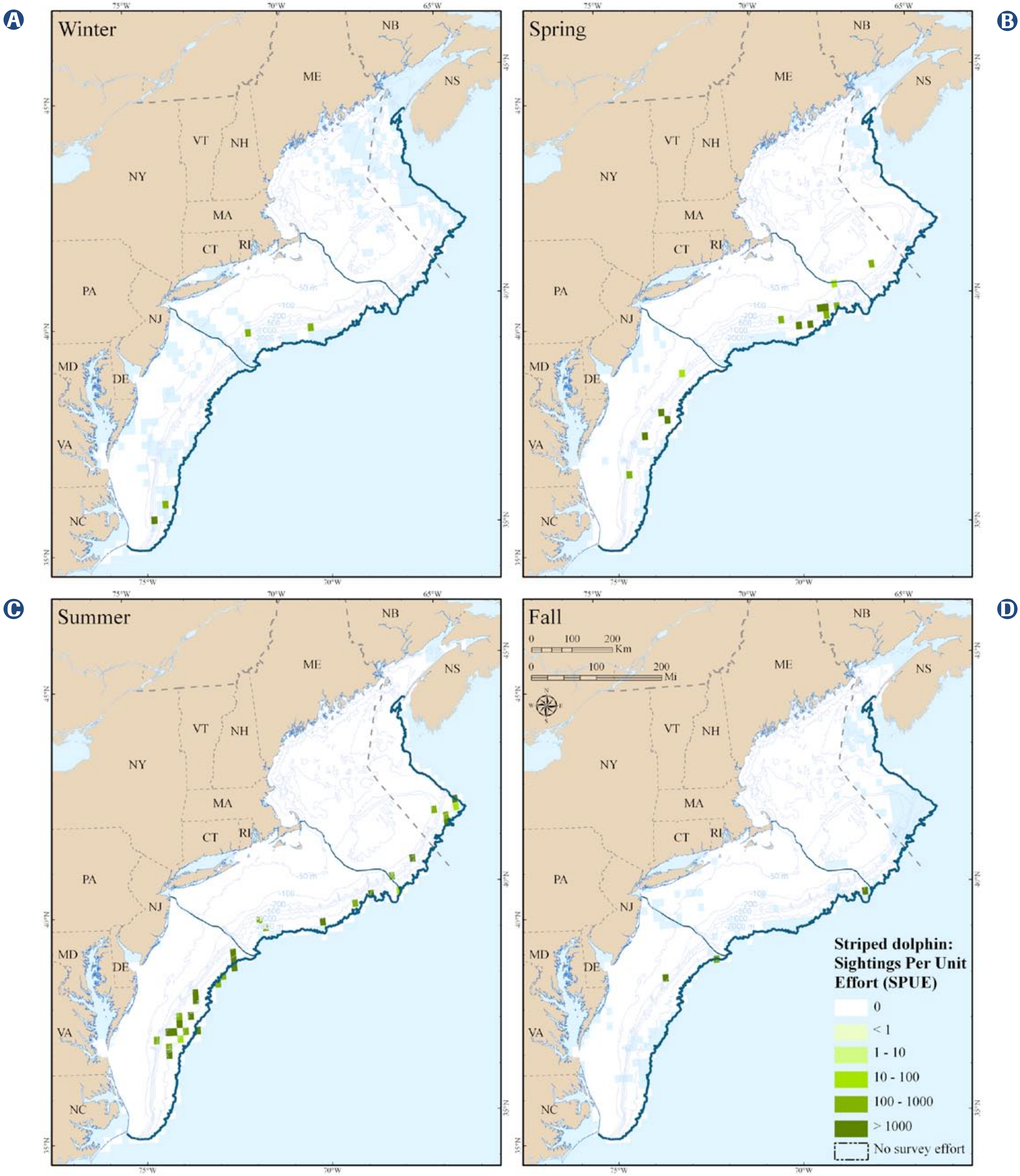


Figure 10-11. Striped dolphin sightings per unit effort (SPUE) by season.

trawl, northeast and mid-Atlantic lobster trap/pot, and other unidentified fisheries, although not all captures have resulted in mortalities (NMFS 2007b). Entanglement of humpback and northern Atlantic right whales in fishing gear such as bottom gillnets, lobster gear, weirs, longlines, and purse seines (Johnson et al. 2005) has been documented. Scar-based studies of humpback and right whales indicate that reported events underestimate true entanglement frequency (Robbins and Mattila 2004, Knowlton et al. 2005). At present, there are few data on where large whale entanglements actually occur within the region, and therefore which areas, if any, pose greatest risk.

The effect of human-generated noise on cetaceans remains a highly controversial and poorly understood conservation issue (see review in Clark et al. 2007 and Parks and Clark 2007; Richardson et al. 1995; NRC 2003). Human-generated sound in the sea comes from a variety of sources, including commercial ship traffic, oil exploration and production, construction, acoustic research, and sonar use. Underwater sounds are also generated by natural occurrences such as wind-generated waves, earthquakes, rainfall, and marine animals. Cetaceans are highly vocal and dependent on sound for almost all aspects of their lives (e.g. food-finding, reproduction, communication, detection of predators/hazards, and navigation), heightening concerns regarding the impacts of human-induced noise (NRC 2003). Due to the behavior of sound in the ocean (particularly low frequency sound), noise can propagate over large distances, thus both spatial and temporal scales of potential impact can be large. There is a great deal of observed variation in noise responses among both cetacean species and individuals of different genders, age classes, with different prior experiences with noise, and in different behavioral states (Southall et al. 2007). Species with similar hearing capabilities have been found to respond differently to the same noise.

Observed effects of noise on cetaceans include changes in vocalizations, respiration, swim speed, diving, and foraging behavior; displacement; avoidance; shifts in migration path; hearing damage; and strandings (Parks and Clark 2007). For example, in a Newfoundland inlet, two humpback whales were found dead near the site of repeated sub-bottom blasting with severe mechanical damage to their ears (Ketten 1995). Sperm whales exposed to the sounds of pingers used in calibration systems to locate hydrophone arrays temporarily stopped communicating, and fell silent, changed their activities, scattered, and moved away from the source of the sound (Watkins and Schevill 1975; Watkins et al. 1985). Responses of cetaceans to noise can often be subtle, and there are many documented cases of apparent tolerance of noise. However, marine mammals showing no obvious avoidance or changes in activities may still suffer important consequences. Observed reactions to noise in marine mammals could result in population-level impacts such as decreased foraging efficiency, higher energetic demands, less group cohesion, higher predation, and decreased reproduction (NRC 2005). However, the whales showed no signs of avoidance or disturbance which may indicate habituation to noise. Alternatively, the noises may have no biologically significant effects. Much research effort is currently focused on better known cetacean populations that have been exposed to long-term human-induced noise to assess population consequences (i.e. North Atlantic right whales, Clark et al. 2009).

The effects of marine contaminants like endocrine disruptors and biotoxins from harmful algal blooms on cetaceans are not fully known. Mass stranding events have been documented and connected to ingestion of contaminated food sources. For example, in the winter of 1989, a mass stranding of humpback whales in Cape Cod Bay, Massachusetts was linked to a recent food source, Atlantic mackerel (Geraci et al. 1989). These mackerel were contaminated with *saxitoxin*, a toxin produced by the microscopic marine algae, *Alexandrium spp.*, which is the cause of paralytic shellfish poisoning in humans. Determination and tracking of the effects of these contaminants is a rapidly evolving science (see review in Rolland et al. 2007). Because of the size, free-swimming nature, and endangered status of many cetaceans, it has been difficult to collect the type of non-lethal samples (e.g. blood and tissue) needed to diagnose diseases or monitor physiological responses to these contaminants. Analysis of free-floating scat samples has provided a suite of new information about cetaceans, their prey and the containments that affect them, including the DNA from the originating animal, DNA from their prey, marine biotoxins, and stress hormones, and is providing many new insights and data about the interaction between cetaceans and contaminants.

Management and Conservation

Regulatory Authorities

All of the species studied in this assessment are federally protected by the National Oceanic and Atmospheric Administration's National Marine Fisheries Service under the Marine Mammal Protection Act (MMPA). The MMPA prohibits, with certain exceptions, the "take" of marine mammals in United States waters and by United States citizens on the high seas, and the importation of marine mammals and marine mammal products into the United States (NOAA 2007b). The Endangered Species Act (ESA) also lists the fin, humpback, sei, sperm, and North Atlantic right whales as "endangered" and prohibits "take" of these species, in addition to mandating that critical habitat is designated for these species, where appropriate, and recovery plans are developed and implemented. Where these species are found within National Marine Sanctuaries, they are also protected under the United States National Marine Sanctuaries Act.

Current Conservation Efforts

Many ongoing cooperative conservation efforts focus on marine mammals, including federal, international, and state agencies and academic institutions and non-profit organizations. Internationally, one of the first protection measures for whales came when right whales were protected by the 1st International Convention for the Regulation of Whaling in 1935. Their protected status has been continued by the International Whaling Commission, since its founding in 1946 (Donovan 1991).

In the United States, as part of their listing as Endangered Species, the ESA requires NMFS to develop and implement recovery plans; many species listed as conservation targets in this assessment have draft plans in review or final plans being implemented. A final Recovery Plan has been published for the North Atlantic right whale under the Marine Mammal Protection Act and is being implemented (NMFS 2005). Critical habitat has also been designated for this species, including portions of Cape Cod Bay and Stellwagen Bank, and the Great South Channel (NMFS 1994). An intensive long-term effort, based primarily at the New England Aquarium in Boston, Massachusetts and NOAA's Northeast Fisheries Science Center in Woods Hole, Massachusetts, monitors the North Atlantic right whale population, identifies risk factors, and develops and implements measures to reduce human-induced mortality and injury. A final Recovery Plan (1991) was also released by NMFS for the conservation of humpback whales that either occur seasonally or are residents of United States waters. The plan has four main objectives: 1) to maintain and enhance historical and current known humpback whale habitats, 2) to identify and reduce human related injury and mortality, 3) to research population structure, and 4) to improve administration and coordination of the recovery plan.

A draft Recovery Plan for fin and sei whales was issued by NMFS, and released for public comment and review. However, it was not finalized and it was subsequently determined that separate Recovery Plans should be issued for each species. A revised Draft Recovery Plan for the fin whale was released by NMFS for public comment in 2006, but a Recovery Plan has not been drafted for the sei whale at this point. The Fin Whale draft Recovery Plan suggests continued international cooperation to protect the fin whale and further research on fin whale population structure (NMFS 2006a). A draft Sperm Whale Recovery Plan was also released and suggests continued research on the structure of sperm whale populations, identification and protection of relevant habitats within and outside of United States waters, reduction of the frequency of human caused injury and mortality, and maximization of efforts to obtain scientific information from stranded or entangled individuals (NMFS 2006c). To date, these two draft plans have not been finalized.

Under Section 118 of the Marine Mammal Protection Act, NMFS convened the Large Whale Take Reduction Team with a goal to develop a Take Reduction Plan (TRP) for large whales. The purpose of the submitted plan was to reduce the level of serious injury and mortality of three strategic stocks of large whales (North Atlantic right, humpback, and fin) in commercial gillnet and trap/pot fisheries (LWTRT 1997). The measures identified in the TRP were also intended to benefit minke whales, which are not designated as a strategic stock, but are known to be taken incidentally in gillnet and trap/pot fisheries. The TRP consists of both regulatory and non-regulatory measures, including broad-based gear modifications, time/area closures, and extensive outreach efforts.

© Kerry Crisley/TNC

NMFS also assembled the Atlantic Trawl Gear Take Reduction Team to develop a TRP to limit the incidental injury and mortality of Atlantic white-sided dolphins, long-finned pilot whales *(Globicephala melas)*, short-finned pilot whales *(Globicephala macrorhynchus)*, and common dolphins *(Delphinus delphis)* in the northeast and mid-Atlantic trawl fisheries (ATGTRT 2007). The bottlenose dolphin TRP aimed to reduce incidental injury and mortality within six months and provided a framework for long-term reduction of dolphin mortality, taking into account the economics of the commercial fishing industry (NMFS 2006b). There is no recovery or management plan for the striped dolphin, as it is not listed as endangered or threatened under the Endangered Species Act and is not subject to high fisheries-related mortality.

Regulations governing activities in SBNMS, situated at the mouth of Massachusetts Bay, provide protection for a portion of the northern habitat range of many species studied in this report. Research at SBNMS has focused on standardized surveys of large whales and tagging programs and multiple monitoring efforts to support spatially-explicit risk assessments of various human-induced threats, including ship strikes, fishing gear entanglement, and shipping noise. This research has supported the rerouting of traffic in Massachusetts Bay to reduce risk of vessel collisions, tools for assessing the impact of noise masking on large whale communication, and support for East-Coast wide regulations on gear types to reduce entanglements. These programs are highly collaborative in nature, involving staff from the sanctuary, NOAA's Northeast Fisheries Science Center and Northeast Regional Office, the United States Coast Guard, as well as academic partners (listed below) and collaborators from private industry in the region (i.e. Marine Acoustics, Inc., ICAN, and Oasis, Inc.).

A variety of government agencies, academic institutions and non-profit organizations are actively involved in cetacean research and/or conservation in the region. Colleges and universities at which there are research programs studying many aspects of cetacean biology, genetics, and distribution include (but are not limited to) Cornell University, Dalhousie University, Duke University, Trent University, University of North Carolina Wilmington, University of Rhode Island, and Woods Hole Oceanographic Institution. Non-profit organizations involved in cetacean research or conservation include the Canadian Whale Institute, Cetacean Society International, Georgia Environmental Policy Institute, Grand Manan Whale and Seabird Research Station, International Fund For Animal Welfare, Marine Mammal Commission, New England Aquarium Right Whale Project, Ocean Conservancy, North Atlantic Right Whale Consortium, Nova Scotia Museum of Natural History, Provincetown Center For Coastal Studies, The Humane Society of the United States, Virginia Aquarium & Marine Science Center, Whale and Dolphin Conservation Society, Whale Center of

New England, World Wildlife Fund Canada, WhaleNet. Other United States and Canadian federal agencies engaged in research and conservation activities include, Fisheries and Oceans Canada/Marine Fish at Division St. Andrews Biological Station, Fisheries and Oceans Canada/Maritimes Species at Risk Office, Florida Fish and Wildlife Conservation Commission/Fish and Wildlife Research Institute, Georgia Department of Natural Resources/Coastal Nongame and Endangered Wildlife Program, and the Office of Naval Research Marine Mammal Program.

Species Accounts

Atlantic White-sided Dolphin *(Lagenorhynchus acutus)*

Atlantic white-sided dolphins, one of the most abundant cetaceans in the Northwest Atlantic (Kenney et al. 1996), are a pelagic species that inhabits Continental Shelf waters. They are most abundant in areas of steepest subsurface topographic relief (Gaskin 1992), and are known to inhabit temperate and sub-polar waters throughout the northern North Atlantic (Cipriano 2002). Within the boundaries of the region, white-sided dolphins are most common in Continental Shelf waters to the 100-m depth contour (CeTAP 1982) from Hudson Canyon (approximately 39°N) to Georges Bank, in the Gulf of Maine, and lower Bay of Fundy. They have also been sighted occasionally in the Gulf of St. Lawrence (Northridge et al. 1997).

Atlantic white-sided dolphins have seasonal distribution patterns in this region. These animals have been sighted in high numbers from Georges Bank to the lower Bay of Fundy from June to September, while an intermediate number of sightings occur from October to December and low sightings occur from January to May. Sightings south of Georges Bank, particularly around Hudson Canyon, occur year round, but at low densities (Payne and Heinemann 1990). This species is sighted in small groups of up to several thousand (superpods) throughout the region, a possible strategy for foraging or cooperative feeding. This species is also known to be associated with fin and humpback whales, since they consume similar prey species (Reeves et al. 2003). Gaskin (1992) suggested a separation between the population in the southern Gulf of Maine and the Gulf of St. Lawrence based on the decrease in sightings during the summer months along the Atlantic coast of Nova Scotia. The life span of Atlantic white-sided dolphins is reported to be up to 22 years for males and 27 years for females. The average adult length is 250 cm for males and 224 cm for females. They are thought to calve every two to three years with a gestation period of 10-12 months (Cipriano 2002). Calving has been estimated to occur from May to August, predominantly in June and July (Sergeant et al. 1980). The species in known for its tendency to mass strand, particularly in the area of Cape Cod Bay (Wiley et al. 2001)

Bottlenose Dolphin *(Tursiops truncatus)*

Bottlenose dolphins utilize a wide variety of coastal, inshore, and pelagic habitats in tropical and temperate waters of the world (Wells and Scott 1999). Bottlenose dolphins have been documented along the entire Western Atlantic coast, and in the eastern Atlantic, including the Azores, the British Isles, the Faroe Islands, the Baltic Sea, and the Mediterranean and Black Seas. Bottlenose dolphin ranges are restricted by temperature, occurring in North American waters of about 10 °C to 32°C; they are rarely seen poleward of 45° in either hemisphere (Wells and Scott 2002). In the Northwest Atlantic region, there are two genetically and morphologically distinct bottlenose dolphin populations, described as the coastal and offshore morphotypes (Duffield 1986).

While the offshore bottlenose dolphin stock occurs in waters beyond the Northwest Atlantic, the offshore stock occurs regionally along the outer Continental Shelf and shelf/slope break (CeTAP 1982; Kenney 1990). This population has been documented in the far northern areas of the region on the Scotian shelf and as far south as coastal areas off Cape Hatteras in the spring and summer (Gowans and Whitehead 1995; NMFS 2008a). The coastal stock, originally thought to one migratory stock, has been proven to be a collection of many complex stocks (NMFS 2001). In this region, the coastal stock is reported to extend from North Carolina to New York and the different groups have been shown to exhibit a variety of patterns, including seasonal residency, year-round residency with large home ranges, and migratory and transient movements (Barco et al. 1999; NMFS 2008a). Coastal dolphins are further defined by their habitat use, where some bottlenose dolphins are seasonal residents in estuarine areas and may be genetically distinct from other coastal migratory stocks. For example, there are several stocks of estuarine bottlenose dolphins that have been identified from North Carolina in the Pamlico Sound (Torres et al. 2005). Seasonally, both northern and southern coastal migratory stocks can be found in the region, with large aggregations of bottlenose dolphins around the Chesapeake Bay mouth during the summer months (Barco et al. 1999). The most northerly resident group has been reported from Cape Cod Bay, but this is atypical (Wiley et al. 1994).

Bottlenose dolphins tend to feed cooperatively and are commonly found exhibiting gregarious behavior while in groups (Caldwell and Caldwell 1972). Female bottlenose dolphins can live more than 50 years and males from 40 to 45 years old (Wells and Scott 1999). Female bottlenose dolphins usually produce calves every three to six years (Wells and Scott 2002). Breeding whales in captivity are over 20 years of age and females can continue to give birth up to 48 years of age (Wells and Scott 2002). Spring and summer or spring and autumn calving peaks are known for most populations (Wells and Scott 2002). Calving occurs after a one-year gestation, peaking in the warmer months. Calves are born at 84-140 cm depending on the region. Calves grow rapidly during their first 1.5-2 years. Females often reach sexual maturity before males (Wells and Scott 2002). Age at sexual maturity is about 5-13 years for females and 9-14 years for males (Wells and Scott 2002).

Fin Whale *(Balaenoptera physalus)*

Fin whales are found in all oceans of the world, but do not range past the ice limit at either pole (Aguilar 2002). The most important habitats identified for fin whales in the north appear to be the Great South Channel, along the 50-m isobath past Cape Cod, over Stellwagen Bank, and past Cape Ann to Jeffreys Ledge (Hain et al. 1992).

The fin whale is the most common large whale from Cape Hatteras northward, accounting for 46% of all large whale sightings and 24% of all cetaceans sighted over the Continental Shelf between Cape Hatteras and Nova Scotia during 1978 - 1982 aerial surveys (CeTAP 1982).

Fin whale movement usually occurs offshore rather than along the coastline which makes it difficult to track migration patterns (Mackintosh 1965; Perry et al. 1999). Consequently, there is little knowledge of the location of winter breeding grounds (Perry et al. 1999).There is some evidence that fin whales migrate to subtropical waters for mating and calving during the winter months and to the colder areas of the Arctic and Antarctic for feeding during the summer months. Some observations suggest site fidelity and seasonal residency by females. Often, the same whales are sighted in the Gulf of Maine year after year (Seipt et al. 1990; Clapham and Seipt 1991; Agler et al. 1993). Fin whales may be solitary or found in pairs, however larger groups may be found near feeding grounds in the region (Gambell 1985).

The fin whale is the second largest animal on Earth (after the blue whale); adult whales are known to range from 20 to 27 m in length and weigh 50 -70 tons. Mature females are approximately 5-10% longer than mature males (Aguilar and Lockyer 1987). Adult males reach sexual maturity at about 5-15 years of age and, as in some other whale species, sexual maturity is reached before physical maturity. Mating occurs in the northern hemisphere from December to February, gestation lasts 11 months, and newly born calves are 6-7m long and weigh about 1-1.5 tons (Aguilar 2002). Calves nurse for six months and are weaned when they are 10-12 m in length. Fin whales grow rapidly after birth and reach 95% of their maximum body size when they are 9-13 years old. Physical maturity is reached at about 25 years of age and fin whales are known to live up to 80-90 years (Aguilar 2002). The reproductive strategy of fin whales is closely integrated and synchronized with their annual feeding cycle; whales mate during the winter and weaning ends the following summer on productive feeding grounds (Laws 1961).

Harbor Porpoise *(Phocoena phocoena)*

Harbor porpoises are found in northern temperate and subarctic coastal waters of the North Atlantic, North Pacific, and Black Sea (Bjorge and Tolley 2002). They are known to prefer shallow inshore waters of the Continental Shelf and are commonly sighted in estuaries, harbors, fjords, and bays. In the Northwest Atlantic, they are known to range from Greenland to Cape Hatteras, North Carolina. Dense aggregations of harbor porpoises appear in the northern Gulf of Maine and Bay of Fundy in waters less than 150 m deep during the summer (Gaskin 1977; Kraus et al. 1983; Palka 1995). In the fall and spring months, they inhabit a more southerly range and are found primarily along the Continental Shelf from New Jersey to Maine from the coastline to over 1800 m in depth (Westgate et al. 1998). There are low numbers of individuals sighted north in Canadian waters and south in the Mid-Atlantic, but the majority of porpoises inhabit the middle range. In the winter, harbor porpoise sightings are predominantly absent from the Gulf of Maine and are sighted in New Jersey to North Carolina and occasionally down to Florida (Read and Westgate 1997). There does not appear to be a coordinated migration of harbor porpoises to the Bay of Fundy area (NOAA 2008d). Harbor porpoises are very difficult to study as they are smaller in size, and spend little time at the surface. Their size typically makes them extremely hard to see from aerial and vessel surveys and therefore their distribution may not be accurately represented here.

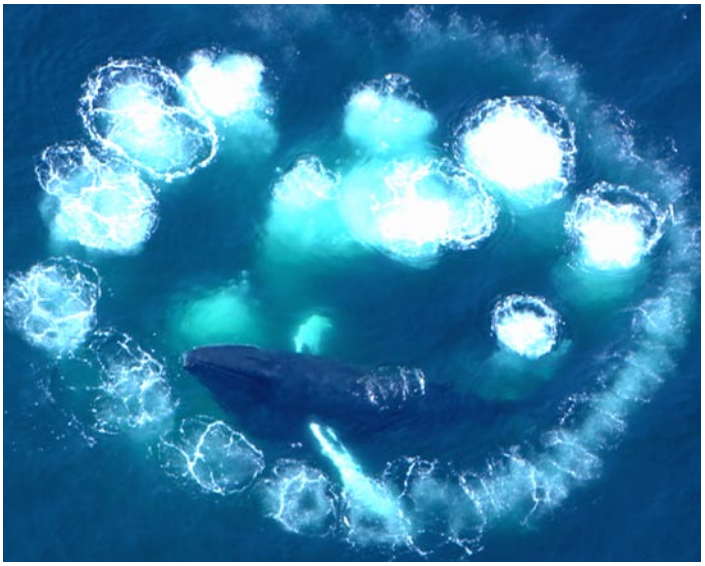
Harbor porpoises are often associated with distributions in prey species. Satellite tagging studies have found harbor porpoises to aggregate around the 92 m isobath and follow underwater ridges and banks where likely sources of prey aggregate during certain seasons (Read and Westgate 1997; Bjorge and Tolley 2002). Harbor porpoises have been shown to feed primarily on Atlantic herring *(Clupea harengus)*, but to also feed on silver *(Merluccius bilinearis)*, red, and white hake (*Urophycis* spp.) (Gannon et al. 1998). They also feed on anchovies and capelin (Read 2002). Calves have been known to feed on euphausiids *(Meganyctiphanes norvegica)* in the Bay of Fundy (Smith and Read 1992).

Adult females are an average of 160 cm in length and about 60 kg while males are usually smaller, growing to an average of 145 cm and 50 kg (Bjorge and Tolley 2002). They are known to live an average of 8-10 years although there have been porpoises known to live to over 20 years of age. Harbor porpoises become sexually mature between 3 and 4 years old and have seasonal patterns of reproduction. There is a defined calving season that varies from region to region but is usually between May and August. Gestation lasts about 10.5 months and calves are weaned after less than a year. Calves are born at 70-75 cm and 5 kg, but grow quickly in their first year and begin to feed on euphausiids after just a few months. In the Atlantic harbor porpoise population, females have calves yearly, but in the Pacific they only calve every other year. Harbor porpoises are not known to be monogamous as they repeatedly mate with several individuals. Once adults, they tend to occur alone or in very small groups (Read 2002).

Humpback Whale *(Megaptera novaeangliae)*

Humpback whales inhabit all major ocean basins from the equator to subpolar latitudes (Clapham 2002). Most humpback whales are known to spend the summer feeding in northern waters and migrate south to low-latitude tropical waters for the winter where they breed and calve. In the North Atlantic Ocean, humpback whales aggregate in several feeding areas: Iceland-Denmark Strait, Norway, western Greenland, Southern Labrador and east of Newfoundland, Gulf of St. Lawrence, and the Gulf of Maine/Nova Scotia region (Katona and Beard 1990; Stevick et al. 2006). Individual humpback whales maintain fidelity to a specific oceanic feeding ground, a preference that is transmitted from mother to offspring (Martin et al. 1984; Clapham and Mayo 1987).

