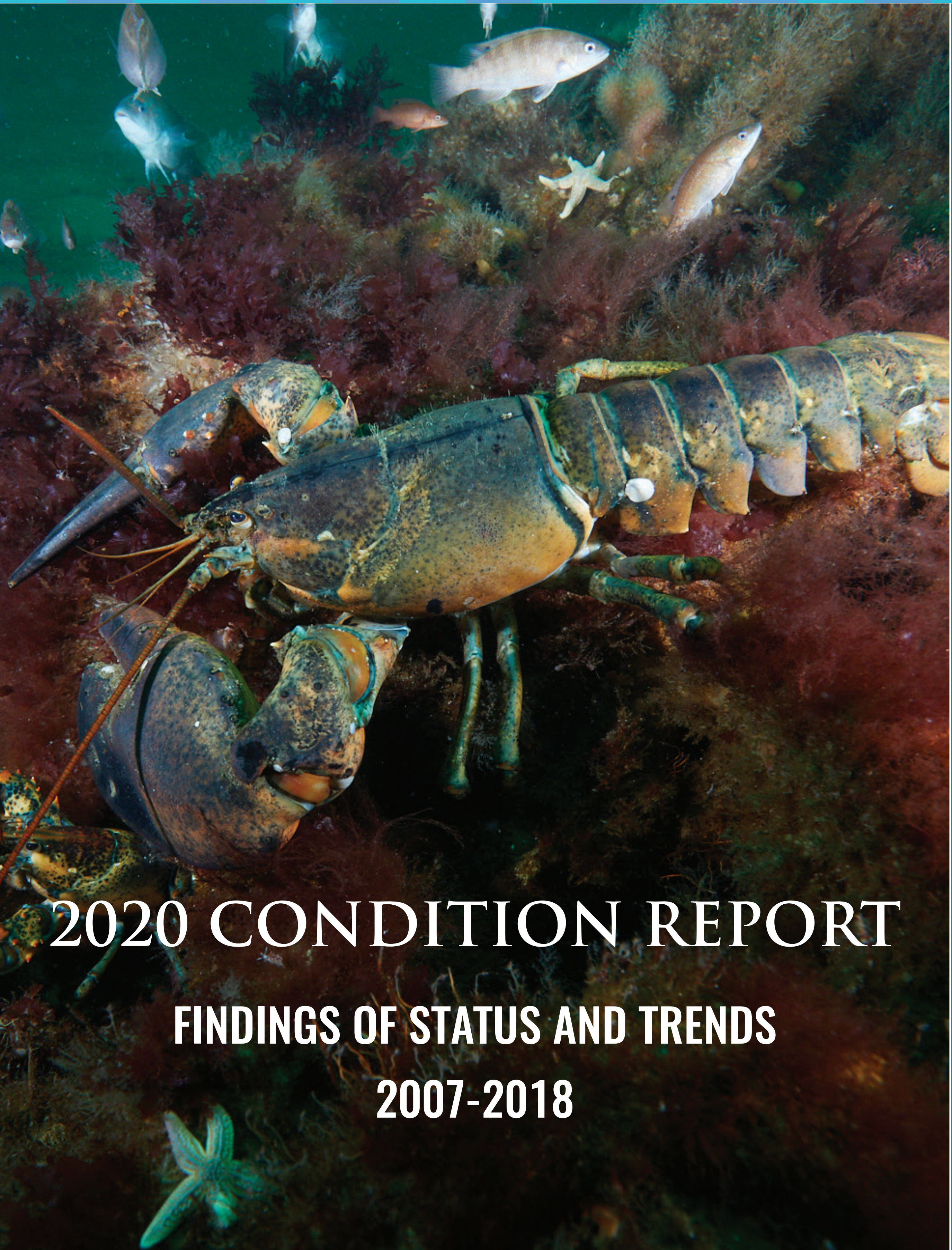
Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

STELLWAGEN BANK NATIONAL MARINE SANCTUARY

National Marine Sanctuaries



STELLWAGEN BANK

2020 CONDITION REPORT

FINDINGS OF STATUS AND TRENDS 2007-2018

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Cover photo: Two American lobsters (*Homarus americanus*) and a school of cunner (*Tautogolabrus adspersus*) use a historic shipwreck as home and habitat. The underwater photographer, Keith Ellenbogen, is the recipient of a Ernest F. Hollings Ocean Awareness Award to use the art of underwater photography to raise awareness about Stellwagen Bank National Marine Sanctuary. Photo: Keith Ellenbogen

Suggested Citation: Office of National Marine Sanctuaries. 2020. 2020 Condition Report: Findings of Status and Trends for 2007-2018. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD. 263 pp.

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OFFICE OF NATIONAL MARINE SANCTUARIES

The Office of National Marine Sanctuaries (ONMS), part of the National Oceanic and Atmospheric Administration (NOAA), serves as the trustee for a system of underwater parks encompassing more than 620,000 square miles of ocean and Great Lakes waters. The 14 national marine sanctuaries and two marine national monuments within the National Marine Sanctuary System represent areas of America's ocean and Great Lakes environment that are of special national significance. Within their waters, giant humpback whales breed and calve their young, coral colonies flourish, and shipwrecks tell stories of our maritime history. Habitats include beautiful coral reefs, lush kelp forests, whale migration corridors, spectacular deep-sea canyons, and underwater archaeological sites. These special places also provide homes to thousands of unique or endangered species and are important to America's cultural heritage. Sanctuaries range in size from less than one square mile to more than 582,000 square miles and serve as natural classrooms, cherished recreational spots, and are home to valuable commercial industries.

STELLWAGEN BANK NATIONAL MARINE SANCTUARY

Stellwagen Bank National Marine Sanctuary (SBNMS) stretches between Cape Ann and Cape Cod and is east of the Boston metropolitan region. The 842-square-mile sanctuary, designated in 1992, hosts one of the most biologically diverse and productive ecosystems in the Gulf of Maine. The underwater landscape was formed by the retreat of glaciers during the Great Ice Age. Renowned for its biological diversity and remarkable productivity, the sanctuary is a critical feeding and nursery ground for several whale and dolphin species, and has become one of the world's premier whale watching destinations. Named an Important Bird Area by Mass Audubon in concert with BirdLife International, the sanctuary's rich waters provide abundant prey for many species and serve as a stopover location for migrating seabirds, as well as a seasonal destination for both summer and winter species. The sanctuary's position astride historic shipping routes and fishing grounds for Massachusetts's oldest ports also makes it a repository for historic shipwrecks representing several hundred years of maritime transport.

FRAMEWORK FOR CONDITION REPORTS

Sanctuary condition reports are tools employed by NOAA to assess the condition and trends of national marine sanctuary resources (NOAA Office of National Marine Sanctuaries 2018a). Condition reports provide a standardized summary of resources in NOAA's sanctuaries, drivers and pressures on those resources, and current conditions and trends for resources and ecosystem services. These reports also describe existing management responses to pressures that threaten the integrity of the marine environment. Condition reports include information on the status and trends of water quality, habitat, living resources, and maritime heritage resources, and the human activities that affect them. They present responses to a set of questions posed to all sanctuaries (Appendix A). The reports also rate ecosystem service status and trends (Appendix B). Resource and ecosystem service status are rated on a six-point scale from good to poor, and the timelines used for comparison vary from topic to topic. Trends in the status of resources and ecosystem services are also reported, and are generally based on observed changes in status since the prior condition report, unless otherwise specified.

Sanctuary condition reports are structured around two frameworks: 1) a series of questions posed to all national marine sanctuaries; and 2) a management-logic model called the Driving forces (Drivers)-Pressure-State-Ecosystem Services-Response (DPSER) framework (detailed below). The first framework is based around the generic structure of an ecosystem, and is used as the logic framework for the reports. The second framework defines the structure of the condition reports themselves.

Although the National Marine Sanctuary System's 14 sanctuaries and two marine national monuments are diverse in many ways, including size, location, and resources, condition reports allow ONMS to consistently analyze the status and trends of abiotic and biotic factors in each ecosystem to inform place-based management. To that end, each sanctuary is asked to answer the same set of questions, located in Appendix A, in the preparation of each condition report. Additional details about how the condition report process has evolved over time are below.

Driving forces (Drivers)-Pressure-State-Ecosystem Services-Response (DPSER) Framework

Beginning in 2019, sanctuary condition reports are structured on a model that describes the interactions between driving societal forces (Drivers), resulting threats (Pressures), resource condition (State), derived benefits (Ecosystem services), and management responses (Response). This DPSER framework recognizes that human activities are ultimately linked to demographic, economic, social, or institutional values and conditions (collectively called drivers). Changes in these drivers affect the nature and level of pressures placed on both natural and heritage resources, which can alter their condition (e.g., the quality of natural resources or aesthetic value). This affects the availability of benefits that humans receive from the resources (ecosystem services[4]), which prompts targeted management responses intended to prevent, reduce, or mitigate the undesirable changes (see Figure FCR.1).

[4] For the purposes of this report, ecosystem services are defined as "benefits that humans desire from the environment" (e.g., recreation or food). They are what link humans to ecosystems, can be goods or services (e.g., food is a good, and coastal protection is a service), are valued by various types of users and can be regulated directly by the environment, or managed by controlling human activities or ecosystem components (e.g., restoring habitats). Whether or not specific services are rendered can be evaluated directly or indirectly based on attributes of the natural ecosystem that people care about. For example, recreational scuba divers care about water clarity and visibility in coral reef ecosystems. These are attributes that can be measured and assigned status and trend ratings, which then allows one to track one or more specific ecosystem services to which they pertain.

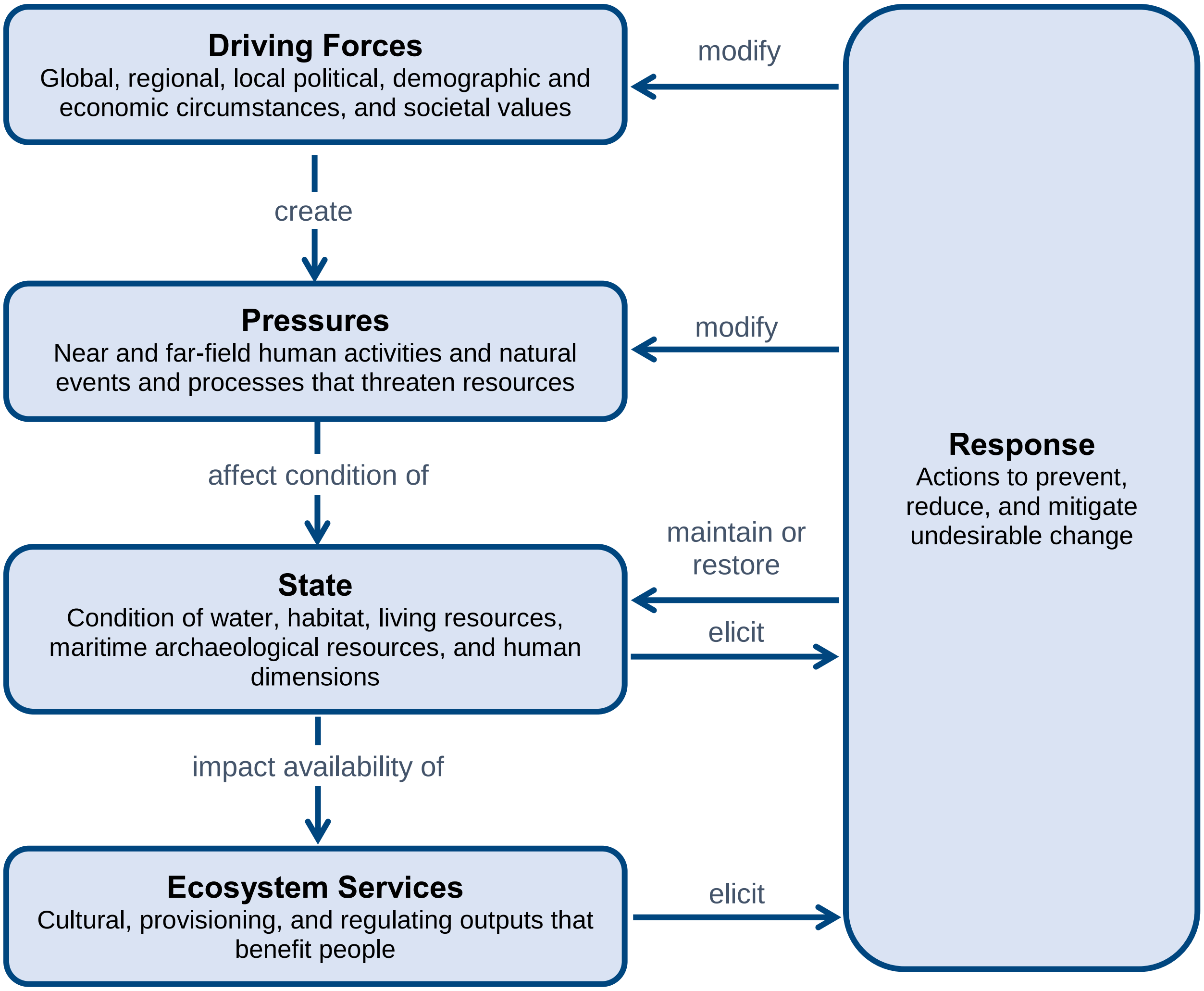


Figure FCR.1. This diagram provides a visual depiction of the DPSER framework, illustrating connectivity between each aspect of the model, and showing how management responses can be incorporated to modify driving forces, pressures, and state. Image: NOAA

ABOUT THIS REPORT

The purpose of a condition report is to use the best available science and most recent data to assess the status of various parts of the sanctuary's ecosystem. The first condition report for SBNMS was released in 2007 (NOAA Office of National Marine Sanctuaries 2007); ratings from that report are provided in Appendix C. This updated condition report marks a second comprehensive description of the status and trends of sanctuary resources. The findings in this condition report document status and trends in water quality, habitat, living resources, and maritime heritage resources from 2007–2018, unless otherwise noted. The report helps identify gaps in current monitoring efforts, as well as causal factors that may require monitoring and potential remediation through management actions in the coming years. The data discussed will not only enable sanctuary resource managers and stakeholders to acknowledge and have a shared perspective on prior changes in resource status, but will also inform management efforts to address challenges stemming from pressures, such as increasing coastal populations and climate change.

The findings in this condition report will provide critical support for identifying high priority sanctuary management actions, specifically helping to shape updates to the SBNMS management plan. The management plan helps guide future work and resource allocation decisions at SBNMS by describing strategies and activities designed to address priority issues and advance core sanctuary programs. The next update to the sanctuary management plan will build on the 2010 management plan, which contains a number of actions to address issues and concerns (NOAA Office of National Marine Sanctuaries 2010). The next management plan review process will begin in 2020. The process will involve significant public input, agency consultations, and environmental compliance work, and depending on the complexity of actions proposed, may take one to three years to complete.

As described above, condition reports use a DPSER framework. The State section of this document reports the status and trends in water quality, habitat, living resources, and maritime heritage resources from 2007–2018, unless otherwise noted. The Ecosystem services section includes an assessment of heritage, food supply, consumptive and non-consumptive recreation, science, and education.

In order to rate the status and trends associated with resources, human activities, and ecosystem services, sanctuary staff consulted with a group of outside experts familiar with the resources, activities, and services in the sanctuary. This group of experts also had knowledge of previous and current scientific efforts in the sanctuary (Appendix D). Evaluations of status and trends were based on the interpretation of quantitative and, when necessary, qualitative assessments, as well as on observations of scientists, managers, and users. An external expert panel was not employed during the 2007 condition report development process, which, in hindsight, was a shortcoming of that process.

Two other important changes to the condition report process since 2007 should be noted. First, in response to feedback provided to ONMS, the process used to generate the current condition report is more quantitatively robust and repeatable. This was achieved by using the NOAA Integrated Ecosystem Assessment (IEA) framework (NOAA 2019a), which takes a literature-based approach to developing indicators for key components of the ecosystem. Status and trend assessments can then be made for the selected indicators over time. This approach ensures that the expert community has quantitative data representative of core ecosystem components available to them as they contribute to assessment ratings.

These indicators continue to be tracked over time, and updated time series data can be used in subsequent assessments.

Another improvement pertains to communication of uncertainty. In the prior report, inferences regarding the level of confidence for each status and trend rating were drawn from the literature reviewed. The new approach used in this report incorporates a level of uncertainty into the symbols for each status and trend rating for every question. Determination of uncertainty is based on both an evaluation of the data utilized to determine the rating (e.g., peer-reviewed literature, expert opinion) as well as the level of agreement among the experts (Appendix D).

This condition report meets the aforementioned standardized format and framework that has been prescribed for all NOAA Office of National Marine Sanctuaries condition reports. To the greatest extent possible, the authors have attempted to make each section's narrative consistent and comparable in terms of content, detail, and length; however, it is important to understand that each section contains different types and amounts of information given the realities and confines of datasets and expert opinions that were available during this process. In addition, this report is the result of a multi-year, collaborative effort across multiple authors, contributors, and reviewers and thus contains stylistic writing differences across some sections. These differences do not detract from the validity or quality of this report. Finally, ratings reflect the collective interpretation of sanctuary staff and outside experts, based on their knowledge and perception of local conditions. Where there was not agreement on ratings, differences in opinion were acknowledged; however, the final ratings were made by sanctuary staff. To reiterate this point, it is important to understand that the interpretation, ratings, and text in this condition report are the responsibility of and determined to be final by ONMS. To emphasize this important point, authorship of the report is attributed to ONMS; subject matter experts are not authors, though their efforts and affiliations are acknowledged in the report. This report has been peer-reviewed and complies with the White House Office of Management and Budget's peer-review standards, as outlined in the Final Information Quality Bulletin for Peer Review (OMB 2004).

EXECUTIVE SUMMARY

In 1992, the U.S. Congress designated Stellwagen Bank National Marine Sanctuary (SBNMS), located off the coast of Massachusetts in the southwestern Gulf of Maine. The sanctuary stretches from Cape Ann to Cape Cod and encompasses 842 square miles surrounding Stellwagen Bank, a shallow, glacially-deposited underwater plateau and the sanctuary's most prominent bathymetric feature. The interaction between tides, currents, winds, and Stellwagen Bank drives remarkable productivity and biodiversity. The sanctuary's rich waters serve as a critical feeding ground and nursery for whales and dolphins, provide a vital stopover and seasonal destination for migrating seabirds, and offer essential habitat for commercially-harvested fish. The sanctuary's proximity to the Boston metropolitan region attracts many valuable commercial and recreational activities such as fishing, shipping, and tourism, and its position astride historic shipping routes and fishing grounds for Massachusetts's oldest ports make it a repository for historic shipwrecks and rich maritime heritage.

The purpose of a condition report is to use the best available science and most recent data to assess the status and trends of various parts of the sanctuary's ecosystem. The first condition report for SBNMS was released in 2007; status and trend ratings from that report are provided in Appendix C. This report marks a second comprehensive update to describe the status and trends of sanctuary resources, including water quality, habitat, living resources, and maritime heritage resources. In addition, this new condition report includes the status and trends of ecosystem services—how humans either derive benefit or accrue costs from different ecosystem attributes that people care about for their lives and livelihoods. Ecosystem services evaluated in this report include heritage, food supply, consumptive and non-consumptive recreation, sense of place, science, and education.

The findings document status and trends in sanctuary resources and ecosystem services from 2007–2018, unless otherwise noted. The report helps identify gaps in current monitoring efforts, as well as causal factors that may require monitoring and potential remediation through management actions in the coming years. The data discussed in this report will not only enable sanctuary resource managers and stakeholders to acknowledge and have a shared perspective on prior changes in resource status, but will also inform management efforts, primarily through the management plan review process, to address challenges stemming from pressures, such as increasing coastal populations and climate change.

The summaries below suggest that water quality in the sanctuary is fairly good, but habitat, living resources, and maritime heritage resources continue to be impacted in various ways by human activities, such as shipping traffic and commercial and recreational fishing. Ecosystem services in the sanctuary are generally improving, and in either good or fair condition.

Human Activities

Stellwagen Bank National Marine Sanctuary is located 25 miles east of the port of Boston. The proximity of the sanctuary to the metropolitan region and surrounding Cape Cod communities make it highly accessible, exposing the sanctuary and its resources to a large range of human activities and pressures. Due to its offshore location, human activities in SBNMS are associated with different pressures on resources than inshore or mainland activities. Understanding the driving forces behind these pressures can aid in predicting the direction and extent of future pressures. The majority of driving forces (factors that lead to pressures) are increasing; these forces include population, per capita income, and gross domestic product (GDP) of international trading partners. Demand for seafood, demand for recreation, and import/export of goods were also identified as specific, primary drivers of pressures on SBNMS resources. Additionally, gasoline prices have been stable and relatively low, making access to the sanctuary relatively affordable. The direction of these drivers indicates that pressures will continue to increase within the sanctuary.

Water Quality

Despite several potential stressors, sanctuary water quality is good/fair and does not appear to be adversely impacted by human activities. The largest effluent contributor in the region and the primary potential human source of nutrients is the Massachusetts Water Resources Authority (MWRA) outfall, which is located approximately 12 nautical miles from the western boundary of SBNMS. Ongoing monitoring suggests that the MWRA outfall is currently not adversely influencing monitored water quality parameters in SBNMS, and no evidence suggests that eutrophication is occurring. The Massachusetts Bay Disposal Site (MBDS) is directly adjacent to the sanctuary's western boundary and receives dredged material deemed suitable for open water disposal. This site incorporates the areas of two historic disposal sites containing toxic materials, though deposited toxic materials show limited mobility, and assessments have not shown any associated contamination of SBNMS. Maintenance dredging and expansion of Boston Harbor will generate 12 million cubic yards of dredged material for disposal in MBDS, but this is not expected to impact sanctuary water quality. Limited data exist to thoroughly evaluate potential impacts to water quality from vessel discharge and sediment perturbation by mobile fishing gear.

Monitoring suggests that concentrations of bacteria and toxigenic phytoplankton species rarely reach or exceed levels of concern in SBNMS and likely pose low risk to human health. However, the presence of toxigenic phytoplankton species indicates the potential for harmful algal blooms (HABs). HAB dynamics in the Gulf of Maine may be related to climate change, but current data show no explicit association between HAB occurrence and increasing temperatures in SBNMS.

Climate change impacts in SBNMS are measurable, and the threat of climate change to ecological integrity is increasing. The Gulf of Maine is warming faster than 99% of the global ocean; increases in both surface and bottom temperatures in SBNMS reflect these trends. Recent work suggests changes in seasonal temperature dynamics, longer summer seasons, and changes to primary production in and around SBNMS. Climate change is causing shifts in phenology and distributions of plankton, fish, whales, and other organisms in the Gulf of Maine. Impacts of climate change on important prey (foundation) species like sand lance and the copepod *Calanus finmarchicus* are particularly concerning, as these changes have the potential to drive cascading ecosystem effects and impact abundance, distribution, and health of top predators. In addition, climate change is causing impacts on commercial and recreational fisheries, local businesses, and communities. More robust monitoring of climate change effects and ocean acidification conditions in SBNMS is necessary to understand trends, seasonal fluctuations, and the possible ramifications for water quality, shell-forming invertebrates, and the larger ecosystem.

Habitat

The sanctuary's diverse underwater landscape is a patchwork of habitats composed of both geologic and biogenic components. Benthic substrate types are generally correlated with seafloor communities and constitute important geologic habitat components. Data suggest measurable degradation of habitat quality over the past ten years, primarily due to direct impacts of bottom-contact gear used in commercial fishing, which occurs extensively throughout SBNMS. Mobile, bottom-tending fishing gear can alter or remove important structural characteristics and/or biological components of the seabed, which is a concern for maintaining habitat integrity. Lower levels of direct impact are evident in the Western Gulf of Maine Closure Area, and the closure led to recovery in some areas. Significant increases in scallop dredging may have impacted the northwest corner of Stellwagen Bank in 2017; this effort has been reduced, but is expected to continue. Overall fishing effort has declined by around 55% since 2009; however, it is unclear whether reductions in effort have resulted in improved sanctuary benthic habitat integrity. Fixed gear has less impact on the seabed, but poses an entanglement risk for protected species. Fishing effort reductions and gear modifications have been implemented to reduce bycatch of small marine mammals and seabirds and to attempt to reduce serious injury and mortality of large whales.

Localized disturbance of benthic habitats was observed after the installation of the sanctuary's only submerged cable, the Hibernia Atlantic cable, in the year 2000. Post-installation monitoring showed that impacts to benthic communities were not significantly different than those caused by commercial fishing. Other potential localized seabed impacts, including anchoring of recreational fishing vessels, should be evaluated.