During spring, summer, and fall, humpback whales can be found from the waters off Nantucket north to the Bay of Fundy and east to the edge of the Continental Shelf. In addition, there is documented exchange with the Scotian Shelf (Clapham et al. 2003). Humpback whale distribution across the northern study range depends on physical factors such as bottom depth and slope (CeTAP 1982; Hamazaki 2002) as well as the abundance and distribution of herring and sand lance (Payne et al. 1986; Payne et al. 1990; Weinrich et al. 1997). Previous work has shown significant spatial variation by season, with the greatest concentrations occurring in the spring in the southern Gulf of Maine. There is also significant temporal variation correlated with trends in prey abundance (Payne et al. 1986; Payne et al. 1990; Weinrich et al. 1997). On an individual level, humpback whales are known to return


© SBNMS

preferentially to some areas within their feeding range (Weinrich 1998; Larsen and Hammond 2004; Robbins 2007). However, they also move among available feeding sites within and between years. In the Gulf of Maine, individual humpback whales move most frequently among a few adjacent aggregation sites, but also undertake larger movements that span the region (Robbins 2007). In addition, although all ages and sexes can be found across the feeding range, the southern Gulf of Maine is more frequently used by mature females and juveniles compared to northern Gulf of Maine and Bay of Fundy areas (Robbins 2007).

In the winter months, habitat requirements appear to be tied to calving needs rather than prey resources. Optimal calving conditions are warm waters and shallow, flat ocean bottoms in protected areas and calm seas often close to islands or coral reefs (Clapham 2002). Recent research suggests that a relatively narrow water temperature range (21.1–28.3°C) is more important than latitude per se in the location of oceanic breeding grounds (Rasmussen et al. 2007). The primary breeding range in the North Atlantic is along the Atlantic margin of the Antilles, from Cuba to Venezuela. Calving takes place there between January and March. Individual females produce a calf every 2–3 years on average (Clapham and Mayo 1987; Clapham and Mayo 1990; Robbins 2007); only approximately 2% of observed calving events are in consecutive years (Robbins 2007).

Adult humpback whales are 14-17 m in length and females are 1-1.5 m longer than males (Clapham and Mead 1999). Age at first birth was estimated to average 5 years in the 1980s (Clapham 1992), but has subsequently increased to over 8 years of age (Robbins 2007). Gestation is about 11 months and lactation is about one year (Clapham 1992). Calves are from 3.96 to 4.57 m at birth and 8-10 m after their first year (Clapham 2002). Trends in offspring survival after weaning have been linked to trends in the relative abundance of primary prey (Robbins 2007; Weinrich and Corbelli 2009).

Humpback whales seen sporadically off the Mid-Atlantic states and the southeast United States in winter are a mixed stock of those that summer in the Northwest Atlantic and those from other oceanic feeding grounds (Barco et al. 2002). This is apparently a supplemental feeding area for young whales, but the factors that drive their presence and distribution are poorly understood.

Minke Whale *(Balaenoptera acutorostrata)*

Minke whales are found from the Canadian Arctic in the summer to the Caribbean and the Straits of Gibraltar in the winter (Perrin and Brownell 2002). Because they are difficult to see by aerial and ship surveys, much remains unknown about their true range (Perrin and Brownell 2002).There appears to be a strong seasonal component to minke whale distribution. They are abundant and appear to feed in New England waters in the spring and summer, but may be relatively undercounted, predominantly because of their solitary nature, small body size, inconspicuous blow, and very short surface intervals. They become scarce in New England waters in the fall and during winter the species appears to be largely absent. There is some evidence that they move south into the West Indies and east of Bermuda, but this is speculative (Mitchell 1991).

Like most other baleen whales, minke whales are generally found over the Continental Shelf. This species tends to be solitary or travel in small groups, but larger aggregations may form near abundant prey (Horwood 1990). Minke whales in the north Atlantic are known to live about 50 years and mature adults range from 8.5 to 8.8 m in length for females and 7.8 to 8.2 m in length for males (Horwood 1990; Jefferson et al. 1993). Females mature at 6-8 years of age and calve in intervals of 1 to 2 years, although some females are known to calve annually (Perrin and Brownell 2002). Calves are probably born between October to August, peaking in July and August after 10 to 11 months gestation (IWC 1991; Katona et al. 1993; Perrin and Brownell 2002). Calves are born at 2.4-3.5 m in length and weigh about 318-454 kg (Katona et al. 1993). The calf is weaned after 4-6 months and once the offspring leaves its mother, it often remains solitary for the rest of its life.

North Atlantic Right Whale *(Eubalaena glacialis)*

North Atlantic right whales historically ranged from Florida and northwestern Africa to Labrador, southern Greenland, Iceland, and Norway (see complete review in Kraus and Rolland 2007a). Currently, this species is found in the Northwest Atlantic in Continental Shelf waters between Florida and Nova Scotia (Winn et al. 1986) in six known habitats: the coastal waters of the southeastern United States; the Great South Channel; Georges Bank/Gulf of Maine; Cape Cod and Massachusetts Bays; the Bay of Fundy; and the Scotian Shelf (Waring et al. 2008). The southeastern United States, Great South Channel, and Cape Cod Bay are explicitly defined as critical habitat under the Endangered Species Act.

North Atlantic right whales move seasonally (Kraus and Rolland 2007b). In the spring, feeding aggregations of right whales are found in the Gulf of Maine especially around the Great South Channel along the 100-m isobath and in Cape Cod Bay (Kenney and Winn 1986; Kenney et al. 1995). The Bay of Fundy is also a well-known feeding site for right whales during the summer and dense aggregations of whales are found there every year. These feeding grounds are areas where bottom topography, water column structure, currents, and tides combine to physically concentrate zooplankton in high quantities (Wishner et al. 1988; Baumgartner et al. 2003). While on feeding grounds, right whales are often associated with nearshore Continental Shelf areas from 100 to 200 m deep, steeply sloped bottom topography, and areas with distinct frontal zones (Winn et al. 1986). Historical whaling records include accounts of whales taken in areas other than current feeding grounds, indicating that there may have been offshore feeding grounds that are unknown today (Kenney 2002).

During the winter, many mature females move south and are found in coastal waters off the southeastern United States, where they are known to give birth (Winn et al. 1986; Kenney 2002). The geographic location of most of the population, including adult males and juveniles, during the winter months is largely unknown. However, recent passive acoustic monitoring efforts in the SBNMS and Jeffreys Ledge indicate that right whales are predictably present in both areas during the winter months (Mussoline et al. in review).

Right whale calving takes place between December and April in the North Atlantic (Kraus and Rolland 2007b). Calving grounds along the southern United States coast are in cool, shallow coastal regions inshore off Georgia and northeastern Florida (Kraus et al. 1993; Kraus and Rolland 2007b). Although the average age of first calving is nine to ten years, calving has been observed in females as young as five years old (Kenney 2002). Calving occurs at three- to five-year intervals, which may be so that the mother can replenish energy stores lost in long migrations and calving (Kraus et al. 2001; Kenney 2002). Right whale calves are usually born after 12-13 months of gestation at 4.5–6.0 m in length (Best 1994; Kenney 2002). Right whale calves weigh approximately 900 kg at birth, and they grow more than a centimeter every day for the first ten months of their lives. Mothers and calves form a strong bond and the calf spends most of its time swimming close to its mother, often carried in the mother's "slip stream," the wake which develops as the mother swims (Hamilton et al. 1995; Moore et al. 2005). Calves reach 9-11 m in length and are weaned at one year. After year one, growth rates vary depending on the population and feeding success (Kenney 2002). Because of an absence of teeth (which can be used to estimate age in other mammals), it is difficult to tell how old right whales are when they die, but it is estimated that they live up to 70 years and perhaps even older (Kenney 2002).

Sei Whale *(Balaenoptera borealis)*

In the Northwest Atlantic, sei whales are found in temperate waters from Labrador and Newfoundland to the southern Gulf of Maine and New Jersey (CeTAP 1982; Mizroch et al. 1984). This species appears to migrate long distances from high-latitude summer feeding areas to lower latitude winter breeding areas, but the location of these winter areas remains unknown (Horwood 2002). In the Northwest Atlantic, sei whales have been sighted along the eastern Canadian coast in June and July on their way to and from the Gulf of Maine and Georges Bank, where they occur in winter and spring (CeTAP 1982). Peak abundance in the region is in the spring along eastern Georges Bank, into the Northeast Channel, and along the southwest edge of Georges Bank in the area of Hydrographer Canyon (CeTAP 1982). Sighted predominantly in offshore deep waters, they have been known to move sporadically into shallower, inshore waters, including sightings in the Great South Channel in 1987 and 1989 and Stellwagen Bank in 1986 (Payne et al. 1990). In the past five years, sei whales have been sighted more frequently inshore than in previous years likely because of prey availability.

Sei whale distribution is thought to be dependent on prey availability and distribution (Baumgartner and Fratantoni 2008). When copepods are abundant throughout inshore Continental Shelf waters, more whales are found inshore in areas such as in the Great South Channel, on Stellwagen Bank, and inshore in the Gulf of Maine (Payne et al. 1990; Schilling et al. 1992; Horwood 2002). The sei whale is often found in deeper waters of the Continental Shelf edge, often near the 2,000-m contour (Mitchell 1975a; Hain et al. 1985). Sei whale distribution has also been correlated with surface and subsurface fronts, bottom topography, and flow gradients at depths shallower than 100 m (Skov et al. 2008). This species usually feeds on zooplankton in the upper 100 m of the water column, which may explain the positive correlation between whale distribution and flow gradients over steep bottom topography (Genin et al. 1994). Like other baleen species, sei whales are often found in groups when prey items are in high abundances, but are generally seen in smaller groups (Horwood 2002).

Mature adult sei whales range from 12 to 18 m in length, with females being larger than males (Martin 1983). Sexual maturity is reached between the ages of 5 and 15, when males are about 12.2 m and females are 13.1 m (Horwood 2002). Conception is thought to occur during the winter in high latitudes. After a gestation period of about 12 months, females give birth to calves about 4.4 m in length. Calves are weaned 6-9 months after birth at about 9 m in length, and females calve approximately every two to three years (Mizroch et al. 1984).

Sperm Whale *(Physeter macrocephalus)*

Sperm whales have the most extensive geographic distribution of any marine mammal besides the killer whale *(Orcinus orca)*. They are found in all deep, ice-free marine waters from the equator to the edges of polar pack ice (Rice 1989). Sperm whales are also known to be present in some warm-water areas; these might be discrete resident populations (Jaquet et al. 2003; Mellinger et al. 2004). Sperm whales exhibit sex-specific migratory behavior. Only adult males move into high latitudes, while all age classes and both sexes range throughout tropical and temperate seas (Whitehead 2002b). There is some evidence of north-south migration, as whales move towards the poles in the summer months, but in many areas of the world sperm whale migration patterns remain unknown (Whitehead 2002a). Offshore surveys have shown that sperm whales are often solitary and can stay submerged for over 60 minutes at recorded depths of over 2,000 m (Watkins et al. 1993), which makes them difficult to spot by surveyors.

Sperm whale distribution on the East Coast of the United States is centered along the Continental Shelf break and over the Continental Slope from 100 to 2,000 m depth and in submarine canyons and edges of banks (CeTAP 1982; Waring et al. 2008; Mitchell 1975b). Sperm whales are also known to move into waters less than 100 m deep on the southern Scotian Shelf and south of New England, particularly between late spring and autumn (CeTAP 1982; Scott and Sadove 1997). Those areas with historically large numbers of sperm whales and resident populations often coincide with areas of high primary productivity from upwelling (Whitehead 2002b). In addition, sperm whale habitats usually have high levels of deep water biomass. Female sperm whales may be restricted by water temperature, as they have only been sighted in areas with sea surface temperatures greater than 15°C.

Sperm whale life span can be greater than 60 years (Rice 1989). Adult female sperm whales reach up to 11 m in length and 15 tons, while males are much larger at 16 m and 45 tons (Whitehead 2002b). Sperm whales have low birth rates, slow growth and maturation, and high survival rates. Although much about sperm whale breeding is unknown, it is estimated that the peak breeding season in the North Atlantic occurs during spring (March/April to May). Gestation for females is estimated to last 15-18 months and calves average 4 m at birth (Perry et al. 1999). Female sperm whales reach physical maturity at 30 years old and 10.6 m long. Males continue growing into their thirties and do not reach physical maturity until about 50 years old. Males reach sexual maturity at 10-20 years of age, but do not appear to breed until their late twenties (Whitehead 2002b). Female sperm whales are inherently social, and related and unrelated female sperm whales live in groups of up to a dozen individuals accompanied by their male and female offspring (Christal and Whitehead 1997). Males leave the female groups when they are 4-21 years old, after which they live in “bachelor schools” of other juvenile males (Whitehead 2002b). Male sperm whales in these bachelor schools in their late twenties and older are known to rove among groups of females on tropical breeding grounds.

Striped Dolphin *(Stenella coeruleoalba)*

Striped dolphins are found around the world in warm temperate and tropical seas (Archer and Perrin 1999). They appear to prefer Continental Slope waters offshore to the Gulf Stream and have been sighted in dense aggregations along the 1,000-m depth contour in all seasons (CeTAP 1982; Perrin et al. 1994). Off the northeastern coast of the United States, striped dolphins are known to range along the Continental Shelf and out to the shelf slope from Cape Hatteras to the southern edge of Georges Bank (CeTAP 1982). There are also striped dolphins off the coast of the United Kingdom and throughout the Mediterranean Sea (Archer 2002). Striped dolphins are usually uncommon in Canadian waters because of the cold temperatures, but sightings in the Nova Scotia region in the past decade indicate that this species may range farther than previously thought (Gowans and Whitehead 1995).

Striped dolphins are usually found in association with convergence and upwelling zones with high primary productivity. They appear to prefer temperatures of 18-22°C, but are sometimes seen in waters down to 10°C and up to 26°C (Archer 2002). This species mates seasonally and gestation is 12-13 months. Calf length at birth is estimated to be 93-100 cm and sexual maturity is reached at 7-15 years for males and 5-13 years for females and at 2.1-2.2 m for both sexes. Striped dolphins are known to live a maximum of 57.5 years (Archer and Perrin 1999).

Literature Cited

Agler, B. A., R. L. Schooley, S. E. Frohock, S. K. Katona, and I. E. Seipt. 1993. Reproduction of photographically identified fin whales, *Balaenoptera physalus*, from the Gulf of Maine. Journal of Mammology. 74(3): 577-587.

Aguilar, A. 2002. Fin whale *Balaenoptera physalus*. In: W. F. Perrin, B. Würsig, and J. G. M. Thewissen, eds. Encyclopedia of Marine Mammals. Academic Press, San Diego, CA. pp. 435-438.

Aguilar, A. and C. H. Lockyer. 1987. Growth, physical maturity and mortality of fin whales *Balaenoptera physalus* inhabiting the temperate waters of the northeast Atlantic. Canadian Journal of Zoology. 65(2): 253-264.

Atlantic Trawl Gear Take Reduction Team (ATGTRT). 2007. Atlantic trawl gear take reduction team meeting: Final summary. http://www.nero.noaa.gov/prot_res/atgtrp/meeting/ATGTRT%20Meeting%20Summary%20-%20April%202007%20FINAL.pdf.

Archer, F. I. 2002. Striped dolphin (*Stenella coeruleoalba*). In: Perrin, W. F., B. Wursig, and J. G. M Thewissen, eds. Encyclopedia of Marine Mammals. Academic Press. pp. 1201-1203.

Archer, F. I., and W. F. Perrin. 1999. *Stenella coeruleoalba*. Mammalian Species. 603: 1-9.

Barco, S. G., W. M. Swingle, W. A. McLellan, R. N. Harris, and D. A. Pabst. 1999. Local abundance and distribution of bottlenose dolphins (*Tursiops truncatus*) in the nearshore waters of Virginia Beach, Virginia. Marine Mammal Science. 15(2): 394-408.

Barco, S. G., W. A. McLellan, J. M. Allen, R. A. Asmutis-Silvia, R. Mallon-Day, E. M. Meagher, D. A. Pabst, J. Robbins, R. E. Seton, W. M. Swingle, M. T. Weinrich, and P. J.
Clapham. 2002. Population identity of humpback whales (*Megaptera novaeangliae*) in the waters of the US mid-Atlantic states. Journal of Cetacean Research Management. 4(2): 135–141.

Baumgartner, M. F., T. V. N. Cole, R. G. Campbell, G. J. Teegarden, and E. G. Durbin. 2003. Associations between North Atlantic right whales and their prey, *Calanus finmarchicus*, over diel and tidal time scales. Marine Ecology Progress Series. 264: 155-166.

Baumgartner, M. F. and D. M. Fratantoni. 2008. Diel periodicity in both sei whale vocalization rates and the vertical migration of their copepod prey observed from ocean gliders. Limnology and Oceanography. 53(5, part 2): 2197–2209.

Best, P. B. 1994. Seasonality of reproduction and the length of gestation in southern right whales *Eubalaena australis*. Journal of Zoology. 232: 175-189.

Bjorge, A. and K. A. Tolley. 2002. Harbor porpoise (*Phocoena phocoena*). In: Perrin, W. F., B.Wursig, and J. G. M Thewissen, eds. Encyclopedia of Marine Mammals. Academic Press. pp. 549-551.

Bowen, W. D. 1997. Role of marine mammals in aquatic ecosystems. Marine Ecology Progress Series. 158: 267–274.

Caldwell, D. K. and M. C. Caldwell. 1972. The World of the Bottlenose Dolphin. J.B. Lippincott Company. New York, NY. 157 pp.

Campbell-Malone, R., S. G. Barco, P-Y. Daoust, A. R. Knowlton, W. A. McLellan, D. S. Rotstein, M. J. Moore. 2008. Gross and histologic evidence of sharp and blunt trauma in North Atlantic right whales (*Eubalaena glacialis*) killed by vessels. Journal of Zoo Wildlife Medicine. 39(1): 37–55.

CeTAP (Cetacean and Turtle Assessment Program, University of Rhode Island). 1982. A characterization of marine mammals and turtles in the mid- and north Atlantic areas of the United States outer continental shelf, final report. Contract #AA551-CT8-48. Bureau of Land Management, Washington, DC. 538 pp.

Christal, J. and H. Whitehead. 1997. Aggregations of mature male sperm whales on the Galápagos Islands breeding ground. Marine Mammal Science. 13: 59-69.

Cipriano, F. 2002. Atlantic White-sided dolphin (*Lagenorhynchus acutus*). In: Perrin, W.F., B.Wursig, and J. G. M Thewissen, eds. Encyclopedia of Marine Mammals. Academic Press. San Diego, CA. pp.49-51.

Clapham, P. J. and C. A. Mayo. 1990. Reproduction of humpback whales (*Megaptera novaeangliae*) observed in the Gulf of Maine. Report to the International Whaling Commission, Special Issue. 12:171-175.

Clapham, P. J. 1992. Age at attainment of sexual maturity in humpback whales, *Megaptera novaeangliae*. Canadian Journal of Zoology. 70: 1470-1472.

Clapham, P. J. 2002. Humpback whales. In: E. D. Perrin, W. F., B.Wursig, and J. G. M Thewissen, eds. Encyclopedia of Marine Mammals. Academic Press. pp. 589-592.

Clapham, P. J. and C. A. Mayo. 1987. The attainment of sexual maturity in two female humpback whales. Marine Mammal Science. 3(3): 279-283.

Clapham, P. J. and I. E. Seipt. 1991. Resightings of independent fin whales, *Balaenoptera physalus*, on maternal summer ranges. Journal of Mammology. 72: 788-790.

Clapham, P. J. and J. G. Mead. 1999. *Megaptera novaeangliae*. Mammal Species. 604: 1-9.

Clapham, P. J., J. Barlow, M. Bessinger, T. Cole, D. Mattila, R. Pace, D. Palka, J. Robbins, and R. Seton. 2003. Abundance and demographic parameters of humpback whales from the Gulf of Maine, and stock definition relative to the Scotian Shelf. Journal of Cetacean Research and Management. 5: 13-22.

Clark, C. W., D. Gillespie, P. Nowacek, and S. E. Parks. 2007. Listening to Their World: Acoustics for Monitoring and Protecting Right Whales in an Urbanized Ocean. In: Kraus, S. D. and R. M. Rolland RM, eds. The Urban Whale: North Atlantic right whales at the crossroads. Harvard University Press, Cambridge, MA. pp 333-357.

Clark C. W., W. T. Ellison, B. L. Southall, L. T. Hatch, S. M. Van Parijs, A. Frankel, and D. Ponirakis. 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implication. Marine Ecology Progress Series 395: 210-222.

Department of Navy. 2005. Marine Resource Assessment for the Northeast Operating Areas: Atlantic City, Narragansett Bay, and Boston. Naval Facilities Engineering Command, Atlantic; Norfolk, Virginia. Contract Number N62470-02-D-9997, Task Order 0018. Prepared by Geo-Marine, Inc., Newport News, Virginia.

Dolphin, W. F. 1987. Observations of humpback whale, *Megaptera novaeangliae*, killer whale, *Orcinus orca*, interactions in Alaska: comparison with terrestrial predator-prey relationships. Canadian Field Naturalist. 101(1): 70-75.

Donovan, G. P. 1991. A review of IWC stock boundaries. Report to the International Whaling Commission, Special Issue. 13:39-68.

Duffield, D. A. 1986. Investigation of genetic variability in stocks of the bottlenose dolphin (*Tursiops truncatus*). Final report to the NMFS/SEFSC, Contract No. NA83-GA-00036, 53 pp.

Flinn, R. D., A. W. Trites, and E. J. Gregr. 2002. Diets of fin, sei, and sperm whales in British Columbia: An analysis of commercial whaling records, 1963-1967. Marine Mammal Science. 18(3): 663-679.

Fujiwara, M., and H. Caswell. 2001. Demography of the endangered North Atlantic right whale. Nature. 414: 537–541.

Gannon, D. P., J. E. Craddock, and A. J. Read. 1998. Autumn food habits of harbor porpoises, *Phocoena phocoena*, in the Gulf of Maine. Fisheries Bulletin. 96(3): 428-437.

Gambell, R. 1985. Fin whale, *Balaenoptera physalus* (Linnaeus 1758). In: S. H. Ridgeway and R. Harrison, eds. Handbook of Marine Mammals. Academic Press, London, UK. pp. 171-192.

Gaskin, D. E. 1977. Harbour porpoise, *Phocoena phocoena* (L.), in the western approaches to the Bay of Fundy 1969-75. Report to the International Whaling Commission. 27: 487-492.

Gaskin, D. E. 1992. Status of Atlantic white-sided dolphin, *Lagenorhynchus acutus*, in Canada. Canadian Field Naturalist. 106: 64-72.

Genin, A., C. Greene, L. Haury, P. Wiebe, G. Gal, S. Kaartvedt, E. Meir, C. Fey, and J. Dawson. 1994. Zooplankton patch dynamics: daily gap formation over abrupt topography. Deep Sea Research. 41: 941-951.

Geraci, J. R., D. M. Anderson, R. J. Timperi, D. J. St. Aubin, G. A. Early, J. H. Prescott, and C. A. Mayo. 1989. Humpback whales (*Megaptera novaeangliae*) fatally poisoned by dinoflagellate toxin. Canadian Journal of Fisheries and Aquatic Sciences. 46: 1895-1898.

Gowans, S. and H. Whitehead. 1995. Distribution and habitat partitioning by small odontocetes in the Gully, a submarine canyon on the Scotian Shelf. Canadian Journal of Zoology. 73: 1599-1608.

Hain, J. H. W., M. A. M. Hyman, R. D. Kenney, and H. E. Winn. 1985. The role of cetaceans in the shelf-edge region of the United States. Marine Fish Review. 47(1): 13-17.

Hain, J. H., M. J. Ratnaswamy, R. D. Kenney, and H. E. Winn. 1992. The fin whale, *Balaenoptera physalus*, in waters of the northwestern United States continental shelf. Report to the International Whaling Commission. 42: 653-669.

Hamazaki, T. 2002. Spatiotemporal prediction models of cetacean habitats in the mid-western North Atlantic Ocean (from Cape Hatteras, North Carolina, USA to Nova Scotia, Canada). Marine Mammal Science. 18(4): 920-939.

Hancock, D. 1965. Killer whales kill and eat a minke whale. Journal of Mammalogy. 46(2): 341-342.

Hatch, L. T., C. W. Clark, R. Merrick, S. M. Van Parijs, D. Ponirakis, K. Schwehr, M. Thompson, and D. Wiley. 2008. Characterizing the relative contributions of large vessels to total ocean noise fields: a case study using the Gerry E. Studds Stellwagen Bank National Marine Sanctuary. Environmental Management. 42: 735–752.

Hatch L. T. and K. M. Fristrup. 2009. No barrier at the boundaries: implementing regional frameworks for noise management in protected natural areas. Marine Ecology Progress Series. 395: 223-244.

Hatch, L.T., C. W. Clark, R. Merrick, S. M. Van Parijs, D. Ponirakis, K. Schwehr, M. Thompson, and D. Wiley. 2008. Characterizing the relative contributions of large vessels to total ocean noise fields: a case study using the Gerry E. Studds Stellwagen Bank National Marine Sanctuary. Environmental Management. 42:735–752.

Haug, T., H. Gjøsæter, U. Lindstrøm, and K. Nilssen. 1995. Diet and food availability for northeast Atlantic minke whales (*Balaenoptera acutorostrata*) during the summer of 1992. ICES Journal of Marine Science. 52: 77-86.

Heithaus, M. 2001. Predator-prey and competitive interactions between sharks (order Selachii) and dolphins (suborder Odontoceti): a review. Journal of Zoology. 253(1): 53-68.

Horwood, J. 1990. Biology and Exploitation of the Minke Whale. CRC Press, Boca Raton, FL.

Horwood, J. W. 2002. Sei Whale (*Balaenoptera borealis*). In: Perrin, W. F., B.Wursig, and J. G. M Thewissen, eds. Encyclopedia of Marine Mammals. Academic Press. pp.1069-1071.

IWC (International Whaling Commission). 1991. Appendix 11. Biological parameters of North Atlantic minke whales in Annex F Report of the sub-committee on North Atlantic minke whales. Report to the International Whaling Commission. 41:160.

IUCN (International Union of Concerned Scientists). 2008. IUCN Red List of Threatened Species. http://www.iucnredlist.org. Accessed 6/28/08.

Jaquet, N., D. Gendron, and A. Coakes. 2003. Sperm whales in the Gulf of California: Residency, movements, behavior, and the possible influence of variation in food supply. Marine Mammal Science. 19(3): 545-562.

Jefferson, T. A., S. Leatherwood, and M. A. Webber. 1993. FAO Species identification guide. Marine mammals of the world. United Nations Environment Programme/Food and Agriculture Organization. Rome, Italy. 320 pp.

Jensen, A. and G. Silber. 2003. Large Whale Ship Strike Database. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-F/OPR-25, 37 pp.

Johnson, A., G. Salvador, J. Kenney, J. Robbins, S. D. Kraus, S. Landry, and P. Clapham. 2005. Fishing gear involved in entanglements of right and humpback whales. Marine Mammal Science. 21(4): 635-645.

Jonsgård, Å. 1966. Biology of the North Atlantic fin whale *Balaenoplera physalus* (L.) Taxonomy, distribution, migration, and food. Hvalradets Skr. 49: 1-62.

Katona, S. K. and J. A. Beard. 1990. Population size, migrations, and feeding aggregations of the humpback whale (*Megaptera novaeangliae*) in the western North Atlantic Ocean. Report to the International Whaling Commission, Special Issue. 12:295-306.

Katona, S. and H. Whitehead. 1988. Are Cetacea ecologically important? Oceanography And Marine Biology: An Annual Review. 26: 553-568.

Katona, S. K., V. Rough, and D. T. Richardson. 1993. A field guide to whales, porpoises, and seals from Cape Cod to Newfoundland. Smithsonian Institution Press, Washington D.C. 316 pp.

Katona, S. K., S. A. Testeverandde, and B. Barr. 1978. Observations on a white-sided dolphin, *Lagenorhynchus acutus*, probably killed in gill nets in the Gulf of Maine. Fishery Bulletin. 76: 475-476.

Kawamura, A. 1982. Food habits and prey distributions of three rorqual species in the North Pacific Ocean. Scientific Report to the Whale Research Institute. Tokyo, Japan. 34:59-91.

Kenney, R. D., M. A. M. Hyman, and H. E. Winn. 1985. Calculation of standing stocks and energetic requirements of the cetaceans of the northeast United States outer continental shelf. NOAA Tech. Memo. NMFS-F/NEC-41, National Marine Fisheries Service, Woods Hole, MA. 39 pp.

Kenney, R. W. and Winn, H. E. 1986. Cetacean high-use habitats of the northeast United States continental shelf. Fishery Bulletin. 84: 345-357.

Kenney, R. D. 1990. Bottlenose dolphins off the northeastern United States. In: S. Leatherwood and R. R. Reeves, eds. The bottlenose dolphin. Academic Press, Inc. San Diego, California.

Kenney, R. D., H. E. Winn, and M. C. Macaulay. 1995. Cetaceans in the Great South Channel, 1979–1989: right whale (*Eubalaena glacialis*). Continental Shelf Research. 15(4-5): 385-414.

Kenney, R. D., P. M. Payne, D. W. Heinemann, and H. E. Winn. 1996. Shifts in Northeast shelf cetacean distributions relative to trends in Gulf of Maine/Georges Bank finfish abundance. In: K. Sherman, N.A. Jaworski and T. Smayda, eds. The northeast shelf ecosystem: assessment, sustainability, and management. Blackwell Science, Cambridge, MA. pp. 169-196.

Kenney, R. D. 2002. North Atlantic, North Pacific, and southern right whales (*Eubalaena glacialis*, *E. japonica*, and *E. australis*). In: Perrin, W. F., B.Wursig, and J. G. M Thewissen, eds. Encyclopedia of Marine Mammals. Academic Press. pp. 806-813.

Ketten, D. R. 1995. Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. In R. A. Kastelein, J. A. Thomas, and P. E. Natchigall, eds. Sensory systems of aquatic mammals, De Spil Publ., Woerden, Netherlands. pp. 391-407.

Knowlton, A. R., M. K. Marx, H. M. Pettis, P. K. Hamilton, and S. D. Kraus. 2005. Analysis of scarring on North Atlantic right whales (*Eubalaena glacialis*): Monitoring rates of entanglement interaction: 1980 - 2002. Report No. Contract #43EANF030107.

Kraus, S. D., J. H. Prescott, and G. S. Stone. 1983. Harbor porpoise, *Phocoena phocoena*, in the United States coastal waters of the Gulf of Maine: A survey to determine seasonal distribution and abundance. National Marine Fisheries Service, Woods Hole, MA. 15 pp.

Kraus, S. D., M. J. Crone, and A. R. Knowlton. 1988. The North Atlantic right whale. In: Audubon Wildlife Report 1988/1989. W. J. Chandler, ed. New York: Academic Press.

Kraus, S. D., R. D. Kenney, A. R. Knowlton, and J. N. Ciano. 1993. Endangered right whales of the southwestern North Atlantic. Final report, Minerals Management Service Contract No. 14-35-0001-30486. Edgerton Research Laboratory, New England Aquarium, Boston, MA.

Kraus, S. D., P. K. Hamilton, R. D. Kenney, A. Knowlton and C. K. Slay. 2001. Reproductive parameters of the North Atlantic right whale. Journal of Cetacean Research and Management, Special Issue. 2: 231-236.

Kraus, S. D., Brown, M. W., Caswell, H., Clark, C. W., Fujiwara, M., Hamilton, P. K., Kenney, R. D, A. R. Knowlton, S. Landry, C. A. Mayo, W. A. McLellan, M. J. Moore, D. P. Nowacek, D. A. Pabst, A. J. Read, and R. M. Rolland. 2005. North Atlantic right whales in crisis. Science. 309: 561–562.

Kraus S. D. and R. M. Rolland, eds. 2007a. The Urban Whale: North Atlantic right whales at the crossroads. Harvard University Press, Cambridge, MA.

Kraus, S. D. and R. M. Rolland. 2007b. Right whales in the Urban Ocean. In: Kraus, S. D. and R. M. Rolland, eds. The Urban Whale: North Atlantic right whales at the crossroads. Harvard University Press, Cambridge, MA. pp. 1-38.

Large Whale Take Reduction Team (LWTRT). 1997. Draft large whale take reduction plan. Submitted to National Marine Fisheries Service. http://www.nero.noaa.gov/whaletrp/plan/1997%20Draft%20ALWTRP.pdf.

Larsen, F. and P. S. Hammond. 2004. Distribution and abundance of West Greenland humpback whales (*Megaptera novaeangliae*). Journal of Zoology. 263: 343-358.

Laws, R. M. 1961. Reproduction, growth, and age of southern fin whales. Discovery Reports. 31: 327-486.

Mackintosh, N. A. 1965. The stocks of whales. Fishing News (Books) Ltd., London, UK. 232 pp.

Macleod, K., R. Fairbairns, A. Gill, B. Fairbairns, J. Gordon, C. Blair-Myers, and E. C. M. Parsons. 2004. Seasonal distribution of minke whales *Balaenoptera acutorostrata* in relation to physiography and prey off the Isle of Mull, Scotland. Marine Ecology Progress Series. 277: 263-274.

Martin, A. R. 1983. The sei whale off western Iceland. I. Size, distribution and abundance. Report to the International Whaling Commission. 33: 457-463.

Martin, A. R., S. K. Katona, D. Mattila, D. Hembree, and T. D. Waters. 1984. Migration of humpback whales between the Caribbean and Iceland. Journal of Mammalogy. 65:330-333.

Mellinger, D. K., K. M. Stafford, and C. G. Fox. 2004. Seasonal occurrence of sperm whales (*Physeter macrocephalus*) sounds in the Gulf of Alaska, 1999-2001. Marine Mammal Science. 20: 48-62.

Mitchell, E. 1975a. Preliminary report on Nova Scotia fishery for sei whales (*Balaenoptera borealis*). Report to the International Whaling Commission. 25: 218-225.

Mitchell, E. 1975b. Preliminary report on Nova Scotian fishery for sperm whales (*Physeter catodon*). Report to the International Whaling Commission. 25: 226-235.

Mitchell, E. 1975c. Trophic relationships and competition for food in Northwest Atlantic whales. Proceedings of the Canadian Society of Zoology Annual Meeting. 1974: 123-133.

Mitchell, E., V. M. Kozicki, and R. R. Reeves. 1986. Sightings of right whales, *Eubalaena glacialis*, on the Scotian Shelf, 1966-1972. Report to the International Whaling Commission, Special Issue. 10: 83-107.

Mitchell, E. D. 1991. Winter records of the minke whale (*Balaenoptera acutorostrata* Lacepede 1804) in the southern North Atlantic. Report to the International Whaling Commission. 41: 455-457.

Mizroch, S. A., D. W. Rice, and J. M. Breiwick. 1984. The sei whale, *Balaenoptera borealis*. Marine Fish Review. 46(4): 25-29.

Mussoline, S. E., C. W. Clark, P. J. Corkeron, R. Dickey, L. T. Hatch, J. Keiran, R. Merrick, A. Rhoads, D. Risch, M. Thompson, M. Weinrich, F. Wenzel, D. Wiley, and S. M. Van Parijs. In review. Seasonal and spatial patterns of North Atlantic right whale upcalling behavior in the northwest Atlantic: implications for management and conservation.

NMFS (National Marine Fisheries Service). 1991. Recovery Plan for the Humpback Whale (*Megaptera novaeangliae*). Prepared by the Humpback Whale Recovery Team for the National Marine Fisheries Service. Silver Spring, Maryland.

NMFS (National Marine Fisheries Service). 1994. Designated critical habitat; northern right whale. Final rule. Federal Register. http://www.nmfs.noaa.gov/pr/pdfs/fr/fr59-28805.pdf. Accessed 06/24/08.

NMFS (National Marine Fisheries Service). 2001. Stock structure of coastal bottlenose dolphins along the Atlantic coast of the US. NMFS/SEFSC Report prepared for the Bottlenose Dolphin Take Reduction Team.

NMFS (National Marine Fisheries Service). 2005. Recovery plan for the North Atlantic right whale (*Eubalaena glacialis*). National Marine Fisheries Service, Silver Spring, Maryland.

NMFS (National Marine Fisheries Service). 2006a. Draft Management Plan for the Fin Whale (*Balaenoptera physalus)*. Silver Spring, Maryland.
http://www.nmfs.noaa.gov/pr/pdfs/recovery/draft_finwhale.pdf. Accessed June 27, 2008.

NMFS (National Marine Fisheries Service). 2006b. Taking of marine mammals incidental to commercial fishing operations; Bottlenose Dolphin Take Reduction Plan Regulations; Sea turtle conservation; Restrictions to fishing activities. Federal Register. Silver Spring, Maryland.

NMFS (National Marine Fisheries Service). 2006c. Draft recovery plan for the sperm whale (*Physeter macrocephalus*). Silver Spring, Maryland. http://www.nmfs.noaa.gov/pr/pdfs/recovery/draft_spermwhale.pdf. Accessed 6/27/2008

NMFS (National Marine Fisheries Service). 2007b. Large Whale Entanglement and Ship Strike Report. National Marine Fisheries Service, Protected Resources Division, Gloucester, Massachusetts.

NOAA (National Oceanic and Atmospheric Administration). 2007b . The Marine Mammal Protection Act of 1972 As Amended. Silver Spring, Maryland. http://www.nmfs.noaa.gov/pr/pdfs/laws/mmpa.pdf . Accessed June 27, 2008.

NOAA (National Oceanic and Atmospheric Administration). 2008a. Bottlenose Dolphin (*Tursiops truncatus*): Western North Atlantic Offshore Stock. Silver Spring, Maryland.http://www.nmfs.noaa.gov/pr/pdfs/sars/ao2008dobn-wnos.pdf. Accessed November 15, 2009.

NOAA (National Oceanic and Atmospheric Administration). 2008b. Bottlenose Dolphin (*Tursiops truncatus*): Western North Atlantic Coastal Morphotype Stocks. Silver Spring, Maryland.
http://www.nmfs.noaa.gov/pr/pdfs/sars/ao2008dobn-wnco.pdf. Accessed November 15, 2009.

NOAA (National Oceanic and Atmospheric Administration). 2008c. Sei Whale (Balaenoptera Borealis): Nova Scotia Stock. Silver Spring, Maryland. http://www.nmfs.noaa.gov/pr/pdfs/sars/ao2008whse-ns.pdf. Accessed November 23, 2009.

NOAA (National Oceanic and Atmospheric Administration). 2008d. Harbor Porpoise (Phocoena phocoena): Gulf of Maine/Bay of Fundy Stock. Silver Spring, Maryland. http://www.nmfs.noaa.gov/pr/pdfs/sars/ao2008poha-gmeb.pdf. Accessed November 20, 2009.

Naud, M-J, B. Long, J-C. Brethes, and R. Sears. 2003. Influences of underwater bottom topography and geomorphology on minke whale (*Balaenoptera acutorostrata*) distribution in the Mingan Islands (Canada). Journal of the Marine Biology Association of the UK. 83: 889-896.

Nemoto, T. 1959. Food of baleen whales with reference to whale movements. Scientific Reports of the Whales Research Institute, Tokyo 14:149-290.

North Atlantic Right Whale Consortium. 2009. 01 November 2007 – 30 April 2009. North Atlantic Right Whale Consortium, New England Aquarium, Boston, MA.

Northridge, S., M. Tasker, A. Webb, K. Camphuysen, and M. Leopold. 1997. White-beaked *Lagenorhynchus albirostris* and Atlantic white-sided dolphin *L. acutus* distributions in northwest European and United States North Atlantic waters. Report to the International Whaling Commission. 47: 797-805.

Nowacek, D., M. P. Johnson, and P. L. Tyack. 2004. North Atlantic right whales (*Eubalaena glacialis*) ignore ships but respond to alerting stimuli. Proceedings of the Royal Society of London. B 271: 227-231.

NRC (National Research Council of the US National Academies). 2003. Ocean noise and marine mammals. National Academy Press, Washington, DC.

NRC (National Research Council of the US National Academies). 2005. Marine mammal populations and ocean noise: determining when ocean noise causes biologically significant effects. National Academy Press, Washington, DC.

Palka, D. 1995. Influences on spatial patterns of Gulf of Maine harbor porpoises. In: A.S. Blix, L. Walle and . Ulltang, eds. Whales, seals, fish and man. Elsevier Science B.V., Netherlands. pp. 69-75.

Parks, S. E. and C. W. Clark. 2007. Acoustic Communication: Social Sounds and the Potential Impact of Noise. In: Kraus, S. D. and R. M. Rolland, eds. The Urban Whale: North Atlantic right whales at the crossroads. Harvard University Press, Cambridge, MA, pp. 310-332.

Payne, M. and D. W. Heinemann. 1990. A distributional assessment of cetaceans in the shelf and shelf edge waters of the northeastern United States based on aerial and shipboard surveys, 1978-1988. National Marine Fisheries Service, Woods Hole, MA. 108 pp.

Payne, P. M., J. R. Nicholas, L. O'Brien, and K. D. Powers. 1986. The distribution of the humpback whale, *Megaptera novaeangliae*, on Georges Bank and in the Gulf of Maine in relation to changes in selected prey. Fisheries Bulletin. 84: 271-277.

Payne, P. M., D. N. Wiley, S. B. Young, S. Pittman, P. J. Clapham, and J. W. Jossi. 1990. Recent fluctuations in the abundance of baleen whales in the southern Gulf of Maine in relation to changes in selected prey. Fisheries Bulletin. 88: 687-696.

Perrin, W. F., C. E. Wilson and F. I. Archer II. 1994. In: S. H. Ridgway and R. Harrison, eds., Handbook of Marine Mammals, Volume 5: The first book of dolphins, Academic Press, London. pp. 129-159.

Perrin, W. F., and R. L. Brownell. 2002. Minke whales (*Balaenoptera acutorostrata* and *B. bonaerensis*) In: Perrin, W.F., B.Wursig, and J. G. M. Thewissen, eds. Encyclopedia of Marine Mammals. Academic Press, London. pp. 750-754.

Perry, S. L., D. P. DeMaster, and G. K. Silber. 1999. The great whales: History and status of six species listed as endangered under the United States Endangered Species Act of 1973. Marine Fisheries Review. 61:1-74.

Pitman, R. L., L. T. Ballance, S. I. Mesnick, and S. J. Chivers. 2001. Killer whale predation on sperm whales: Observations and implications. Marine Mammal Science. 17(3): 494-507.

Rasmussen, K., D. M. Palacios, J. Calambokidis, M. T. Saborio, L. Dalla Rosa, E. R. Secchi, G. H. Steiger, J. M. Allen, and G. S. Stone. 2007. Southern Hemisphere humpback whales wintering off Central America: insights from water temperature into the longest mammalian migration. Biology Letters. 3: 302-305.

Read, A. 2002. Porpoises, overview. In: Perrin, W.F., B.Wursig, and J. G. M. Thewissen, eds. Encyclopedia of Marine Mammals. Academic Press. pp. 982-983.

Read, A. J. and A. J. Westgate. 1997. Monitoring the movements of harbour porpoises (*Phocoena phocoena*) with satellite telemetry. Marine Biology. 130: 315-22.

Reeves, R. R., B. D. Smith, E. A. Crespo, and G. Notarbartolo di Sciara. 2003. Dolphins, Whales and Porpoises: 2002-2010 Conservation Action Plan for the World's Cetaceans. IUCN/SSC Cetacean Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK.

Rice, D. W. 1989. Sperm whale *Physeter macrocephalus.* In: S. H. Ridgway and R. Harrison, eds. Handbook of Marine Mammals, Volume 4: The First Book of Dolphins, Academic Press, London. pp. 177-233.

Richardson, W. J., C. R. Greene, C. I. Malme, and D. H. Thomson. 1995. Marine Mammals and Noise. Elsevier, New York, NY. 576 pp.

Robbins, J., and D.K. Mattila. 2004. Estimating humpback whale (*Megaptera novaeangliae*) entanglement rates on the basis of scar evidence. Report to the National Marine Fisheries Service. Order number 43ENNF030121.

Robbins, J. 2007. Structure and dynamics of the Gulf of Maine humpback whale population. Ph.D., University of St. Andrews.

Rolland, R. M., K. E. Hunt, G. J. Doucette, L. G. Rickard, and S. K. Wasser. 2007. The Inner Whale: Hormones, Biotoxins, and Parasites. In: Kraus, S.D. and R. M. Rolland, eds. The Urban Whale: North Atlantic right whales at the crossroads. Harvard University Press, Cambridge, MA. pp 232-266.

SBNMS (Stellwagen Bank National Marine Sanctuary). 2009. Science: Shifting the Boston Traffic Separation Scheme (TSS). http://stellwagen.noaa.gov/science/tss.html. Accessed November 13, 2009.

Scheifele, P. M. and M. Darre. 2005. Noise levels and sources in the Stellwagen Bank National Marine Sanctuary and the St. Lawrence River Estuary. Marine Conservation Series MSD-05-1. U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Marine Sanctuaries Division, Silver Spring, MD. 26pp.

Schilling, M. R., I. Seipt, M. T. Weinrich, S. E. Frohock, A. E. Kuhlberg, and P. J. Clapham. 1992. Behavior of individually-identified sei whales Balaenoptera borealis during an episodic influx into the southern Gulf of Maine in 1986. Fishery Bulletin. 90: 749–755.

Scott, T. M., and S. S. Sadove. 1997. Sperm whale, *Physeter macrocephalus*, sightings in the shallow shelf waters off Long Island, New York. Marine Mammal Science. 13: 317-321.

Seipt, I. E., P. J. Clapham, C. A. Mayo, and M. P. Hawvermale. 1990. Population characteristics of individually identified fin whales, *Balaenoptera physalus*, in Massachusetts Bay. Fishery Bulletin. 88: 271-278.

Sergeant, D. E., D. J. St. Aubin, and J. R. Geraci. 1980. Life history and Northwest Atlantic status of the Atlantic white-sided dolphin, *Lagenorhynchus acutus*. Cetology. 37: 1-12.

Shoop, C. R., and R. D. Kenney. 1992. Seasonal distributions and abundances of loggerhead and leatherback sea turtles in waters of the northeastern United States. Herpetology Monographs. 6: 43-57.

Skov, H., T. Gunnlaugsson, W. P. Budgell, J. Horne, L. Nottestad, E. Olsen, H. Soiland, G. Vikingsson, and G. Waring. 2008. Small-scale spatial variability of sperm and sei whales in relation to oceanographic and topographic features along the Mid-Atlantic Ridge. Deep Sea Research II. 55(1-2): 254-268.

Smith, R. J., and A. J. Read. 1992. Consumption of euphausiids by harbor porpoise (*Phocoena phocoena*) calves in the Bay of Fundy. Canadian Journal of Zoology. 70: 1629-1632.

Smith, S. and H. Whitehead. 2000. The diet of Galapagos sperm whales *Physeter macrocephalus* as indicated by fecal sample analysis. Marine Mammal Science 16(2): 315-325.

Stevick, P. T., J. Allen, P. J. Clapham, S. K. Katona, F. Larsen, J. Lien, D. K. Mattila, P. J. Palsbøll, R. Sears, J. Sigurjønsson, T. D. Smith, G. Vikingsson, N. Øien, and P. S. Hammond. 2006. Population spatial structuring on the feeding grounds in North Atlantic humpback whales. Journal of Zoology. 270:244-255.

Southall, B. L., A. E. Bowles, W. E. Ellison, J. J. Finneran, R. L. Gentry, C. R. Greene Jr., D. Kastak, D. R. Ketten, J. H. Miller, P. E. Nachtigall, W. J. Richardson, J. A. Thomas, and P. L. Tyack. 2007. Marine mammal noise exposure criteria: initial scientific recommendations. Aquatic Mammology. 33: 411-521.

Swingle, W. M., S. G. Barco, and T. D. Pitchford. 1993. Appearance of juvenile humpback whales feeding in the nearshore waters of Virginia. Marine Mammal Science 9(3): 309-315.

Torres, L. G., W. A. McLellan, E. Meagher, and D. A. Pabst. 2005. Seasonal distribution and relative abundance of bottlenose dolphins, *Tursiops truncatus*, along the US mid-Atlantic Coast. Journal of Cetacean Research and Management. 7(2): 153–161.

Waring, G. T., E. Josephson, C. P. Fairfield-Walsh, and K. Maze-Foley, eds. 2008. US Atlantic and Gulf of Mexico Marine Mammal Stock Assessments - 2007. NOAA Tech. Memo. NMFS-NE-205. National Marine Fisheries Service, Woods Hole, MA. 423 pp.

Watkins, W. A. , M. A. Paker, K. M. Fristrup, T. J. Howald, and G. Notarbartolo Di Sciara. 1993. Sperm whales tagged with transponders and tracked underwater by sonar. Marine Mammal Science. 9(1):55-67.

Watkins, W. A., and W. E. Schevill. 1975. Sperm whales (*Physeter catodon*) react to pingers. Deep Sea Research. 22: 123-129.

Watkins, W. A., K. E. Moore, and P. Tyack. 1985. Sperm whale acoustic behaviors in the southeast Caribbean. Cetology 49:1-15.

Weinrich, M. T., M. Martin, R. Griffiths, J. Bove, and M. Schilling. 1997. A shift in distribution of humpback whales, *Megaptera novaeangliae,* in response to prey in the southern Gulf of Maine. Fishery Bulletin. 95: 826-836.

Weinrich, M. T. 1998. Early experience in habitat choice by humpback whales *Megaptera novaeangliae.* Journal of Mammalogy. 79: 163-170.

Weinrich, M., 1999. Behavior of a humpback whale (*Mepagptera novaeangliae*) upon entanglement in a gill net. Marine Mammal Science. 15: 559-563.

Weinrich, M., and C. Corbelli. 2009. Does whale watching in Southern New England impact humpback whale (*Megaptera novaeangliae*) calf production or calf survival? Biological Conservation. 142:2931-2940.

Wells, R. S. and M. D. Scott. 2002. Bottlenose dolphins. In: Perrin, W. F., B. Würsig, and J. G. M. Thewissen, eds. Encyclopedia of marine mammals. Academic Press, San Diego, CA. pp.122-128.

Wells, R. S. and M. D. Scott. 1999. Bottlenose dolphin - *Tursiops truncatus* (Montagu, 1821) In: Handbook of Marine Mammals. Ridgway, S. H. and S. R. Harrison, Vol. 6: The second book of dolphins and porpoises. pp. 137 – 182.

Westgate, A. J., A. J. Read, T. M. Cox, T. D. Schofield, B. R. Whitaker, and K. E. Anderson. 1998. Monitoring a rehabilitated harbor porpoise using satellite telemetry. Marine Mammal Science. 14(3): 599-604.

Whitehead, H. 2002a. Estimates of the current global population size and historical trajectory for sperm whales. Marine Ecology Progress Series. 242: 295-304.

Whitehead, H. 2002b. Sperm whales (*Physester catodon*). In: Perrin, W.F., B.Wursig, and J. G. M Thewissen, eds. Encyclopedia of Marine Mammals. Academic Press. pp.1165-1172.

Wiley, D. N., G. Early, C. A. Mayo, and M. J. Moore. 2001. The rescue and release of mass stranded cetaceans from beaches on Cape Cod, MA: A review of some response actions. Aquatic Mammals. 27(2): 162-171.
Wiley, D. N., F. W. Wenzel and S. B. Young. 1994. Extralimital residency of bottlenose dolphins in the western North Atlantic. Marine Mammal Science 10(2): 223-226.

Wiley, D. N., J. C. Moller and K. Zilinskas. 2003. The distribution and density of commercial fisheries and baleen whales within the Stellwagen Bank National Marine Sanctuary: July 2001-June 2002. Marine Technology Society Journal. 37(1): 35-53.

Wiley, D. N., J. C. Moller, R. M. Pace, and C. Carleson. 2008. Effectiveness of Voluntary Conservation Agreements: Case Study of Endangered Whales and Commercial Whale-Watching. Conservation Biology. 22(2): 450-457

Winn, H. E., C. A. Price and P. W. Sorensen. 1986. The distributional biology of the right whale (*Eubalaena glacialis*) in the western North Atlantic. Report to the International Whaling Commission, Special Issue 10:129-138.

Wishner, K., E. D. Durbin, A. Durbin, M. Macaulay, H. Winn, and R. Kenney. 1988. Copepod patches and right whales in the Great South Channel off New England. Bulletin of Marine Science. 43(3): 825-844.

CHAPTER

11

Sea Turtle

Adam Whelchel and Melissa Clark

Introduction

© David Vogel, U.S. Fish & Wildlife

Sea turtles are an important component of the north Atlantic ecosystem because they are highly migratory, long-lived, slow growing, and utilize a diverse array of oceanic, neritic, and terrestrial ecosystems. For these very reasons, sea turtles present a unique conservation challenge. While they have been the focus of a multitude of international treaties, conventions, national laws, and regulatory protection, there is still a clear need for greater understanding of temporal and spatial distribution and migratory patterns, degree and importance of threat sources on various life stages, and ongoing population trend analyses via international monitoring and research efforts. Three sea turtle species were chosen for inclusion in this analysis.