Legacy contaminants and metals in benthic habitats have been reported; however, they do not appear to remobilize beyond sites where they have been identified, and no population effects have been documented. Limited data suggest emerging contaminants are present within Massachusetts Bay at low concentrations, with uncertain biological ramifications, and may be shifting or increasing with the continued introduction of new chemicals. No data exist regarding microplastics in SBNMS, though surface water concentrations of microplastics in the Gulf of Maine are far lower than in the North Atlantic. Abundance of marine debris in SBNMS depends on natural forces and human drivers, which may increase with increasing population growth and coastal development. Additional work to characterize and quantify emerging contaminants and microplastics in SBNMS habitats is needed.

SBNMS is an urban sanctuary, and impacts to its acoustic environment are a concern. Designated shipping lanes such as the Boston Traffic Separation Scheme (TSS) cut through the sanctuary and are used by most commercial vessels transiting to the port of Boston. Commercial fishing vessels use the sanctuary year-round. The whale watching industry has expanded, and the numbers of recreational boaters and whale watchers are rising. Human-generated underwater noise from vessels, particularly from large commercial ships, can degrade habitat quality and interrupt behavior and communication of many marine species. Increasing noise levels and impacts of noise to some marine mammal and fish species have been documented in the sanctuary and are expected to continue. SBNMS has been at the forefront of raising awareness of the potential threat of noise to organisms and has pioneered the use of several advanced passive acoustic monitoring methods and technologies to further the study of ocean noise and its impacts.

Living Resources

The large-scale circulation of the Gulf of Maine and influx from the Maine Coastal Current, along with tidal fluctuations, local wind forcing, and long-term climate dynamics, drive a strong seasonal cycle of stratification, nutrient availability, and primary production that forms the foundation of the SBNMS food web and ecosystem. SBNMS supports over 575 species of invertebrates, fish, seabirds, and marine mammals. Community structure and local stability in SBNMS are maintained by several foundational species that serve as prey or biogenic habitat, including calanoid copepods, Atlantic herring, sand lance, sponges, and anemones. The status and trends of these species are variable, but generally good to fair, though data are limited in some cases, and several species may be particularly vulnerable to climate change.

Calanus finmarchicus is a crucial, lipid-rich copepod and food source for several ecologically and economically important species in SBNMS, including larval cod and haddock, herring, sand lance, and the critically endangered North Atlantic right whale. Despite a general downward trend in abundance and shifts in distribution in the larger Gulf of Maine driven by climate change, *C. finmarchicus* has persisted regionally.

Sand lance is a key prey species for marine mammals, seabirds, and commercially important fish in SBNMS and the larger Gulf of Maine. Data suggest that the abundance and distribution of sand lance at local and/or regional scales influence the abundance and distribution of predators including humpback whales, great shearwaters, and Atlantic cod. Sand lance are dependent on shallow, coarse grain sand habitats to escape predation and lay their eggs. Their geographic restriction to sand habitat, as well as their winter dormancy and possible water temperature-induced spawning, raises concerns about their ability to adapt to accelerated climate change. Sand lance exhibit natural, dramatic fluctuations in spatial and temporal abundance, but what drives these cycles is unknown. Atlantic herring also exhibit patchy distributions and variable abundance within SBNMS. Herring and sand lance populations in the SBNMS region typically oscillate out of phase, suggesting either bottom-up forcing of such patterns, or an effect of direct species interactions (predation, competition, or overfishing) in determining abundance. Declines in recruitment, variability in abundance and distribution, patch characteristics that increase vulnerability to overfishing, and potential climate change impacts are concerns for ecologically and commercially important forage species.

Porifera (sponges) and Cnidaria (hydroids and anemones) serve important roles as benthic, structure-forming organisms in SBNMS, as they provide shelter for associated species and contribute to habitat complexity. These species are physically fragile and sensitive to direct disturbance. Changes in the abundance and distribution of these taxa over time correspond both to larger regional and local processes as well as human-caused disturbance, but the current status of these species is uncertain.

Stellwagen Bank National Marine Sanctuary serves as important habitat for several species whose presence and health contribute to the economic, ecological, and conservation value of the sanctuary. The status of these eight focal indicator species is mixed. Select human activities have caused severe, widespread, and/or persistent impacts to some species. Impacts from commercial fishing and commercial and recreational vessel activity are primary concerns. However, ongoing efforts to monitor and mediate threats has led to some improvement in other species, resulting in a collective rating of fair for focal species.

The sanctuary and surrounding waters are primary foraging grounds for humpback whales and critically endangered North Atlantic right whales, and poor ratings for both species drove the overall fair rating for focal species. North Atlantic right whales are at risk for extinction, as their population has been in decline since 2010, and only 12 births have been documented since 2017. Despite positive population growth of

Gulf of Maine humpback whale populations, frequent fisheries interactions and serious injury and mortality in most years warrants a poor rating for this species.

SBNMS is a hot spot for reports of entangled humpback whales, though the locations of entanglement origin are often unknown. Recent SBNMS research shows that humpback whales are tightly collocated with sand lance in southern SBNMS, where trap/pot fisheries operate. In addition, recreational tuna vessels often target areas where whales are present, which can have adverse impacts for whales. In response to the critical status of right whales, NOAA's Atlantic Large Whale Take Reduction Team, which includes SBNMS, recommended modifications to their Large Whale Take Reduction Plan to further reduce the risk of serious injury and mortality from entanglement, including reductions in the use of vertical lines and changes to closure areas.

Ship strikes to right and humpback whales in SBNMS have likely decreased following a number of actions. These include 1) working with multiple partners to shift the Boston TSS away from primary feeding areas for large whales; 2) a NOAA Fisheries regulation to limit the speed of vessels larger than 65 ft at certain times; 3) the installation of a real-time passive acoustic monitoring system along the TSS following the construction of two deepwater liquefied natural gas ports; 4) the development of an app to alert mariners to the presence of right whales; and 5) the development of a corporate responsibility report card program to evaluate mariner compliance with speed restrictions. Recreational boat strikes remain a concern for humpback whales. Recreational boating in SBNMS is mostly seasonal, but is intensive during high season and could produce concerning levels of noise.

Noise levels in the ocean and in SBNMS have increased dramatically during the last 50 years. SBNMS research has focused on characterizing the sanctuary's low-frequency "noise budget" associated with large commercial vessels by using automatic identification system (AIS) data to document the distribution and density of vessel traffic-associated noise and its potential to "mask" biologically-important acoustic signals. Work by SBNMS and colleagues shows that baleen whale species have lost over two thirds of their communication space, primarily due to ambient noise and AIS vessel activity in SBNMS. Data also show that vessel noise can significantly impact humpback whale communication and foraging behavior. Constant high levels of low-frequency sound in SBNMS also reduced communication space for commercially important Atlantic cod and haddock during winter spawning times. Efforts to mitigate noise impacts on marine species are ongoing.

Commercial fishing occurs extensively throughout SBNMS. While large whales experience high entanglement risk from trap/pot fisheries, smaller marine mammals and seabirds are at greater risk from gillnet fisheries. Grey seals are the most commonly bycaught marine mammal, while harbor porpoise and Atlantic white-sided dolphins are also at risk of bycatch in gillnets. Great shearwaters comprise the highest bycatch of any animal in the sanctuary and are the most frequently bycaught seabird in the Gulf of Maine. Gillnets account for the vast majority of mortalities in seabirds.

Atlantic white-sided dolphins and great shearwaters are the most commonly sighted toothed whale and seabird species in SBNMS, respectively, and recent work suggests that these species may prey on sand lance. Bluefin tuna on Stellwagen Bank frequently prey on sand lance as well as herring. Abundance of bluefin tuna has increased in the Gulf of Maine and the western Atlantic, resulting in a 2017 increase in the annual bluefin tuna quota. Atlantic cod distributions are also strongly influenced by sand lance in SBNMS.

Atlantic cod is a culturally, ecologically, and economically important species in the Gulf of Maine, and SBNMS and has historically been the focus of commercial and recreational cod fishing. Research indicates that the Atlantic cod population is at a historic low and has contracted to the western Gulf of Maine, including SBNMS. This shift in distribution is primarily driven by sand lance abundance. The hyper-aggregation of cod in a small area in SBNMS makes this species vulnerable to overexploitation. SBNMS and colleagues have documented spawning aggregations of cod in SBNMS using several acoustic technologies. The western Gulf of Maine, including SBNMS, is possibly the last area with consistent aggregations of cod in the Gulf of Maine stock. A combination of fishing pressure, species interactions, and environmental change contributes to continued population decline.

Lobster are iconic in the Gulf of Maine and SBNMS. Abundance is at an all-time high following increases in growth and reproduction aided by warming water temperatures. However, consistent declines in young-of-the-year lobster since 2012 in the Gulf of Maine and the poor status and recruitment of southern New England lobster suggest that prolonged temperatures above a certain threshold negatively impact lobster, and climate change may have an adverse impact on lobsters in SBNMS in the future.

Biodiversity in SBNMS has changed since the 2007 condition report; this change was primarily driven by variability in fishing and climate at both regional and local scales. Data show that fish species richness in SBNMS and the region has increased since 2006 and fish community composition has shifted over time. Seabird community data specific to SBNMS are limited, but regional data collected along Massachusetts coastlines suggest possible changes in relative abundance over time. There are diverse communities of seafloor invertebrates within SBNMS, including three species considered rare within the Gulf of Maine region. However, it is difficult to assess the status of seafloor communities from 2007–2018 due to the disruption of a long term monitoring station, which compromised the ability to assess change over time. Additional monitoring, particularly for seabirds and invertebrates, and at regional and local scales, is needed.

The number of non-indigenous species in SBNMS is likely low, though limited information on these species is available. High levels of vessel traffic in and around the sanctuary have the potential to introduce non-indigenous species through ballast water or fouling on hulls or other equipment (fishing nets, etc.). In addition, climate change may result in increased introductions of non-indigenous species due to altered species ranges influenced by warming waters and changes in ocean circulation. *Didemnum vexillum*, an invasive tunicate, was documented in the sanctuary in small, isolated areas dominated by hard bottom habitats, but this species is unlikely to be an issue in SBNMS because its preferred habitat (hard bottom) is not abundant.

Maritime Heritage Resources

Forty-seven historic shipwreck sites have been inventoried in the sanctuary, representing a long, rich maritime history. The condition of the sanctuary's heritage resources varies due to natural deterioration and human impacts, and as non-renewable resources, their decline is irreversible. Commercial fishing activity continues to be the greatest source of disturbance to maritime heritage resource integrity. Incidental contact from fishing gear has impacted nearly every maritime heritage resource in SBNMS. The diminished condition of some heritage resources has reduced their historical, archaeological, scientific, or educational value.

Recreational diving in SBNMS has increased since 2007, and some evidence suggests that divers occasionally disturb wrecks through movement of artifacts or by anchoring on wrecks; degradation from recreational diving, however, does not appear to be widespread. More frequent monitoring and documentation of shipwreck sites is required to track site degradation over time and to broaden our knowledge of and connection to New England maritime history and our sense of place.

Ecosystem Services

Seven ecosystem services were evaluated for this condition report: heritage, food supply, consumptive recreation, non-consumptive recreation, sense of place, science, and education.

Maritime heritage is the recognition of historical or heritage legacy. There are significant products telling the stories of historic shipwrecks in the sanctuary, all of which indicate there is significant economic value associated with maritime heritage in SBNMS. At the same time, resource indicators show some decline in integrity due to natural degradation and commercial fishing gear damage, but overall, damage is not severe.

Consumptive recreation includes recreational activities that result in the removal of or damage to natural and cultural resources. For SBNMS, this activity is primarily recreational fishing. While the number of charter boat and party boat anglers has declined over most of the time period of interest, private boat registrations have generally remained stable but increased recently. Local communities are also highly engaged in recreational fishing. Yet, the resource (recreational fishing stocks) condition is mixed. These factors suggest that there is significant and augmented economic value associated with consumptive recreational resources in SBNMS, but there are mixed results among the indicators, as well as information gaps. In addition, very little information is available for fishing on private household boats, and there is a lack of other ancillary socioeconomic data for recreational fishing.

Sanctuary visitors also participate in non-consumptive recreational activities that do not result in the removal of or damage to natural and heritage resources. The primary non-consumptive recreational activities conducted in SBNMS include whale watching and other wildlife observation, scuba diving, sailing, and motor boating. Economic indicators suggest there are significant economic contributions associated with non-consumptive recreation in SBNMS that are either stable or increasing. As of 2008, the majority of whale watching in the New England region occurred within SBNMS, amounting to spending of approximately $100 million (2017$). Resource indicators suggest that, with the exception of an increase in bird sightings, there has been a decline in the natural resources that support non-consumptive recreation in the sanctuary, however, the decline is not widespread across affected resources.

Sense of place is the aesthetic and spiritual attraction of a particular location, as well as the level of recognition and appreciation given to efforts to protect a place's iconic elements. Several studies show that people put positive economic value on natural resources and are willing to pay to protect them. These valuation corollaries, trends in environmental attitudes, and growth in real per capita incomes suggest that economic indicators are positive and increasing. Though there has been a decline in some natural resources, like whales, it has not been widespread across all relevant resources, and other indicators, like water quality, have not been affected.

The ecosystem service of science is defined as the capacity to acquire and contribute information and knowledge. Research occuring in SBNMS, led by sanctuary staff and partners, is expanding and has gained international recognition. There is, however, a noteworthy information gap of indicators to estimate the economic value and contributions of science in SBNMS. Non-economic indicators, on the other hand (the number of research hours and days on the R/V *Auk*, citizen science hours, and the number of volunteers) have been increasing or stable through time. Further, SBNMS is at the forefront of anthropogenic noise and humpback and fin whale research. As a result of the research being conducted in SBNMS by site staff and partners, the body of scientific work in SBNMS has contributed significantly to the state of knowledge of resource conditions.

Many people of all ages study ecosystems and their importance through both formal and informal education. When people derive benefits from educational experiences or products resulting from the sanctuary, this is considered an ecosystem service. Although there have been no economic valuation studies done for education programs in SBNMS, studies of other environmental education programs indicate a positive value for hands-on education experiences. Further, several non-economic indicators have been increasing. Specifically, the number of volunteers and volunteer hours has increased since 2011, and related social media presence, as measured by the number of SBNMS followers on Facebook and Twitter, has increased since 2015, indicating that education work in SBNMS has contributed to public knowledge about SBNMS resources.

The food supply ecosystem service is defined as the capacity to support market demands for nutrition-related commodities, namely fish, through various fisheries. Economic indicators have mixed results. From 2007 to 2016, the total value of landings (cumulative revenue across all years, in 2017$) from species caught in the sanctuary was in excess of $194 million. Trends in both landings values and pounds from 2007 to 2016 for sea scallops, lobster, and Atlantic mackerel were generally increasing. Additionally, some resource indicators suggest a decline in the natural stock, but it is important to note that this trend is not widespread or across all stocks (e.g., there may be emerging stocks as a result of changing species distributions within the region). More information is needed for both economic and non-economic indicators on costs-and-earnings to assess whether there are above normal returns on investments that result in more fishing effort, and non-economic indicators are needed that gauge the socio-demographic profiles of fishers.

In Conclusion

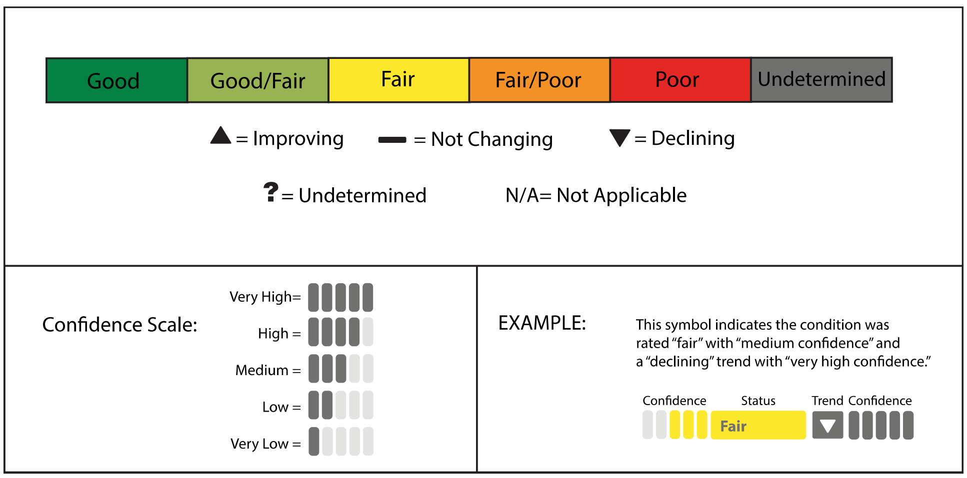
The findings in this condition report will provide critical support for identifying high priority sanctuary management actions, specifically helping shape updates to the SBNMS management plan. The revised management plan will guide future work and resource allocation at SBNMS by describing strategies and activities that address priority issues and advance core sanctuary programs. Likely issues that the revised management plan will need to address include, among other things, climate change, water quality monitoring, the effects of underwater noise, and a better understanding of the maritime cultural landscape, in addition to renewed education, outreach, and citizen science efforts. The management plan review process will begin in 2020 and will build on the 2010 management plan. The process will involve significant public input, agency consultations, and environmental compliance work, and depending on the complexity of actions proposed, may take one to three years to complete.

STELLWAGEN BANK NATIONAL MARINE SANCTUARY SUMMARY OF RESOURCE CONDITIONS

The various resource status and trend evaluations presented in this report are summarized below. Each question used to rate the condition and trends sanctuary resources is listed, followed by:

1) A set of rating symbols that display key information. The first symbol includes a color and term to indicate status. The next symbol indicates trend. A shaded scale adjacent to both symbols indicates confidence (see key for example and definitions).
2) The status description, which is a statement that best characterizes resource status and corresponds to the assigned color rating and definition as described in Appendix A. The status description statements are customized for all possible ratings for each question.
3) The rationale: a short statement or list of criteria used to justify the rating.

Key:



Drivers/Pressures

Question 1: What are the states of influential human drivers and how are they changing?

Status Description: Selected drivers are influencing pressures in ways that result in severe impacts that are either widespread or persistent.

Rationale: Increasing demand at multiple scales for food, ocean transportation, and recreation, influenced heavily by population growth and increasing income, enhances commercial and recreational activities with adverse impacts that include habitat damage, entanglement, ship strikes, noise, and contaminant discharges.

Question 2: What are the levels of human activities that may adversely influence water quality and how are they changing?

Status Description: Some potentially harmful activities exist, but they have not been shown to degrade water quality.

Rationale: Several human activities have the potential to adversely influence water quality, but generally do not seem to be doing so. Potential activities of concern include the Massachusetts Water Resources Authority (MWRA) outfall and other effluent discharges, vessel discharges, ballast water discharges, disposal of dredged material, resuspension of sediments from bottom-contact fishing gear, and airborne industrial discharges.

Question 3: What are the levels of human activities that may adversely influence habitats and how are they changing?

Status Description[5]: Selected activities have caused measurable resource impacts, but effects are localized and not widespread or persistent.

Rationale: Some activities, such as the use of mobile gear and anthropogenic noise, are of particular concern, as they can alter structural characteristics of habitat. Other activities that occur, but result in more localized habitat disturbance, include the dumping of dredged material adjacent to the sanctuary and submarine cable installation.

Question 4: What are the levels of human activities that may adversely influence living resources and how are they changing?

Status Description: Selected activities have caused severe impacts that are either widespread or persistent.

Rationale: Fixed and mobile commercial fishing methods, shipping, and recreational activities such as fishing and whale watching are of particular concern, as they can cause negative impacts on living resources. Improvements in gear management and decreases in overall fishing effort have resulted in reduced impacts on living resources, ship strikes of whales have decreased, and efforts are underway to mitigate noise impacts on marine mammals.

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[5] The status rating for this question was changed from "undetermined" to "fair." The expert workshop participants recommended an undetermined rating primarily due to the lack of vessel monitoring system (VMS) data. Staff have subsequently acquired and analyzed VMS data. The data show that these impacts, in combination with other impacts such as noise and vertical lines from trap fishing, warrant the rating of "fair" for the status of sanctuary habitats, which include the seafloor and water column.

Question 5: What are the levels of human activities that may adversely affect maritime heritage resources and how are they changing?

Status Description: Selected activities have caused severe, persistent, and widespread impacts.

Rationale: Incidental contact from fishing gear has affected nearly every maritime heritage resource in the sanctuary and continues to negatively impact archaeological site conditions. Recreational diving has also caused some local impacts but is not considered to be causing widespread degradation of maritime archaeological sites.

Water Quality

Question 6: What is the eutrophic condition of sanctuary waters and how is it changing?

Status Description: Eutrophication has not been documented, or does not appear to have the potential to negatively affect ecological integrity.

Rationale: MWRA hydrographic modelling (Zhao et al. 2017a) suggests that eutrophication is not occurring. Dissolved oxygen has not approached hypoxic or anoxic conditions over time. Background nitrogen may be decreasing regionally, which would decrease the probability of eutrophication.

Question 7: Do sanctuary waters pose risks to human health and how are they changing?

Status Description: One or more water quality indicators suggest the potential for human health impacts, but human health impacts have not been reported.

Rationale: Toxigenic algae are present but not observed to cause demonstrable threats to human health. Observed water quality changes over the last 12 years may be related to changes in the North Atlantic Oscillation.

Question 8: Have recent changes in climate altered water conditions and how are they changing?

Status Description: Climate-related changes have caused measurable, but not severe, degradation in some attributes of ecological integrity.

Rationale: Climate change is influencing the primary production cycle in the region, and has the demonstrated capacity to produce cascading effects within the ecosystem. Additional changes in water temperature, dissolved oxygen, stratification, sea level, precipitation, and storm activity have been documented or modeled, with some suggestion of changes in pH, though more monitoring is needed to more robustly identify acidification trends and effects.

Question 9: Are other stressors, individually or in combination, affecting water quality, and how are they changing?

Status Description: Undetermined

Rationale: Ongoing contaminant monitoring has focused on a handful of legacy contaminants, leaving the majority of emerging organic contaminants unmeasured. No data exists to determine changes over time, which is the primary factor driving the rating and trend. More monitoring is needed in this area.

Habitat Resources

Question 10: What is the integrity of major habitat types and how is it changing?

Status Description: Selected habitat loss or alteration has caused measurable but not severe degradation in some attributes of ecological integrity.

Rationale: Data suggest measurable changes in habitat quality, likely due to the use of bottom-contact commercial fishing gear. Some habitat attributes show degradation, while others show improvement. Significant habitat degradation is observed in isolated areas due to chronic disturbance. Use of bottom-contact gear is intensive in SBNMS, but diminishing due to regulatory controls and fleet consolidation. An increase in scallop dredging started in 2017 and will continue. Seabed disturbance from anchoring and other activities might also be locally important and should be evaluated.

Question 11: What are contaminant concentrations in sanctuary habitats and how are they changing?

Status Description: Undetermined

Rationale: Legacy contaminants have been reported in benthic habitats. However, they infrequently exceed thresholds of concern, do not appear to remobilize beyond sites where they have been identified (e.g., MBDS), and no indications of acute life history or population effects have been observed. Compounds of emerging concern are present, but poorly documented or monitored; thus, their status and trends could not be assessed. More monitoring is needed in this area.

Living Resources

Question 12: What is the status of keystone and foundation species and how is it changing?

Status Description: The status of keystone or foundation species may preclude full community development and function, but has not yet led to measurable degradation.

Rationale: Foundation species considered include Calanoid copepods, Atlantic herring, sand lance, sponges, and anemones. Calanoid copepods have persisted in the western Gulf of Maine despite recent warming. Atlantic herring have recovered from overfishing, but poor recruitment may result in a future decline in biomass. Sand lance are tightly linked to isolated shallow sand habitat on top of Stellwagen Bank and exhibit variable, unpredictable local abundance. The status of sponges and anemones is uncertain.

Question 13: What is the status of other focal species and how is it changing?

Status Description: Selected key species are at reduced levels, but recovery is possible.

Rationale: The eight focal species considered include North Atlantic right whale (poor and worsening), humpback whale (poor and improving), harbor porpoises (fair and undetermined), Atlantic white-sided dolphins (good and undetermined), great shearwaters (good/fair and undetermined), Atlantic cod (fair/poor and worsening), lobster (good and improving), and bluefin tuna (undetermined and improving). The overall rating is driven by the precarious status of North Atlantic right whales, whose recovery is dependent on additional management intervention, and humpback whales, which have been experiencing an unusual mortality event since 2017.

Question 14: What is the status of non-indigenous species and how is it changing

Status Description: Non-indigenous species are present and may preclude full community development and function, but have not yet caused measurable degradation

Rationale: Invasive species exist in the sanctuary and have for many decades; however, their abundance and distribution are poorly documented. The invasive tunicate, *Didemnum vexillum* has been found in isolated, small areas dominated by hard bottom habitats.

Question 15: What is the status of biodiversity and how is it changing?