Technical Team Members

Kara Dodge, University of New Hampshire
Melissa Clark, The Nature Conservancy, Eastern Division
Mark Swingle, Virginia Aquarium and Marine Science Center
Adam Whelchel, Ph.D., The Nature Conservancy, Connecticut

Selection of Target Species

The three species of sea turtle selected for the assessment are currently found within the Northwest Atlantic region:

- Green sea turtle *(Chelonia mydas)*
- Leatherback *(Dermochelys coriacea)*
- Loggerhead *(Caretta caretta)*

The Kemp's ridley turtle *(Lepidochelys kempii)* is the fourth species of turtle found in the region. Currently, there is not adequate information on the distribution of this species in the region to include it in this report.

Population Status and the Importance of Northwest Atlantic region

In the United States, all three target species are federally listed as endangered or threatened species. Loggerhead turtles are considered threatened throughout their range; green sea turtles are listed as endangered in Florida and the Pacific Coast of Mexico and threatened for all other

© Linda Schonknecht

populations; leatherback turtles are listed as endangered throughout their range. According to the International Union for Conservation of Nature (IUCN) Red List (2007a, b, c), both the loggerhead and green turtles are categorized as "Endangered" while the leatherback is considered "Critically Endangered." These species are protected against international trade (CITES 1979).

Variable and/or sporadic survey efforts coupled with species specific sources of variation (e.g., remigration intervals and clutch frequency) have precluded a comprehensive global population abundance and trend analysis over long periods for these species. For the loggerhead, the two primary global nesting aggregations with greater than 10,000 nesting females per year are South Florida (United States) and Masirah (Oman, Arabian Sea) (Baldwin et al. 2003; NMFS USFWS 2008). Over the past decade, estimates for United States nesting aggregations have fluctuated between 47,000 and 90,000 nests per year, with 80% of nesting occurring in eastern Florida (NMFS USFWS 2008). Over an 18 year period, the total number of nests in Florida has declined by 28% with a more pronounced decline of 43% since 1998. Declining population trends have also been reported over the past decade for nesting aggregations outside Florida including the southeastern United States, the Bahamas, and Mexico (NMFS USFWS 2008). For the green turtle, the mean annual number of nesting females has declined by approximately 48% (173,429 to 90,403 individuals) to 67% (266,133 to 88,499 individuals) over the last three generations across 32 globally distributed subpopulations (IUCN Marine Turtle Specialist Group 2004). Despite the global decline of green turtles over the past 150 years, all but one of the subpopulation index sites (Venezuela, Aves Island) in the IUCN's Western Atlantic Ocean and Caribbean Region witnessed percentage increases including the United States (Florida). This IUCN region represents approximately 30% of the overall global population of nesting females. For the leatherback, population decreases and collapse have been documented in major nesting areas globally. A recent assessment puts the current adult population in the North Atlantic between 34,000 and 94,000 adult females (Turtle Expert Working Group 2007). For seven Atlantic Ocean populations with a minimum of 10 years of nesting data, populations appear to be stable or increasing with the exception of West Africa and Western Caribbean (Turtle Expert Working Group 2007). Standardized nest counts suggest that the Florida population has increased from 98 nests (1989) to 900 nests per season (2006).

In the Northwest Atlantic, the most comprehensive study of the distribution of loggerhead and leatherback turtles was completed by Shoop and Kenney (1992). Based on three years of aerial and shipboard surveys, they estimated that the total summer population of loggerhead was between 2,200 and 11,000 individuals and the leatherback population was between 100 and 900 individuals (Shoop and Kenney 1992).

Ecosystem Interactions and Ecological Dependencies

Sea turtle diet varies by species, life stage and habitat zone (i.e., oceanic, neritic (< 200m)). During the loggerhead's post-hatchling transition stage, individuals forage on organisms associated with floating material such as *Sargassum* including hydroids and copepods (Witherington 2002). During the oceanic stage, juveniles typically consume coelenterates and salps (Bjorndal 1997, 2003). As juveniles transition from oceanic to neritic habitats, diets become more diverse and shift according to season and geographic position. In the North Atlantic, neritic stage adults forage primarily on mollusks and benthic crabs. The diet of oceanic stage adults is currently unknown (NMFS USFWS 2008).

Information regarding green turtle ecosystem interactions during the juvenile oceanic stage is largely unknown. Upon recruitment back to coastal areas, neritic juveniles subsist primarily on sea grasses and marine algae (NMFS USFWS 2007a). The availability of food items within coastal foraging areas may vary seasonally and interannually. The diet of migratory oceanic adults is currently unknown.

Leatherbacks forage primarily on pelagic gelatinous organisms including jellyfish (medusae), siphonophores, and salps in temperate and boreal latitudes (NMFS USFWS 1992, 2007b). Surface feeding is the most commonly observed foraging habit for leatherbacks, but dive data indicate that they may forage throughout the water column.

The ecological significance of these species within both the neritic and oceanic zones during juvenile and adult life stages may be relatively limited due to current population sizes in the Northwest Atlantic. As populations of these long-lived, slow growing species recover, their importance and potential habitat modification ability (e.g., bioturbation, infaunal mining) may become more apparent particularly for loggerhead and green turtles within coastal estuaries of the Northwest Atlantic (Bjorndal 2003). The large migrations undertaken by leatherback turtles across geographically disparate habitats may further limit this species' ecological influence; however, this species' highly specialized diet may help regulate population levels of preferred prey items in certain coastal and shelf habitats within the region.

Northwest Atlantic Distribution and Important Areas

Methods

Geospatial data for turtles were obtained from the United States Navy's Marine Resource Assessments, primarily collected via aerial and shipboard surveys during daylight hours, weather permitting. Data used were from the Navy's Northeast Marine Resource Assessment study region, which covers the entire region except for the mouth of the Chesapeake Bay west of 75.67°W longitude. This gap was filled with data from the Navy's Southeast Marine Resource Assessment study region, shown in pink in Figure 1. The seasons used in the Northeast were winter: January – March; spring: April – June; summer: July – September; and fall: October - December. The dates used in the Southeast were winter: December 6 - April 5; spring: April 6 - July 13; summer: July 14 - September 16; and fall: September 17 - December 5. Therefore, data for each study were processed independently, but displayed together on the map.

A standard approach to overcoming potential survey bias introduced by uneven effort (actual sightings or artifact of enhanced survey effort) is by using effort-corrected sightings data (Kenney and Winn 1986; Shoop and Kenney

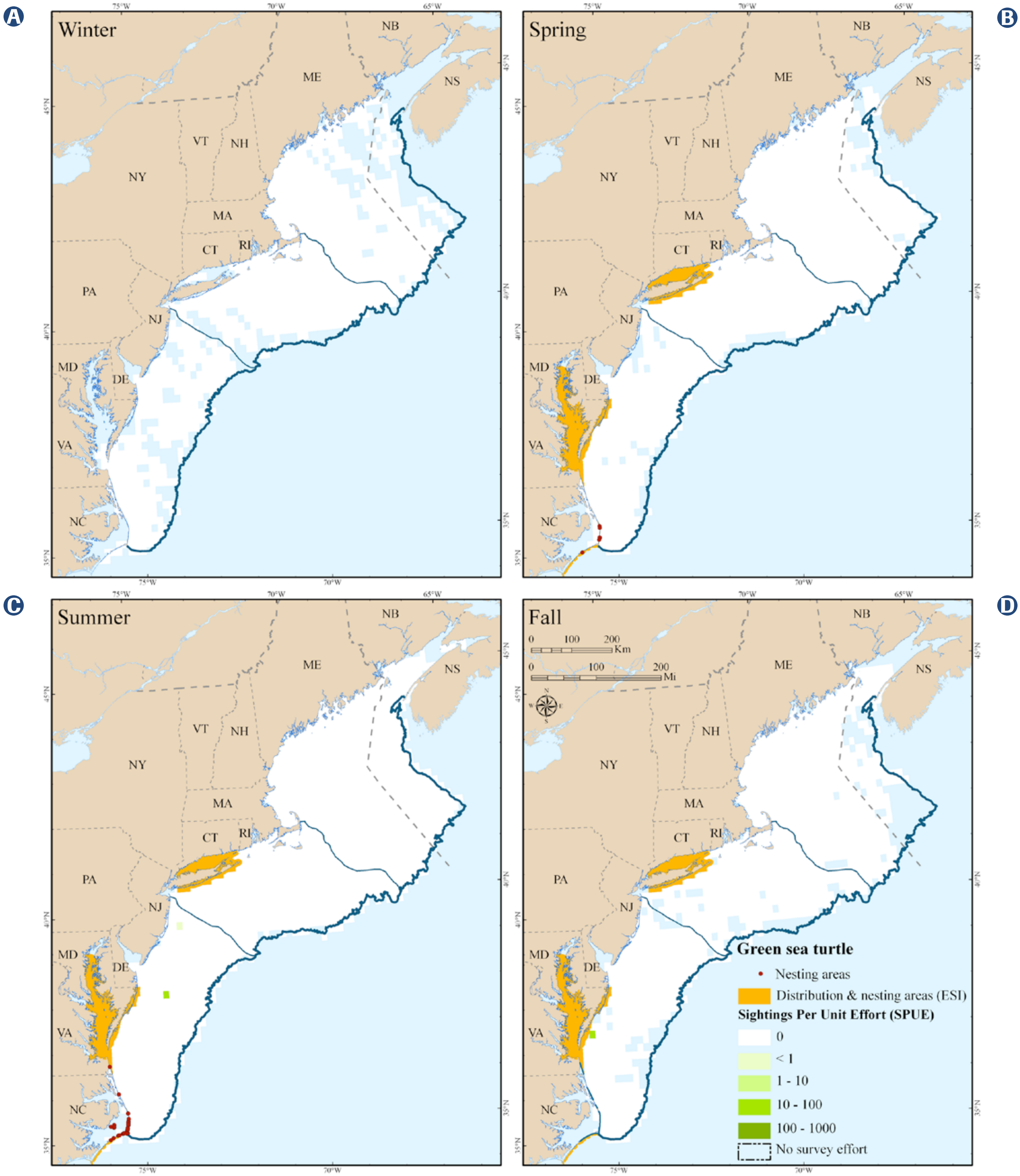


Figure 11-1. Green sea turtle sightings per unit effort (SPUE) and nesting locations by season.

1992). Calculating sightings per unit effort (SPUE) allowed for comparing data spatially and temporally within a study area (Shoop and Kenney 1992). SPUE is calculated as:

SPUE = 1000*(number of animals sighted)/effort

Data obtained from the Navy included point shapefiles of valid sightings for all turtle species and pre-calculated effort grids for each season. The original sightings data were taken from National Marine Fisheries Service and Northeast Fisheries Science Center (NMFS-NEFSC) aerial surveys, NMFS-NEFSC shipboard surveys, and the North Atlantic Right Whale Consortium database. The data were carefully screened and verified by Navy contractors before inclusion in the model. Invalid records were not included in the analysis. The data set constitution (multiple efforts, geographic scope over several decades) precludes the ability to assess trends. Sightings were spatially and temporally oriented towards marine mammals with opportunistic recording of sea turtles. Using the formula above, SPUE was calculated for each species, for each season, and for each ten minute square.

Nesting data, compiled from state sources, were mapped and incorporated into the analysis to identify important coastal areas. For Virginia and North Carolina, nesting locations were obtained from state experts. For the other states in the region, the National Oceanic and Atmospheric Administration (NOAA) Environmental Sensitivity Index (ESI) data were used to represent the nesting and distribution areas.

Maps, Analysis, and Areas of Importance

Leatherback Turtle

The assessment results suggest that the distribution of leatherbacks within the region varies by season (Figure 11-1). Observations (n = 187; years = 1979 to 2003) were primarily in the summer months. The sightings during the spring and fall were limited and widely distributed. No observations were available during the winter months. Observations during the summer months were concentrated along the inner Continental Shelf and adjoining coastal areas from Maryland to southern Long Island, New York. In addition, a relatively large number of sightings were concentrated along the shelf break off Virginia to the northern portions of the region. The leatherback had a more northern distribution than the loggerhead turtle, with multiple sightings in the Gulf of Maine, the Southern New England shelf, and off the coast of Nova Scotia. Documented nesting initiated during the months of April, May, and June occurred in North Carolina (n=4). According to the ESI data, areas of concentration were more northern in extent than the other two species: northern New Jersey, Connecticut, and Rhode Island Coasts.

The seasonality of the sightings, with the majority of the sightings in the summer, follow the general pattern of increased turtle sightings as waters warm in the summer months (Braun-McNeil and Epperly 2002). The relatively high concentrations of sightings in the south central portion of inner shelf and coastal areas suggests that those areas are potentially of greater importance for the leatherback. The data set precludes an assessment by life stage (adult, juvenile) as well as use of larger coastal estuaries such as Chesapeake Bay, Delaware Bay, and Long Island Sound.

Green Sea Turtle

Green sea turtle observations in the region included in the dataset were limited to five sightings during the summer and fall months in the south central portions of the shelf (Figure 11-2). A limited number of nests initiated during the months of June, July, and August were documented in northern North Carolina (n=15) and the ocean coast of Virginia (n=1). Areas of concentration, as per the ESI data, were more widespread than the loggerhead turtles: around Long Island, the Maryland and Virginia Shore, and the majority of the Chesapeake Bay. Because of the limited amount of data currently available for this species, interpretations of potentially important areas in the region are unwarranted.

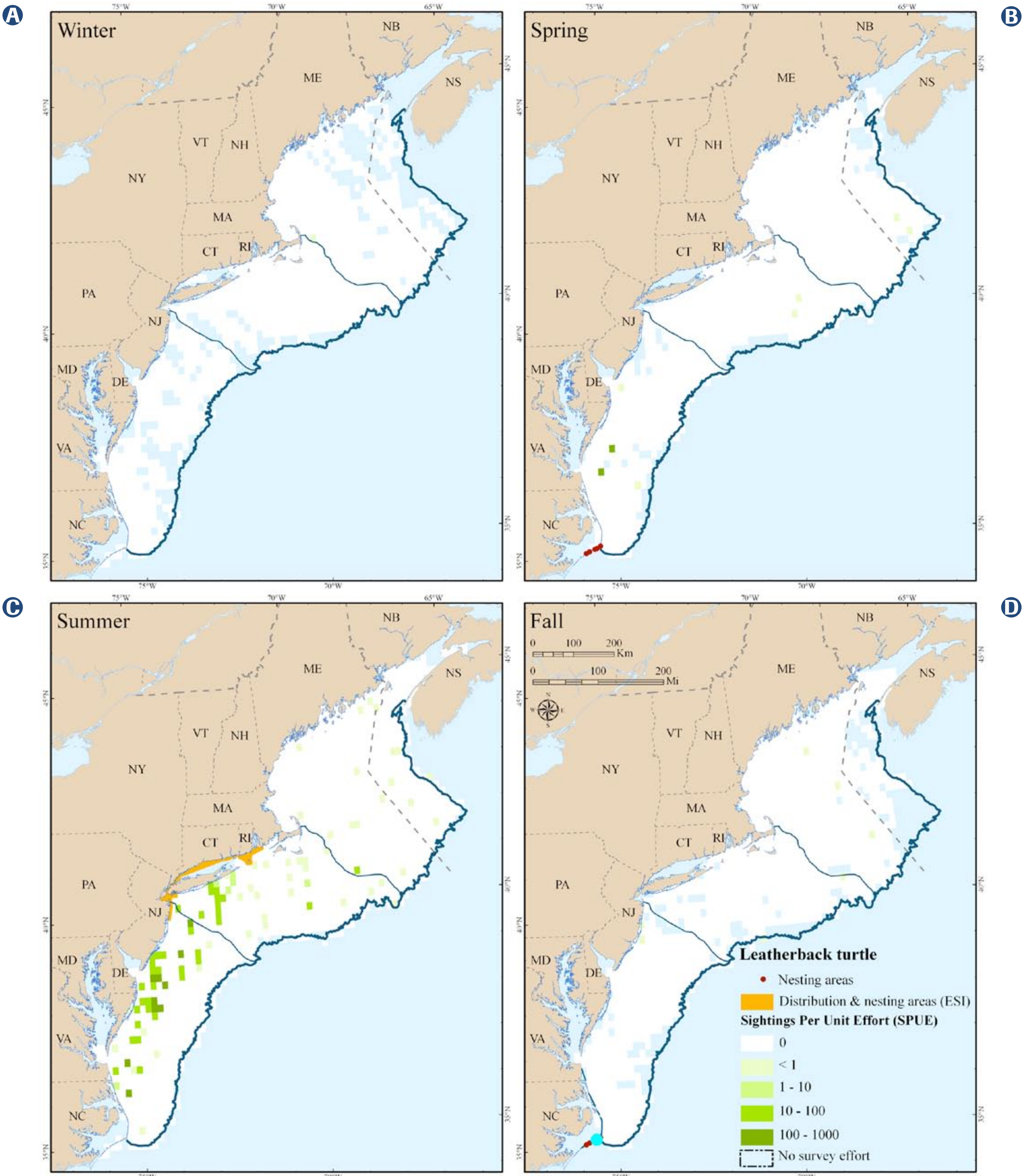


Figure 11-2. Leatherback turtle sightings per unit effort (SPUE) and nesting locations by season.

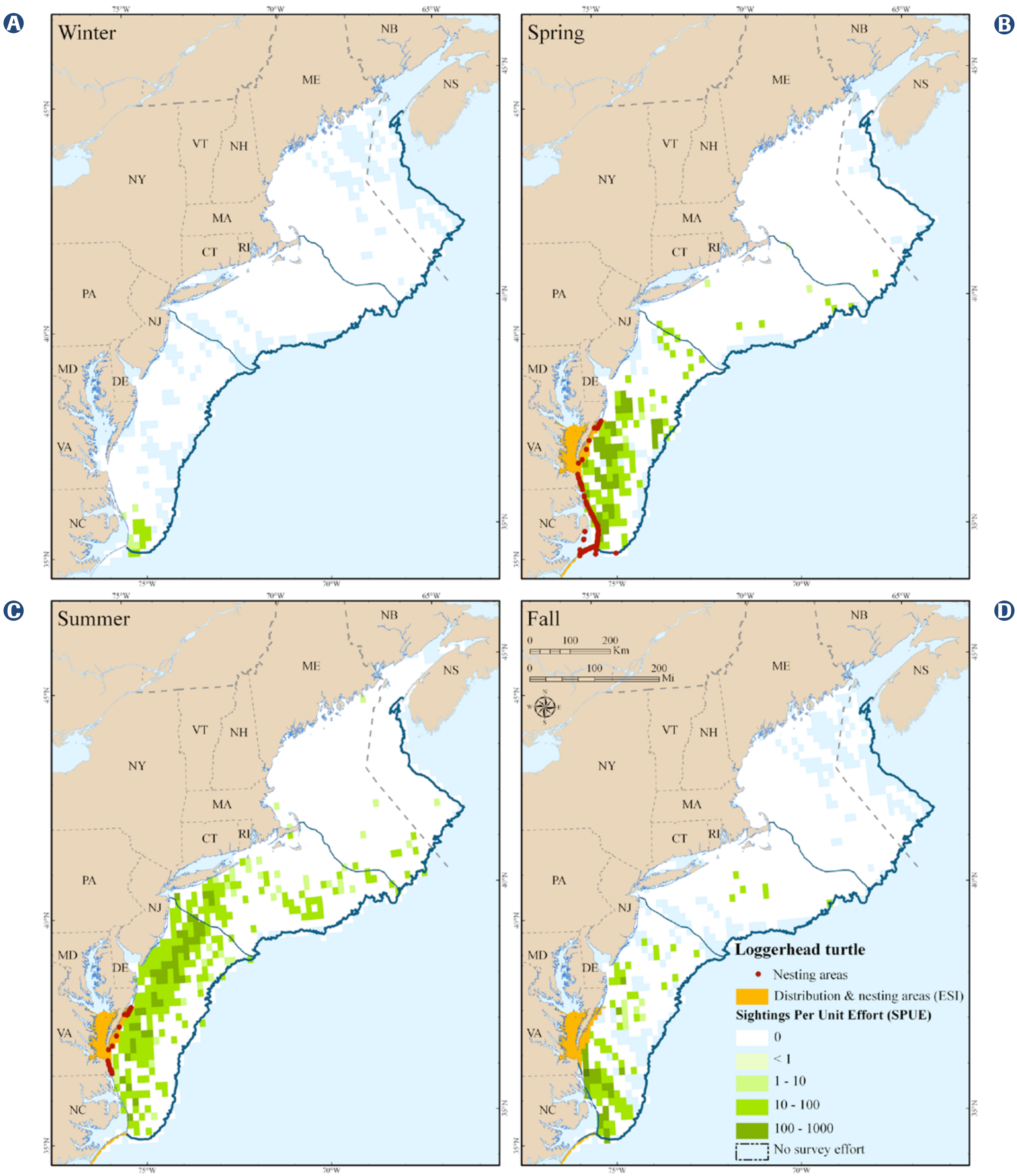


Figure 11-3. Loggerhead turtle sightings per unit effort (SPUE) and nesting locations by season.

Loggerhead Turtle

Based on the observations (n = 1,876; years = 1979 to 2003), the loggerhead turtle was the most abundant of the target turtles in the region (Figure 11-3). The assessment results indicate that the distribution of loggerheads within the region varied by season. During the winter months (December – February), individuals were confined to southern portions of the region on the shelf or along the shelf break. During the spring (March – May) and particularly the summer months (June – August), the number and northward extent of observations increased. Areas of frequent observations were concentrated on the shelf from Cape Hatteras up to Delaware Bay during the spring. During the summer months, the distribution extended up to Long Island, New York with a higher number of observations in closer proximity to the coast. A contraction in distribution and abundance of observations was apparent during the fall (September – November). Areas of loggerhead turtle concentration identified in the ESI data were in the southern part of the region, specifically northern North Carolina, mouth of the Chesapeake Bay, and the Virginia coast.

© Donna A. Dewhurst, U.S. Fish & Wildlife

Nesting by loggerhead turtles was confined to primarily the northern North Carolina and secondarily in Virginia along the ocean coast south of Chesapeake Bay with a total of 503 documented nests. Nesting dates have ranged from May through September with peaks during June and July.

Interpretation of the aggregate dataset suggests that the southern portion of the region, in association with the continental shelf and shelf break, were utilized year round particularly off of Cape Hatteras. The Continental Shelf, coupled with adjoining coastal systems in the south central portion (Long Island to Cape Hatteras), represented relatively high concentrations or potential areas of greater importance. Furthermore, the concentration of observations along the shelf break in the warmer months is noteworthy. The data set precludes an assessment of habitat use by life stage (adult, juvenile) as well as use of larger coastal estuaries such as Chesapeake Bay, Delaware Bay, and Long Island Sound.

Human Interactions

Threats to sea turtles in the region vary by species. For loggerheads, the most comprehensive threat assessment to date is provided in the Recovery Plan for the Northwest Atlantic population (NMFS USFWS 2008), perhaps the largest nesting aggregation globally. This study assessed the impacts of seven threat categories (i.e., fisheries bycatch, resource use (nonfisheries), construction and development, ecosystem alterations, pollution, species interactions, and other factors) for eight life stages across three ecosystems utilized by this species (terrestrial (nesting beaches), neritic, and oceanic). The study quantified impacts using a stage-based demographic model with a conversion to a "total estimated adjusted annual mortality" (units = number of adult females) by threat category, life stage, and ecosystem type.

The results indicate that the principal threats to loggerheads in the Northwest Atlantic are fisheries bycatch; specifically, in order of magnitude of the threat, bottom trawl (neritic – juvenile and adult), demersal longline (neritic – juvenile and adult), demersal large mesh gillnet (neritic – juvenile and adult), and pelagic longline (oceanic – juvenile). Total estimated annual mortality was greatest within this threat category for the neritic juveniles followed by the neritic adults. There is currently insufficient data to accurately estimate mortality of oceanic adults and neritic juveniles and adults due to pelagic longlines in the Northwest Atlantic. The resource use (nonfisheries) category assessment indicates that legal harvest of neritic juveniles and adults (isolated to the Caribbean) results in estimated mortality similar to demersal longline and gillnets.

The next largest threat categories are primarily the terrestrial ecosystem impacts to nesting females (direct and indirect), eggs, hatchlings, and post-hatchlings. The principal sources of mortality are habitat modification from beach replenishment projects and armoring (nesting females, eggs, hatchlings), erosion of active nesting beaches due to climatic events (eggs), light pollution on nesting beaches (hatchlings), predation by native species (eggs, hatchlings, and post-hatchlings), and other factors such as climate change and natural catastrophes (eggs).

Secondary sources of mortality identified by this study include pollution: marine debris ingestion (neritic and oceanic juvenile and adult), entanglement in derelict gear (particularly neritic juvenile and adult), and oil pollution (all ecosystems – most life stages). Additional data are required to clarify the estimated mortalities from these sources. Vessel strikes (propeller and collisions) were also indentified as a large mortality source for neritic juvenile and adults.

Anthropogenic impacts to green turtles occur at all life stages (reviewed by IUCN's Marine Turtle Specialist Group 2004; NMFS USFWS 2007a). The greatest current threat is the legal and illegal harvest of eggs, juveniles, and adults from both terrestrial nesting beaches and neritic foraging areas. Of particular concern to the recovery of this slow-to-mature species is the harvest of juveniles in the Caribbean Sea (for example, in Nicaragua 11,000 juveniles and adults were taken annually during the 1990s), Southeast Asia, Eastern Pacific, and Western Indian Ocean (NMFS USFWS 2007). Illegal and legal harvest of juveniles and adults occurs throughout the world in over 30 nations. The IUCN report (2004) identifies entanglement in fisheries gear (e.g., drift nets, shrimp trawls, longlines, pound nets) as the primary threat in marine environments. Habitat degradation of nesting areas in the form of beach replenishment and armoring, coastal development, and sand removal have also been identified as principal threats during terrestrial life stages (Lutcavage et al. 1997). Light pollution at nesting beaches results in disorientation of emerging hatchlings and decreased nesting success. Alterations in water quality of coastal estuaries due to development related increases in effluent and contaminant loading (PCBs, heavy metals) has been linked to adverse impacts to green turtles including recent increases in disease (e.g., Fibropapilloma, resulting in internal and external tumors) (George 1997). Affliction rates have reached as high as 62% and 69% in Florida and Hawaii, respectively (NMFS USFWS 2007a). Population level impact from this disease is currently unknown. Red tide events in coastal feeding areas have been linked to increased mortality in juveniles and adults (NMFS USFWS 2007a). In Florida, boat strikes have been singled out as a large source of injury and mortality (Singel et al. 2003). Declines in coastal estuary habitat suitability for green turtles are widespread throughout this species' range including the larger systems along the western Atlantic coast.

Anthropogenic impacts to leatherback turtles occur at all life stages; however, accurate estimates of the relative importance of impacts currently do not exist (NMFS USFWS 2007b). The principal threat to the terrestrial portion of their life cycle is the decrease in the quantity and suitability of nesting habitat. Detrimental habitat alterations include coastal development, beach armoring, sand mining, accumulation of wood and marine debris (reduced access), and artificial lighting. Many of these impacts can alter habitat indirectly by modifying thermal profile and advancing erosion. Currently, many of the globally significant nesting areas remain remote and are not subject to these types of activities. This may not remain the case as human populations increase and migrate towards coastal areas. As with other sea turtle species, the legal and illegal harvest of eggs and nesting adults is globally extensive and in some cases severe (e.g., Malaysia). Harvest of eggs is particularly detrimental for this species given the relatively low hatching success (NMFS USFWS 2007b).

In the oceanic and neritic zones the principal impact is incidental capture by artisanal and commercial fisheries (reviewed by NMFS USFWS 2007b), primarily by pelagic longlines (Lewison et al. 2004; NMFS 2001). Localized declines in populations have coincided with increased use of longline and gillnet fisheries (e.g., in Mexico). Kaplan (2005) estimated a 5% annual mortality due to longline fisheries for the eastern Pacific population with an aggregate of 28% annual mortality due to coastal impacts (e.g., egg/adult harvest and inshore fisheries bycatch). An estimated 50,000 individuals were taken by pelagic longline fisheries globally in 2000 (Lewison et al.

2004). This level of take suggests pelagic longlines are one of the more important human impacts. In United States waters, the pelagic longline and shrimp trawl fisheries have been identified as the largest documented source of leatherback mortality (NMFS 2001). Alternative methods and gear innovations (e.g., circle vs. J hooks; bait switching, TEDs) have reduced bycatch levels in recent years (NMFS USFWS 2007b). Fixed fishing gear (e.g., gill nets, pot/trap buoy lines, pound nets) is problematic in coastal foraging grounds (James et al. 2005) and in close proximity to nesting areas. Other documented impacts include vessel strikes, ingestion of marine debris (e.g., plastics, hooks, nets, oil), and high contaminant levels (e.g., pesticides, heavy metals).

Resource limitation in the eastern Pacific during cyclical climatic events (El Niño Southern Oscillation) has been linked to decreased reproductive success and increased vulnerability to anthropogenic mortality (NMFS USFWS 2007b). This is not currently the case in the western Atlantic, however, anthropogenic climatic changes that alter oceanic structure could influence prey availability and subsequent reproductive condition. Increased temperatures at nesting sites have been linked to changes in hatchling sex ratios on some beaches (NMFS USFWS 2007b).

Recent work with molecular markers suggests that this species' lower natal philopatry (tendency to return to the place of an individual's birth) and physiological ability to utilize higher latitudes and colder waters have enabled it to recolonize nesting and neritic foraging habitat (NMFS USFWS 2007b). This characteristic may have important ramifications for recovery as detrimental human interactions are reduced. The molecular marker studies also revealed low genetic diversity or division of populations globally, highlighting the need to exercise conservation measures based on larger population aggregates (e.g., French Guiana, Suriname) that appear to be stable or increasing (NMFS USFWS 2007b).

Conservation

Regulatory Authority

All life stages of all three turtle species are currently protected on United States nesting beaches and in United States waters by the Endangered Species Act (ESA). In the United States, National Marine Fisheries Service (NMFS) and United States Fish and Wildlife Service (USFWS) jointly manage all three species; USFWS has lead jurisdiction on nesting beaches while NMFS has lead jurisdiction for marine waters.

Current Conservation Efforts

Global conservation efforts for all three species are principally comprised of international conventions and treaties. The United States is one of 12 signatory nations on the only international treaty dedicated solely to sea turtles: Inter-American Convention for the Protection and

Conservation of Sea Turtles. One of the most significant conservation efforts to date for sea turtle species is the United States embargo (November 21, 1989) on shrimp harvested with commercial gear that may adversely impact sea turtles (Public Law 101-162, Section 609 (16 U.C.S. 12537)). Under authority of the ESA and the Magnuson-Stevens Fishery Conservation and Management Act, NMFS has initiated a series of regulations designed to reduce adverse impacts to sea turtles including requiring use of turtle excluder devices (TEDs) and circle hooks, gillnet closures, and pound net modifications. In 2003, NMFS initiated a program (Strategy for Sea Turtle Conservation and Recovery in Relation to Atlantic and Gulf of Mexico Fisheries) to comprehensively identify strategies to reduce bycatch across jurisdictional boundaries for priority gear types on a per-gear basis versus by individual fishery for the Atlantic and Gulf of Mexico. There are currently NMFS USFWS Recovery Plans for United States populations in the Atlantic (October 29, 1991), Pacific (January 12, 1998) and Eastern Pacific (January 12, 1998) for green sea turtles, and for United States Caribbean, Atlantic, and Gulf of Mexico (April 6, 1992) and the United States Pacific (January 12, 1998) populations for loggerheads. Five year reviews of these Recovery Plans occurred in 1991 (56 FR 56882) and 2007 (70 FR 20734).

© Ryan Hagerty

Species Accounts

Loggerhead Turtle *(Caretta caretta)*

The loggerhead turtle is distributed globally in both temperate and tropical portions of the Indian, Pacific, and Atlantic Oceans. Distribution in the Atlantic Ocean extends from Argentina to Newfoundland while distribution in the eastern Pacific Ocean ranges from Chile to Alaska. This species nests on highly energetic, oceanic beaches. Hatchlings utilize the neritic convergent zones along the Continental Shelf while juveniles occupy oceanic (> 200m) areas followed by a transition back to neritic habitats. Adults are considered primarily neritic with occasional use of oceanic habitat.

Green Sea Turtle *(Chelonia mydas)*

The green turtle is distributed globally primarily between 30° north and south latitude in most of the major oceans and in association with inshore and neritic waters of 140 countries. Along the Gulf of Mexico and the Atlantic coast the species ranges from Texas to Massachusetts with breeding subpopulations in the State of Florida. This species nests on coastal beaches located between 30° north and south latitude. Hatchlings are pelagic during a near surface development stage. Juveniles use oceanic habitats, followed by neritic habitats when they achieve certain age and size thresholds. Adults are both oceanic and neritic, returning to coastal beaches to nest.

Leatherback Turtle *(Dermochelys coriacea)*

The leatherback is distributed globally in sub-polar, temperate, and tropical portions of the Indian, Pacific, and Atlantic Oceans. Distribution within the western Atlantic includes the entire eastern United States continental coast from the Gulf of Maine south to Puerto Rico and the Gulf of Mexico. This species nests on high energy, continental beaches. Hatchlings likely occupy oceanic zones in tropical waters while juveniles (<100 cm CCL) are associated with both oceanic and coastal waters with temperatures above 26° C. Adults utilize both oceanic and coastal waters with temperatures above 12° C on average.

Literature Cited

Baldwin, R., G. R. Hughes, and R. I. T. Prince. 2003. Loggerhead turtles in the Indian Ocean. Pages 218-232 in Bolten, A.B. and B.E. Witherington (eds.). Loggerhead Sea Turtles. Smithsonian Books, Washington D.C.

Bjorndal, K. A. 1997. Foraging ecology and nutrition of sea turtles. Pages 199-231 in Lutz, P.L. and J.A. Musick (eds.). The Biology of Sea Turtles. CRC Press. Boca Raton, Florida.

Bjorndal, K. A. 2003. Roles of loggerhead sea turtles in marine ecosystems. Pages 235-254 in Bolten, A.B. and B.E. Witherington (eds.). Loggerhead Sea Turtles. Smithsonian Books. Washington, D.C.

Braun-McNeil, J. and S. P. Epperly. 2002. Spatial and temporal distribution of sea turtles in the Western North Atlantic and the U.S. Gulf of Mexico from Marine Recreational Fishery Statistics Survey (MRFSS). Marine Fisheries Review. 64(4):50-56.

CITES Convention on International Trade in Endangered Species of Wild Fauna and Flora. Signed at Washington, D.C., on 3 March 1973. Amended at Bonn, on 22 June 1979. Appendix I.

George, R. H. 1997. Health problems and diseases of sea turtles. Pages 363-409 in Lutz, P. L. and J. A. Musick (eds.). The Biology of Sea Turtles. CRC Press, Boca Raton, Florida.

IUCN (International Union for Conservation of Nature). 2004. Green Turtle *(Chelonia mydias)* Assessment. (Assessor: Seminoff, J.A.) Marine Turtle Specialist Group, Washington, DC. http://www.iucn-mtsg.org/red_list/cm/MTSG_Chelonia_mydas_Assessment_April-2004.pdf.

IUCN (International Union for Conservation of Nature). 2007a. Red List of Species: Loggerhead Turtle. Washington, DC.

IUCN (International Union for Conservation of Nature). 2007b. Red List of Species: Green Turtle. Washington, DC. http://www.iucnredlist.org/apps/redlist/details/4615/0.

IUCN (International Union for Conservation of Nature). 2007c. Red List of Species: Leatherback Turtle. Washington, DC. http://www.iucnredlist.org/apps/redlist/details/6494/0.

James, M. C., C. A. Ottensmeyer, and R. A. Myers. 2005. Identification of high-use habitat and threats to leatherback sea turtles in northern waters: new directions for conservation. Ecology Letters. 8:195-201.

Kaplan, I. C. 2005. A risk assessment for Pacific leatherback turtles *(Dermochelys coriacea)*. Canadian Journal of Fisheries and Aquatic Sciences. 62(8):1710-1719.

Kenney, R. D. and H. E. Winn. 1986. Cetacean high-use habitats of the northeast United States Continental Shelf. Fishery Bulletin. 84(2): 107–14.

Lewison, R. L., S. A. Freeman, and L. B. Crowder. 2004. Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. Ecology Letters. 7:221-231.

Lutcavage, M. E., P. Plotkin, B. Witherington, and P. L. Lutz. 1997. Human impacts on sea turtle survival. Pages 107-136 in Lutz, P.L. and J.A. Musick (eds.). The Biology of Sea Turtles. CRC Press, Boca Raton, Florida.

NMFS (National Marine Fisheries Service). 2001. Stock assessments of loggerhead and leatherback sea turtles and an assessment of impacts of the pelagic longline fishery on the loggerhead and leatherback sea turtles of the western North Atlantic. NOAA Technical Memorandum. NMFS-SEFC-455.

NMFS USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 1992. Recovery Plan for Leatherback Turtles in the U.S., Caribbean, Atlantic and Gulf of Mexico. Silver Springs, Maryland. http://ecos.fws.gov/docs/recovery_plan/920406.pdf.

NMFS USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 2007a. 5-Year Review: Summary and Evaluation, Green Sea Turtle (Chelonia mydas). Silver Spring, Maryland. http://www.nmfs.noaa.gov/pr/pdfs/species/greenturtle_5yearreview.pdf.

NMFS USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 2007b. 5-Year Review: Summary and Evaluation, Leatherback Turtle *(Dermochelys coriacea).* Silver Spring, Maryland. http://www.nmfs.noaa.gov/pr/pdfs/species/leatherback_5yearreview.pdf.

NMFS USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 2008. Recovery Plan for the Northwest Atlantic Population of the Loggerhead Sea Turtle *(Caretta caretta),* Second Revision. Silver Spring, MD. http://www.nmfs.noaa.gov/pr/pdfs/recovery/turtle_loggerhead_atlantic.pdf.

Shoop, R. and R. D. Kenney. 1992. Seasonal distributions and abundances of loggerhead and leatherback sea turtles in waters of the northeastern United States. Herpetological Monographs. 6:43-67.

Singel, K., T. Redlow, and A. Foley. 2003. Twenty-two years of data on sea turtle mortality in Florida: trends and factors. Proceedings of the Twenty-second Annual Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum. NMFS-SEFSC-503.

Turtle Expert Working Group. 2007. An Assessment of the Leatherback Turtle Population in the Atlantic Ocean. NOAA Technical Memorandum. NMFS-SEFSC-555.

Witherington, B. E. 2002. Ecology of neonate loggerhead turtles inhabiting lines of downwelling near a Gulf Stream front. Marine Biology. 140:843-853.

CHAPTER 12

Coastal & Marine Birds

Bob Allen and Mark Anderson

Introduction

© Barry Truit/TNC

This assessment examines trends in populations of those seabirds, shorebirds, and waterbirds that interact regularly with the marine environment. For the purposes of this assessment, the terms "seabird," "shorebird," and "waterbird" are defined as:

Seabirds are colonial species that feed in salt waters, and often migrate spectacular distances from breeding grounds to wintering areas. Some, such as the Audubon's Shearwater, come onto land only to breed, otherwise spending their lives at sea. In some cases, these birds may connect geographically disparate marine environments. Arctic Terns, for instance, breed along the coast of New England and Canada, but also use marine environments along the coast of Africa and on the continent of Antarctica. Within this region, a number of coastal and marine bird species are listed as state and federally threatened or endangered. World-wide, a higher percentage of seabird species are at risk of extinction than any other bird group.

Shorebirds, such as the piping plover, Semipalmated Sandpiper, and Greater Yellowlegs, spend their lives on sandy beaches, mudflats, and river and lake shores, and generally only interact with the edge of the marine environment.

Waterbirds, such as gulls, and colonial wading birds, such as herons, generally interact with the marine environment in the coastal zone. For instance, most gull species are found foraging within a few miles of land. Others, such as herons and egrets, feed in the marine/coastal zone in marshes and along brackish creeks.

Technical Team Members

Bob Allen, The Nature Conservancy, New Jersey
Doug Forsell, U.S. Fish and Wildlife Service
Scott Johnston, U.S. Fish and Wildlife Service
David Lee, Ph.D., North Carolina State Museum of Natural Sciences (retired)
Dan Morse, The Nature Conservancy, Eastern Division
Kathy Parsons, Ph.D., Manomet Center for Conservation Sciences, MA
Joe Smith, Ph.D., The Nature Conservancy, New Jersey

Selection of Target Species

Over 80 species of seabirds utilize this region to some extent (Nisbet et al. 2008). The conservation needs of these species were assessed in several ways. First, high priority stopover sites and wintering concentrations for many species identified by (need source of map) were noted as outstanding features along Northwest Atlantic coastline and added to the characterization of coastal shoreline units (see the Coastal chapter of this document). Second, key breeding areas for beach and salt marsh breeding birds identified through a separate analysis of the North Atlantic Coast, Chesapeake Bay and Northern Appalachian ecoregions (Anderson et al. 2006a and b; Samson et al. 2003) were reproduced here to reemphasize their importance to the region. Third, a small subset of seabirds, for which the North Atlantic Coast ecoregion plays an important role, were identified and targeted for conservation action. The criteria used to identify these target species were as follows:

1) Species that primarily breed on offshore islands or primarily forage in marine waters during at least one part of year;
2) Species ranked as High or Highest Concern in North American Waterbird Conservation Plan rankings, High or Highest Concern by the Mid-Atlantic/New England Marine regional rankings in the Waterbird Conservation Plan, listed as a Seaduck Joint Venture declining species, or listed as an Atlantic Coast Joint Venture high priority pelagic/marine species;
3) Species for which the population trend is declining or unknown, or the population size is small.

The team assessed which species have available consistent datasets that cover the entire region or the portion of the region in which the species is found. The single largest eliminator of species was lack of standardized data across the region. More species can be added as additional information becomes available.

This process resulted in the selection of six marine targets:

- Arctic Tern (*Sterna paradisaea*)
- Audubon's Shearwater (*Puffinus lherminieri*)
- Barrow's Goldeneye (*Bucephala islandica*)
- Harlequin Duck (*Histrionicus histrionicus*)
- Razorbill (*Alca torda*)
- Roseate Tern (*Sterna dougallii*)

Three coastal species were added from coastal assessments, as discussed above:

- Least Tern (*Sternula antillarum*)
- Piping Plover (*Charadrius melodus*)
- Red Knot (*Calidris canutus rufa*)

Population Status and the Importance of Northwest Atlantic region

The Northwest Atlantic region is extremely important to populations of Roseate Tern, Arctic Tern, Least Tern, Harlequin Duck, Audubon's Shearwater, Barrow's Goldeneye, Red Knot, and Piping Plover. In all cases, significant percentages of the total species population breed, migrate through, winter, or have foraging concentrations in this region. In the case of the Red Knot, almost the entire population of the *rufa* race relies upon a small number of stopover locations within the Northwest Atlantic region. Fifty to 75% of the Caribbean population of Audubon's Shearwater forages in one area off the coast of North Carolina during the late summer. Eighty percent of the Atlantic population of breeding Piping Plovers can be found in the Northwest Atlantic region.

The conservation status of these species is mixed. Most species are considered of "least concern" at the global scale by the International Union for the Conservation of Nature (IUCN). However, in many cases, the significant populations or subspecies of these species that are found in the Northwest Atlantic region are threatened. Roseate Tern, Least Tern, Harlequin Duck, Red Knot, and Piping Plover are listed as threatened or endangered by the United States Fish and Wildlife Service (USFWS) or the Canadian Wildlife Service (CWS). All species except the Audubon's Shearwater are listed as threatened or endangered by one or more states or provinces. Piping Plover have a NatureServe rank of G3 (vulnerable). Roseate Tern, Least Tern, Harlequin Duck, Audubon's Shearwater, and Red Knot are considered G4 (apparently secure). Arctic Tern, Razorbill, and Barrow's Goldeneye are ranked G5 (secure).

Ecosystem Interactions and Ecological Dependencies

The habitat needs of seabirds, shorebirds, and waterbirds are diverse - birds can be found in most coastal and marine environments. Sandy beaches and islands and tidal flats and bays along the Northwest Atlantic coast are particularly important habitats for many species of birds for breeding, migration, and wintering. Shallow waters (for example, sand shoals) are often very productive as foraging areas for many species of birds. Shallow waters along rocky coasts are often important foraging or wintering habitat for many species of birds that primarily breed in the northern reaches of this region and beyond. Complicating this array of habitat needs is the temporal variability in those needs: species often have different requirements during the breeding, migration, and wintering seasons. Seabirds and shorebirds depend on the resources of this region in a variety of ways, including for:

Breeding areas: Places where coastal features such as salt marshes, rocky coastline, gravelly or sandy beaches, and offshore islands, provide critical habitat for nesting. Breeding species include various Terns, Gulls, Piping Plover, and the American Oystercatcher.

Wintering areas: Surf breaks along rocky shores, sand shoals, and offshore islands where migratory sea ducks concentrate in the winter to feed on invertebrates such as mussels or shrimp. In this region, over a million individual sea ducks congregate in sites that are traditionally returned to year after year. Wintering species include Surf Scoter, Black Scoter, Long-tailed Duck, Harlequin Duck, Red-throated Loon, and Common Loon.

Summer foraging areas: Temporal resource pockets where marine birds congregate to feed on fish, squid, plankton, and other abundant food resources. Some species, such as the Audubon's Shearwater, concentrate a large percentage of their population in the same foraging areas from year to year.

Stopover and staging sites: Stopover sites are areas where migrating species stop to feed and refuel. Because many seabirds and shorebirds breed in the far north and winter in the southern hemisphere, productive stopover sites are important to maintaining the species. Intertidal areas, mudflats, and sandy beaches laden with horseshoe crab eggs are particularly important to many shorebird species. "Long-jump" migrators, those which fly long distances between staging sites, are particularly at risk from degraded sites. For example, the red knot gathers in large numbers at a few sites, the loss of which may seriously affect their ability to migrate successfully. Critical sites include the Delaware Bay shoreline, where eggs from spawning horseshoe crabs attract the second highest number of shorebirds of any location in North America, and the Bay of Fundy's tidal mudflats, which serve as important staging areas during fall migration.

Aspects of the life history of many marine birds are not well known, but radio tracking has revealed that individual species may use a network of breeding, staging, and wintering areas (Silverman et al. 2008). Critical migratory areas for many species overlap, forming important and well-known areas for conservation (Figure 12-1). These important shoreline areas are noted in the coastal chapter as outstanding features along the Northwest Atlantic coastline and associated with coastal shoreline units.

The seabird and shorebird targets share common predator types, though the species of predators may differ. Mammals, including raccoons, foxes, and skunks, commonly prey upon the eggs and nestlings of breeding birds. In many cases, the populations of these mammalian meso-predators (medium-sized predators) are tied to

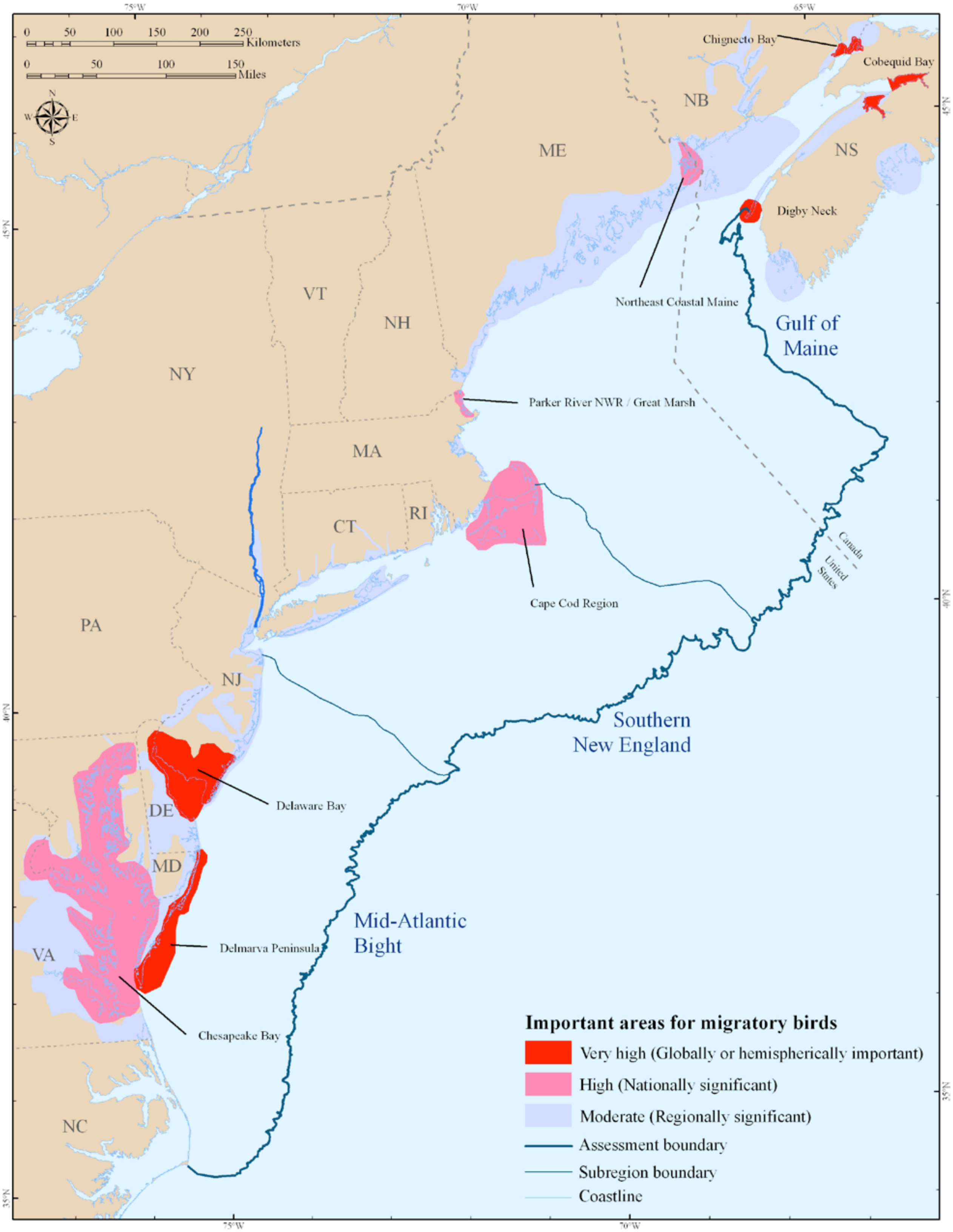


Figure 12-1. Coastal migratory stopover sites in the Northwest Atlantic region (very high = four bird groups or a hemispherically important shorebird site, high = three bird groups or an internationally important shorebird site, medium = 2 bird groups or a regional important shorebird site).

the human landscape and very much affected by human behaviors in the area (e.g. landfills, fast food restaurants, land use). Birds of prey, such as owls and hawks, will prey upon nestlings and adults. In some cases, gulls can be a significant source of predation on the eggs and nestlings of colonial breeding birds. The seabird and shorebird targets primarily feed on small forage fish or marine invertebrates. For example, Roseate Terns prefer small schooling fish such as sand eels *(Ammodytes americanus)*. Audubon's Shearwaters feed on small fish and squid in deep open marine waters. Within Northwest Atlantic region, Red Knots feed on horseshoe crab eggs, mussels, and mussel spat.

The implications of the loss of seabirds, shorebirds, or waterbirds to marine ecosystems in the region are poorly understood. Although seabirds and shorebirds may compete with a number of fish and mammal species for forage fish resources, this relationship is not very well understood. The clearest case of competition with seabirds and shorebirds comes from gulls. Gulls compete with red knots for access to horseshoe crab eggs; recent research indicates that the presence of gulls actually excludes red knots from quality foraging areas (Karpanty et al. 2006). Gulls also compete with Roseate and Arctic Terns for limited breeding locations such as islands and beaches. Gull competition is known to have caused the abandonment of Tern colonies (Gochfield et al. 1998).


© Aaron McCall/TNC

Northwest Atlantic Distribution and Important Areas

Data

Occurrence data for all target species were collated and mapped in order to determine important areas for these species. Data for the Roseate and Arctic Terns came from the state of Maine element occurrences, USFWS Gulf of Maine Coastal Program, and the National Audubon Society's Maine Coast Seabird Sanctuaries program reports. Most of these data were from the past ten years. For the Harlequin Duck, spatial data includes element occurrences from TNC's North Atlantic Coast ecoregional plan and the states of Maine and Rhode Island. New Jersey records come from New Jersey Audubon reports and the Birds of New Jersey (Walsh et al. 1999). The Canadian Wildlife Service provided abundance and location data for Canada. Data for Barrow's Goldeneye winter distribution in Maine were provided by the Maine Department of Inland Fisheries and Wildlife. Spatial data used for the Audubon's Shearwater are based upon the Continental Shelf shape file for North Carolina's Continental Shelf Important Bird Area. Red Knot important sites were based upon Delaware and New Jersey natural resource agency shorebird surveys and the 2008 East Coast-wide surveys coordinated by the New Jersey Department of Environmental Protection. Least Tern and Piping Plover important sites were based upon state agency surveys and reports and, in some limited cases, state heritage element occurrences.

Table 12-1. Criteria used to determine critical areas for seabird and shorebird conservation targets.