Status Description: Selected biodiversity loss or change is suspected and may preclude full community development and function, but has not yet caused measurable degradation.

Rationale: Changes in sanctuary biodiversity are likely driven by variability in multiple factors at local and regional scales. At a local scale, fishing activities focused on species with high residency may impact biodiversity. Regional-scale factors include fishing of highly mobile species and climate change. The resulting shifts in species interactions at both spatial scales may also influence biodiversity in SBNMS.

Maritime Heritage Resources

Question 16: What is the condition of known maritime heritage resources and how is it changing?

Status Description: The diminished condition of selected maritime heritage resources has reduced, to some extent, their aesthetic, cultural, historical, archaeological, scientific, or educational value, and may affect the eligibility of some sites for listing in the National Register of Historic Places.

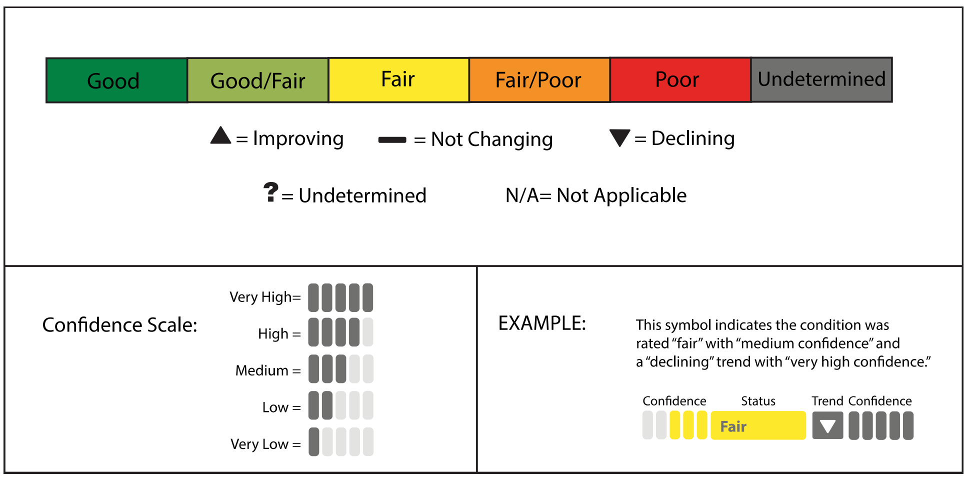
Rationale: Shipwreck sites are known to experience damage from mobile and fixed fishing gear, as these sites create structure on the seabed that can attract commercially important fish species, and thus fishing effort. Damage to shipwreck sites from fishing gear has been documented. Shipwreck sites are also visited by scuba divers. Scuba diving in the sanctuary has increased since 2007, but seems to be well-managed by dive operators to avoid site disturbance.

STELLWAGEN BANK NATIONAL MARINE SANCTUARY SUMMARY OF ECOSYSTEM SERVICES

The various resource ecosystem service evaluations presented in this report are summarized below. Each ecosystem service is listed, followed by

1) A set of rating symbols that display key information. The first symbol includes a color and term to indicate status, the next symbol indicates trend, and a shaded scale adjacent to both symbols indicates confidence (see key for example and definitions).
2) The status description, which is a statement that best characterizes status and corresponds to the assigned color rating and definition as described in Appendix B.
3) The rationale, a short statement or list of criteria used to justify the rating.

Key:



Cultural (Non-Material Benefits)

Heritage

Status Description: Unable to fully provide the ecosystem service due to prior or existing human activity, but performance is acceptable.

Rationale: Indicators show that historic SBNMS shipwreck stories are told in newspapers, magazines, and museums in New England. The dissemination of historic shipwreck information and stories indicates there is economic value for this resource. The resource indicators show that in-water shipwreck resources are fair and worsening.

Consumptive Recreation

Status Description: Ability to provide ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

Rationale: The number of charter and party boat anglers declined from 2007–2016, while the number of private boat registrations remained stable from 2007–2015 and increased in 2016. Local communities are also highly engaged in recreational fishing. The resource indicator for the most sought after stock (Atlantic cod) is poor, but alternative stocks (haddock, pollock, etc.) are sustainably managed and responsibly harvested.

Non-Consumptive Recreation

Status Description: Unable to fully provide the ecosystem service due to prior or existing human activity, but performance is acceptable.

Rationale: Some commercial operations have noted that demand for whale watching has steadily increased and the number of reports mentioning bird sightings has been increasing. Income and population in the area have also been increasing, and stable fuel prices have led to increased non-consumptive recreational activity in the sanctuary. The resource indicators show that there is a decline in some of the focal and foundation species used for non-consumptive recreation.

Sense of Place

Status Description: Ability to provide ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

Rationale: Studies show a positive willingness to pay for marine protected areas. Opinion polls show that over the past several years, the percentage of people that prioritize environmental protection at the risk of economic growth is increasing. The resource indicators show variation in their rankings.

Science

Status Description: The capacity to provide the ecosystem service has been enhanced or remained unaffected.

Rationale: The number of research hours and days on the R/V *Auk*, citizen science hours, and the number of volunteers have been increasing. Further, SBNMS is at the forefront of research focused on anthropogenic noise, humpback whales, and fin whales.

Education

Status Description: The capacity to provide the ecosystem service has been enhanced or remained unaffected.

Rationale: Studies show that parents have a willingness to pay for hands-on ocean conservation and stewardship programs. The number of Twitter and Facebook followers of SBNMS has increased over the past few years. Education activities at SBNMS have contributed to the public's understanding of SBNMS resources and programs.

Provisioning (Material Benefits)

Food Supply

Status Description: Ability to provide ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

Rationale: Pounds caught and value of landings show variability over the study period. Data indicate a shift from smaller to larger commercial vessels operating in the sanctuary. The groundfish fishery is still recovering, while lobster and sea scallop fisheries have been increasing.

SITE HISTORY AND RESOURCES

Overview

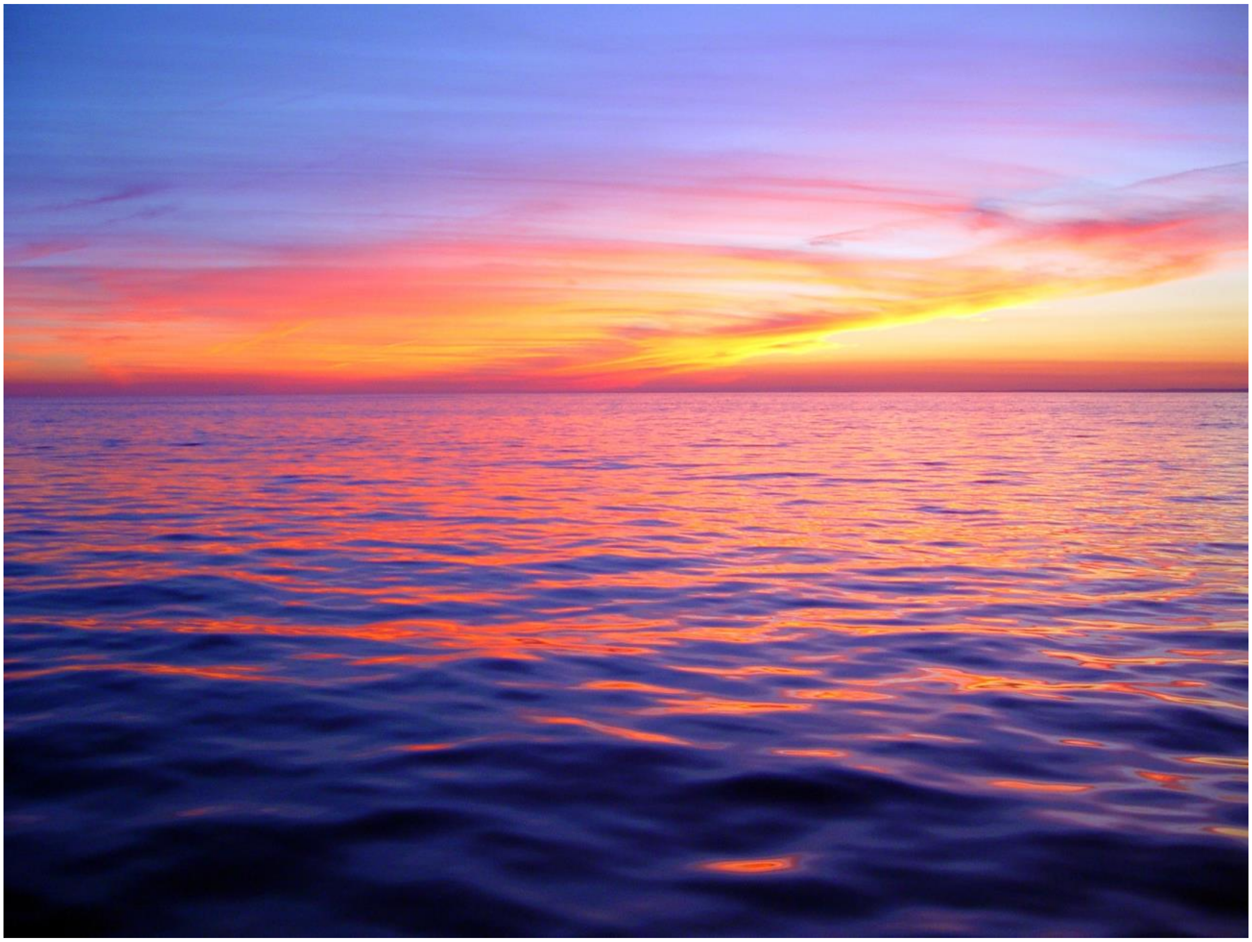


Figure SH.1. The sun sets over the ocean in Stellwagen Bank National Marine Sanctuary. Photo: NOAA

Stellwagen Bank National Marine Sanctuary is one of 14 national marine sanctuaries and two marine national monuments comprising a national system of ocean and Great Lakes areas selected for their ecological, recreational, historical, and aesthetic values (Figures SH.1, SH.2). Congressionally designated in 1992, the sanctuary's mission is to conserve, protect, and enhance biodiversity, ecological integrity, and cultural legacy, while facilitating compatible uses. The sanctuary is administered by the Office of National Marine Sanctuaries within NOAA, which is part of the Department of Commerce.

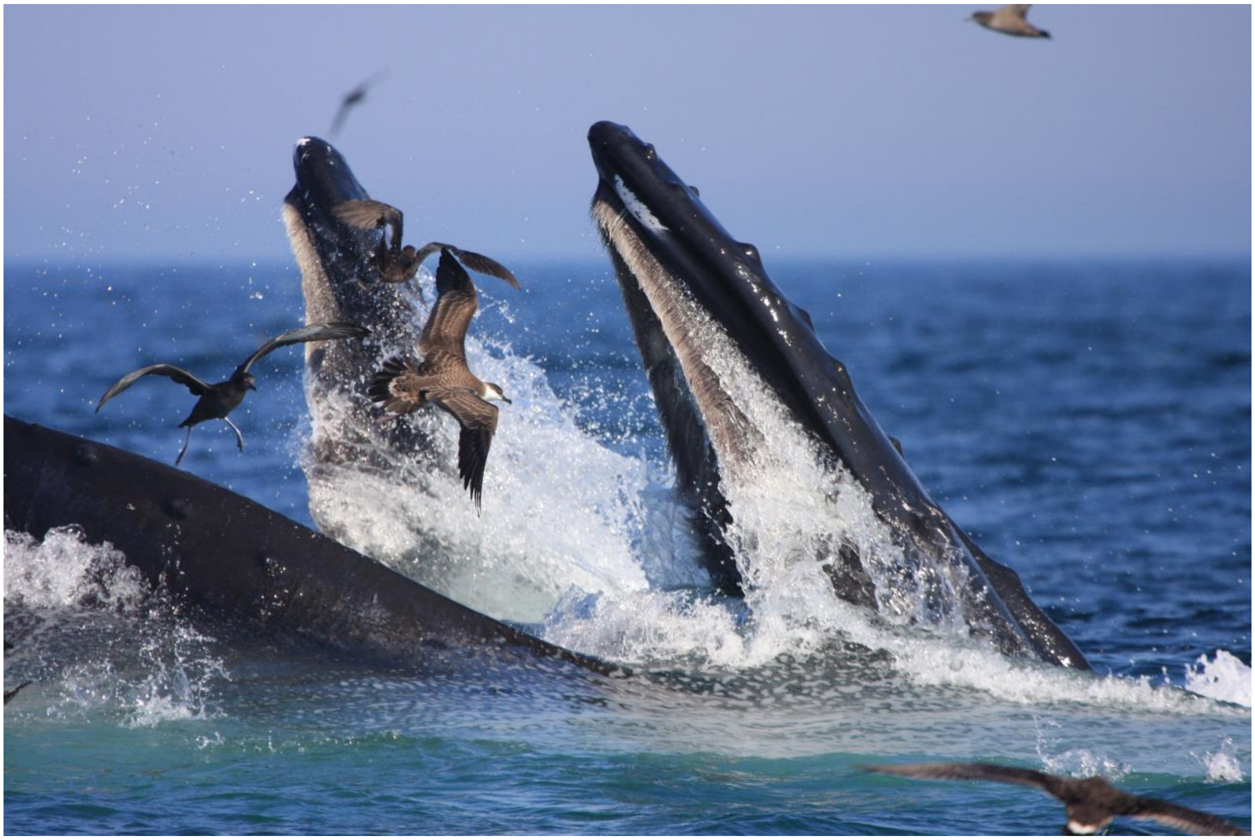


Figure SH.2. Humpback whales and seabirds frequent the sanctuary. Photo: NOAA

Location

Stellwagen Bank National Marine Sanctuary is located in the southwestern Gulf of Maine and stretches between Cape Ann and Cape Cod at the mouth of Massachusetts Bay (Figure SH.3). The sanctuary encompasses 842 square miles in a topographically diverse area that geologists estimate was created some 18,000 years ago during the retreat of the Great Ice Age glaciers, a time when Stellwagen Bank was emergent land and may have hosted Pleistocene mammals and potentially Native Americans. Today, the dominant feature of the sanctuary is a shallow, glacially-deposited, primarily sandy underwater bank, curving in a southeast to northwest direction for 19 miles. The bank is roughly six miles across at its widest point, which is located at its southern end. Water depths within the sanctuary range from 65 feet to more than 600 feet.

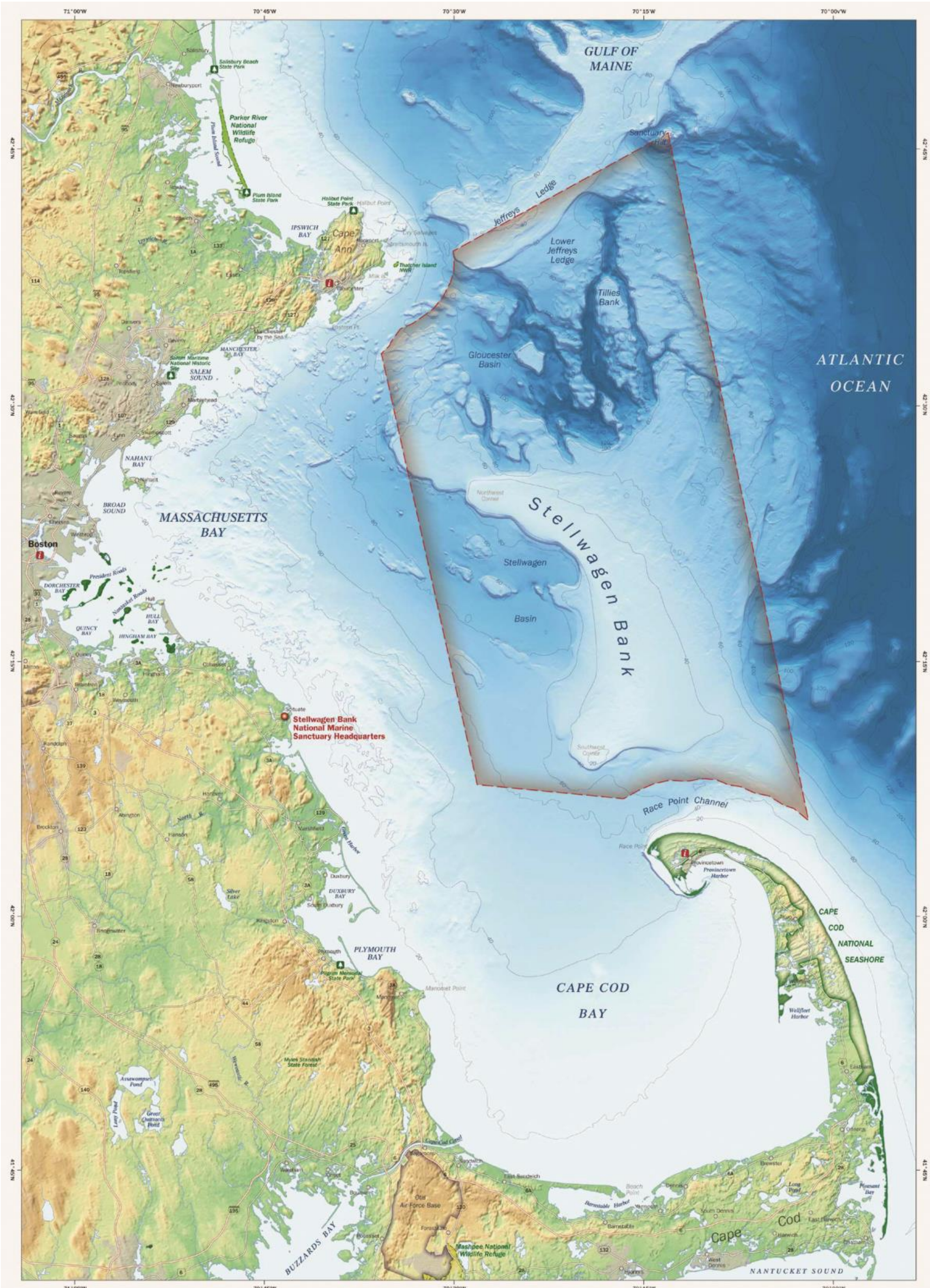


Figure SH.3. The sanctuary is located between Cape Ann and Cape Cod, in the southwest corner of the Gulf of Maine. Image: NOAA

Discovery of the Bank

There is little to no documentation in the historic record regarding the earliest encounters with what is now known as Stellwagen Bank. Native peoples were undoubtedly aware of the shallow bank and its associated productivity. Narrative accounts of early European voyages of exploration to New England provide evidence of the region's varied and abundant marine resources prior to wide-scale exploitation. Early published accounts include those of Giovanni da Verrazano (1524), Bartholomew Gosnold and John Brereton (1602), Martin Pring (1603), James Rosier and George Waymouth (1605), Samuel de Champlain (1605–1606), and John Smith (1614). Each of these explorers noted the richness and potential commercial value of New England fisheries. Descriptive and qualitative data can be extracted from these narratives to provide a general sense of abundance, distribution, and diversity in Massachusetts Bay prior to large-scale fisheries exploitation. Publications from the second half of the 17th century, such as William Wood's *New England's Prospect* (1634) and John Josselyn's *New-Englands Rarities Discovered* (1672), also document the condition of marine resources observed by early New England settlers. One of the earliest documented encounters was by Captain John Smith, who was sent by the King of England to prospect for fishing grounds around 1614. In 1614, he remarked:

> You shall scarce find any bay, shallow water or cove of land, where you may not take clams, or lobsters, or both at your pleasure, and in many places load your boat if you please, nor isles where you find not fruits, birds, crabs, and mussels, or all of them, for taking at low water. And in the harbors we frequented, a little boy might take of cunners, and pinnacks, and such delicate fish, at the ship's stern, more than six or ten can catch in a day; but with a casting-net, thousands when we pleased: and scarce any place, but cod, cusk, halibut, mackerel, skate, or such like, a man may take with a hook and line what he will. And, in diverse sandy bays, a man may draw with a net great store of mulletts, bass and diverse other sorts of such excellent fish, as many as his net can draw on shore: no river where there is not plenty of sturgeon, or salmon, or both; all which are to be had in abundance observing but their seasons (Smith 1624).

In 1616, Captain Smith drafted an incredibly accurate chart of the Gulf of Maine, and in the vicinity of Stellwagen Bank, he drew his ship, a convention to identify good fishing grounds. In 1635, he embellished the chart with a pyramid of "cod heads" under the ship to denote that this area was especially good for fishing (Figure SH.4) (Smith 1624).

Figure SH.4. Explorer John Smith's *Map of New England*, 1616. Image: Smith 1624

Cape Cod and Stellwagen Bank also teemed with whales in the early 17th century. In 1620, William Bradford of the Plymouth Plantation observed:

> Cape Cod was like to be a place of good fishing, for we saw daily great whales of the best kind for oil and bone, come close aboard our ship, and in fair weather swim and play about us. There was once one, when the sun shone warm, came and lay above water as if she had been dead, for a good while together, within half a musket shot of the ship, at which two were prepared to shoot to see whether she would stir or no. He that gave fire first, his musket flew into pieces, both stock and barrel, yet, thanks be to God, neither he nor nay man else was hurt with it, though many were there about. But when the whale saw her time, she gave a snuff, and [went] away (Heath 1986).

> And every day we saw whales playing hard by us, of which in that place, if we had instruments and means to take them, we might have made a very rich return, which to our great grief we wanted. Our master and his mate, and others experienced in fishing, professed we might have made three or four thousand pounds' worth of oil. They preferred it before Greenland whale-fishing, and purpose the next winter to fish for whale here (Heath 1986).

Mariners and fishers transiting Massachusetts Bay recognized the shoal waters of Stellwagen Bank as a navigational aid and rich fishing ground not long after European settlement of New England began. Known as Middle Bank for several centuries, it was later named Stellwagen Bank after Henry Stellwagen, a Lieutenant of the U.S. Navy on loan to the U.S. Coast Survey. Henry Stellwagen commanded the U.S. Coast Survey steamer *Bibb* during a scientific mapping survey of the bank in 1854. Accompanying Henry Stellwagen on his surveying vessel were two other individuals of note — an amateur surveyor by the name of Alexander Wadsworth Longfellow, brother of the famous poet, and a fellow hydrographer, Edward Cordell. In 1869, Cordell, by then in charge of his own survey ship, discovered a similar-sized bank on the west coast, which would eventually be named after him. Today, both Cordell and Stellwagen Banks are among the significant marine areas designated as national marine sanctuaries.

Setting

SBNMS is one of the most biologically diverse and productive areas in the Gulf of Maine. The area supports marine mammals and fishery resources that constitute important regional ecological and economic resources. Due to its accessibility, the region is used extensively for a variety of human uses, such as whale and seabird watching, wreck diving, recreational boating, and commercial and recreational fishing.

Beginning in the Colonial Period, groundfish, invertebrate, and pelagic fisheries became vital commercial resources for the New England region. Overfishing has contributed to stock collapses and a decline in commercial fishing, but a reduced, active, domestic commercial fishery continues throughout the Gulf of Maine. The productivity of Stellwagen Bank and its proximity to the coast gave rise to 400 years of vessel traffic across what is now the sanctuary. As a result, several hundred historic vessel losses are recorded within the sanctuary.

Today, New England has a diverse economy. With an adjacent population of approximately eight million people, the unique features, location, and resources of SBNMS draw business interests and recreational users, with concomitant, growing pressures on the integrity of the sanctuary ecosystem.

Water

The high productivity that defines the sanctuary as a special place and attracts wildlife and human users is driven by water circulation and its interaction with the seafloor. Located along the western edge of the Gulf of Maine, water circulation in the sanctuary is heavily influenced by the southerly flowing Maine Coastal Current. This current, in combination with twice-daily tidal fluctuations and riverine input, serves to turn the sanctuary into a mixing bowl of nutrient-laden waters. Once exposed to the shallow, sunlit waters on top of the bank, nutrients become fuel for seasonal plankton blooms that, in turn, become the foundation for a complex food web. The food web and its inherent productivity make SBNMS one of the most important seasonal feeding areas for whales, seabirds, and bluefin tuna in the western North Atlantic.

Habitat

The underwater landscape of the sanctuary, which includes Stellwagen Bank, surrounding banks, and basins, is a patchwork of habitat composed of both geologic and biologic features. These features provide shelter from predators and the flow of tidal and storm-generated currents, serve as sites that enhance capture of prey, such as drifting zooplankton or species associated with particular features, and serve as foci for fish spawning activities, including egg-laying and brooding young. All organisms have particular habitat requirements, and the important attributes of habitat vary between species and between life-history stages within species.