	Habitat	Breeding	Wintering	Stopover or Concentration
Arctic Tern	Marine	A site with greater than 10 pairs that has been occupied within the past 15 years		
Least Tern	Coastal	A site with greater than 50 pairs		
Roseate Tern	Marine	A site with greater than 10 pairs that have been occupied within the past 15 years		
Piping Plover	Coastal	A site with more than four piping plover pairs during the most recent year for which we have data, or where there were greater than four pairs at any point during the past five years and the population continues to be more than three pairs		
Razorbill	Marine	A site with more than 20 pairs hat have been occupied in five of the past ten years	One well-known wintering concentration area wa	
Barrow's Goldeneye	Marine		A site where ten or more Barrow's goldeneye have been observed in some years (State of Maine and the Canadian Wildlife Service)	
Harlequin Duck	Marine		A site with greater than 25 birds occupying the area for more than one month per year	
Red Knot	Coastal			An important stopover areas was defined as a beach where more than 500 individuals have been recorded in one day, has been used consistently over the past 10 years, and is relatively protected from human disturbance
Audubon's Shearwater	Marine			The area of concentration was based upon water depth information and expert opinion (David Lee)

Methods

As opposed to the data collection methods using in other chapters in this assessment, bird data is not available in ten-minute squares. In most cases, occurrences were mapped based on spatial records using the above data sources. In a few cases, only the name of an island was available, in which case the location of the island was researched, and then the occurrence was mapped. Due to the variation in data available by species, a separate metric was defined for each species (Table 12-1).

Maps, Analysis, and Areas of Importance

Arctic Tern

Within Northwest Atlantic, Arctic Terns nest along the coast of Maine. In 1999-2002, there were about 12,800 pairs along the Atlantic coast of Maine and Canada. Arctic Tern breeding numbers are known to have been higher in 1950s, but declined into the 1970s and have fluctuated since (Hatch 2002).

Important areas for Arctic Terns

Breeding: Islands along the coast of Maine (Figure 12-2)

Audubon's Shearwater

During the late summer, Audubon's Shearwaters are concentrated along the edge of the Continental Shelf off the coast of North Carolina, with a less important concentration area extending northward to the Virginia border. The total breeding population size of the Caribbean population (the same population found off North Carolina in the late summer) is estimated at 3800 pairs in 2008. Species experts believe the population to have likely decreased, but no long-term data exist (D. Lee, personal communication).

Important areas for Audubon's Shearwater

Foraging Concentration: The edge of the Continental Shelf off the coast of North Carolina (Figure 12-3)

Barrow's Goldeneye

Most wintering Barrow's Goldeneye are outside of the Northwest Atlantic region, but within the region they are found along the coasts of Maine, Nova Scotia, and New Brunswick. Their population trend is unknown.

Important areas for Barrow's Goldeneye

Wintering: Shallow marine waters along the coasts of Maine, Nova Scotia, and New Brunswick (Figure 12-4)

Harlequin Duck

Harlequin Ducks are found along the Atlantic coast as far south as New Jersey. However, the most significant wintering populations are along the coasts of Maine, Nova Scotia, and New Brunswick. Their population has been decreasing over the past 30 years, but has been stable or even slightly increasing for the past 15 years.

Important areas for Harlequin Ducks

Wintering: Rocky coasts and islands of Maine, Nova Scotia, and New Brunswick (Figure 12-5)

Razorbill

Seven percent of the Razorbill population is found within the Northwest Atlantic region. Their population is thought be stable.

Important areas for Razorbills

Wintering: Nearshore marine water along the coast of Maine, Nova Scotia, and New Brunswick (Figure 12-6)

Roseate Tern

While Roseate Terns nest from Long Island to Maine, 80% nest on two islands: Great Gull Island off of Long Island, NY, and Bird Island, MA. Roseate Tern populations have been decreasing over the past 100 years, but may have stabilized over past 10 years (Gochfield et al. 1998).

Important areas for Roseate Terns

Breeding: Great Gull Island off of Long Island, NY, and Bird Island, MA (Figure 12-7)

Least Tern

Least Terns breed from southern Maine to North Carolina. Their population has been decreasing over the past 30 years, but may have stabilized over the past 10 years.

Important areas for Least Terns

Breeding: Sandy beaches on Cape Cod, Long Island, Virginia barrier islands, and New Jersey barrier islands and mainland beaches (Figure 12-8)

Piping Plover

Piping Plovers are distributed from Maine to North Carolina, but the largest populations are, in order, Massachusetts, New York, Virginia, and New Jersey. Their population has been decreasing over the past 100 years, but has been increasing over the past 20 years since their federal listing as an endangered species (Elliot-Smith and Haig 2004).

Important areas for Piping Plovers

Breeding: Sandy beaches on Cape Cod, Long Island, Virginia barrier islands, and New Jersey barrier islands and mainland beaches (Figure 12-9)

Red Knot

Red knots migrate through the Northwest Atlantic region during the spring and fall. Their population has decreased by over 90% since 1990 and has been predicted to go extinct within 5-10 years.

Important areas for Red Knots

Spring stopover: The most important stopover location is the sandy beaches on both the New Jersey and Delaware sides of Delaware Bay. Barrier islands along the Virginia coast are also proving to be important stopovers for migrating red knots.

Fall stopover: Although in much smaller numbers than the spring stopover in the Delaware Bay, Red Knots utilize sandy beaches on Cape Cod and the southern Atlantic coast of New Jersey during the fall migration (Figure 12-10)

Human Interactions

For species that use coastal areas for feeding, nesting, and roosting within the Northwest Atlantic region, human activity that displaces birds is a key source of disturbance. Such coastal areas are both important habitat for birds and in high demand for human recreation. Disturbance of birds at breeding colonies, nest sites, roosting areas, and feeding areas, while not causing direct mortality, can impact survival and reproduction in these species (Peters and Otis 2007, Rodgers and Schwikert 2002, Sabine et al. 2008, Shepherd and Boates 1999). Human activity in these habitats can promote increases in predators such as raccoons, skunks, and gulls that directly prey upon eggs, young, and adults of these bird species (Erwin et al. 2001).

© Harold E. Malde

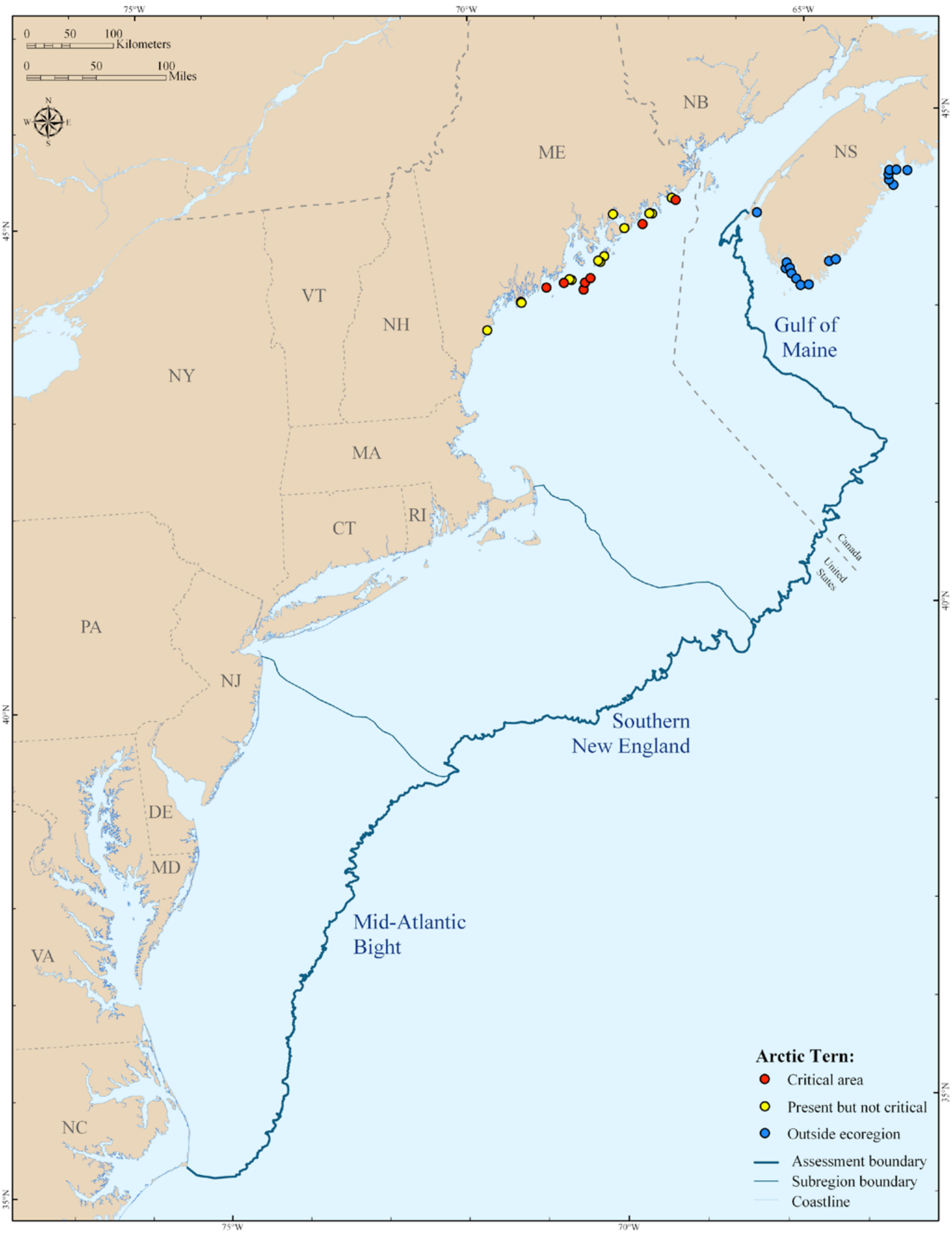


Figure 12-2. Critical areas for Arctic Terns.

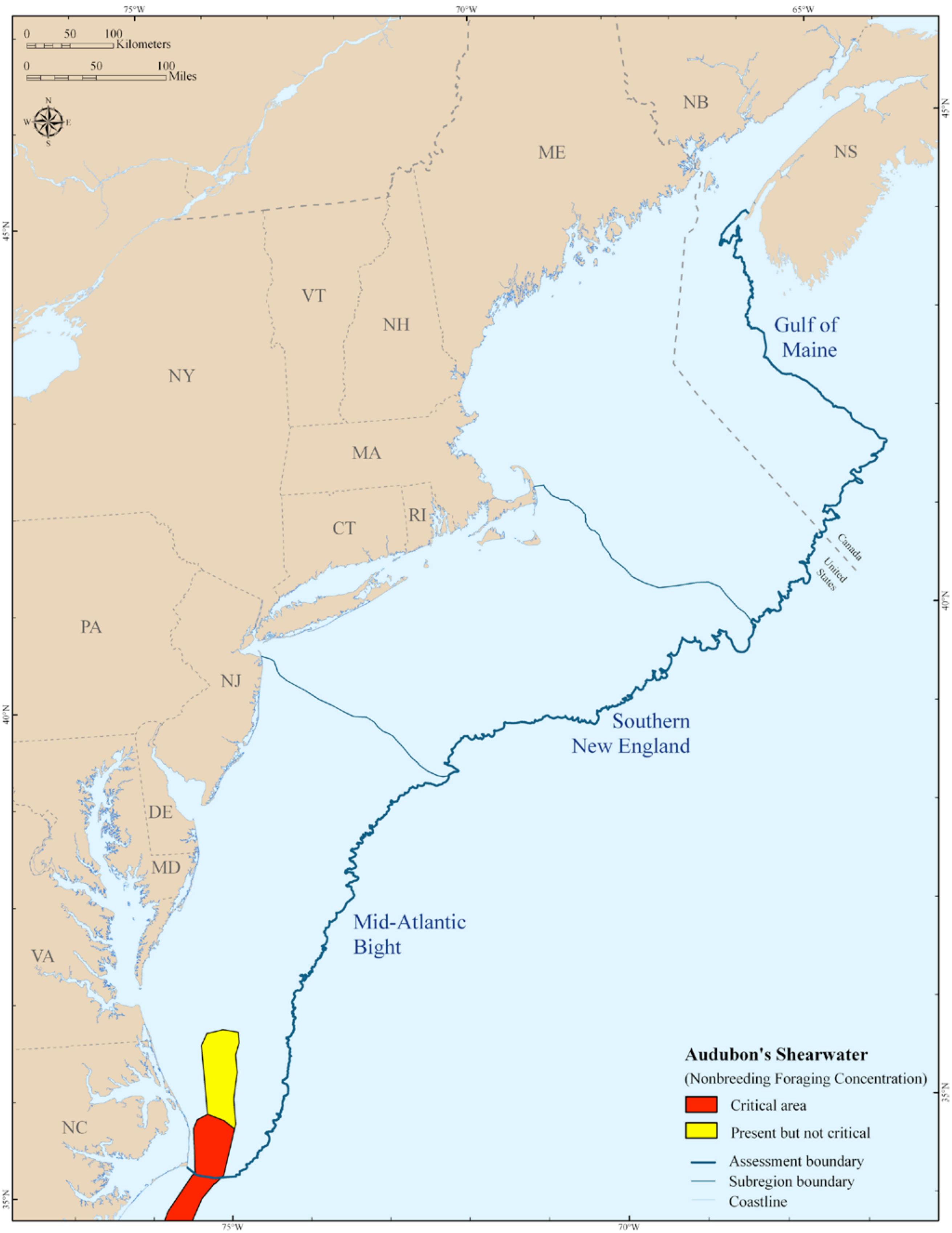


Figure 12-3. Foraging concentration (nonbreeding area) for Audubon's Shearwater.

Figure 12-4. Critical wintering areas for Barrow's Goldeneye.

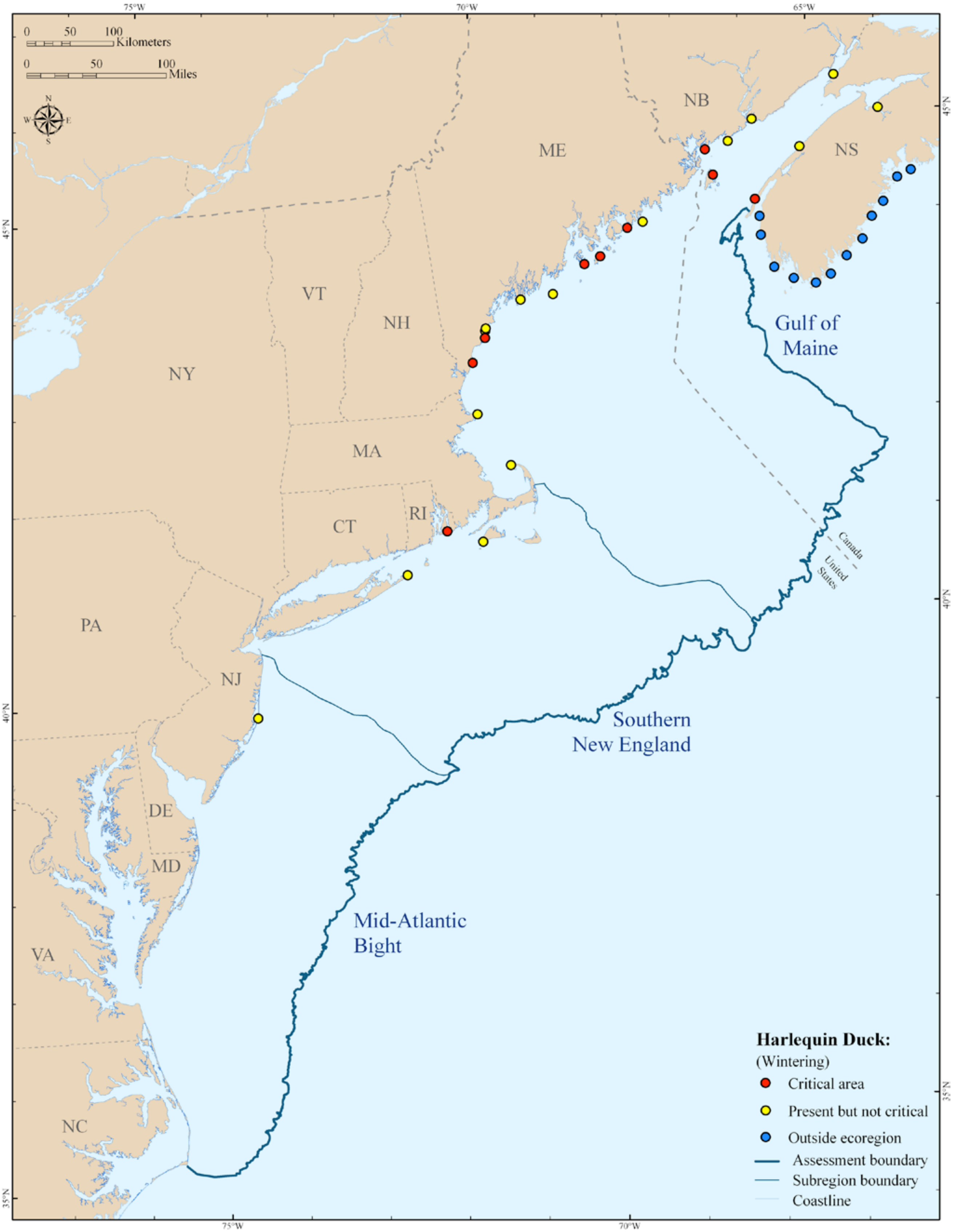


Figure 12-5. Critical wintering areas for Harlequin Duck.

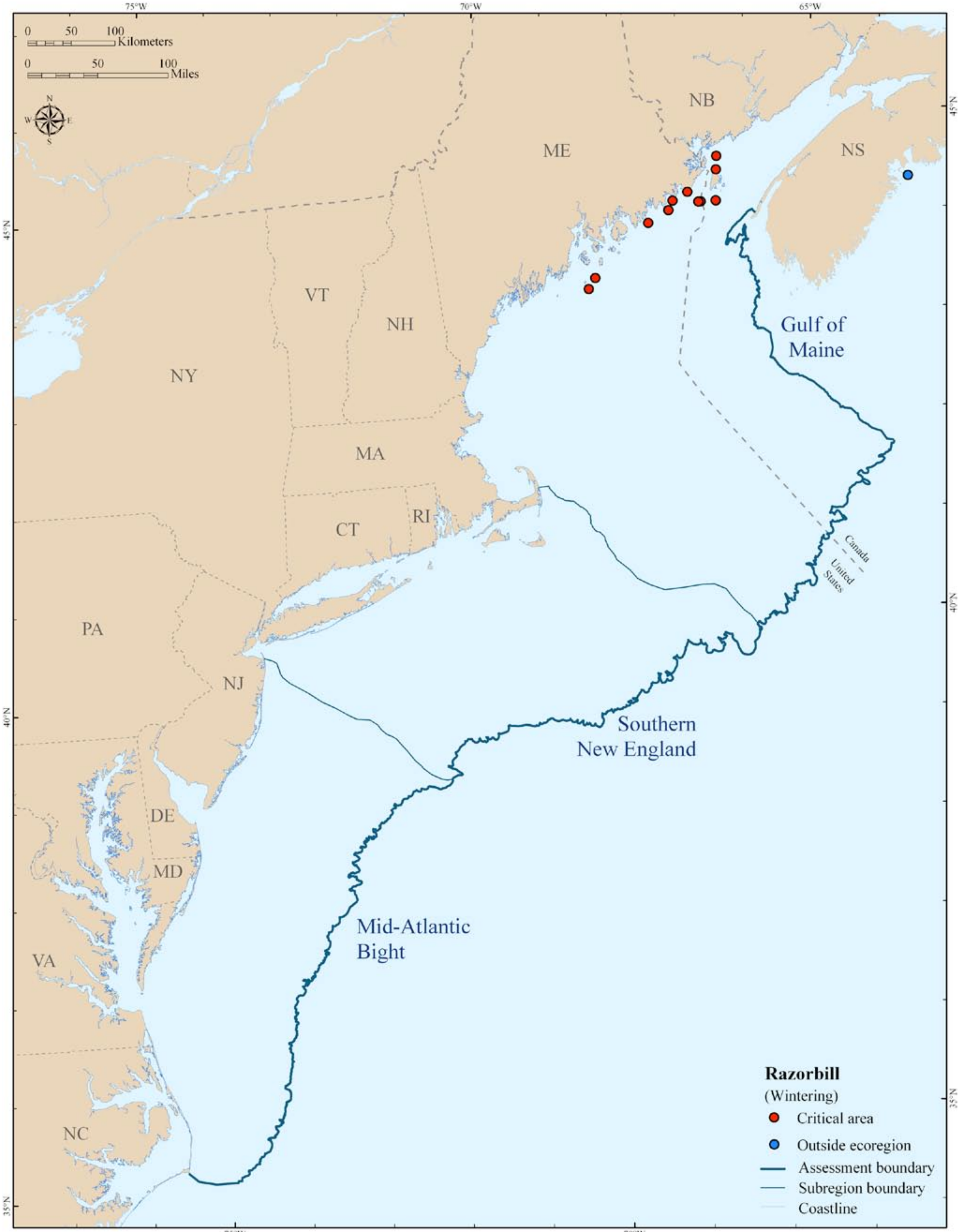


Figure 12-6. Critical wintering areas for Razorbill.

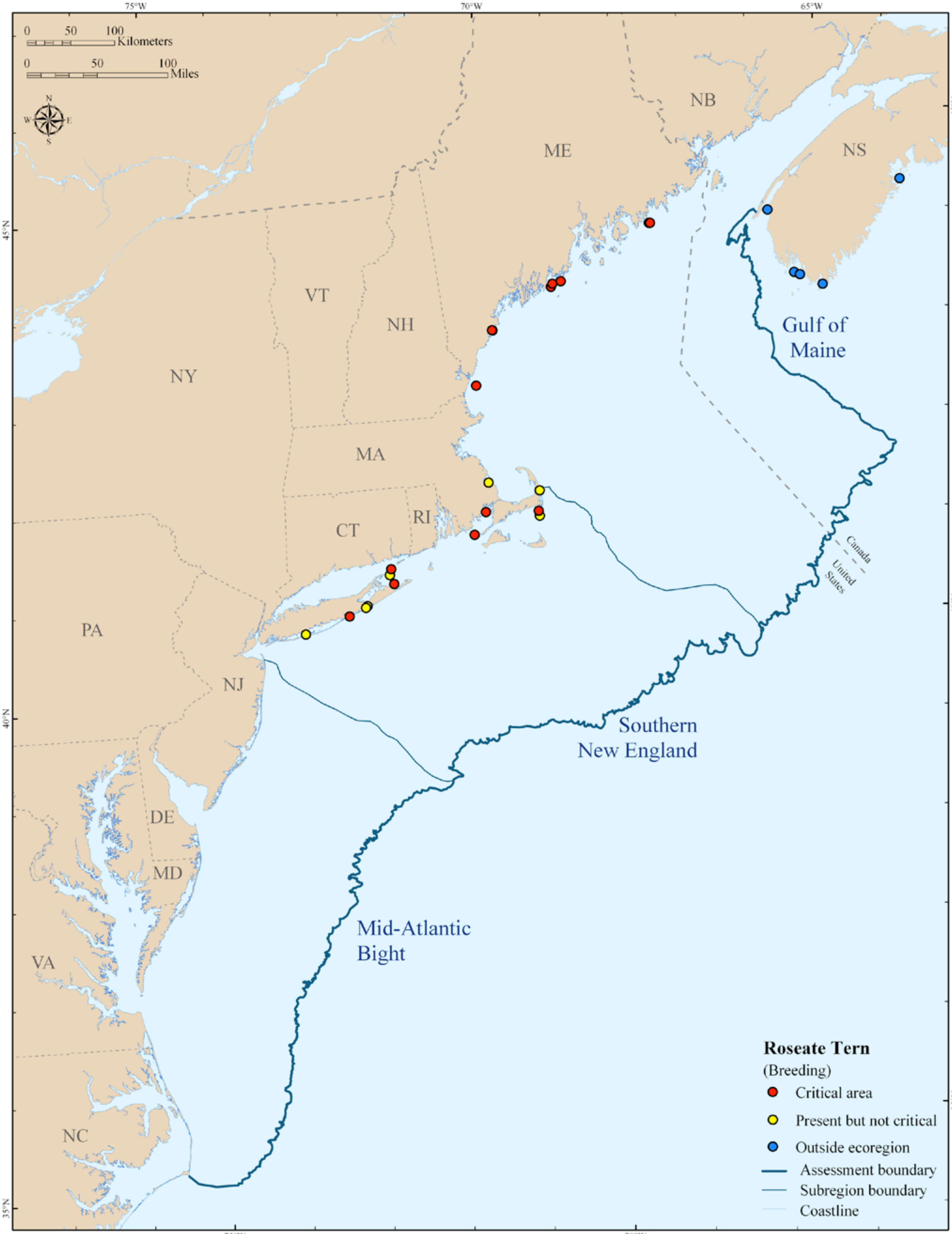


Figure 12-7. Critical breeding areas for Roseate Tern.