SBNMS contains all of the five major seafloor habitat types found in the Gulf of Maine: gravel, piled boulder, sand, mud, and rocky outcrop (Figures SH.5-SH.7). The percent cover of these sediment types are: gravel: 34% (boulder reefs are included in the gravel category), sand: 28%, and mud: 38% (NOAA Office of National Marine Sanctuaries 2010). Rocky boulder ledges and outcrop comprise less than 1% of the sanctuary (Valentine et al. 2001). These habitats are spread across a series of shallow banks and deep basins in a patchwork that make the sanctuary a diverse landscape. Within each habitat type, there are many microhabitats formed by the combination of water masses, sediments, and inhabiting organisms. For example, northern cerianthids, a type of tube-building anemone that burrows in mud, serve as important habitat for redfish, hake, and a multitude of invertebrates that live in and around the tubes.

Figure SH.5. Gravel habitat can be found in the sanctuary. Photo: USGS

Figure SH.6. Boulder habitat can also be found within the sanctuary. Photo: National Undersea Research Center-University of Connecticut

Figure SH.7. A lobster shelters in a rocky reef. Photo: D. Costa/NOAA

In general, species composition of seafloor communities is highly correlated with grain size of benthic sediments, and as such, seafloor substrata constitute an important habitat component for many organisms in the sanctuary. Studies on the continental shelf of the northeastern United States, including portions of the sanctuary, indicate that substrate and water mass characteristics are highly correlated with the composition of benthic communities (e.g., Auster et al. 2001, Skinder 2002). These habitat features may therefore serve as proxies for the distribution of biological diversity where detailed information on the distributions and abundances of species is lacking (Cook and Auster 2006). Infaunal invertebrates (those that burrow into the seafloor), show strong associations with sand grain size and unconsolidated mud sediments in the sanctuary (Grannis 2005). Epifaunal species, those that live on the seafloor, are linked to variation in larger grain sizes at the scale of the Gulf of Maine (Skinder 2002).

Although macroalgae (e.g., seaweeds) once grew on Stellwagen Bank, bottom trawling has virtually removed this marine algae, and it no longer appears to play a substantive role in structuring seafloor habitats in the sanctuary (Cahoon et al. 1993). Instead, benthic invertebrates make up the majority of biogenic structure on the seafloor. Microscopic examination of surface sediment samples showed that pennate diatoms dominated the benthic microflora (more than 97% of total cells) (Cahoon et al. 1993).

Biological communities are formed by the interaction of populations within habitats in a particular area. The interaction of fish, such as sand lance, with their habitat is of particular concern and has been well-studied in SBNMS. For the purposes of this document, the ecological role of seafloor habitats is largely defined by our understanding of links between these habitats and the distribution and abundance of fishes.

An increasingly recognized element of sanctuary habitat is its acoustic environment. The sanctuary is home to many soniferous species that are protected and/or managed by NOAA under multiple U.S. statutes, notably the Endangered Species Act (ESA) and the Marine Mammal Protection Act. The sanctuary's location is also a busy place for human commerce, particularly maritime transportation, and thus is subjected to high levels of sound-producing activities.

Living Resources

SBNMS's extraordinary primary productivity, complex oceanography, and diverse seafloor terrain provide habitat for well over 575 species of marine life, including over 80 species of fish, 53 species of seabirds, and 22 species of marine mammals (NOAA Office of National Marine Sanctuaries 2010) (Figures SH.8—SH.10).

Every major taxonomic group of invertebrates that occurs in the global marine environment is present in the sanctuary. This includes a diversity of sponges, hydroids, and anemones, bryozoans, bivalves, gastropods, sea stars, sea cucumbers, sand dollars, and tunicates, among others.

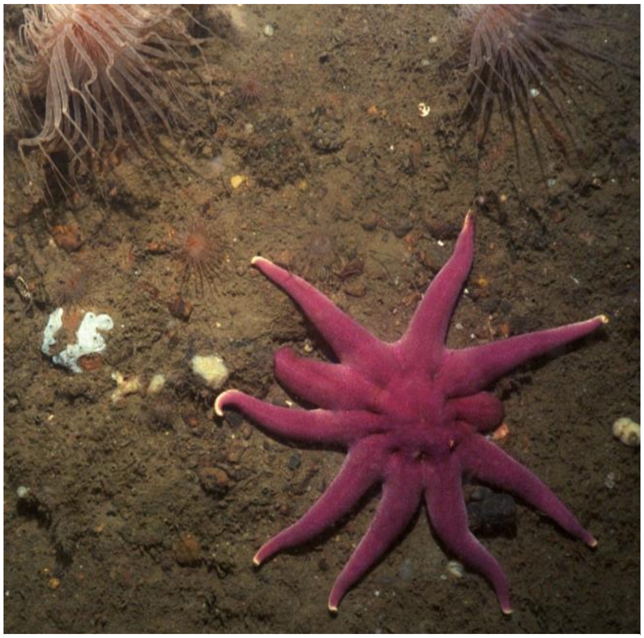


Figure SH.8. Many sea stars can be found in the sanctuary. Photo: USGS

Figure SH.9. Whales and seabirds feed in the sanctuary waters. Photo: NOAA

Figure SH.10. Shipwrecks in the sanctuary serve as homes for fish and invertebrates like this lobster. Photo: NOAA

The benthic fish community includes Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), silver hake (*Merluccius bilinearis*), various flatfish, sand lance (*Ammodytes dubius* and *A. americanus*), Atlantic mackerel (*Scomber scombrus*), and Atlantic herring (*Clupea harengus*), the latter three of which are considered to be forage fish. Populations of these species are seasonally prolific in Stellwagen Bank and serve as primary prey for humpback (*Megaptera novaeangliae*), fin (*Balaenoptera physalus*), and minke whales (*Balaenoptera acutorostrata)*, as well as many finfish and seabirds (NOAA Office of National Marine Sanctuaries 2010). Substantial commercial and recreational fisheries exist for herring and mackerel.

The sanctuary is the seasonal home to two species of endangered sea turtles, the Atlantic or Kemp's ridley (*Lepidochelys kempii*) and the leatherback (*Dermochelys coriacea*). Green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles occur occasionally in the Gulf of Maine. The leatherback is a summer visitor to SBNMS and is the only species of sea turtle that journeys to cold waters for feeding activities. Kemp's ridleys are observed in waters off Massachusetts as juveniles, having either swum or drifted north in the Gulf Stream from hatching areas off the southern coast of Mexico.

The rich biological environment of the sanctuary also attracts a diversity of seabirds that feed on prey ranging from copepods to fish. Frequent visitors include shearwaters and storm petrels (Procellaridae), gannets (*Morus bassanus)*, phalaropes (Phalaropus spp.), gulls (Laridae), terns (Sterna spp.), jaegers (Stercorarius spp.), alcids (Alcidae), and various sea duck species (Anatidae). These species arrive in relatively high numbers, with some species numbering in the tens of thousands. More occasionally, roseate terns (*Sterna dougallii*), a federally listed species, as well as Arctic (*Sterna paradisaea*) and common (*Sterna hirundo*) terns, both state listed species, have been observed in the sanctuary. The significance of the sanctuary as seabird habitat led to its designation as an Important Bird Area by the Massachusetts Audubon Society and BirdLife International.

The abundance of preferred prey species attracts marine mammals, and whales are the most charismatic occupants of sanctuary waters. Seventeen species of cetaceans have been observed in the sanctuary and ten are known to regularly frequent the sanctuary. Of these, humpback whales are perhaps the most conspicuous because of their large size, charismatic behavior, and distinctive markings. SBNMS is recognized as one of the primary North Atlantic feeding grounds of the humpback whale. The critically endangered North Atlantic right whale *(Eubalaena glacialis)* is one of the world's most endangered whale species. Every year, approximately one third of the endangered North Atlantic right whale population utilizes the sanctuary and nearby waters for feeding and nursing calves. Fin (or finback) whales, the second largest of the world's whales, are regularly seen in the sanctuary, along with the smaller minke whales. Harbor (*Phoca vitulina)* and gray (*Halichoerus grypus)* seals are also commonly observed in the sanctuary.

Maritime Heritage Resources

Numerous prehistoric and historic heritage sites are believed to lie within SBNMS as a result of prehistoric, glacially-lowered sea levels, which created opportunities for native peoples to hunt and gather coastal resources in what is now SBNMS. Archaeological evidence of these activities may exist, but is not yet confirmed. More recently, hundreds of years of fishing, whaling, and maritime transportation have made the sanctuary a repository for historically significant maritime heritage resources. Since sanctuary researchers began investigating SBNMS's maritime heritage in 2000, archaeologists have inventoried 47 shipwreck sites and identified 12 of these shipwrecks by name (Lawrence et al. 2015). Six shipwreck sites containing seven vessels have been recognized as historic properties and listed on the National Register of Historic Places.

The steamship *Portland* is considered the sanctuary's most historically significant wreck and is the most intact nineteenth-century New England coastal steamship located to date. Listed on the National Register of Historic Places in 2005, it is highly significant to the history of New England, specifically Boston, Massachusetts and Portland, Maine. Constructed in 1889, the 291-foot steamship (Figure SH.11) was lost in an 1898 gale that now bears its name. The Historical Maritime Group of New England located its wreckage in 1989, and in July 2002, NOAA researchers confirmed its identity as the *Portland* shipwreck.

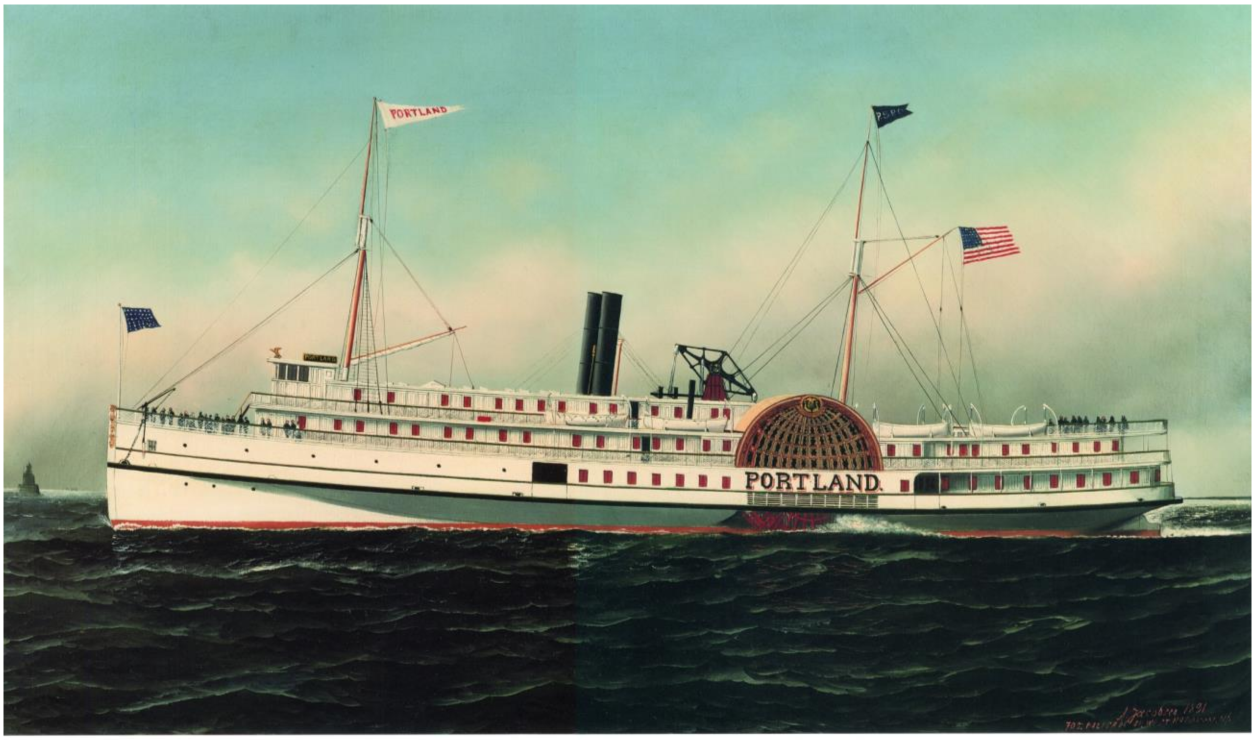


Figure SH.11. The steamship *Portland* is one shipwreck found in the sanctuary. Image: Antonio Jacobsen courtesy of Maine Historical Society

Also listed on the National Register of Historic Places (in 2006) are the wrecks of two coal-carrying schooners (colliers) that collided in December 1902. The *Frank A. Palmer* and the *Louise B. Crary* were carrying coal to Boston when they collided and sank. At 274.5 feet, the *Frank A. Palmer* was the longest four-masted schooner ever built, while the *Louise B. Crary* was a slightly smaller, five-masted vessel. Side scan sonar images collected in 2002 and 2003 clearly show the hulls of the two large sailing vessels, their bows locked together for all time (Figure SH.12).

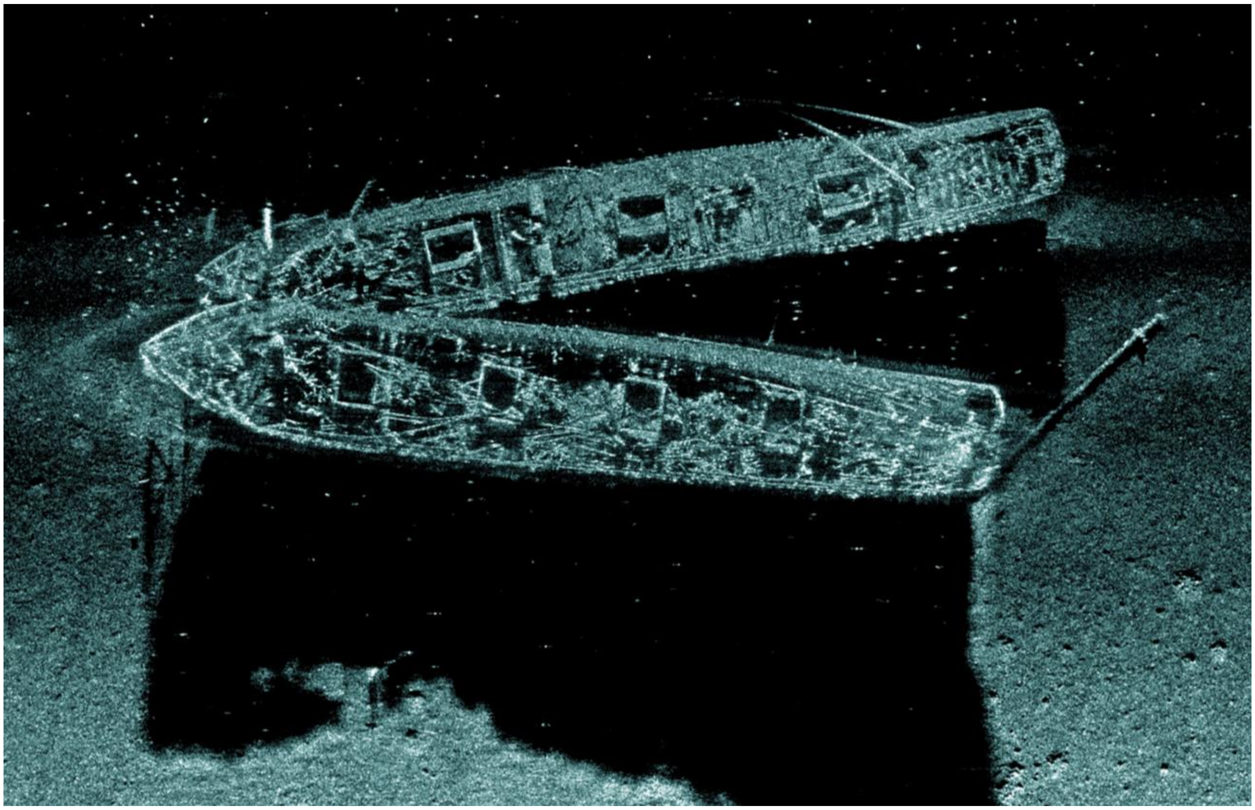


Figure SH.12. A 2002 sidescan image of the coal schooners *Frank A. Palmer* and *Louise B. Crary*. Of the 21 crew members of both vessels, only 10 survived the collision. Image: NOAA

Archaeologists have located and investigated several other collier shipwreck sites with varying degrees of preservation. The five-masted schooner *Paul Palmer* caught fire and sank off Highland Light in 1913. Built in 1902, its history includes several other instances when it was nearly destroyed by fire, revealing the peril faced by mariners and shipowners. Much of the hull was destroyed by the fire that sank the *Paul Palmer,* as well as subsequent storms and trawling, but many of the vessel's iron fittings can still be found. The shipwreck has become a striking oasis of biodiversity, providing habitat for encrusting invertebrates and fishes on an otherwise flat and sandy seafloor (Figure SH.13).

After colliers, the second most common category of shipwreck located thus far is the twentieth century commercial fishing vessel, the majority of which are wooden-hulled, eastern rig draggers. Constructed from the 1920s through the 1970s, these side trawlers exemplify the transition from hook-and-line fishing to engine-powered trawling. Several of the eastern rig dragger shipwrecks in the sanctuary are remarkably intact, with extant pilot houses and masts. Others are much more fragmented as a result of damage from nets and trawl doors from more recent trawling activity (Lawrence et al. 2015).

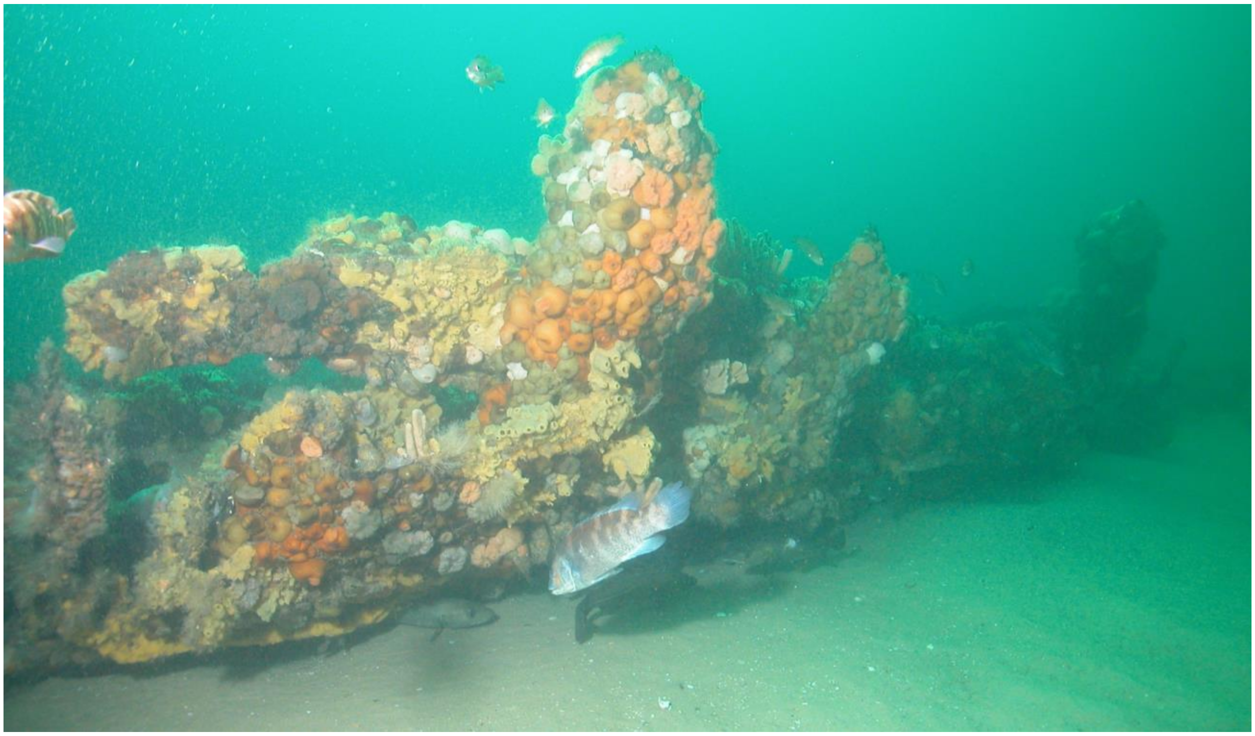


Figure SH.13. The wreck of the *Paul Palmer* provides habitat for many organisms. Photo: NOAA

Archaeological surveys have also revealed the story of another emblematic New England commodity: granite. Four shipwrecks on the sanctuary's seafloor carried granite cargoes. Beginning in the 1820s, Massachusetts and Maine quarries cut stone that was shipped throughout the world. Two sanctuary shipwrecks carried large stones used in construction of architectural structures and two carried stone cargoes used to create urban streets. One vessel, the two-masted schooner *Lamartine*, exemplifies some of this trade's history. *Lamartine* carried a cargo of sewer basin covers and curbing destined for the streets of New York when it sank in 1893. Built in 1848, the schooner sailed broadly in the U.S. coasting trade, transporting bulk cargoes of coal and lumber before transitioning into the granite trade.

DRIVING FORCES AND PRESSURES ON THE SANCTUARY

The condition of natural and heritage resources in marine sanctuaries is affected by both natural processes and human activities. Driving forces are the characteristics of human societies that influence the nature and extent of human activities. This section describes the known drivers and pressures affecting SBNMS resources and addresses five questions related to their influence on major sanctuary resources components: water, habitat, living resources, and maritime heritage resource quality. Trends in drivers and pressures support the assessment of sanctuary resources described in the State section of this report and can aid in forecasting the direction and extent of future pressures.

The general approach used herein is to integrate drivers with pressures in discussions of each pressure; however, since there are several drivers that affect several different pressures, they are addressed in this introduction. Quantitative details are included in this section and are not repeated in subsequent sections discussing each pressure.

Prominent drivers affecting resources in SBNMS include:

1. Population and per capita income
2. Gross domestic product
3. Fuel prices

These high-level drivers operate at multiple scales ranging from local to international and affect demand for resources (e.g., food and access), and thus, levels of activity that can alter resource conditions (e.g., development, shipping traffic, boating, pollution, noise, etc.).

Societal values, measured by opinion polls on environmental quality and the level of environmental protection, determine demand and affect supply of all goods and services humans consume. The institutions humans create to supply many goods and services are sometimes slow to adapt to changing societal values. The indicators used for drivers reflect, to a large extent, societal values via the relationship between the demand and supply of different goods and services and the relevant pressures they place on sanctuary natural and cultural resources. These indicators also capture economic factors that may influence or correlate with other human activities that exert pressure on sanctuary resources, such as trade, recreation, and waste generation.

Driving Forces

Population and Per Capita Income

International and domestic demand for goods and services, resulting from increases in population and real per capita income, is and will remain a primary driver of pressures on sanctuary resources. The U.S. population increased 0.9% per year between 2000 and 2015 and is forecasted to increase 1.0% per year through 2030 (Woods and Poole Economics, Inc. 2016). In 2010, 123 million people (39% of the nation's population) lived along the U.S. coast. By 2020, NOAA predicts another 10 million people will move to a coastal county (NOAA 2018a).

The population of Massachusetts has increased, consistent with national trends. Nearly 5.14 million Massachusetts residents (out of the state's total 6.79 million residents) now live within Massachusetts's coastal counties. More than eight million people reside in the 14-county study area identified as

SBNMS's local economy (Appendix E: Figure App.E.1). The area includes counties adjacent to and inland from SBNMS, which receive most of the socioeconomic contribution of activities within the sanctuary. Socioeconomic contributions to SBNMS's local economy include income, jobs and economic output (Figure DP.DF.1, U.S. Census Bureau 2015, Appendix E: Table App.E.1, Figure App.E.2).

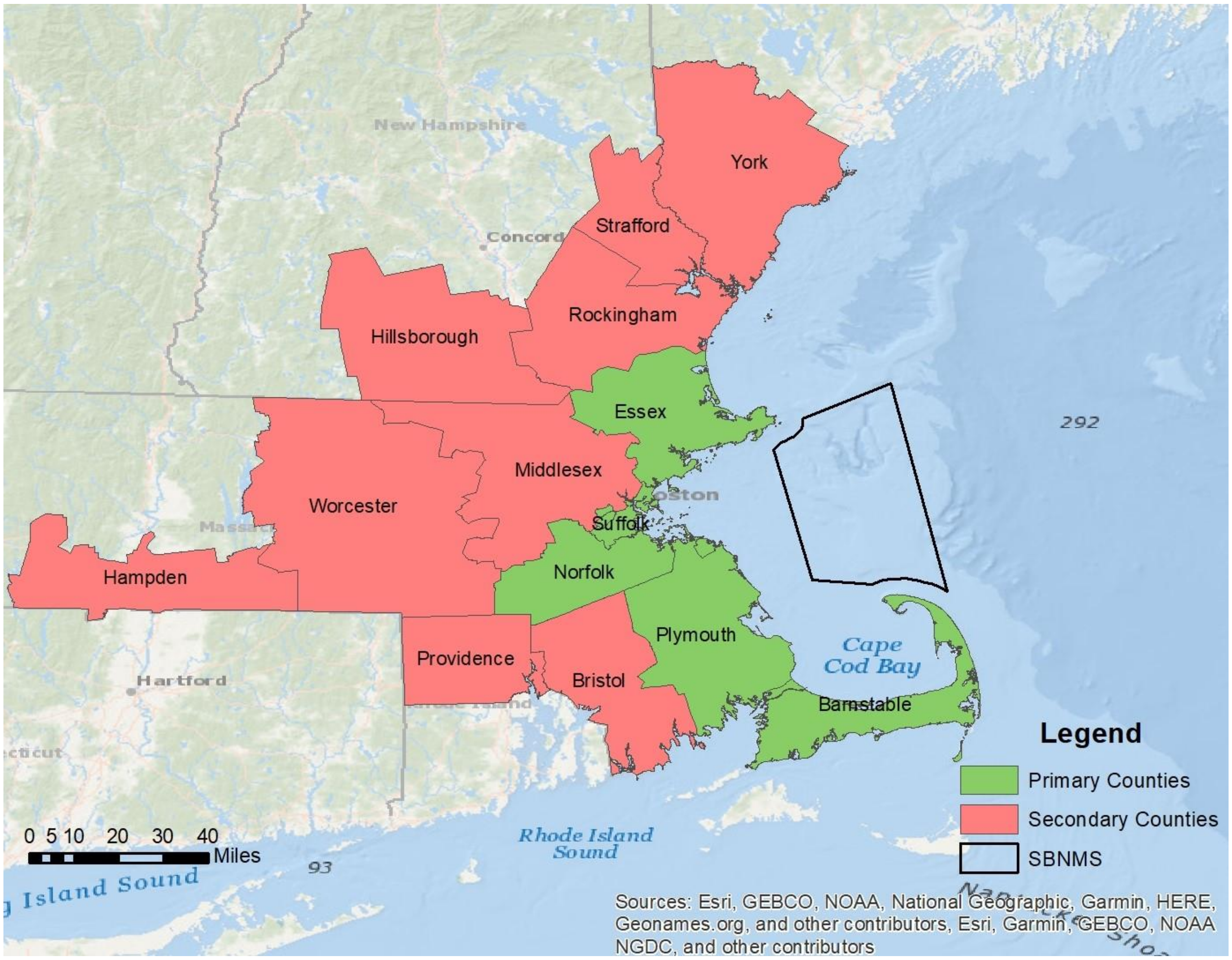


Figure DP.DF.1. Map depicting the 14 coastal counties whose local economy is impacted by SBNMS. Image: R. Shea/NOAA

Between 2000 and 2015, average annual population growth rates were 0.9% for the U.S., 0.45% for Massachusetts, and 0.45% for the 14-county study area. Between 2015 and 2030, average annual growth rates are projected to be 0.98% for the U.S., 0.52% for Massachusetts, and 0.56% for the 14-county study area (Woods and Poole Economics, Inc. 2016, Appendix E: Table App.E.2, Figure App.E.2).

Meanwhile, the standard of living in the 14 counties adjacent to the sanctuary has increased faster than that in the rest of the United States (Woods and Poole Economics, Inc. 2016). Between 2000 and 2015, average annual real per capita income (adjusted for inflation) increased 1.28% in the United States, 1.54% in Massachusetts, and 1.6% in the 14-county study area. Between 2015 and 2030, average annual real per capita income is projected to increase by 1.6% in the United States, 1.7% in Massachusetts, and 1.6% in the 14-county study area (Woods and Poole Economics, Inc. 2016, Appendix E: Table App.E.3, Figure App.E.3). Given the projected growth in population and per capita income, it can be expected that many of the uses of and therefore, pressures on SBNMS driven by these factors will continue to increase in the foreseeable future.

Gross Domestic Product

Another high-level driver of pressures on U.S. resources, including those in SBNMS, is the real (adjusted for inflation) gross domestic product (GDP) of Canada, the European Union, China, Japan, and South Korea. Increases in GDP in these countries result in increased demand for all goods, including seafood and other fishery products. Seafood is bought and sold in a global market such that demand from entities/countries such as the European Union, Canada, China, Japan, and South Korea[6] affects prices of species caught in SBNMS, and thus, affects fishing behavior on and around the bank itself. Between 2010 and 2017, these entities/countries imported 80-95% of the exported component of the commercial product categories that species caught in SBMNS fall into (NOAA Office of Science and Technology 2017). In other words, while it is unknown what share of fish caught in SBNMS are sold locally versus internationally, international consumer demand for fish products caught in SBNMS puts pressure on those resources at the macro level. (See Appendix E: Table App E.4 for more information).

Fuel Prices

Fuel prices are an important and more immediate driver of many ocean activities. Ocean users consider fuel prices in their decisions to conduct activities like commercial fishing, ocean recreation, or offshore gas exploration. Gasoline prices declined 29% between 2012 and 2017, while diesel prices declined 35% during the same time period, affecting levels of visitation to the sanctuary and various uses (U.S. Energy Information Administration 2017, Appendix E: Figure App.E.4). Lower fuel prices decrease costs of commercial fishing and ocean recreation activities, which may lead to increases in these activities. The offshore location of SBNMS requires all users to purchase fuel, suggesting that lower fuel prices could lead to increased pressure on sanctuary resources. However, oil producers may be less likely to invest in oil exploration and drilling during periods of low fuel prices when costs of research and exploration may exceed gains. This reduces pressures related to offshore oil development, including pollution, habitat destruction, and noise. In addition, alternative renewable energy sources, such as wind or tidal, could lead to less demand for oil and gas, lower fuel prices, and decreased incentives for investment in oil exploration and drilling near the sanctuary.

In summary, population growth, per capita income, and fuel prices are high-level drivers operating at multiple spatial scales (local to international) that may influence multiple pressures discussed in the following section.

Pressures

The following section discusses the various pressures that impact sanctuary resources, including noise, marine debris, whale watching, recreational diving, recreational fishing and boating, commercial fishing, commercial shipping, liquefied natural gas deepwater ports, submarine cables and pipelines, and climate change.

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[6] U.S. GDP increases averaged 1.3% per year between 2000 and 2015. Between 2000 and 2017, real GDP average annual increase was 2.2% for Canada, 1.7% for the European Union, 9.8% for China, 1.0% for Japan, and 4.3% for South Korea. Between 2018 and 2022, GDPs are forecasted to increase at a slower pace with an annual average of 1.8% in Canada, 1.8% in the European Union, 5.9% in China, 0.6% in Japan, and 3.0% in South Korea (Trading Economics 2017, Appendix E: Table App.E.4).

Noise

Many marine organisms, including marine mammals, turtles, fish, and invertebrates, rely on sound for their survival (Figure DP.N.1). In general, sound can be perceived underwater over greater distances than sight or smell, and sound is the primary way that many marine species gather and understand information from other organisms and their ocean environment.

The level of ocean noise pollution in general and in SBNMS in particular has increased dramatically during the last 50 years. Noise generated by human activities can have a detrimental effect on marine life. Studies have documented behavioral responses, lost listening opportunities, and physical injury to wildlife due to exposure to anthropogenic (human-induced) noise (Gedamke et al. 2016). Sources of underwater noise include large commercial shipping traffic, such as container ships, freighters, barges, and tankers; smaller recreational and commercial vessels; sonars used in military training; pile drivers and dredging used in marine construction; airguns and other seismic sources used in energy exploration; sonars and other active acoustic sources used in research activities; and aerial sources, such as overflights.

Exposure to high decibel noise, especially in close proximity, can cause injuries to marine organisms, including marine mammals, turtles, fish, and invertebrates (see review in Gedamke et al. 2016). Acute impacts can include tissue damage as well as rupturing or hemorrhaging of body parts. Higher level noise exposure can also cause marine mammals and other organisms to acquire temporary or permanent hearing loss (Southall et al. 2019). Over a wider range of exposure levels and distances, elevated underwater noise levels can mask biologically important acoustic signals that marine animals use to survive and reproduce (e.g., those used for echolocation, interspecies communication, mother/calf contact, predator-prey cues, and navigation/larval settlement) as well as cause behavioral alterations (such as changes in migration patterns or abandonment of important habitats) (Southall et al. 2019). These alterations can have adverse effects on animals' energy and physiology, which in turn can reduce their abilities to survive and reproduce (reviewed in Francis and Barber 2013).

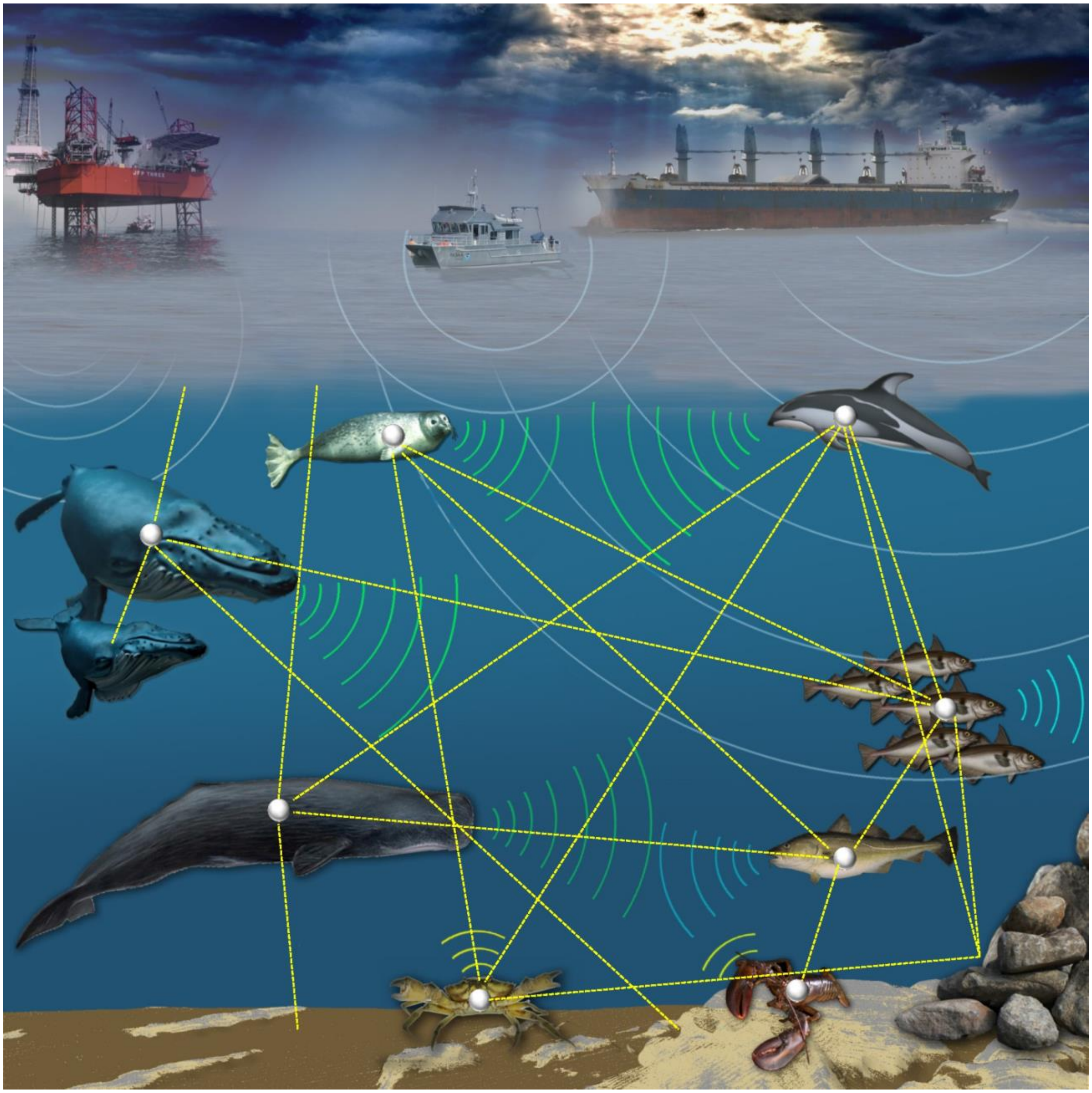

Figure DP.N.1. Many marine organisms, including marine mammals, turtles, fish, and invertebrates, rely on sound and hearing for their survival. Increasing human activity within our oceans over the last 100 years has also meant increasing levels of human-induced noise. Image: M. Thompson/NOAA

Marine Debris

According to NOAA's Marine Debris Program, marine debris is any persistent, manufactured, or processed solid material that is directly or indirectly, intentionally or unintentionally, disposed of or abandoned in the marine environment. Marine debris can include a wide variety of objects (e.g., lost fishing gear, lost vessel cargo, plastics, metal military debris, household goods, or balloons) from multiple sources (e.g., stormwater runoff, landfills, recreational and commercial activities, military activities) (Keller et al. 2010) (Figures DP.MD.1, DP.MD.2).

Figure DP.MD.1. Derelict fishing nets wrap around shipwrecks. Photo: NOAA

Figure DP.MD.2. Mylar balloon floats in SBNMS. Photo: NOAA

Plastic is the most prevalent type of marine debris found in the ocean. Plastic debris can come in all shapes and sizes, but those that are less than five millimeters in length are called microplastics. Recent research suggests these microplastics can accumulate in seafood, particularly shellfish (Avio et al. 2017).

Many types of marine debris exist in the sanctuary and collect at various places in the sanctuary. The prevalence of debris within the sanctuary is affected by both natural forces (e.g., currents) and human drivers, including population growth and increasing coastal development.

Marine debris in SBNMS threatens the marine environment, human health, and safe navigation. For example, ingestion of or entanglement in marine debris may lead to death in animals like sea turtles, marine mammals, birds, and benthic organisms (NOAA Marine Debris Program 2014a, 2014b). Entanglement in commercial fishing gear, such as lines, nets, and derelict gear is observed throughout SBNMS and may result in drowning, starvation, physical trauma, systemic infections, or increased susceptibility to other threats, such as ship strikes. Raw observer data reported in Northeast Fisheries Science Center (NEFSC)'s Observer Program suggests that marine mammals and seabirds are the main interactors with marine debris, with apparently few turtles involved (NEFSC 2019). There is no evidence that large whales have been entangled in marine debris in the sanctuary. Marine debris can also alter the condition and structure of benthic habitats (NOAA Marine Debris Program 2014a, 2014b, 2016).

Whale Watching

Whale watching on the east coast of the United States had its start in the mid-1970s on Stellwagen Bank, with trips from a single operator departing from Provincetown, Massachusetts. There are currently eight whale watching companies that offer daily trips during a season that generally runs from April through October (Figure DP.WW.1). For some companies, the season has expanded in recent years, starting as early as March and ending as late as mid-November. As the industry has matured, the vessels have gotten larger, their speeds have increased, and, for some companies, the number of trips per day has increased.

Figure DP.WW.1. Many whale watching vessels travel to SBNMS to view whales. Photo: NOAA

Calculations from printed whale watch company schedules indicated there were more than 3,650 individual whale watching trips scheduled in 2018. The majority of the scheduled trips, almost 2,000, occurred in July and August. Since the primary feeding ground for local humpbacks (the preferred whale to watch due to its dramatic behaviors) is Stellwagen Bank, it is assumed that most trips travel to the sanctuary, as that is historically where most whale watches have occurred in past years.

Similar to other vessels, whale watch vessels pose a threat to whales in terms of potential collisions, behavioral disturbance, and noise. However, for vessels watching whales, the window of time that they are near whales is limited to daylight hours (generally 10:00 am–6:00 pm). Industry growth seems to have leveled off, with companies widely spaced around the Massachusetts Bay/Cape Cod Bay region, allowing for a dispersed distribution of boats and ship tracks in the sanctuary. When whale abundance is reduced due to natural, cyclical declines in prey, the few remaining whales may be inundated with vessel visits, but companies usually have enough whales to select from to minimize the concentration of effort on individual animals.

Almost all of the Massachusetts-based whale watching companies (except those from Cape Ann) have now joined Whale SENSE, a voluntary education and recognition program offered to commercial whale watching companies in the U.S. Atlantic and Alaska Regions. Whale SENSE is sponsored by NOAA Fisheries, Whale and Dolphin Conservation, and SBNMS. Developed in collaboration with the whale watching industry, Whale SENSE recognizes whale watching companies committed to responsible practices. Non-member companies report that they too follow the Northeast Region Whale Watch Guidelines (developed in 1994 by the industry, NOAA Fisheries, SBNMS, and non-governmental organizations focused on whale conservation) (GARFO 2019a).

In addition to the large commercial whale watch vessels, there is a growing contingent of smaller recreational boats that make occasional visits to the sanctuary to watch whales. Many of these boaters may not be following whale watch guidelines; some have been observed (e.g., reports from sanctuary staff, sanctuary advisory council members, non-governmental organizations, and small boat passengers) traveling directly into whale feeding areas (including across bubble nets), where they pose whale strike and behavioral disturbance threats (Lynch 2017).

Although the number of "for hire" whale watching operators has declined over the past decade (from 15 companies in 2007 to eight in 2018), that was due to consolidation in the industry, not a reduction in demand. Demand for whale watching is expected to remain strong as the population and real per capita incomes increase in the U.S., Massachusetts, and the 14-county study area adjacent to the sanctuary. As demand for whale watching increases, pressures from wildlife viewing are also expected to increase. For example, in 2018, one company began offering helicopter-based whale watching tours. Similarly, the demand for whale watching and general boating from private household boats is expected to increase.

Recreational Diving

Recreational scuba diving in the sanctuary has increased since 2007. Almost 15% of the sanctuary is less than 130 feet deep, which is within depth limits of recreational diving. However, strong currents and exposed waters create challenging conditions. Technical diving allows access to depths greater than 130 feet. There are several areas on top of Stellwagen Bank (including the Sponge Forest), as well as shallow areas on parts of southern Jeffreys Ledge and Sanctuary Hill, which are interesting dive sites due to their complex habitat (Figure DP.RD.1). In addition, there are several shipwreck sites, both historic and modern, that are visited by recreational divers. There are an estimated one dozen dive charters that visit SBNMS wrecks each year, but dive operators appear to be managing their dive operations well to avoid disturbing these sites. In addition to organized dive charters, there are independent recreational divers who visit wrecks, and there is evidence that these divers may occasionally disturb wrecks and/or artifacts.

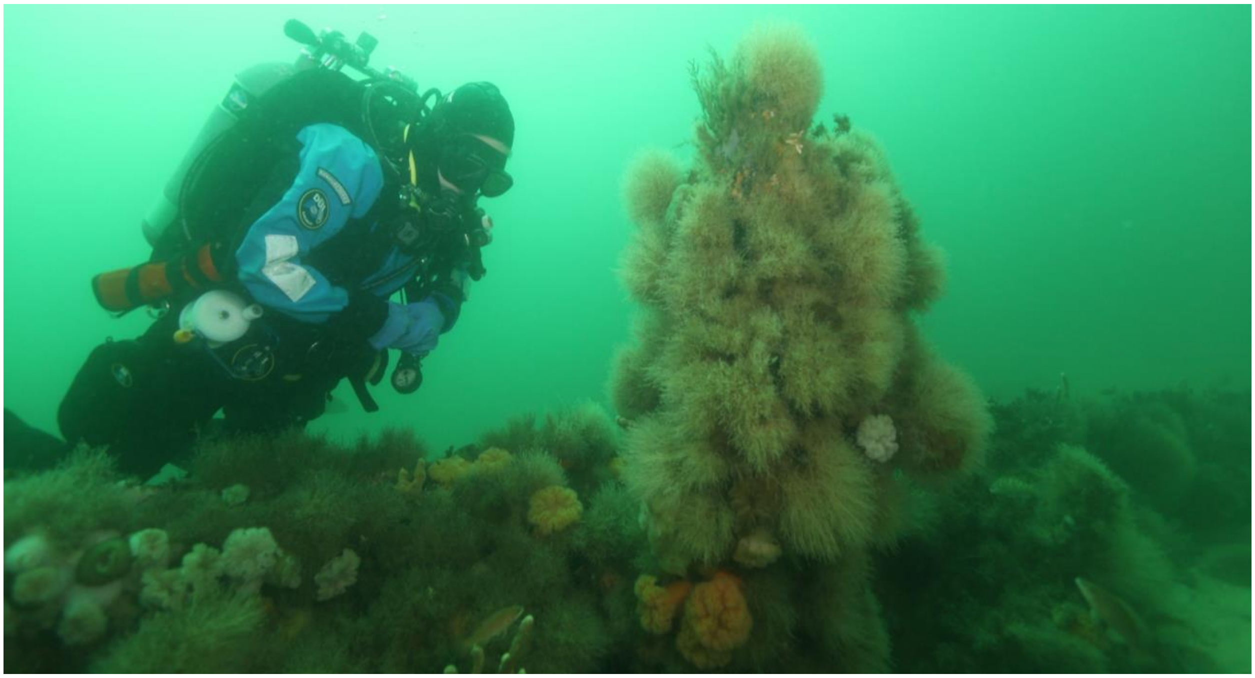

Figure DP.RD.1. A diver explores a shipwreck in SBNMS. Photo: NOAA

Recreational Fishing and Boating

Figure DP.RF.1. Fishers can recreationally fish for tuna in the sanctuary. Photo: On The Water Media Group

The sanctuary is a popular destination for recreational vessels, such as fishing boats, party boats, sailboats, powerboats, and charters. Recreational fishing in the sanctuary targets groundfish species and pelagic species (Figure DP.RF.1). In 2007, the recreational fishing fleet harvested approximately 25% of all Atlantic cod harvested in the Gulf of Maine (NEFMC 2014a). Since 2007, harvest levels have fluctuated each year, but have generally remained constant (NEFMC 2014a). In 2016, recreational landings of Atlantic cod within the Gulf of Maine exceeded the harvest limit by 92% (Federal Register 2017). As a result, in July 2017, NOAA Fisheries prohibited retention of Atlantic cod for the rest of the 2017 fishing year (Federal Register 2017). Recreational fishing is also a significant component of the overall landings in other fisheries, such as haddock.

There are 65 small boat harbors and over 80 boating and yacht clubs along the Massachusetts coast allowing for easy access to the sanctuary. Recreational boaters typically transit to the sanctuary from Boston, Cape Cod Canal, Cape Cod Bay, Provincetown, and Cape Ann. Recreational boaters are most numerous and often aggregate within the sanctuary during whale watching season (i.e., April to October). On a calm summer day, recreational boats can number in the hundreds. Potential impacts from recreational boating and fishing activities include targeted removal of large spawning and breeding fish, disturbance of whale feeding, strikes to whales, and discharge of pollutants.

Recent rule changes regarding discharge of pollutants from recreational vessels may impact SBNMS. In 2014, the U.S. Environmental Protection Agency (EPA) designated all Massachusetts state waters as "No Discharge Zones," making it illegal to discharge treated or untreated sewage in state waters; however, these regulations do not apply to the sanctuary because it is entirely outside of state waters. However, it is unclear whether this has changed recreational boating discharge in SBNMS.

Although charter and party fishing effort in the SBNMS region declined from 2010 to 2015, there was an uptick in effort from 2015 to 2016. With increasing population and real per capita incomes in the U.S., Massachusetts, and the 14-county study area adjacent to the sanctuary, pressures from party boats, charter boats, and private household boats would be expected to increase in the future. The vast majority of private boats that visit the sanctuary are 26 feet or longer. Massachusetts registrations for vessels of this size have been increasing, and with real per capita income expected to increase, the number of registered boats is likely to increase further. Additionally, gas prices, which are a fundamental factor in boating demand, have been stable and are forecasted to remain stable over the long term, supporting increased future demand for boating. However, the sportfishing participation rate of those aged 18-34 has been declining since 1980 (ASA 2016). While pressures from private boating are expected to increase in the future, it is difficult to predict exactly how recreational fishing pressures will impact SBNMS.

Commercial Fishing

Commercial fishing (Figure DP.CF.1) is a significant pressure on the natural and historic resources of SBNMS. Numerous commercial fisheries operate in the sanctuary, including scallops, Northeast multispecies (i.e., groundfish), lobster, and herring (see text box). These fisheries use a wide variety of gear types, with the most common identified in Table DP.CF.1.[7] In addition to fish species, commercial fishing also impacts populations of invertebrates, seabirds, and mammals, as well as the condition of historic resources due to incidental contact by fishing gear.

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[7] Other gear types used in the sanctuary but not in the top six are: midwater pair trawl (87 trips), tuna harpoon (55 trips), pelagic longline (10 trips), and ocean quahog dredge (8 trips). Commercial fishing for bluefin tuna with rod and reel is an important fishery in the sanctuary, but is managed separately from the Northeast multispecies fishery and therefore is not included in the Data Matching and Imputation System data.