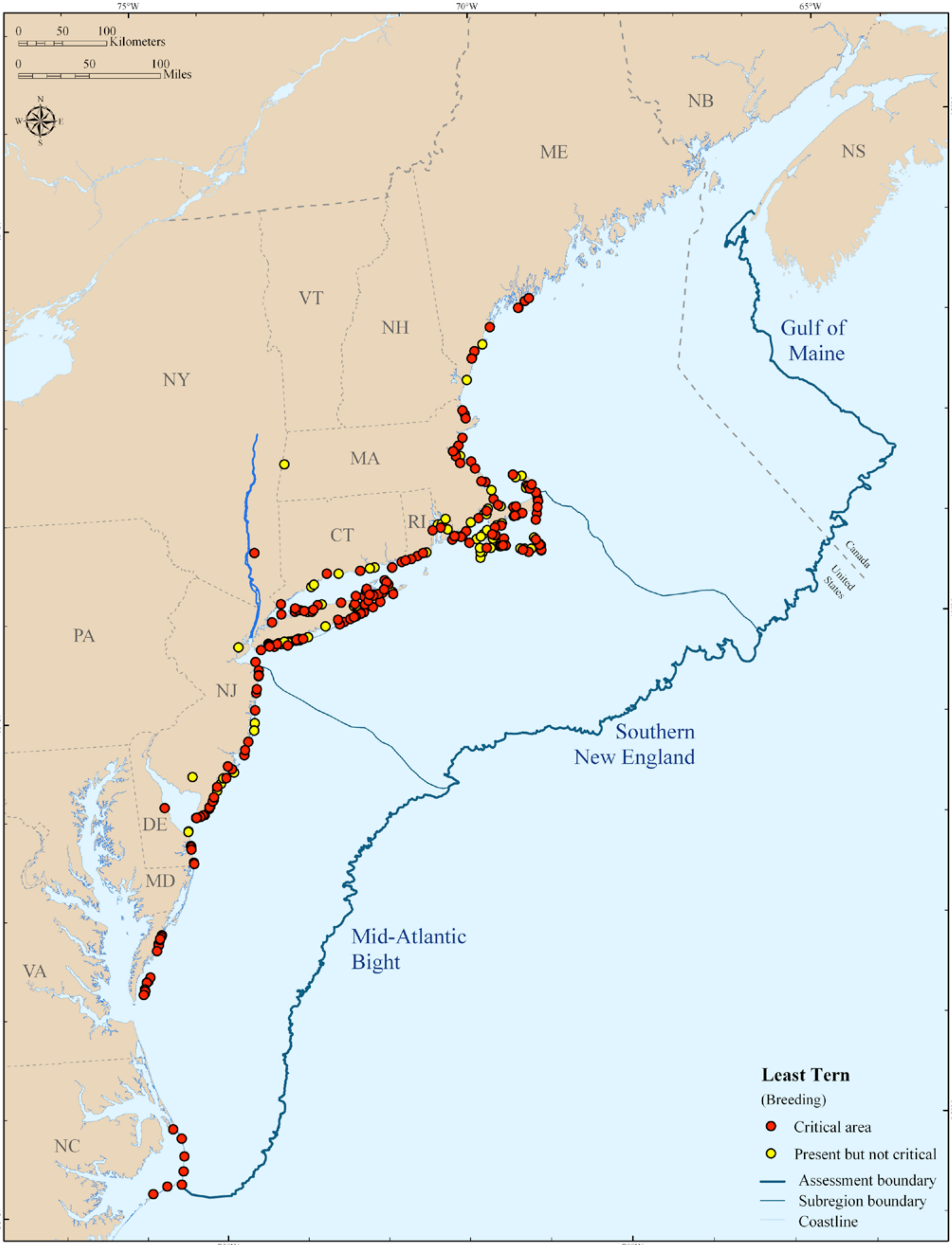


Figure 12-8. Critical breeding areas for Least Tern.

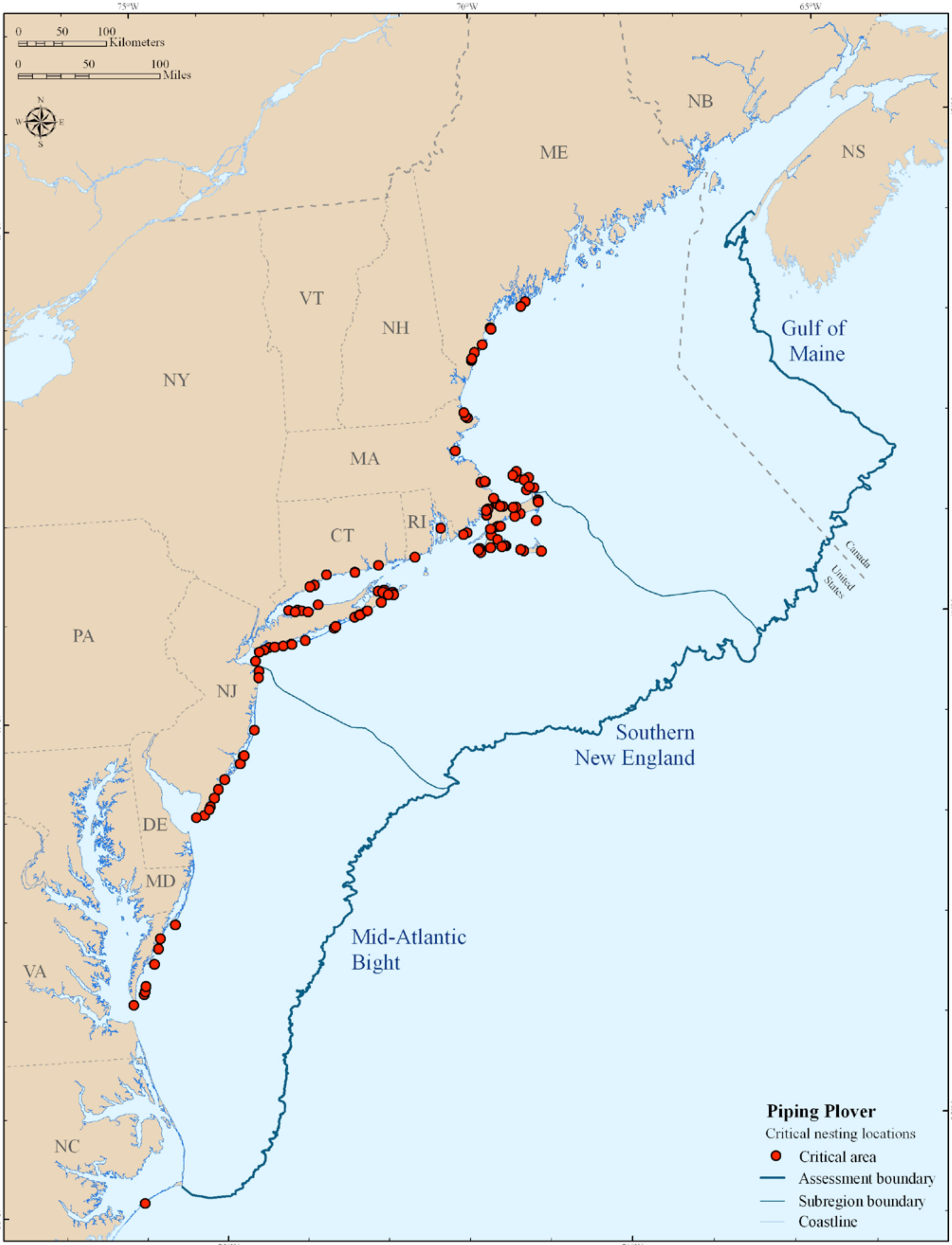


Figure 12-9. Critical nesting locations for Piping Plover.

Figure 12-10. Critical migration stopover areas for Red Knot.

Most of the habitat used by these species is dynamic, shifting in distribution over space and time as currents and storms continually shape coastal areas. Activities such as dredging, jetty building, bulkheading, and beach replenishment all have the potential to alter the quality and extent of habitat available to these species by interrupting natural habitat dynamics. Human activities can also directly disturb habitat. For example, in stopover areas for Semipalmated Sandpiper in the Bay of Fundy, commercial bait harvesting can degrade feeding habitat and foraging efficiency of these birds (Shepherd and Boates 1999).

For species using offshore areas, such as Harlequin Duck and Razorbill, little is known about how human activities may indirectly affect their populations within the Northwest Atlantic region, although it had been documented that Razorbills experience mortality via fisheries bycatch (Murray et al. 1994, Piatt and Nettleship 1987). Because habitat requirements for benthic feeding species are also poorly known, the effect of human activities such as bottom dredging or sand extraction is unclear.

Management and Conservation

Regulatory Authorities

The primary regulatory agency for birds in the United States is the USFWS. In Canada, it is the CWS. In addition, state and province-based natural resource agencies have trustee responsibilities for birds.

Current Conservation Efforts

Current conservation activities for Roseate Terns, Least Terns, Arctic Terns, and Piping Plovers are coordinated by the USFWS and CWS with state and conservation nonprofit partners. The conservation actions geared towards these species are primarily aimed at protection and management of nesting sites. Efforts for Roseate Terns (and, to a lesser extent, Arctic Terns) include vigorous nesting colony management, including predator and competitor removal. On some islands, gull control is important to Roseate Tern colony viability. For Least Terns and Piping Plovers, efforts to reduce the impact of domestic and wild predators and to reduce human disturbances to nesting and foraging areas, especially at beaches that are popular recreation areas, are particularly important. Actions at many beaches across the region include the installation of symbolic fencing to discourage human beachgoers from

entering Plover and Tern nesting areas, installation of predator exclosures around Plover nests, and outreach to beachgoers to reduce direct human disturbance of foraging plovers.

Managing beach use at key stopover feeding areas is also a part of Red Knot conservation. Docents, symbolic fencing, and informational signage are used in the effort to educate the public and discourage beach use at critical feeding areas along the shores of Delaware Bay during the several weeks when red knots pass through the Northwest Atlantic region on migration routes. Another key management effort to ensure high-quality stopover feeding areas for this species is regional management of the horseshoe crab harvest. The states have different approaches to managing harvests, but overall harvest has been greatly reduced over the past ten years specifically to increase the amount of horseshoe crab spawning on Delaware Bay beaches. On these beaches, competition with gulls for horseshoe crab eggs is suggested to be another limiting factor for red knots and, as a result, efforts are under way to develop a way to exclude gulls from key feeding areas as horseshoe crab stocks rebuild.

Thus far, there is little direct management of Audubon's Shearwater and Razorbill in American and Canadian waters. The state of Maine has undertaken efforts to inform hunters about areas frequented by Barrow's Goldeneye in order to avoid accidental hunting mortality caused by hunters mistaking Barrow's Goldeneye with Common Goldeneye (which can be hunted legally).

Species Accounts

Arctic Tern *(Sterna paradisaea)*

The Arctic Tern has a circumpolar Arctic breeding distribution (Hatch 2002). Within the Northwest Atlantic region, nesting occurs along the coast of Maine. Arctic terns that breed within this region migrate south over the Atlantic Ocean to wintering grounds in Antarctica, and then migrate back north in the spring along the same route.

Arctic Terns arrive in the Northwest Atlantic region in April and May (Hawksley 1953). Nesting occurs primarily on rocky, gravelly, or sandy substrate on small offshore or barrier islands in Maine. Most eggs are laid from mid-May through mid-June, and begin hatching in the first half of June and continue through mid-July. After fledging, young birds feed near the colony for about ten days before dispersing and initiating migration. During the breeding season, the adults are generally found foraging within 20 km of their colonies.

© Donna Dewhurst/US Fish & Wildlife

Migration to non-breeding grounds in Antarctica is probably accomplished by tremendous flights broken up by stops at four to five feeding areas, though the true number and location of these feeding areas is unknown (Hatch 2002). It is likely that Arctic Terns do not feed in waters near the equator. These flights are primarily oceanic, but birds from the region may fly east to Europe and move southward along the coast of Africa towards Antarctica. After arrival in Antarctica in the northern hemisphere's mid- to late autumn, Arctic Terns forage around Antarctica, often completely circumnavigating the continent during the nonbreeding season. They then begin the northern migration back to the Arctic in March.

Roseate Tern *(Sterna dougallii)*

Roseate Terns primarily breed in the tropics in the Caribbean, western Atlantic, western Indian Ocean, and a variety of sites in the western Pacific (Gochfeld et al. 1998). However, the Terns also breed in a few temperate zones along the eastern coast of North America, the western coast of Europe, and the southern coast of Japan.

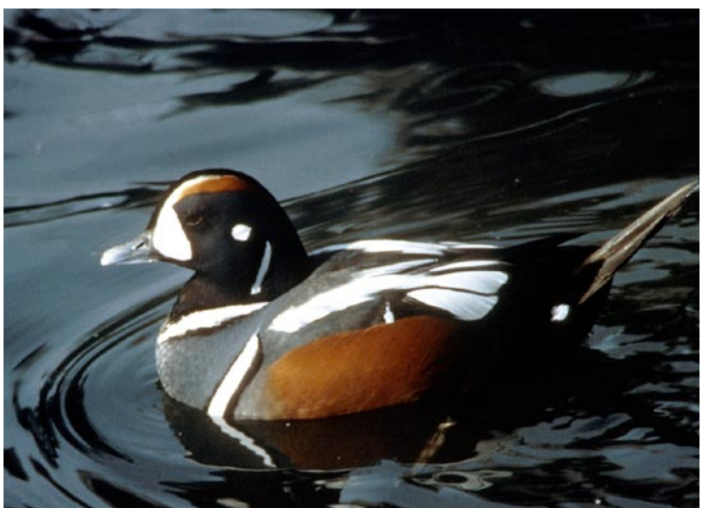
Roseate Terns arrive in the Northwest Atlantic region in April and early May (Shealer and Kress 1994). They nest on rocky or sandy substrate on small offshore or barrier islands, in this region primarily on two islands along the coasts of Long Island and Massachusetts, with a small number of nesting sites in Maine. Within the Northwest Atlantic region, all Roseate Terns nest within much larger Common Tern nesting colonies. Most eggs are laid from mid-May through mid-June, but can be laid as late as early July. Eggs begin hatching in the first half of June and continue through mid-July. After fledging, many Roseate Terns stage at Stratton Island and Saco Bay in southern

Maine and Monomoy Island National Wildlife Refuge in Massachusetts for up to three weeks before initiating their southern migration.

Roseate Terns are thought to migrate south during July and August from the breeding areas along the northeastern United States and Canada to the Caribbean and then to Brazil (Kirkham 1988). The winter range is poorly understood, but they have been found in significant numbers near Bahia, Brazil. In spring, their northern migration is likely oceanic since they are rarely seen from land until they arrive in the northeastern United States.

Harlequin Duck *(Histrionicus histrionicus)*

Harlequin Ducks breed from Iceland west to eastern Siberia (Robertson and Goudie 1999). Within North America, there are two distinct breeding populations: an eastern population that breeds from Labrador south to Newfoundland and a western population that breeds from Wyoming north through Alaska and western Canada



© Glen Smart/US Fish & Wildlife

(Robertson and Goudie 1999). There are no breeding harlequin ducks within the Northwest Atlantic region. However, most of the eastern North American breeding population (thought to be somewhat less than 1,500 individuals) winters in the region along the coasts of Nova Scotia and New Brunswick south to New Jersey (Vickery 1988, Mittelhauser 2002).

Harlequin Ducks build nests along fast-moving white-water rivers and streams in May and June. Most eggs hatch in late June and July. After breeding, from July through October, the ducks gather in larger groups before migration to the coast. No harlequin ducks have ever been observed migrating, so it is unknown whether they fly directly from breeding to wintering areas (the most likely scenario, as they have not been sighted migrating) or stop over at points in between. Harlequins winter along rocky coastlines in shallow marine waters. Birds can be observed on wintering grounds as early as September, but the largest numbers arrive in October and November.

Audubon's Shearwater *(Puffinus lherminieri)*

There are no breeding Audubon's Shearwaters within the Northwest Atlantic region. Within this region, the largest concentration of this species is found offshore of Cape Hatteras, North Carolina in the fall.
Audubon's Shearwaters initiate courtship in late November and begin egg-laying in January-May in the Bahamas (approximately 60% of the breeding population), Cayo del Agua, and the Lesser Antilles from the Virgin Islands to north of Tobago (Lee 2000). Breeding activity is nocturnal. Most of their nests are found in burrows, on cliffs, or under boulders on rocky open ground.

After breeding in spring to early summer in the Caribbean, most Audubon's Shearwaters follow the Gulf Stream north off the southeastern coast of the United States. Approximately 50-75% of the species' population can be found during the summer and early fall in a major foraging concentration area near Cape Hatteras, North Carolina (Lee and Socci 1989). Here they occur "along [the] inner edge of the Gulf Stream or over waters 50 to 500 fathoms deep" (Lee 1995). They can be found within the Gulf Stream as far north as Massachusetts in late summer.

Red Knot *(Calidris canutus rufa)*

The Red Knot is a western hemispheric subspecies of a globally distributed migratory shorebird (Harrington 2001). The five subspecies of red knot have varied distributions and migration strategies but only the *rufa* subspecies occurs within the Northwest Atlantic. This subspecies spends its breeding season in the Arctic tundra of North America and its non-breeding season in coastal areas at the southern tip of South America. Between these two areas, numerous stopover sites, including Delaware Bay and the barrier islands of Virginia, are important for refueling during migration.

Red Knots arrive on breeding grounds from late May to early June. While they breed on the tundra, knots spend most of migration and nonbreeding periods in marine intertidal areas where they primarily feed on small mollusks in sandy area, mudflats, and peat banks. In addition, in the Delaware Bay, they feed heavily on eggs deposited by horseshoe crab on sandy beaches during northward spring migration (Harrington 2001).

Southward migration from the Arctic begins by mid-July and knots are again seen within the Northwest Atlantic during this time. They begin arriving at stopover areas in South America in the Guianas and northern Brazil by mid-August and spend the rest of the boreal winter in southern Argentina and Tierra del Fuego (Harrington 2001). Return migration begins along the coast of South America from February through early April and birds arrive on the Delaware Bayshore from mid-April through early June.

Least Tern *(Sternula antillarum)*

The Least Tern has an extensive breeding range in coastal areas throughout the United States, Central America, the Caribbean, and northern South America as well as along large river systems in the United States (Thompson et al. 1997). Within this broad range, the Tern breeds colonially on sandy beaches free of vegetation. Little is known about movements of Least Terns during the non-breeding season, but Terns leave breeding areas of the United States, northern Mexico and the Caribbean and spend the non-breeding season in Central and South America (Thompson et al. 1997).

The breeding season begins in April to May, depending on the location. Breeding pairs are monogamous and participate in courtship rituals. Nests consisting of simple scrapes in the sand house clutches of two to three eggs. Upon hatching, young need to be fed by adults until fledging (20 days) and up to several weeks beyond fledging, even after they have dispersed from the breeding colony.

© Gene Nieminen/USFWS

Migration timing and destinations are poorly known, although marked birds breeding in coastal Massachusetts migrated to northern South America for the non-breeding season (Thompson et al. 1997).

Piping Plover *(Charadrius melodus)*

The Piping Plover is a shorebird that breeds throughout the Northwest Atlantic area on beaches from North Carolina north to eastern Canada (Elliot-Smith and Haig 2004). There is also an inland population that breeds along rivers and in wetlands throughout the northern Great Plains of the U.S. and Canada. These separate breeding populations may receive subspecific designation in the future based on evidence that there is little mixing of individuals between the two populations. During the non-breeding season, individuals occur along the coasts of the southeastern United States and the Gulf Coasts of the United States and Mexico during the non-breeding season.

On breeding areas, arrival varies from mid-March at southern latitudes to early May at the northernmost parts of the range. Pairs are monogamous and courtship proceeds with males establishing territories and creating nest scrapes in the sand. Nest initiation begins after pair formation from early May to early June. The incubation period is approximately 30 days. Newly hatched young can forage independently but are attended by parents for an additional 30 days until they fledge. Post breeding behavior, migration timing, and important stopover sites of piping plover are poorly known but they depart their breeding grounds by mid-August. They begin arriving at non-breeding areas in August and arrivals can continue into November.

Razorbill *(Alca torda)*

This husky member of the Alcidae is a colonial breeder that forms colonies in the low Arctic on rocky coastlines and islands from eastern North America east to northwest Russia (Hipfner 2002). The greatest concentration of breeding Razorbills is in Iceland. A small fraction of the world's population breeds in North America in Maine, Nova Scotia, and Newfoundland. Important nonbreeding sites for North American populations are the Gulf of Maine, Bay of Fundy, and Georges Bank.

Razorbills, like many seabirds, are long-lived, maintain long-term breeding pair bonds, and are faithful to nest site locations. Age at first breeding is also late, at four to five years (Hipfner 2002). Egg laying ranges from late may to early June depending on the colony location, and laying timing within colonies tends to be synchronous. Females lay just one egg in nests that are primarily built in or near rock crevices on cliffs. Upon hatching, young remain at the nest site for approximately 20 days. Although not fully developed, they leave the nest site and move out to sea where they are still attended and fed by parents. Young are able to feed independently roughly one month after nest departure. Post breeding movements, juvenile dispersal and general non-breeding ecology are poorly known in this species (Hipfner 2002).

Barrow's Goldeneye *(Bucephala islandica)*

This cavity nesting duck has a known breeding distribution centered in two discrete areas: montane (subalpine highland) regions of western Canada and Alaska and a more recently discovered area of southeastern Quebec (Eadie et al. 2000). This latter population uses the Northwest Atlantic region during the non-breeding season. The nonbreeding range encompasses much of the northern coastlines of eastern and western North America as well as inland lake areas.

During the breeding season Barrow's Goldeneyes establish territories centered on lakes and ponds. Pairs are known to maintain bonds between years and are site faithful. Nesting extends from late April through early June depending on the location. Cavities in live or dead trees are used, and females remain faithful to nest cavities between years. The male generally only maintains the breeding territory up until incubation. It then leaves the territory and joins post-breeding congregations of other males. Upon hatching, ducklings are able to feed themselves and are led from the nest to a nearby body of water.. Cohesion of the group gradually breaks down and young become able to fly at approximately five weeks of age. Post-breeding movements are poorly known, but birds appear to remain inland until freezing occurs which prompts movement to coastal areas. Non-breeding distribution is limited to specific benthic habitats associated with preferred food items, such as mussels (Eadie et al. 2000).

Literature Cited

Anderson, M.G., B. Vickery, M. Gorman, L. Gratton, M. Morrison, J. Mailet, A. Olivero, C. Ferree, D. Morse, G. Kehm, K. Rosalska, S. Khanna, and S. Bernstein. 2006a. The Northern Appalachian / Acadian Ecoregion: Ecoregional Assessment, Conservation Status and Resource CD. The Nature Conservancy. Boston, MA.

Anderson, M. G., K. Lombard, J. Lundgren, B. Allen, S. Antenen, D. Bechtel, A. Bowden, M. Carabetta, C. Ferree, M. Jordan, S. Khanna, D. Morse, A. Olivero, N. Sferra, and A. Upmeyer. 2006b. The North Atlantic Coast: Ecoregional Assessment, Conservation Status Report and Resource CD. The Nature Conservancy, Eastern Conservation Science, Boston, MA.

Chipley, R.M., G.H. Fenwick, M.J. Parr, and D.N. Pashley. 2003. The American Bird Conservancy Guide to the 5000 Most Important Bird Areas in the United States. Random House, New York, NY. 518 pp.

Eadie, J. M., J. L. Savard, and M. Mallory. 2000. Barrow's Goldeneye *(Bucephala islandica).* In A. Poole, ed. The Birds of North America Online. Cornell Lab of Ornithology, Ithaca.

Elliot-Smith, E., and S. M. Haig. 2004. Piping Plover *(Charadrius melodus)*. In A. Poole, ed. The Birds of North America Online. Cornell Lab of Ornithology, Ithaca.

Erwin, R. M., B. R. Truitt, and J. E. Jimenez. 2001. Ground-nesting waterbirds and mammalian carnivores in the Virginia barrier island region: Running out of options. Journal of Coastal Research 17:292-296.

Gochfeld, M., J. Burger, and I. Nisbet. 1998. Roseate Tern *(Sterna dougallii)*. In A. Poole, ed. The Birds of North America Online. Cornell Lab of Ornithology, Ithaca.

Harrington, B. A. 2001. Red Knot *(Calidris canutus)*. In A. Poole, ed. The Birds of North America Online. Cornell Lab of Ornithology, Ithaca.

Hatch, J. J. 2002. Arctic Tern *(Sterna paradisaea)*. In A. Poole, ed. The Birds of North America Online. Cornell Lab of Ornithology, Ithaca.

Hawksley, O. 1957. Ecology of a breeding population of Arctic Terns. Journal of Field Ornithology 28:57-92.

Hipfner, M. J., and G. Chapdelaine. 2002. Razorbill *(Alca torda)*. In A. Poole, ed. The Birds of North America Online. Cornell Lab of Ornithology, Ithaca.

Karpanty, S. M., J. D. Fraser, J. Berkson, L. J. Niles, A. Dey, and E. P. Smith. 2006. Horseshoe crab eggs determine red knot distribution in Delaware Bay. Journal of Wildlife Management. 70:1704-1710.

Kirkham, I. R., and D. N. Nettleship. 1988. Status of Roseate Tern in Canada. Journal of Field Ornithology. 28:505-515.

Lee, D. S. 1995. Observations of marine birds off the coast of North Carolina. The Chat. 59:114-171.

Lee, D. S. 2000. Status and conservation priorities for Audubon's shearwaters in the West Indies. In E. A. Schreiber, and D. S. Lee, eds. Status and Conservation of West Indian Seabirds, Special Publication No. 1 Society of Caribbean Ornithology, Alexandria, VA.

Lee, D. S., and M. C. Socci. 1989. Potential effects of oil spills on seabirds and selected other oceanic vertebrates off the North Carolina coast. Occasional Papers of the North Carolina Biological Survey. 64 pp.

Mittelhauser, G. H., J. B. Drury, and P. O. Corr. 2002. Harlequin Ducks *(Histrionicus histrionicus)* in Maine, 1950-1999. Northeastern Naturalist. 9:163-182.

Murray, S., S. Wanless, and M. P. Harris. 1994. The effects of fixed salmon *Salmo salar* nets on guillemot *Uria aalge* and razorbill *Alca torda* in northeast Scotland in 1992. Biological Conservation. 70: 251-256.

Nisbet, I. C. T., R. R. Veit, and S. A. Auer. 2008. Marine birds of the Eastern USA and the Bay of Fundy: distribution, numbers, trends, threats and management. Nuttall Ornithological Monographs, in press.

Peters, K. A., and D. L. Otis. 2007. Shorebird roost-site selection at two temporal scales: is human disturbance a factor? Journal of Applied Ecology. 44: 196-209.

Piatt, J. F., and D. N. Nettleship. 1987. Incidental catch of marine birds and mammals in fishing nets off Newfoundland, Canada. Marine Pollution Bulletin. 18:344-349.

Robertson, G. J., and R. I. Goudie. 1999. Harlequin Duck *(Histrionicus histrionicus)*. In A. Poole, ed. The Birds of North America Online. Cornell Lab of Ornithology, Ithaca.

Rodgers, J. A., and S. T. Schwikert. 2002. Buffer-zone distances to protect foraging and loafing waterbirds from disturbance by personal watercraft and outboard-powered boats. Conservation Biology. 16: 216-224.

Sabine, J. B., J. M. Meyers, C. T. Moore, and S. H. Schweitzer. 2008. Effects of human activity on behavior of breeding American Oystercatchers, Cumberland Island National Seashore, Georgia, USA. Waterbirds 31: 70-82.

Samson, D.A., Anderson, M.G., Zaremba, R., McCarthy, K.,and J.McCann. 2003. Chesapeake Bay Lowlands Ecoregional Conservation. Plan; First Iteration, Edited. The Nature Conservancy, Mid-Atlantic Division, Charlottesville, VA.

Shealer, D. A., and S. W. Kress. 1994. Post-breeding distribution movements and prey selection of Roseate Terns at Stratton Island, Maine. Journal of Field Ornithology.65:349-362.

Shepherd, P. C. F., and J. S. Boates. 1999. Effects of a commercial baitworm harvest on Semipalmated Sandpipers and their prey in the Bay of Fundy hemispheric shorebird reserve. Conservation Biology.13: 347-356.