Collaborative Fisheries Management

SBNMS does not manage fisheries in the sanctuary. Rather, it relies on three regional fishery management authorities to manage species occurring in the sanctuary. The New England Fishery Management Council (NEFMC) and the Mid-Atlantic Fisheries Management Council (MAFMC) are authorized by the Magnuson-Stevens Fisheries Conservation and Management Act; the Atlantic States Marine Fisheries Commission (ASMFC) is authorized by the Atlantic Fisheries Act of 1942 and the Atlantic Coastal Fishery Cooperative and Management Act. In addition to these three councils, NOAA Fisheries directly manages highly migratory species, such as bluefin tuna and sharks, that frequent sanctuary waters.

Species or species complexes in federal waters are managed under fishery management plans prepared by the NEFMC and MAFMC. For those species that cross jurisdictional boundaries, one of these authorities will take the lead on management plan development and coordinate implementation with the other as affected. The ASMFC prepares coastal fishery management plans for any fishery resource that moves among, or is broadly distributed across, waters under the jurisdiction of one or more states or waters under the jurisdiction of one or more states and the U.S. exclusive economic zone, which explains why some species are double listed below. The respective authority(ies) for managing fisheries for the following species, which occur in the sanctuary, is as follows:

NEFMC:

- Northeast multispecies (cod, haddock, pollock, halibut, yellowtail flounder, winter flounder, windowpane flounder, witch flounder, American plaice, white hake, ocean pout, redfish)
- monkfish
- Atlantic herring
- scallops
- skates (thorny and smooth)
- red crab
- Atlantic salmon
- whiting complex (silver hake, red hake, and offshore hake)

MAFMC:

- spiny dogfish
- Atlantic mackerel
- squid
- bluefish
- surf clam
- butterfish
- summer flounder
- black sea bass
- scup
- ocean quahog
- tilefish

ASMFC:

- American lobster
- northern shrimp
- menhaden
- tautog
- striped bass
- Atlantic sturgeon
- American eel
- bluefish
- Atlantic menhaden
- Atlantic herring
- scup
- summer flounder
- winter flounder
- black sea bass
- spiny dogfish and coastal sharks
- river herring (alewife and blueback herring)

The regulation of fishery resources in SBNMS is a collaborative process whereby sanctuary staff work within the framework of the various councils and with the Greater Atlantic Regional Fisheries Office (GARFO) to address sanctuary concerns.

Figure DP.CF.1. A bottom trawler fishes on Stellwagen Bank. Photo: NOAA

Table DP.CF.1. Top six gear types used in SBNMS based on effort (trips). Fixed gear comprised 62.9 percent and mobile gear comprised 32.7 percent. Source: GARFO 2019b

Type of Gear	Fixed or Mobile?	Number of Trips	Percent
Bottom gill net	Fixed	25,051	35.3%
Bottom trawl	Mobile	18,587	26.2%
Lobster trap	Fixed	17,002	24.0%
Scallop dredge	Mobile	4,598	6.5%
Hand line/rod and reel	N/A	3,131	4.4%
Longline, Bottom	Fixed	2,589	3.6%
	TOTAL	70,958	100.0%

Commercial fishing also provides food, an essential ecosystem service, which supports much needed employment and income in coastal communities. The section on food supply in Ecosystem Services discusses the value of commercial fishing in more detail.

SBNMS is one of the more important fishing grounds in the Gulf of Maine due to its productivity and close proximity to ports around Massachusetts and Cape Cod Bays. Figure DP.CF.2 illustrates the distribution of fishing throughout the sanctuary. The sanctuary's accessibility allows for day trips by smaller vessels (<50 feet), which are more limited geographically with respect to their fishing grounds when compared to larger vessels. The productivity of the sanctuary largely results from the persistence of forage fish such as sand lance, herring, and mackerel. The sanctuary provides a diverse array of fishery resources, allowing fishers to target different species depending on regulatory constraints and/or seasons. Larger vessels (>50 feet) that conduct multi-day trips also fish the sanctuary, but because of their greater range, are not as reliant on it as day boats.

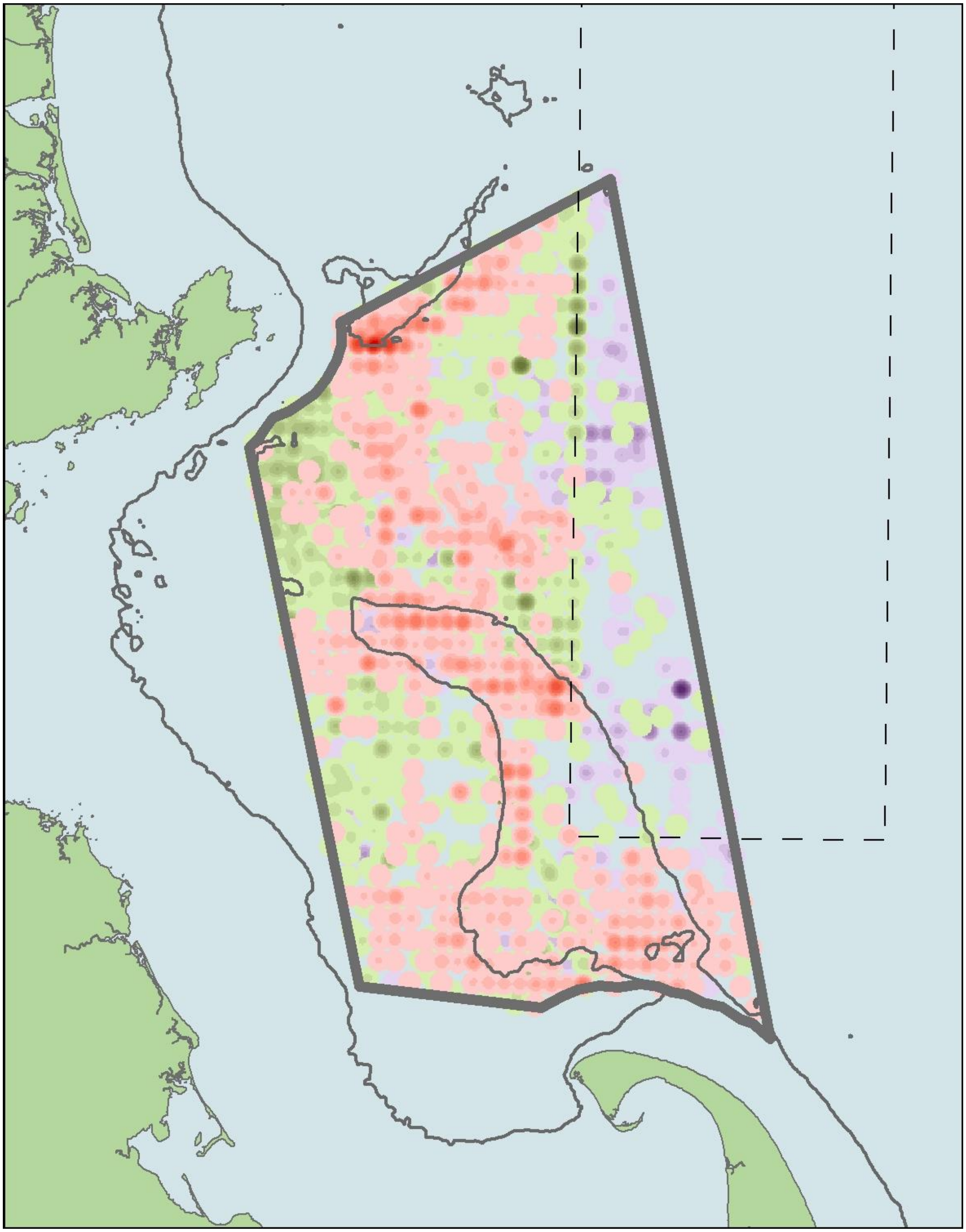


Figure DP.CF.2. Spatial distribution of commercial and recreational “for hire” fishing based on vessel trip report (VTR) data in 2016. Pink circles represent commercial, mobile bottom-tending gear, green circles represent commercial fixed gear, and purple circles represent “for hire” party and charter gear. Note: the dashed polygon represents the western Gulf of Maine habitat closed area, which overlaps 22% of SBNMS. The area of overlap is called the “sliver.” The closed area began as a groundfish closed area in 1998 and was then overlaid with a habitat closure in 2004. Bottom-tending gear (except for lobster) is prohibited within this closed area. VTR reports of gillnet gear in the overlap area are a reporting error. Source: VTR Data – 1,000 meter search radius, Jenks Natural Breaks Symbology

Landings by weight in SBNMS account for a relatively large portion of cod, yellowtail flounder, and Atlantic mackerel caught in the Gulf of Maine (see Figure DP.CF.3 for Gulf of Maine statistical areas). Around 31% of cod and 20% of Atlantic mackerel caught in the Gulf of Maine (as shown in Figure DP.CF.3) comes from SBNMS. In terms of the value of landings in SBNMS, cod account for roughly 30% of the total region's value and yellowtail flounder account for about 29% (Table DP.CF.2). In 2010, one 10 mile by 10 mile-square covering the northwest corner of SBNMS accounted for 45% of the Gulf of Maine cod landings (Richardson et al. 2014). This was due to the abundance of sand lance, preferred prey for cod.

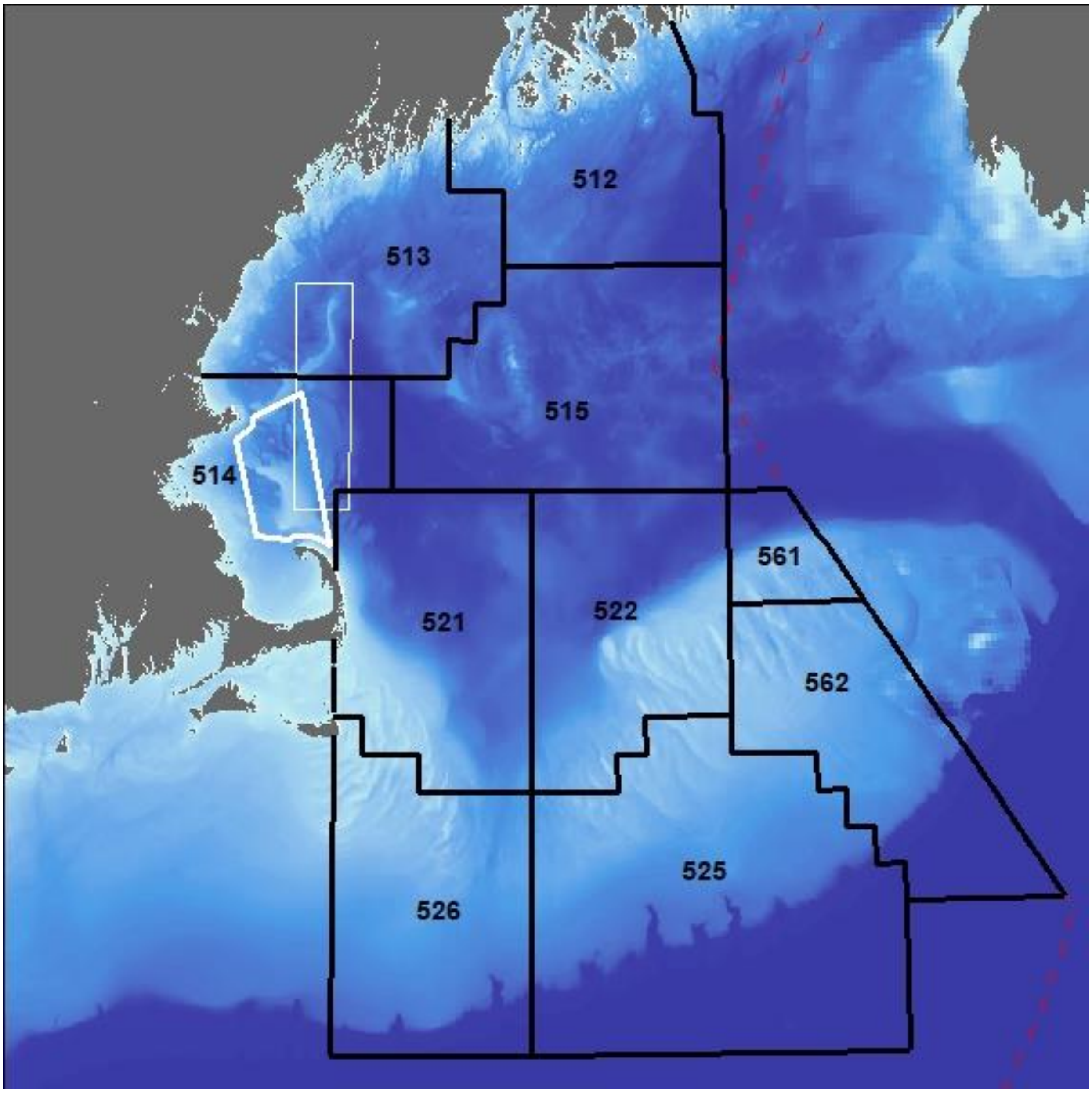


Figure DP.CF.3. NOAA Fisheries statistical areas that comprise the Gulf of Maine. The SBNMS boundary and its overlap with the Western Gulf of Maine Closure Area are shown in area 514. Image: M. Thompson/NOAA

Table DP.CF.2. Landings value for the top five species in SBNMS and as a percent of the Gulf of Maine[1], 2007–2016 Total (2017$). Source: GARFO 2017a

Species	Value in Stellwagen Bank National Marine Sanctuary	Value Landed in Gulf of Maine	Percentage of Region
Cod	$63,570,163	$211,261,718	30.1%
Lobster	$35,450,731	$631,686,228	5.6%
Sea scallop	$33,250,766	$1,865,094,849	1.8%
Yellowtail flounder	$10,514,552	$36,842,558	28.5%
Haddock	$7,579,083	$144,599,665	5.2%

1. The Gulf of Maine is defined by the statistical areas shown in Figure DP.CF.3.

Data Sources and Types

Commercial fishing in the sanctuary is characterized in this report through the use of NOAA Fisheries' Data Matching and Imputation System (DMIS) and from the NOAA Fisheries Vessel Monitoring System (VMS). These systems have different purposes; DMIS is a reporting tool, while VMS is primarily an enforcement tool.[8]

DMIS supports the region's quota monitoring programs by matching different data sources associated with a fishing trip. The three main data sources matched are vessel trip reports (VTRs), dealer reports, and trip notifications/declarations. VTR is the primary means of collecting catch data from commercial and recreational fishers. Other data sources include observer reports, species catch reports, and permit information. Since DMIS records only contain partial data information from data sources, VTR point data were added to DMIS records from 2007–2016, if points were determined to overlap with the sanctuary.

DMIS does not include data on fishers who own only a federal lobster permit or a federal highly migratory species (i.e., bluefin tuna) permit. Specifically, the highly migratory species permit categories not included in DMIS are "general category", "angling", and "charter/headboat", which make up the majority of highly migratory species permit holders. However, highly migratory species longline permit holders are required to submit VTRs and therefore are included in the DMIS data. Highly migratory species permit holders are not required to record the exact location where a tuna was caught, rather they are only required to list "area 4", a large reporting area extending from shore out to the exclusive economic zone. NOAA Fisheries does produce an annual stock assessment report for the Atlantic and Gulf of Mexico, but the data are not collected or analyzed in a way that provides estimates for specific locations, such as SBNMS. Individuals holding only a federal lobster permit do not have to submit a VTR and are therefore not included in DMIS.

VTR data are considered a reliable estimator of commercial fishing activity at the spatial scale of the sanctuary (NOAA Office of National Marine Sanctuaries 2010; see p. 147). Data were gathered and/or analyzed to document and typify the spatial distribution, landings value (ex-vessel, dockside sales paid to

[8] VMS data used in this report was treated in accordance with NOAA Administrative Order 216-100. It is the policy of the National Marine Fisheries Service not to release confidential data, other than in aggregate form, as the MSA protects the confidentiality of those submitting data.

fishers) and volume, and species composition representative of commercial fisheries in the sanctuary. Ex-vessel or landings value is the price paid to fishers upon direct sale of fish landed.

VMS data are another important data source that complement VTR data. While VTR is a reporting tool that provides catch data and a single fishing location per trip, VMS provides vessel locations while transiting and fishing. The VMS system uses specialized computers and integrated global positioning systems installed on required vessels to transmit, via satellite, the vessel's identification, location, speed, and the permit under which the vessel is operating. The advantage of VMS data is that it provides an accurate representation of the vessel's position; however, a disadvantage is that it applies to only a subset of fishing vessels in the sanctuary. For example, "for hire" recreational fishing vessels, commercial tuna vessels, and lobster vessels are not required to use VMS, unless they carry another permit with a VMS requirement (e.g., scallop or multispecies groundfish). Another disadvantage is that VMS data do not differentiate between time spent transiting and actively fishing. This report assumes that a trawl vessel moving at 4 knots or less is actively fishing and a dredge vessel moving at 5 knots or less is actively fishing (Muench et al. 2017, Palmer and Wigley 2007, 2009). Vessel locations are transmitted hourly (except for scallop vessels, which report every half hour), so vessel location between polls is unknown. At fishing speeds of 4-5 knots, and greater transit speeds, a vessel could move between 4 and 10+ nautical miles over the course of an hour, which is a relatively large distance at the scale of the sanctuary.

How has fishing changed?

Fisheries management in New England is notoriously complex due to several reasons, such as the variety of species, overfishing, intensive regulations, and conflicts between different fishing interests, for example mobile gear and fixed gear.

The regulatory landscape for commercial fishing changed dramatically over the time period analyzed in this report (2007–2018). Perhaps the most important change in fisheries management during this time was the implementation of catch shares (hereafter referred to as sector management) in the multispecies (groundfish) fishery.

Sector management was implemented on May 1, 2010 through Amendment 16 to the Northeast Multispecies Fishery Management Plan. Sector management is an output control regulatory system that allocates a portion of the total annual harvest of groundfish species to cooperatives called sectors. The total allowable catch for each fish stock can be traded or leased among sectors, creating a market-based approach to the fishery (Labaree 2012).

Prior to 2010, a variety of input controls were used to manage the multispecies fishery, such as days at sea, area closures, size limits, and gear restrictions. These input controls resulted in high rates of bycatch, which is one of several reasons why sector management was adopted. The major shift from input controls to output controls (i.e., sector management) necessitated major changes in the industry, from data collection, monitoring, and reporting protocols to fishing strategies. Fishing effort and its spatial footprint are now driven more by regulatory constraints than by fish locations.

The vessels that opted not to join a sector, approximately 46% in 2010 and 43% in 2015, remained in the "common pool" fleet and were subject to traditional input controls like days at sea (NEFSC 2018a). There are currently 16 sectors operating in New England, of which about three regularly fish in SBNMS. Sectors can fish anywhere they choose and are not geographically restricted as long as they hold a quota for all stocks in the area. While sectors account for the majority of fishing effort in the sanctuary, other types of commercial fishing are also prevalent (see description above).

Commercial Shipping

SBNMS sits at the mouth of Massachusetts Bay, which is open to commercial vessel traffic traveling to and from the Port of Boston, one of the most modern and efficient container ports in the United States. Annually, the port handles more than 1.3 million tons of general cargo, 1.5 million tons of non-fuel bulk cargo, and 12.8 million tons of bulk fuel cargo. General cargo includes consumer goods like clothes, furniture, cars, and food. As the per capita income of the SBNMS region and the USA increases, this may increase demand for consumer goods, increasing shipping and the number of vessels traversing the area.

The designated Transportation Separation Scheme (TSS; an area that is highly regulated in terms of ship navigation) for Boston passes through SBNMS in a roughly east-west direction. These designated shipping lanes are used for numerous types of domestic and foreign-flagged vessels, including container ships (some with hazardous materials), liquefied natural gas and oil tankers, and barges, as well as an increasing number of cruise liners. Automatic identification system (AIS) ship traffic data indicate that many vessels comply with the use of designated shipping lanes, however, such compliance is not mandatory; therefore, commercial vessel traffic occurs throughout the sanctuary.

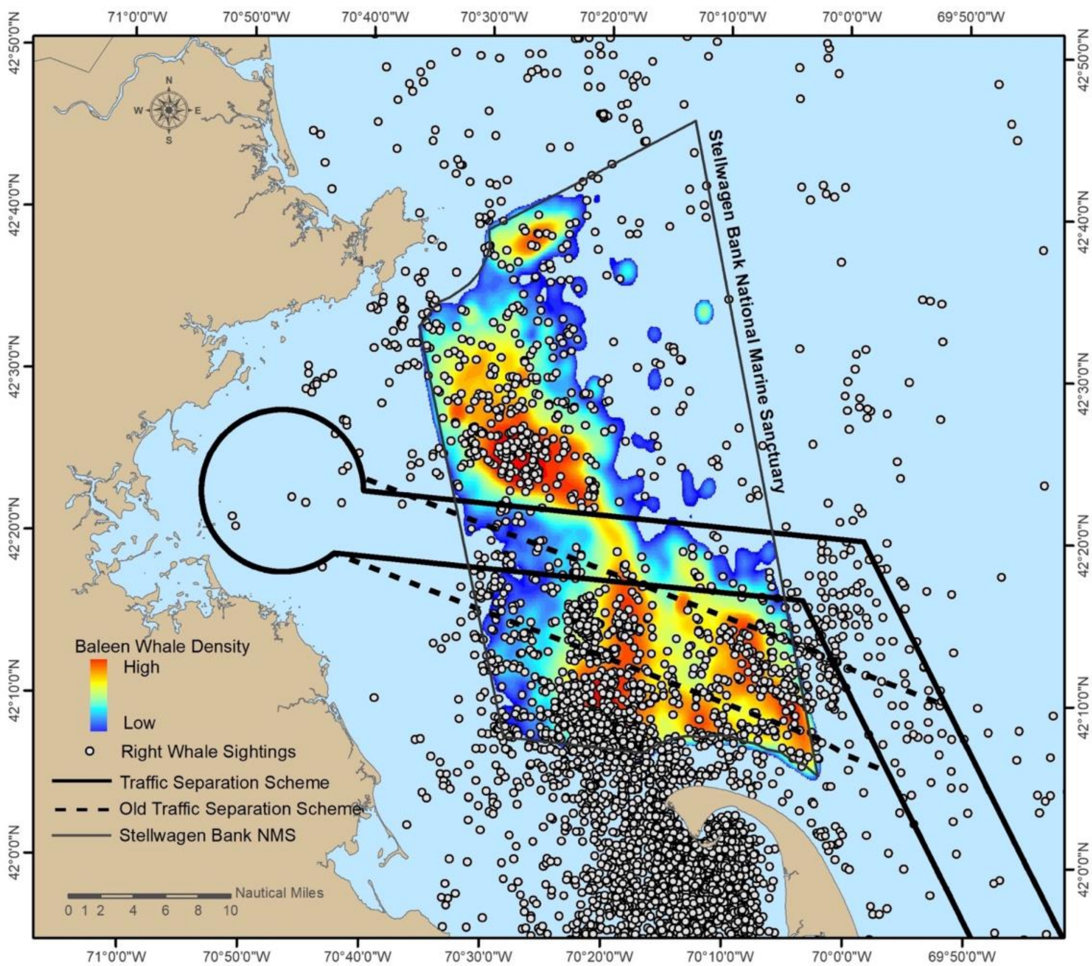


Figure DP.CS.1. Map of SBNMS and surrounding region illustrates baleen whale density within the sanctuary, right whale sightings, and original and current Boston TSS lanes. Image: M. Thompson/NOAA

The vast majority of vessel traffic through the sanctuary involves transits to and from the port of Boston, Massachusetts. Data from Massachusetts Port Authoristy show that cargo volume in the Port of Boston has increased since 2012 (Figure DP.CS.2). In 2015, the port handled 237,000 containers, 60,000 automobiles, and 121,000 metric tons of cement. Other major forms of cargo processed at the port include petroleum, liquefied natural gas, gypsum, and salt. In 2015, 328,305 cruise ship passengers passed through Boston, and approximately 114 vessel calls were scheduled for the 2016 cruise season.

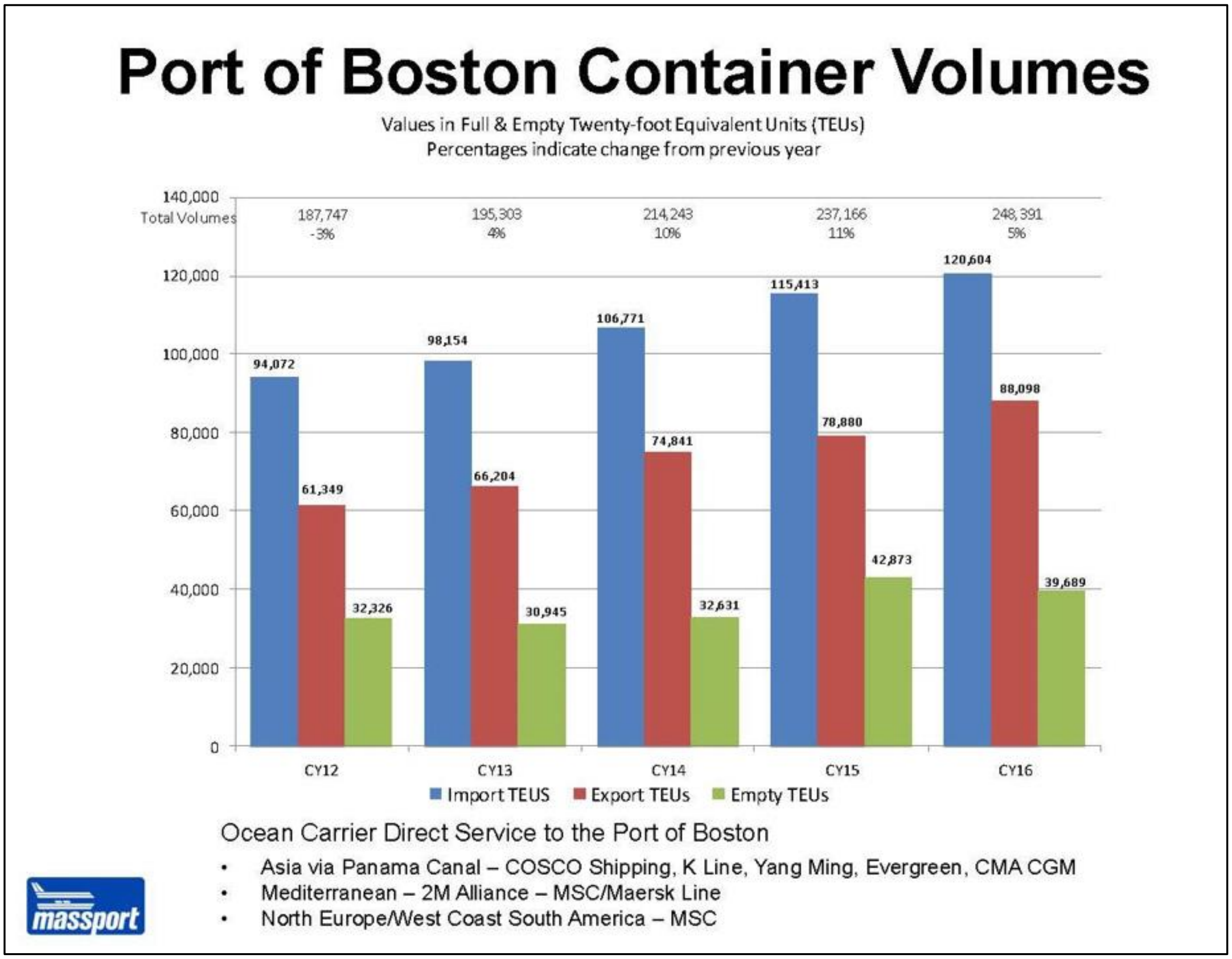


Figure DP.CS.2. Volume of cargo (in twenty-foot equivalent units, or TEUs) shipped through the Port of Boston, 2013–2017. Image: Massport 2019

Boston's Conley Terminal is the only full-service container facility in New England, and the port is responsible for $4.6 billion dollars of economic activity and 7,000 direct jobs. In 2016, the Conley Terminal experienced record growth (a double-digit increase in imports and exports), including a visit by the 1,100-foot COSCO Container Ship *Xin Mel Zhou*, the largest ship ever to service the port. The enlargement of the Panama Canal to allow passage by larger vessels [~8,500 twenty-foot equivalent units (TEUs), "post-Panamax" vessels] will potentially result in larger and possibly faster vessels crossing the sanctuary to the port. The Conley Terminal is currently built to accommodate ships from 4,000–6,000 TEUs, and work is underway to improve the port to provide access to larger "post-Panamax" vessels. Shipping companies indicate they will be using ships capable of carrying 10,000–12,000 TEUs in the future. In 2016, the port received a grant of $42 million from the U.S. Department of Transportation and $107.5 million from the State of Massachusetts for port improvement to accommodate larger ships.

Impacts from commercial vessels include pollutant discharges, introduction of contaminants and invasive species that may be released in or near the sanctuary in ballast water, noise disturbance, and whale strikes.

Large, ocean-going commercial traffic (e.g., container ships, tankers, cruise ships, etc.) produce low-frequency noise through cavitation (the bursting of bubbles from their propellers), as well as other on-board sources (e.g., machinery) (Richardson et al. 1995). Large vessels transit the sanctuary regularly through the TSS lanes to access the Port of Boston (Figure DP.CS.3). Additional vessel types in the sanctuary are typically seasonally prolific, including smaller and more regional commercial, recreational, military, and research vessels. Smaller vessel types usually produce reduced sound levels (measured as energy or pressure) and higher frequency noise (Richardson et al. 1995). However, seasonal concentrations of smaller vessels can result in significant potential for disturbance of resident marine mammal and seabird species, including disruption of feeding, communication, mating, and predator avoidance (e.g., McKenna et al. 2017).

SBNMS conducted research into the relative abundance and distribution of ships and whales in the TSS, and in 2007 worked with the Boston Port Operators Group, Massachusetts Port Authority, U.S. Coast Guard, NOAA Fisheries, and the International Maritime Organization (IMO) to move the TSS lane that crosses the sanctuary. Shifting of the TSS lane (Figure DP.CS.1) was designed to reduce the co-occurrence of baleen whales and ships transiting the sanctuary. When compared to the original route, the realigned TSS lane contained 81% fewer baleen whale sightings and 58% fewer right whale sightings (Wiley et al. 2013). The TSS shift became active in July of 2007 and SBNMS AIS monitoring indicates mariner compliance is near 100%.

In addition to vessel location, ship speed is an important element of ship strike risk. In 2008, NOAA Fisheries published a “Final rule to implement speed restrictions to reduce the threat of ship collisions with North Atlantic right whales” (Federal Register 2008). This rule requires that vessels 65 feet or greater in length travel at 10 knots or less during times and in areas of historic right whale aggregations. These areas are known as seasonal management areas, two of which overlap portions of SBNMS.

Figure DP.CS.3. Commercial vessel transiting the sanctuary and humpback whales. Photo: NOAA/Whale Center of New England

The number of ships in the sanctuary is driven by the demand for imports and exports. Demand from the European Union, Canada, China, Japan, and South Korea is the main driver of exports. Given that GDP in those countries is expected to grow, as is the U.S. population and real per capita income, this pressure is likely to continue.

Liquefied Natural Gas Deepwater Ports

A deepwater liquefied natural gas (LNG) port is a system of pipelines, mooring buoys, anchors, risers, and related equipment that is regulated under the Deepwater Port Act (DWPA) and administered by the U.S. Coast Guard and the Maritime Administration. Two LNG deepwater ports, one owned by Northeast Gateway and the other by Neptune LNG LLC, were installed adjacent to the western boundary of SBNMS in 2008 and 2009, respectively. Based on information provided by the U.S. Coast Guard and the Maritime Administration, ONMS found that the projects, considered individually and together were likely to have significant, constant, and long-term adverse effects upon sanctuary resources because of: 1) increased risk of ship strikes to the sanctuary's endangered whale populations, including the North Atlantic right whale; 2) increased acoustic exposure to marine mammal and fish species; 3) increased risk of whale entanglement and loss of benthic habitat in the sanctuary due to displaced fishing effort; 4) possible re-suspension of toxic materials during construction; 5) diminished visual aesthetics; and 6) entrainment of planktonic and fishery resources by LNG carriers at port and during transit. During consultation with the primary agencies, ONMS made recommendations to mitigate potential impacts on marine mammals, including installation of a passive acoustic monitoring system to detect the presence of marine mammals. The two ports were subsequently licensed in 2007, and operations began in 2008 and 2009.

By 2016, the two ports had hardly been used as a consequence of increased land-based, domestic production of natural gas. Consequently, Neptune requested permission to decommission its port in 2016; however, decommissioning has neither been approved nor commenced. Northeast Gateway has kept its port operational, which includes the continued operation of the 10 right whale listening buoys that bisect the sanctuary in the TSS.

Outfall Discharges and Dump Sites

Municipal Waste Discharges

Massachusetts Bay and Cape Cod Bay have historically received inputs of municipal waste in the form of effluent or sludge from numerous pipes extending from municipal wastewater treatment plants along the coast of Massachusetts. These discharges into Boston Harbor, combined with sewer outfalls, were once considered to be the greatest point sources of contaminants, such as metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and nutrients, to the Massachusetts Bay area (Hunt et al. 2006). Improved treatment and pre-treatment methods and technologies have helped to dramatically lessen the quantity of pollutants discharged into the Massachusetts Bay and Cape Cod Bay systems (Werme et al. 2017, Libby et al. 2017). However, as the population of the area is expected to increase, so too will the amount of waste. This could put additional pressures on SBNMS if technologies and infrastructure do not develop at a pace consistent with the population.

The Massachusetts Water Resources Authority (MWRA) wastewater treatment plant on Deer Island, completed in 2000, provides effective, secondary treatment of wastewater and has eliminated the discharge of sludge into coastal waters. The ocean outfall for this facility is located approximately 23.12 kilometers (12.48 nautical miles) from the western boundary of SBNMS (Figure DP.OD.1). Long-term average flow from the outfall is 350 million gallons per day of treated secondary wastewater (MWRA 2018). In a dry year like 2016, annual average flow can drop to 281 million gallons per day (Werme et al. 2017). Potential stressors from the outfall or other point and non-point sources of pollution include eutrophication, discharge of toxic chemicals, and discharge of agents that alter biological processes (e.g., endocrine disruptors) (Libby et al. 2017, Werme et al. 2017).

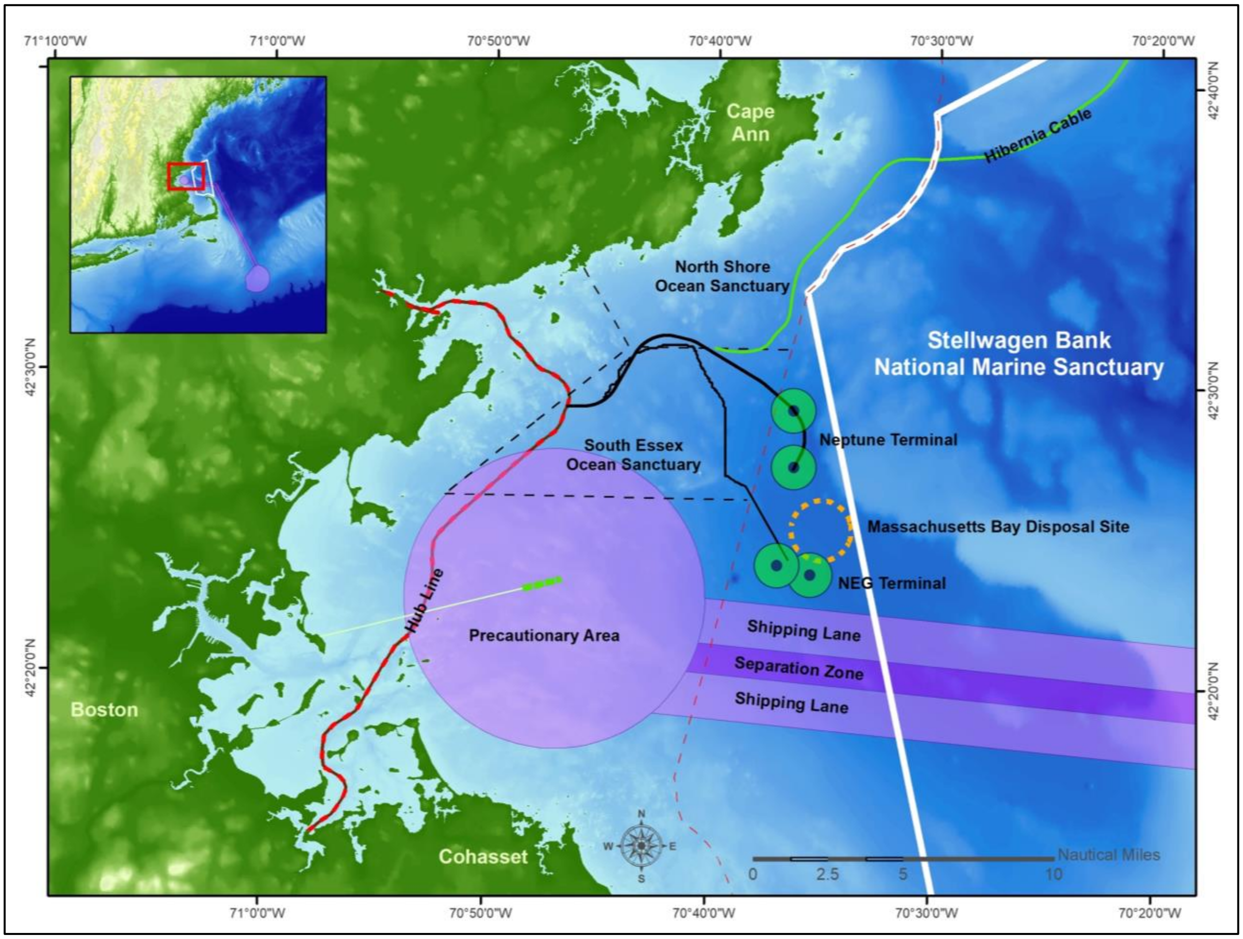


Figure DP.OD.1. Location of sewer outfalls, the MWRA outfall, industrial discharge sites, LNG deepwater port sites, which are connected to the HubLine gas pipeline, and dumping/disposal sites within Massachusetts Bay. Image: NOAA Office of National Marine Sanctuaries 2010

Massachusetts Bay Disposal Site

The Massachusetts Bay Disposal Site (MBDS) receives dredged material that is deemed suitable for open water disposal. The MBDS is located directly adjacent to the western boundary of the sanctuary in Stellwagen Basin and encompasses an area of two nautical miles in diameter (Figure DP.OD.1). Only materials considered by the U.S. Army Corps of Engineers (USACE) and the U.S. Environmental Protection Agency (EPA) to be relatively free of hazardous substances are eligible for disposal at this site. Known hazardous and radioactive materials were dumped in and around this site in the 1940s and 1950s (Wiley et al. 1991). This site incorporates the areas of two historic disposal sites: the Industrial Waste Site (IWS), an area once authorized for the disposal of toxic, hazardous and radioactive materials in barrels, and the Interim MBDS (also known as the Foul Area Disposal Site), designated only for the disposal of dredged materials. The proximity of the dump site to the sanctuary generated concern that previously-dumped toxic materials might be leaking and potentially impacting sanctuary habitats. However, in 1993, the EPA and NOAA concluded that the MBDS would not threaten resources within the sanctuary, and subsequent assessments have not shown any contamination (Sturdivant and Carey 2017, USACE 2015).

In 2017, USACE began maintenance dredging of Boston Harbor, which will generate approximately 1 million cubic yards of dredged material suitable for ocean disposal. After completion of maintenance dredging, USACE will initiate the Boston Harbor Deep Draft Navigation Project to allow for the passage of larger cargo vessels. This project will generate approximately 11 million cubic yards of suitable dredged material, which will be deposited in the MBDS. The EPA and USACE are proposing to use this dredged material to create a protective cover over the IWS barrel field. This is intended to sequester any contaminants and to reduce the risk of contaminants from historic disposal entering the food web of Massachusetts Bay (USACE 2015, U.S. EPA 2017).

Submarine Cables and Pipelines

There is only one submerged cable in the sanctuary. The Hibernia Atlantic cable is a 12,200 kilometer private fiber-optic submarine cable system in the North Atlantic Ocean, connecting Canada, the United States, Ireland, and the United Kingdom (Figure DP.SCP.1). It was installed in 2000 and has a life expectancy of 25 years.[9]

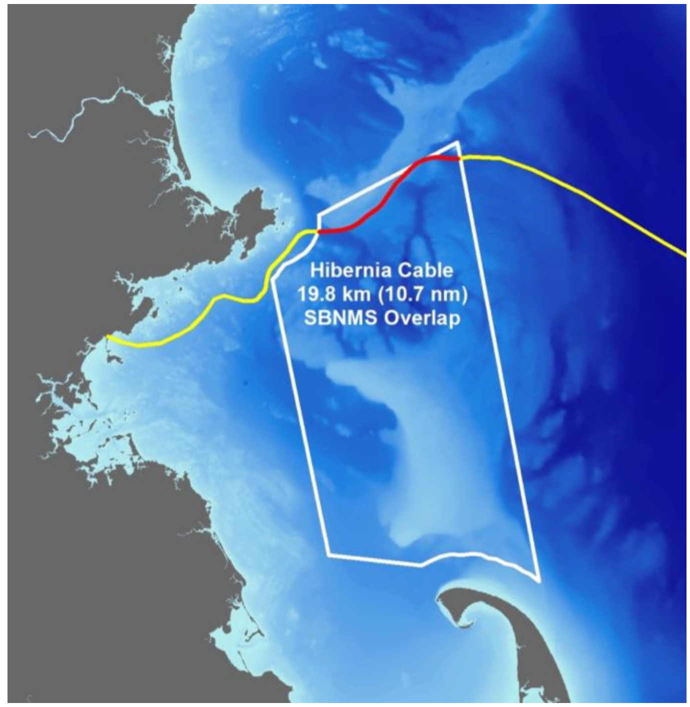


Figure DP.SCP.1. Location of the Hibernia Atlantic Cable in SBNMS. Image: M. Thompson/NOAA

Potential impacts from cable or pipeline installation include habitat disturbance, post-installation mechanical impacts, and exposure to the electromagnetic field of the cable. Current cable installation methods are similar to those used for the Hibernia Atlantic cable: trenching to an intended burial depth of 1.5-2.0 meters or covering with rock or other materials if burial is not possible. Habitat disturbance impacts depend in part on the sediment types along the cable route and whether or not the cable can be buried. Monitoring of the Hibernia Atlantic cable route indicated that while there was minimal long-term impact to infauna and epifauna communities along the cable route, sedimentary processes did not return the trench and local seabed area to pre-existing conditions (Auster et al. 2013b). Extensive portions of the fiber-optic cable were exposed immediately following installation (complete burial had been the goal), and 10 years after installation, the trench along the cable pathway was still identifiable in sidescan sonar along most of the route. Research from Australia (Sherwood et al. 2016) found limited impacts to community composition or biomass along a cable route, and concluded that electromagnetic fields from high voltage-direct current cables pose little to no risk to marine life.

It is important to consider potential future impacts of submarine cables on sanctuary resources, as SBNMS has and may continue to receive future applications to construct cables in the sanctuary, and impacts from other submarine cable operations may not be as benign as the Hibernia Atlantic cable.

[9] Per the ONMS permit, the cable's disposition at the end of its service will be determined after consultation between the cable owner and NOAA.

Climate Change

Climate change was identified as an emerging threat in the 2007 condition report. Potential impacts from climate change are now better understood, and data suggest a wide range of impacts to the Gulf of Maine and SBNMS (Hare et al. 2016, Dupigny-Giroux et al. 2018). Most notably, the Gulf of Maine has experienced dramatic warming in the last decade (0.23 degrees Celsius per year) and was identified as one of the fastest warming areas in the global ocean (Pershing et al. 2015). Global and regional impacts of climate change include sea-level rise and coastal erosion, increased flooding, altered patterns of precipitation and runoff, altered storm frequency and intensity, alteration to currents, higher surface and deep-water temperatures, and increased carbon dioxide inputs resulting in ocean acidification. Because biological processes in the ocean are closely tied to physical properties, climate change is causing a variety of biotic responses within ocean and coastal ecosystems, including changes in the ability to maintain and increase biodiversity. Changes in species range, distribution, and phenology (timing of natural events) are strongly predicted to lead to increases in resource mismatches (mismatches in food and habitat resources) and other ecological disruptions. As species follow environmental optima in response to climate change, novel species are increasingly likely to occupy the sanctuary, potentially altering community structure and ecosystem functions (Lipton et al. 2018, Reidmiller et al. 2018). Non-native and invasive species are also expected to increase in prevalence (Reidmiller et al. 2018, Grieve et al. 2016, Sorte 2014).

The accelerated warming experienced by the Gulf of Maine over the last decade was attributed to a northward shift in the Gulf Stream and associated eddy currents (Pershing et al. 2015, Dupigny-Giroux et al. 2018). Warming is occurring during all seasons, with the fastest rates occurring in summer (Thomas et al. 2017). The duration of summer sea-surface temperatures has expanded by two days per year (Dupigny-Giroux et al. 2018). Warming waters have negatively impacted the Gulf of Maine ecosystem in several ways, from declines in primary prey species (such as copepods) to shifting distributions of valuable commercial fish stocks (including American lobster and Atlantic cod), marine mammals, seabirds, and sea turtles, as well as changes in sessile seafloor communities. Such community shifts have already resulted in and will continue to result in socioeconomic stress in New England (Dupigny-Giroux et al. 2018, Lucey and Nye 2010).

Ocean acidification is caused by absorption of increasing amounts of atmospheric carbon dioxide by the ocean. Impacts in SBNMS from ocean acidification are likely to manifest first in animals and plants with calcium carbonate skeletons or shells, including calcareous larval fishes and plankton, copepods, shellfishes, sea stars, sea urchins, and crustaceans. Effects may include larval mortality and diminished recruitment, shell thinning, reduced growth rates and reproduction, and increased stress and susceptibility to disease. Some affected planktonic species form the base of the food web, and shifts in the abundance of these species could have cascading and devastating impacts for consumers at higher levels, including humans. Ekstrom et al. (2015) predicted that coastal and oceanic waters of the northeastern U.S. and western Atlantic Ocean will exhibit measurable increases in ocean acidification by 2030. They also indicated that Massachusetts's commercial and recreational shellfisheries are highly vulnerable to ocean acidification, and as a result, businesses and communities will be forced to adapt to changing resource availability.

Sea level has already risen by ~1 foot since the early 1900s and is predicted to rise 2 to 4.5 feet by 2100 in the northeastern U.S., including the Gulf of Maine (Dupigny-Giroux et al. 2018). This could cause saltwater to enter historically freshwater coastal areas, destroying critical nursery areas and coastal infrastructure. Impacts from high waves and storm surge will also increase, as will the frequency and impacts of nuisance flooding and erosion. Natural resources at risk include intertidal shellfish, fishes, sea turtles, marine mammals, and shore, sea, and terrestrial birds, although vulnerabilities vary and still remain largely uncertain (Powell et al. 2017). Coastal communities, businesses, Native American cultural and maritime heritage resources, and some of the sanctuary's operational facilities and assets may also be affected.

STATE OF DRIVERS AND PRESSURES

Below are answers to questions related specifically to the drivers and pressures discussed above. The status and trends of sanctuary resources are addressed in the next section.

Driver Rating (Question 1)

Driving forces help to explain the origins of pressures on resources and potentially estimate the future trends of those pressures. More specifically, drivers help to illustrate the direction and magnitude of demand for different ecosystem goods and services. Drivers include societal values, demographics, and economic factors that result in pressures on the resources. Societal values may include levels of conservation awareness, political leanings, or changing opinions about the acceptability of specific behaviors (e.g., littering, fishing). Societal values inform preferences that determine the demand and supply of all goods and services humans consume. Drivers reflect the relationship between the demand and supply of goods and services humans consume. This economic activity leads to relevant pressures of that activity on sanctuary natural and cultural resources. That said, the remaining demographic and economic factors (i.e., income) that comprise these drivers shed light on the extent to which consumers can actually realize or express their preferences in markets for ecosystem goods and services.

Other driving forces may include specific changes in the demographics of an area (age structure, population, etc.), demand for ocean products, economic situations, industrial development patterns, or business trends. An overall rating for the status and trends of drivers is made in the following question (Question 1).

1. What are the states of influential human drivers and how are they changing?

Status Description: Selected drivers are influencing pressures in ways that result in severe impacts that are either widespread or persistent.

Rationale: Increasing demand at multiple scales for food, ocean transportation, and recreation, influenced heavily by population growth and increasing income, enhances commercial and recreational activities with adverse impacts that include habitat damage, entanglement, ship strikes, noise, and contaminant discharges.

The most influential drivers of pressures impacting sanctuary resources are:

- Demand for seafood
- Demand for other imported and exported goods via water transport
- Demand for recreation (e.g., boating, whale watching, fishing)

These are referred to as primary drivers, which exert pressures that directly impact sanctuary resources.

Secondary drivers operate further from SBNMS (offshore or inland) and may indirectly exert pressures on sanctuary resources. Secondary drivers include:

- Demand for local development (e.g., housing, transportation, personal services, education, and sewage/waste disposal)
- Demand for energy and communication (e.g., cables and pipelines)

The primary indicators used to understand past and future trends are presented in the drivers section above. They are reviewed again here.