Silverman, E., M. Koneff, K. Fleming, and J. Wortham. 2008. Atlantic Coast Wintering Sea Duck Survey, U.S. Fish & Wildlife Service Unpublished Document, MD.

Thompson, B. C., J. A. Jackson, J. Burger, L. A. Hill, E. M. Kirsch, and J. L. Atwood. 1997. Least Tern (*Sterna antillarum*). In A. Poole, ed. The Birds of North America Online. Cornell Lab of Ornithology, Ithaca.

Vickery, P. 1988. Distribution and population status of Harlequin Ducks (*Histrionicus histrionicus*) wintering in eastern North America. Wilson Bulletin. 100:119-126.

Walsh, J., V. Elia, R. Kane, and T. Halliwell. 1999. Birds of New Jersey. New Jersey Audubon Society, Bernardsville, NJ. 704 pp.

CHAPTER

13

Humans Within Northwest Atlantic Ecosystems: An Overview of Uses & Values

Jay Odell and Kate Killerlain Morrison

Introduction

© Kerry Crisley/TNC

Each of the assessment's habitat and species focused chapters (2-12) includes a "Human Interactions" section summarizing the environmental stresses and impacts of specific human uses. Review of these sections reveals some common themes – pollution, climate change effects, fishing, coastal habitat loss, energy production, recreational activities, and waterborne transportation can all have negative impacts on multiple habitats and species.

However, eliminating *all* of these impacts is not a sensible or realistic goal – management goals need to encompass both socio-economic and ecosystem conservation objectives. Ecosystem based management approaches offer promise for simultaneous achievement of goals for sustaining living marine resources, consumptive human uses, and human health and well-being. However, in addition to detailed information on marine habitats and species, ecosystem based management requires detailed information on how different human communities (geographic and sectoral) perceive, use and value natural resources.

It is now widely held that the focus of natural resource management is people rather than natural resources as it is primarily human behavior rather than nature that is being "managed". Experts continually recommend "...an integrated approach to management that considers the entire ecosystem, **including humans**...to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide **the services humans want and need**... (emphasis added)" (SCS 2005). The assessment has been developed with a goal of furthering understanding on how human activities, both existing and proposed, are linked to natural resources--but much more work remains to be done.

The Conservancy's Marine Ecoregional Assessments have recently begun to include more socio-economic information. The field of socio-economics is concerned with a broad range of issues involving the interaction between society, politics and culture and the relationship between individuals, the choices they make and the economic market.

Environmental Impact Assessments measure anticipated changes in natural resources and Social Impact Assessments describe the effects of social changes. "Although economic analysis can be considered as one part of social science analysis, economic impact analysis addresses how efficiently investments of capital and other resources are returned in present and future benefits to society (i.e., whether the economic benefits of an action or policy outweigh the costs). Economic impact analysis focuses on resource supply and demand, prices, and jobs, while social impact analyses consider how public or private actions may alter the ways in which people live, work, play, relate to one another, organize to meet their needs and generally cope as members of society. The term also includes cultural impacts involving changes to the norms, values, and beliefs that guide and rationalize their cognition of themselves and their society (NMFS, 1994).

© Gabriel Nordyke, Marine Photobank

The Northwest Atlantic region is densely populated and includes coastal communities that are tightly linked to and highly dependant on coastal and marine ecosystems for commerce, recreation and aesthetic amenities. Accordingly, there are significant economic incentives for increased private use and profit from use of public trust resources. Consequently, local, state and federal agencies seek to minimize natural resource impacts and maximize sustainable use using a variety of regulatory tools. Although, some of our environmental laws such as the National Environmental Policy Act and the Magnuson-Stevens Fishery Conservation and Management Act require social impact assessments on local communities, available data needed to inform such assessments is often quite sparse when compared to the volume of information on natural resources.

Similarly, this assessment does not provide enough socio-economic information and spatial data on human uses to fully describe the linked social-ecological system within the Northwest Atlantic planning area. High quality socio-economic data can be used to develop better management alternatives and more appropriate mitigation packages. The Social Impact Assessment methodology (NMFS, 1994) emphasizes the need for information on a wide range of indicators including:

- **Population Characteristics** (Population Change, Ethnic and racial distribution, Relocated populations, Influx or outflows of temporary workers, Seasonal residents)
- **Community and Institutional Structures** (Voluntary associations, Interest group activity, Size and structure of local government, Historical experience with change, Employment/income characteristics, Employment equity of minority groups, Local/regional/national linkages, Industrial/commercial diversity, Presence of planning and zoning activity
- **Political and Social Resources** (Distribution of power and authority, Identifications of stake holders, Interested and affected publics, Leadership capability and characteristics);
- **Individual and Family Changes** (Perceptions of risk, health, and safety, Displacement/relocation concerns, Trust in political and social institutions, Residential stability, Density of acquaintanceship, Attitudes toward policy/project, Family and friendship networks, Concerns about social well-being
- **Community Resources** (Change in community infrastructure, Native American tribes, Land use patterns, Effects on cultural, historical, and archaeological resources).

Socio-economic information can inform decisions on individual site-specific projects and is also needed to support the comprehensive marine spatial planning approaches being developed worldwide. Marine spatial planning can reduce conflicts by providing a blueprint for aligning human uses with their socially and ecologically compatible times and places. These approaches require analysis of tradeoffs between different uses and maintenance of ecosystem services. The data contained in this assessment is designed to help support marine spatial planning processes but tradeoff analyses need to developed in stakeholder driven and very transparent public contexts and are beyond the scope of our work.

There are many approaches for acquisition of the socio-economic data that is needed, including:

- Ethnographic research
- Focus groups and interviews
- Cost-benefit analysis
- Non-market valuation
- Network/power analysis
- Opinion polls and surveys
- Input-Output economic models (market valuation)
- Mapping human use patterns
- Community/participatory mapping

Accurate and verifiable socio-economic information is very difficult to acquire and it is costly to develop new data sets; a comprehensive socio-economic analysis was well beyond the scope of this assessment. However, information was collected using three of the approaches listed above: an opinion survey, an economic model and preliminary human use mapping. For each approach, this chapter summarizes: (1) what we measured, (2) how we measured it, (3) whether or not it can be illustrated spatially, and (4) limitations of the tool.

Stakeholders Survey

In early 2008, the Conservancy conducted a regional survey of marine stakeholders to gain a better understanding of marine resource stakeholder's priorities and concerns and their thoughts on effective strategies for coastal and marine conservation in the region. Survey questions were designed to reveal stakeholders' views about the current status of the region, data gaps, and how assessment data products might be designed to maximize their utility. Despite the limitations noted below, survey results were useful for informing early stages of assessment work plan development. The survey was used as a communications tool to stimulate interest and participation from potential technical team members, peer reviewers and data providers.

What did we measure?

Information collected included stakeholder opinions on which region-wide stressors were of the greatest concern: Coastal development and related effects (32 percent); Global climate change (21 percent); Fishing-related threats including overharvest, bycatch and habitat damage (20 percent); Pollution, including non-point, point-source, sediments, nutrients and toxins (16 percent). Specific threats to habitats and species included: non-point source pollution, nearshore habitat loss, benthic habitat impacts, and energy development.

How did we measure it?

The survey was conducted in January and February 2008 with an online survey tool (SurveyMonkey.com). The survey invitation was sent by email on January 30, 2008, and sent a second time on February 7 to those who had not yet responded. A total of 279 recipients received the email invitation. This report summarizes results from 139 respondents (49 percent response rate); please see Appendix 13-1 for survey results.

Could we illustrate it spatially?

While it is possible to extract geographic locations based on respondent affiliation, a spatial illustration would be of low utility. In addition, respondents were answering each question through a regional lens, rather than through their individual state or town.

Limitations

Survey respondents were identified by Conservancy staff who sought to achieve balanced representation from state and federal agencies, universities and research organizations, non-profit and conservation organizations and maritime industry groups (commercial fishermen and/or members of fisheries related associations or trade groups). Industry groups were underrepresented but a large comprehensive survey of all identified stakeholders was not feasible given time and budget constraints.

Input-Output Economic Model

The Conservancy contracted with the Woods Hole Oceanographic Institution's Marine Policy Center to produce a "Regional Economic Analysis of the Northwest Atlantic Marine Eco-Region", completed in August 2008. This analysis utilized the IMPLAN Input-Output Model to assess the impact of the coastal and marine economy in the Northwest Atlantic region. Some of the key findings from the report are reproduced or summarized below; please refer to Appendix 13-2 for the full report, glossary of terms, IMPLAN tables and NAICS Industry Codes.

What did we measure?

The analysis was based on an economic input-output (IO) model of an economy comprising the coastal counties from Maine to North Carolina. Primary and secondary industry sectors that depend on the ocean were identified, and the economic significance of those sectors to the regional economy was assessed. The model measured the value of industries in coastal and marine economies for 2006, the most recent year of available coastal county data. The model also measures the contribution of those sectors to state and region (dollar values generated and numbers of employees generated). While this analysis did not include data from a time series, the authors described trends by comparing results of the 2006 model to those from a similar study completed in 1995.

How did we measure it?

The Input–Output model was developed using the industry standard software, Impact Analysis for Planning Software (IMPLAN). IMPLAN is a commercially available input-output model (IO) which is widely used to characterize a snapshot of the linkages between different industrial sectors in an economy. It is constructed of linear algebraic equations that describe how the products of sets of industries are used in the manufacture of other goods, to satisfy consumer demands and to supply export markets. Specific industrial sectors (labeled as "ocean sectors") were identified that depend upon the ocean as a source of natural resources, as a sink for wastes or nutrients, for transportation, or as an aesthetic resource. The IO model yields estimates of direct output and labor impacts (*i.e.*, sales revenues and employment) from the ocean sectors, and indirect and induced impacts, which are summarized in the form of economic "multipliers." These multipliers are a measure of the connectedness of an industrial sector to the rest of the relevant economy. Changes in the production of goods in an industry will affect other sectors to which it is linked, either through changes in the purchase of goods from those sectors or through changes in the sale of its products to other industries or consumers.

Once constructed, an IO model yields information about direct, indirect, and induced output and labor impacts and value-added. Value-added is a measure of the net value (roughly the value of labor or total wages) created when products are purchased from some industries and combined using a technology and labor into another product in the economy. Importantly, value-added is the measure used to construct estimates of gross domestic product (GDP), and estimates of value added from the Northwest Atlantic coastal county model can be used to measure the contribution of that economy to the regional or national economy. Please see Appendix 13-2 for a full description of methods.

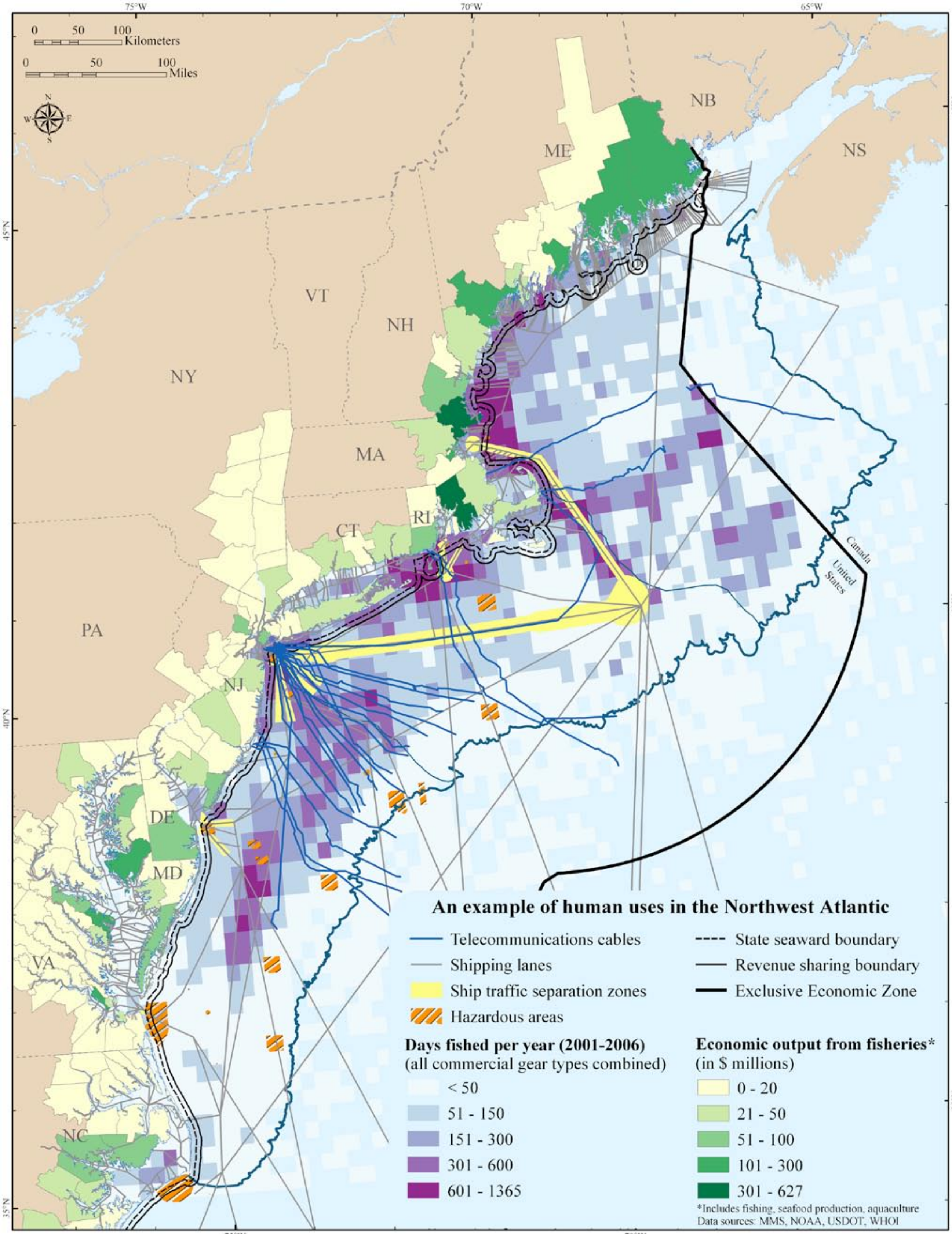


Figure 13-1. Selected spatial data illustrating some of the human uses of the Northwest Atlantic region.

Results

A brief summary is presented here; please refer to Appendix 13-2 for detailed results. Annual coastal-and ocean-related economic output in the Northwest Atlantic region is estimated at $362 billion. Corrected for inflation, there has been a 17% increase from 1995 to 2006 in direct output in the region's broadly defined (primary and secondary) ocean sectors. Annual ocean-related employment in the Northwest Atlantic region stands at almost 3 million persons. There has been a 25% increase from 1995 to 2006 in employment in the region's broadly defined ocean sectors.

Can we illustrate it spatially?

Economic activity for each sector can be mapped to the resolution of counties (Figure 13-1.) Additional IMPLAN model outputs have been mapped by coastal county, including maps for revenue output for each industry and one map of all the industries combined (IMPLAN totals). Spatial data on human uses in the ocean cannot be related to IMPLAN outputs without additional work to develop data and modeling approaches to explicitly link the spatial distribution of ocean and shore based activities.

Limitations

- Marine and coastal industries are often hard to extract in aggregate categories
- Economic impacts may be inflated and exaggerate the value of a sector
- Data is binned at state or county level making higher resolution spatial illustration difficult.
- Coastal county data is not linked to spatial data on offshore activity. Unless there is data describing the geographic distribution of human activities in the ocean, it is not possible to distribute data on outputs, employment or value-added over the ocean.
- Traditional IO models do not yield estimates of net economic value, as represented by consumer and producer surpluses.
- With IMPLAN results, only one part of the marine/coastal market was measured. For example, a cost-benefit analysis that looks at the economic values between strategies would involve consumer and producer surplus data.
- The IMPLAN model does not measure non-market values or ecosystem services values (i.e. resources that are "unpriced"). Non-market benefits comprise consumer surpluses for environmental amenities that are not traded in established markets, and, therefore, are not produced by an industry.

Further research to evaluate spatial linkages between socio-economic and ecological data is needed to inform marine spatial planning processes. This work could include linking economic data to the relevant places where resource uses occur, and quantifying the market values of for specific human uses at varying intensities. Additionally, non-market valuation methods are needed to inform ecosystem based management decisions to meet goals for long-term sustenance of ecosystem services that have no direct market value (e.g. erosion and pollution control, cultural, aesthetic).

Human Use Mapping

Coastal and marine spatial planning to support ecosystem based management requires high quality and high resolution spatial data on human uses. During the course of this assessment, spatial data was acquired on human uses with the data on coastal and marine habitats and species.

Map layers from diverse sources were obtained that contained data on pollution, shoreline development, coastal sand mining, recreational and commercial fishing, shipping lanes, telecommunications cables, energy development, hazardous waste dump sites, shipwrecks, military use areas, and administrative boundaries.

Unfortunately, nearly all of these map layers had limitations that precluded their utility for full integration and analysis with geophysical and ecological data within the assessment. Several of the human use spatial data layers did not cover a substantial portion of the planning area and layers had little to none of the metadata needed to evaluate spatial data accuracy and appropriate use. Therefore, spatial data on human uses is not being distributed with the assessment.

However, Figure 13-1 is included to illustrate some of the human activity within the assessment study area using some of the more credible and authoritative data on human uses. The source data used to create this image includes Fishing Vessel Trip Report data information kindly provided by NOAA Fisheries, binned by ten minute square to provide a general regional scale sense of the distribution and intensity of commercial fishing activity and also shows fishery related (including seafood processing and aquaculture) economic activity by coastal county from the report described above and included as Appendix 13-2. Additional map layers are overlaid on this image depict shipping lanes, hazardous waste dump site locations, and a subset of existing telecommunications cables. The Conservancy looks forward to working with state and federal agencies and other interested parties to develop marine spatial data on human uses that is robust enough to support marine spatial planning approaches.

LITERATURE CITED

NMFS (National Marine Fisheries Service). 2004 Operational Guidelines – Fishery Management Process, Appendix 2(g), Guidelines for Assessment of the Social Impact of Fishery Management Actions, http://www.nmfs.noaa.gov/sfa/reg_svcs/social_impact_guide.htm Accessed March 20, 2010

SCS (Scientific Consensus Statement on Marine Ecosystem-Based Management) 2005. http://www.compassonline.org/pdf_files/EBM_Consensus_Statement_v12.pdf Accessed March 20, 2010.

CHAPTER

14

Next Steps

Jay Odell, Mark Anderson, and Jennifer Greene

Introduction

© Doug Wechsler

This assessment focused on gaining a better understanding the ecology and physical processes of the marine environment and the interacting life histories of its inhabitants. Our aim was to comprehend, and make explicit, many of the spatial elements needed for the conservation of biodiversity. The assessment products provide a new context for marine spatial planning and other approaches needed to achieve better alignment of human activities with the places to sustain biodiversity and ecosystem services throughout the region. The next step in the assessment process (Phase Two) is the creation of a narrative report that describes the priority places and strategies for consideration within the Northwest Atlantic region, based on analysis by teams of experts, of information gathered in Phase One.

Ecosystem-Based Management and Marine Spatial Planning

New approaches are urgently needed because the current and future human demands and dependence on this region's ocean resources are substantial. Offshore energy production, aquaculture, commercial and recreational fishing, sand and gravel extraction, tourism, and shipping contribute immensely to the nation's economy, but place intense demands on ocean ecosystems. For the most part, ocean spaces are regulated on a sector-by-sector, case-by-case basis without sufficient consideration for tradeoffs between sectors, ecosystem interactions and the effects of human activities on marine biodiversity. The unintended and undesirable result of status quo ocean resource management is no longer news — the ocean is in trouble, suffering from the cumulative impacts of diverse human activities that severely damage marine habitats and threaten living marine resources.

In 2009, the Council on Environmental Quality responded to a Presidential Memorandum by forming the Interagency Ocean Policy Task Force. The task force engaged the nation's ocean stakeholders to develop new national policy for adoption of *"ecosystem-based management as a foundational principle for the comprehensive management of the ocean, our coasts, and the Great Lakes"* to *"protect, maintain, and restore the health and biological diversity of ocean, coastal, and Great Lakes ecosystems and resources".* The task force also used a public process to develop a new national framework to *"implement comprehensive, integrated, ecosystem-based coastal and marine spatial planning and management in the United States"* (OPTF 2009).

Using the Data to support Marine Spatial Planning

We would like to emphasize that marine spatial planning is not a panacea for effectively addressing all marine conservation issues. For some species, spatial prioritization may not be a practical or realistic conservation approach, and many conservation challenges require new policy development to develop solutions that are not explicitly place-based.

Our long term goal is to ensure protection of representative, resilient, and redundant areas encompassing the full range of diversity within the regions at large scales while allowing sustainable use of marine resources.

Marine spatial planning, when informed by science, can provide the foundation for marine ecosystem based management to help meet goals for marine biodiversity conservation and sustainable marine resource use. The information and spatial data contained in this assessment provides a solid initial foundation for examining the regional implications of local decisions, but additional customization and refinement to enhance its utility for supporting marine spatial planning processes is needed.

Addressing Data Gaps

The assessment team spent many months searching for, discovering, and analyzing diverse spatial data layers. Subsequently, we identified several large data gaps. While substantial progress can still be made in the absence of these data, filling these gaps will allow for a more comprehensive and effective marine spatial planning process. There were several types of gaps identified: lack of access to existing data, lack of adequate sampling density or geographic extent for existing data, lack of confidence in data due to inadequate metadata and finally, instances where critical data has not yet been collected at all. The following specific data needs were highlighted:

- Additional sediment sampling data to improve resolution in poorly sampled areas.
- High resolution benthic mapping data (e.g., acoustic surveys).
- Spatial data on the distribution and abundance of oysters, bay scallops, hard clams, and other shellfish.
- Fishery-independent survey data on the distribution and abundance of coastal and marine pelagic species (e.g., Atlantic menhaden, Atlantic herring, bluefin tuna, and sandbar shark).
- Pelagic habitat models based on oceanographic features and species distribution.
- LiDAR survey data to support sea level rise adaptation planning in areas where current coverage is lacking.
- Integration of nearshore trawl survey data with NMFS groundfish surveys (e.g., state trawl surveys, Atlantic State Marine Fisheries Commission's NEAMAP survey)
- Data on seasonal migratory routes for whales, dolphins, large pelagic fish, sea turtles, sea birds, and shorebirds.
- Human use data (e.g. higher resolution data on recreational and commercial fishing, vessel traffic, coastal sand and gravel mining, and other coastal and marine resource uses).

Developing Interactive Decision Support and Advancing Data Analyses

The data products created in this assessment can be used "off the shelf" to support individual project decisions, conservation plans, or more comprehensive marine spatial planning efforts. Moreover, the Phase Two report includes preliminary identification of priority conservation areas selected in consideration of all of the areas identified in chapters 2-11 of this report, and additional details on specific next steps for improving and using assessment data products.

One of the more important challenges for marine spatial planning is to explicitly consider multiple management objectives (e.g., energy production, environmental conservation, fishery production, transportation). Consideration of explicit trade-offs among multiple objectives and examination of alternative scenarios for meeting them are the newest and most rapidly developing areas of marine spatial planning (Beck et al. 2009). Although our Phase Two report focuses on identifying high priority marine conservation areas, we recognize that decision makers will need to consider trade-offs as they seek spatial management solutions that meet multiple objectives. We plan to work with partners to develop decision support systems for marine spatial planning - robust systems that enable diverse stakeholders and decision makers to visualize and explore spatial data to create their own preferred marine area management scenarios. We anticipate that these decision support systems will include tools for comparing scenario alternatives with respect to their ability to meet specific stakeholder group and management objectives, including marine biodiversity conservation.

The frontier for marine spatial planning is in interactive decision support systems which provide transparency and engage a diverse array of people in the planning process. Interactive systems can capture, share, and compare many people's ideas about planning options, help people understand the real world implications of different management regimes and environmental conditions, and reveal tradeoffs between biodiversity impacts and potential economic gains associated with various management scenarios. Further development of the NAM ERA web mapping application with agency and stakeholder partners could help provide a model for the next generation of interactive decision systems needed to support effective marine spatial planning processes.

Over the course of the project, we also identified additional data processing and analysis steps to increase the utility of the assessment for supporting marine spatial planning. Analysis of trawl survey data to produce a new benthic habitat model based on the distribution of fish communities is underway and a high priority for completion. This model will complement and enhance the ecological marine unit and benthic habitat model presented in Chapter 3. Another high priority focus is further analysis to produce higher resolution spatial data on priority conservation areas, and information on the sensitivity and resilience of those areas to specific human activities. We anticipate working with partners to develop new maps illustrating which human uses are most ecologically compatible with specific places, seasonally or year-round. These maps should also include information on the estimated cumulative ecological impacts of multiple uses over time.

Taking Action to Achieve Tangible, Lasting Marine Conservation Results

Around the Nation, states have been organizing themselves into regional ocean partnerships to identify shared solutions for shared ocean management challenges. In the Northwest Atlantic region the Northeast Regional Ocean Council (NROC) and the Mid-Atlantic Regional Council on the ocean (MARCO) have emerged as new institutions that are now well positioned to implement coastal and marine spatial planning (CMSP) pursuant to the new national framework. Additionally, several states in the region have CMSP initiatives that are well underway.

The Conservancy looks forward to playing a helpful role in the success of these new institutions and their member states through collaborative engagement with agency, academic, and resource user partners. This engagement can include contributions of data, tools, and policy advice; we are mindful that our contributions must be considered in the context of many others, and we are hopeful that this assessment will be critically reviewed and used as appropriate to inform decisions.

Finally, we would like to emphasize that this assessment, built from the generous contributions of many other scientists, merely adds another layer to the foundation for future efforts to better understand the ecological structure and functions of Northwest Atlantic coastal and marine systems. We look forward to that work, in service of finding management solutions that work for people and nature.

Literature Cited

Beck, M. W., Z. Ferdaña, J. Kachmar, K. K. Morrison, P. Taylor and others. 2009. Best Practices for Marine Spatial Planning. The Nature Conservancy, Arlington, VA.
http://www.nature.org/initiatives/marine/files/msp_best_practices.pdf

OPTF (Ocean Policy Task Force). 2009. The White House Council on Environmental Quality. Interim Report of the Interagency Ocean Policy Task Force.
http://www.whitehouse.gov/administration/eop/ceq/initiatives/oceans/interimreport. Accessed March 21, 2010.

The Nature Conservancy
Protecting nature. Preserving life.™

Marine Conservation Program
Eastern U.S. Division
11 Avenue de Lafayette, 5th Floor
Boston, MA 02111
(617) 542-1908
www.nature.org

For additional information please email jgreene@tnc.org.