- Population and real per capita income (adjusted for inflation) in the U.S., Massachusetts, and the 14-county study area (where most of the socioeconomic impacts and contributions from SBNMS resources occur) have been increasing and are expected to continue increasing. These indicators are related to all of the primary and secondary drivers, as an increase in population and income would be expected to lead to increasing demand, all else being equal (Appendix E: Figure App.E.1 and Figure App.E.2).
- The standard of living in the 14 counties adjacent to the sanctuary has increased faster than the rest of the U.S. between 2000 and 2015. Between 2015 and 2030, average annual real per capita income is projected to increase in the country, state of Massachusetts, and the 14-county study area (Woods and Poole Economics, Inc. 2016, Appendix E: Table App.E.3 and Figure App.E.3).

As explained in the drivers section, population and real per capita income are key influences behind the demand for commercial seafood products, recreational fishing, boating, and non-consumptive recreation (e.g., whale watching and other wildlife observation). These activities increase noise through commercial cargo vessel traffic, commercial fishing vessels, and recreational boating activity. The increased demand for these goods and services also leads to pressures on fish stocks, vessel strikes, entanglement in commercial fishing gear, and habitat destruction from various fishing methods that disturb bottom habitats. Vessel discharges also lead to pressures from pollutants and introduction of invasive species via bilge water discharges. Increased commercial vessel traffic leads to the demand for harbor dredging and dredge disposal. Population and real per capita income are also key drivers behind the demand for seabed cable services (e.g., telecommunications and energy). Increasing population size and real per capita income may lead to future development projects that alter and could impact sanctuary habitats.

General pressures resulting in habitat destruction and pollution via development and wastewater are also driven by population and real per capita income.

- The real (adjusted for inflation) GDP of Canada, the European Union, China, Japan, and South Korea are indicators of demand for imported and exported goods via water transport through the Port of Boston, as well as the demand for seafood. Because the species caught in SBNMS fall into the category of species heavily imported by these countries, a real GDP increase in these countries increases demand for all goods, including, for example, seafood and other fishery products from SBNMS. Any increase in demand for commercial seafood also places additional pressures on fish stocks and potentially results in increased prices, given managed fishery (seafood) supply is often capped. In addition, higher exports of other goods increase vessel traffic at ports and harbors. As stated above, the real GDP in all the countries listed here increased, but the rate of increase is expected to slow from 2018 to 2022 (Trading Economics 2017, Appendix

E: Table App.E.4). Still, the trend in GDP is likely to result in continued demand for products from SBNMS.

GDP of foreign countries also drives demand for commercial vessel traffic via the export of goods and services through local ports. Noise from both commercial vessel traffic and commercial fishing boats changes accordingly. Entanglements and habitat destruction from commercial fishing gear are also driven by demand for seafood products from these countries. Additionally, more commercial vessel traffic requires harbor development, dredging, waste disposal, and increases the risk of invasive species introductions via bilge water discharges.

- The price of fuel is a reliable indicator of the demand for recreational boating. Because it also affects the cost of research and exploration, it is also a reliable indicator of the willingness of oil and gasoline producers to invest in exploration and drilling near SBNMS. Gasoline prices declined between 2012 and 2017 (U.S. Energy Information Administration 2017, Appendix E: Figure App.E.4), resulting in increased visitation to SBNMS. The price of gasoline may reduce the willingness of producers to invest in exploration and drilling in and around the sanctuary, as the costs of research and exploration may be prohibitive. This reduces profits to the oil and gas industry and the pressures related to development, including pollution, habitat destruction, and noise.

Recreational boating and commercial vessel traffic can result in discharge of pollutants, noise, and whale strikes, with consequences for whale health and survival, whale and fish feeding, and fish spawning behaviors. Commercial fishing has additional impacts, such as habitat destruction, marine mammal entanglement, bycatch, reductions in biomass and wider ecological impacts, damage to shipwrecks (cultural resources), and discharge of pollutants. Although question 2 (human activities impacting water quality) is rated as "good/fair," the rating for question 4 (human activities impacting living marine resources) is "fair/poor," and the rating for question 5 (human activities impacting maritime heritage resources) is "poor." Due to the predominance, breadth, and persistence of the effects of the drivers on living marine resources, the rating across all drivers is "fair/poor" with a "worsening" trend.

Pressure Ratings (Questions 2–5)

Questions 2–5 address pressures and their potential effects on sanctuary resources. Human activities that adversely impact water quality are the focus of Question 2. These include terrestrial point source discharges, commercial and recreational vessel-based activities, fishing activities, coastal development, and the Massachusetts Bay Disposal Site (MBDS).

Question 3 covers human activities that may adversely influence habitats. Human activities often have structural impacts (e.g., removal or mechanical alteration) to habitats. Fishing activities that physically disrupt the seafloor (e.g., trawls and dredges), anchoring, commercial dredging, and pipe and cable installation are described as resulting in structural impacts.

Human activities that have the potential to negatively impact living resources are the focus of Question 4. These include activities that remove plants or animals as well as activities that have the potential to injure or degrade the condition of living resources. Activities that can facilitate the introduction or spread of non-indigenous species are also relevant to this question.

Activities that influence maritime heritage resource quality are the subject of Question 5. These include activities that diminish resource quality through intentional or inadvertent destruction. Importantly, and unlike most natural resources, maritime archaeological resources are non-renewable. Once degraded or destroyed, their archaeological value is lost forever.

2. What are the levels of human activities that may adversely influence water quality and how are they changing?

Status Description: Some potentially harmful activities exist, but they have not been shown to degrade water quality.

Rationale: Several human activities have the potential to adversely influence water quality, but generally do not seem to be doing so. Potential activities of concern include the Massachusetts Water Resources Authority (MWRA) outfall and other effluent discharges, vessel discharges, ballast water discharges, disposal of dredged material, resuspension of sediments from bottom-contact fishing gear, and airborne industrial discharges.

In the 2007 SBNMS condition report, this question was rated "good/fair" and "not changing." Since then, levels of human activity within and around the sanctuary have evolved commensurate with regional growth and increasing stakeholder demand. The cumulative impacts of multiple anthropogenic activities, such as shipping, bottom trawling, changing land use within the watershed and airshed, cable and pipe laying, and sediment disposal, have the potential to impact SBNMS water quality. These activities generally do not seem, nor have they seemed since the timing of the previous condition report, to be adversely influencing water quality; therefore, this question is still rated "good/fair" (medium confidence). However, as the availability of data on many of these human activities is limited, the trend rating is now “undetermined” (medium confidence).

Terrestrial point source discharges, such as wastewater or industrial discharges, have the potential to influence regional water quality by contributing variable loads of nutrients or pollutants. Effluent discharge from the Deer Island Wastewater Treatment Plant, the largest effluent contributor in the region, has not significantly changed over time, with observed effluent volumes strongly correlating to rainfall (Figure S.WQ.9.1). Importantly, an increased proportion of effluent receives maximum possible treatment before discharge compared to the initial years of outfall operation from 1999–2006 (Werme et al. 2017). Continued monitoring of key water quality parameters suggests the MWRA outfall is not adversely influencing monitored water quality parameters in the sanctuary. Non-point source inputs derived from river or stormwater sources could potentially have adverse impacts on water quality, but require further monitoring and evaluation. The influence and impact of the Merrimack River may have particular relevance to sanctuary water quality, as it is the source of one of the largest volumes of riverine discharge in close proximity to the northern boundary of the sanctuary.

Both point and non-point sources of pollution are land-based, and relate to land use and human development patterns. Analysis of land development in Massachusetts from 2005–2013 suggests eastern Massachusetts continues to experience high rates of land development, with the highest rates of development occurring around the I-495 belt. This belt of increasing development encompasses significant land area within watersheds that drain into coastal bays and greater Massachusetts Bay (Woods and Poole Economics, Inc. 2016, Appendix E; Lautzenheiser et al. 2014), yet explicit relationships between the rate and extent of coastal land development and sanctuary water quality are unclear.

Airborne industrial discharges that travel offshore into the sanctuary may also be of concern, but little is known about the potential of these airborne discharges to adversely influence sanctuary water quality.

There is significant commercial and recreational vessel traffic in the sanctuary, and associated vessel discharges have some potential to influence water quality (Figure S.P.2.1). However, there is limited data available to suggest that vessel discharges are causing significant adverse impacts to water quality.

The 2010 SBNMS management plan estimated an average of 2,257 transits by deep draft commercial vessels annually. Preliminary processing of fiscal year 2017 Boston Harbor pilot data suggests a total of 1,182 total transits. This rudimentary comparison may indicate reduced commercial shipping and associated discharges in 2017 compared to previous years. While there is also potential for ballast water discharges from vessels to impact water quality, it is considered unlikely that the amount of ballast water discharged in the sanctuary could result in significant water quality concerns, but this may merit further evaluation.

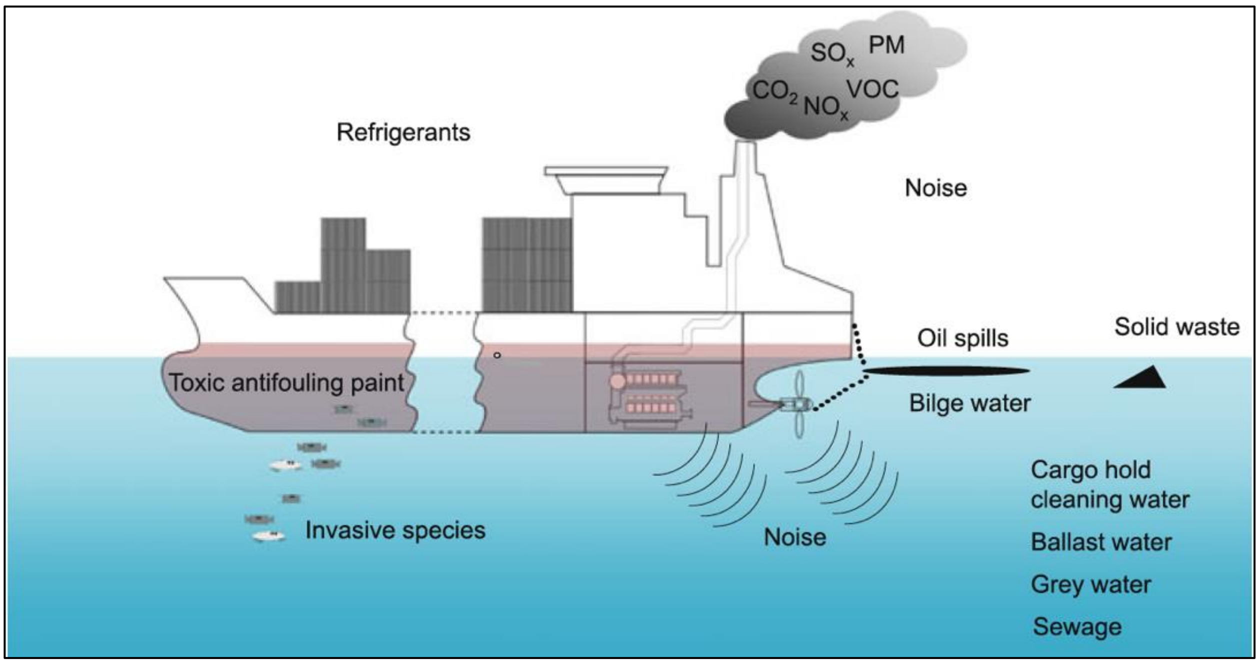


Figure S.P.2.1. Large vessels may impact water and habitat quality via a number of different discharges or activities. Image: Andersson et al. 2016

Commercial fishing data suggest the number of vessels operating in SBNMS has varied from year to year between 2007 and 2016. However, when looking at the trend of commercial fishing vessels operating in SBNMS between 2007 and 2016, the number of boats has remained fairly constant, with a possible increase in the number of vessels over 70 feet in length. Fishing vessels can also impact water quality via trawling activities that resuspend soft sediments and associated nutrients or contaminants, increase turbidity in bottom water habitats, or alter the nepheloid layer (Churchill 1989, Martín et al. 2014). Sediment trap observations within the Gulf of Maine indicate that trawl activity significantly perturbs and resuspends sediment and benthic organisms, but no information is available regarding whether potential remobilization is more than a local, short-term phenomenon within the sanctuary's benthic environments (Pilskaln et al. 1998).

The use of a dredged material disposal site in Massachusetts Bay (MBDS) will increase with the planned deepening of the Port of Boston, but all material to be deposited within the MBDS must be deemed suitable for unconfined, open-water disposal. The disposal strategy proposes to further bury historically-deposited hazardous materials using dredged material and entails no significant perturbation or resuspension of contaminated sediments (Butman et al. 1992, USACE 2015). Extensive testing of the disposal strategy, along with hydrographic modeling, suggests this activity will not have an impact on local or regional water quality and will not result in contaminant introduction.

3. What are the levels of human activities that may adversely influence habitats and how are they changing?

Status Description[10]: Selected activities have caused measurable resource impacts, but effects are localized and not widespread or persistent.

Rationale: Some activities, such as the use of mobile gear and anthropogenic noise, are of particular concern, as they can alter structural characteristics of habitat. Other activities that occur, but result in more localized habitat disturbance, include the dumping of dredged material adjacent to the sanctuary and submarine cable installation.

The 2007 rating for this question was "fair/poor" and "declining." According to the expert panel for this report, some activities, such as the use of fixed gear and human activities resulting in noise, are of particular concern to the sanctuary habitat, however, there are efforts underway to monitor and mitigate these continuing threats. Data availability across all activities is generally limited. Since 2014, NOAA Fisheries has implemented effort reductions, vertical line reductions, requirements for weaker links on lines, and other management measures to reduce the risk of serious injury and mortality of large whales due to entanglement.

Human activities can impact the structural (physical), biological, oceanographic, acoustic, and/or chemical characteristics of the habitat. Structural impacts, such as removal or mechanical alteration of habitat, can result from various fishing methods (e.g., trawls, traps, dredges, longlines, and even hook-and-line in some habitats), dredging of channels and harbors, dumping dredged material, anchoring, laying pipelines and cables, and installing offshore structures. Removal or alteration of critical biological components of habitats can occur due to several of the above activities, including bottom trawling that is ongoing and relatively widespread. The Swept Area Seabed Impact (SASI) method for analyzing the effects of fishing was applied by the New England Fishery Management Council (NEFMC) Habitat Plan Development Team using susceptibility and recovery scores assigned individually for each combination of habitat and gear type, for physical habitats and their associated benthic communities. The primary assumption of SASI is that the area over which trawling gear is applied, when adjusted for gear contact

[10] The status rating for this question was changed from "undetermined" to "fair." The expert workshop participants recommended an undetermined rating primarily due to the lack of vessel monitoring system (VMS) data. Staff have subsequently acquired and analyzed VMS data. The data show that these impacts, in combination with other impacts such as noise and vertical lines from trap fishing, warrant the rating of "fair" for the status of sanctuary habitats, which include the seafloor and water column.

with the seabed, is a proxy for seabed impact. Further, seabed impact, as modified to account for the vulnerability of habitat features encountered, is taken as a suitable proxy for the adverse effects of fishing on fish habitat. It is unclear how adverse effects from trawling are currently impacting SBNMS water quality and contaminant levels, or how this may be changing over time (Pittman 2019).

Changes in water circulation and quality often occur when channels are dredged, or the system is altered by changing frequency and intensity of coastal storms. Alterations in circulation can lead to changes in transport of planktonic prey, waste removal, water quality (e.g., salinity, clarity, and sedimentation), recruitment patterns, and a host of other ecological processes. Chemical alterations most commonly occur from ocean discharges of wastewater, spills, other point and non-point source discharge from vessels or adjacent land areas, and river inputs to the sanctuary. Airborne contaminants can also be a source of pollutant input. All of these sources can have both acute and chronic impacts. Many of these human activities can be controlled through management actions in order to limit their impact on protected resources.

For SBNMS, one of the primary focuses of habitat quality is the assessment of benthic habitats. Of the many human activities that are conducted within the sanctuary, only a few have the potential to adversely influence benthic habitat quality.

The use of trawls and dredges in commercial fishing is considered one of the primary activities that adversely influence benthic habitat integrity. Much of the potential disturbance from towing gear across the seabed is generated during the first pass of the gear (Cook et al. 2013, Ocean Studies Board 2002), but disturbance may be chronic if the area is subjected to multiple tows of such gear over time. While trawling and dredging is legally allowed in 78% of the sanctuary, not all of this area is suitable for mobile gear due to bottom roughness such as boulder reefs, steep slopes, or obstructions such as shipwrecks. Figures S.P.3.1 and S.P.3.2 depict areas where mobile bottom-tending gear have impacted the seabed over the past 10 years. Commercial fishing with fixed gear (e.g., traps and sink gillnets) can also impact benthic habitat integrity (Grabowski et al. 2014), but is considered somewhat less of a concern because the footprint of the impacted area is smaller.

VMS data provide the most accurate spatial representation of some types of commercial fishing effort. VMS data from 2009–2018 were analyzed to better understand commercial fishing effort in SBNMS. Data from each year were categorized by gear type based on gear codes. Gear types included bottom trawl, dredge, mid-water trawl, purse seine, pot/trap, gillnet, hook, and pelagic hook. Fishing effort, defined as hours fished, was calculated for all gear types and used as a proxy for habitat impacts. VMS data are reported at 60-minute intervals for all non-scallop dredge vessels and at 30-minute intervals for scallop dredge vessels. Active fishing was defined as VMS data logged at speeds of 4 knots or less for all non-dredge vessels and 5 knots or less for dredge vessels. Hours fished for non-dredge gear types was calculated by summing the total number of points categorized as fishing. Hours fished for dredge vessels was calculated by summing the total number of points categorized as fishing and dividing by 2 to account for the faster reporting interval.

The following figures show the spatial distribution of fishing effort from VMS data. Figure S.P.3.1 reveals the change in effort for commercial dredge and bottom trawl fishing over the 2009–2018 time period. Figure S.P.3.2 reveals the cumulative effort for that time period for all VMS gear, and indicates effort across gear types.

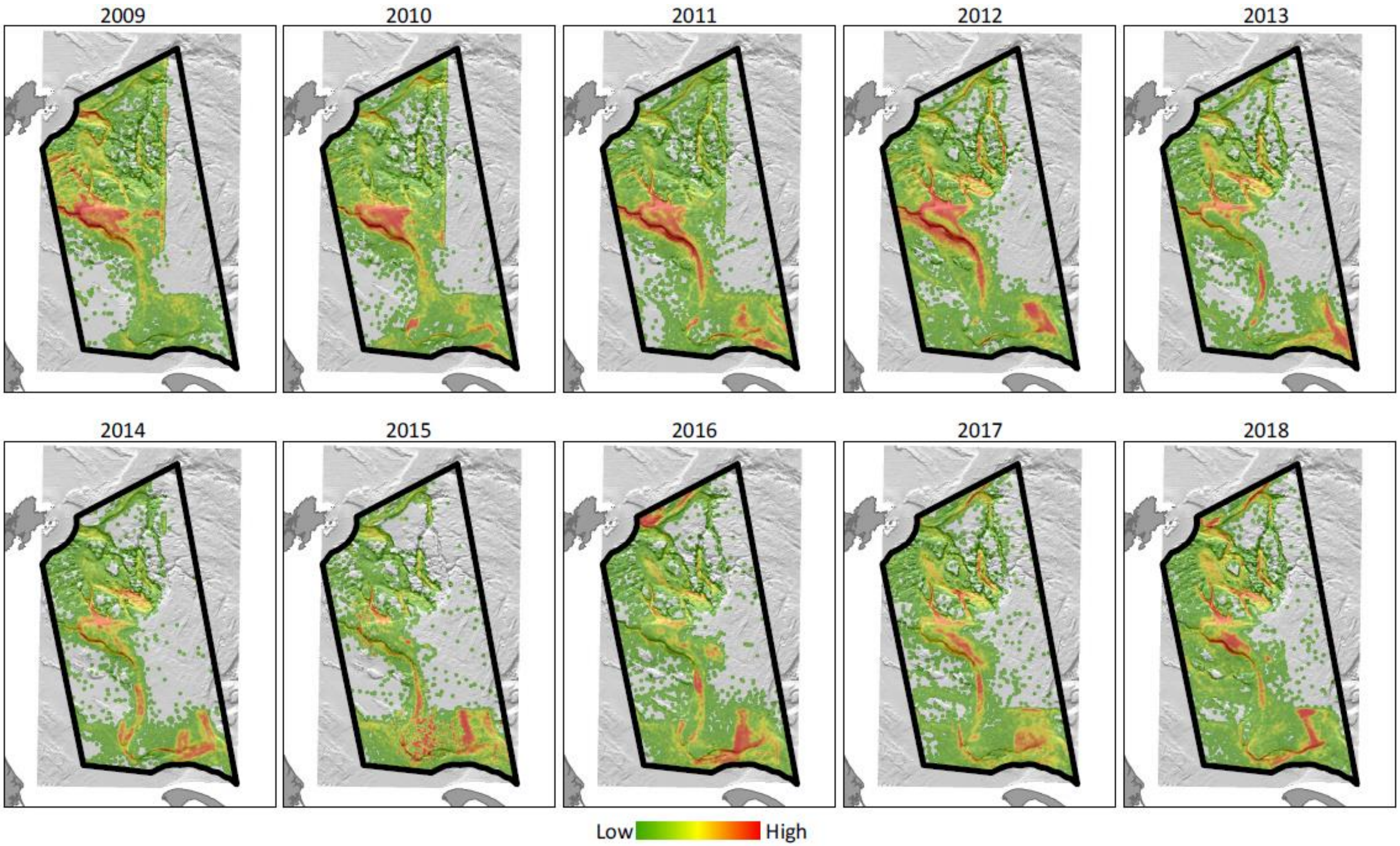


Figure S.P.3.1. Spatial distribution for all VMS-reported commercial dredge and bottom trawl fishing effort by year for the period 2009–2018. The large triangle-shaped area with no data on the east side of the sanctuary represents the Western Gulf of Maine Closure Area where it overlaps 22% of SBNMS. Bottom tending gear (except for lobster) is prohibited from this closed area. VMS points were interpolated using the ArcGIS kernel density function with a 500 meter search radius. Symbology is identical across maps. Source: NOAA Office of Law Enforcement 2019

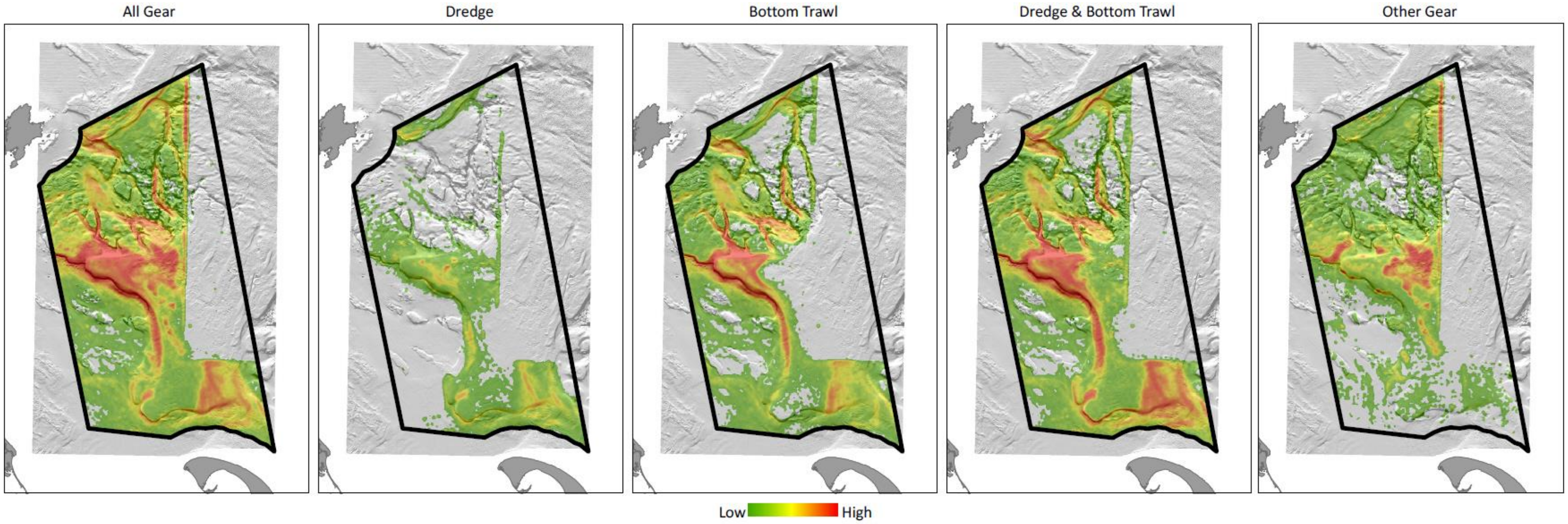


Figure S.P.3.2. Spatial distribution of VMS-reported commercial fishing effort for 2009–2018. Left to right, the panels show: all gears that use VMS (bottom trawl, dredge, mid-water trawl, purse seine, pot/trap, gillnet, hook, and pelagic hook); dredge data (scallop and clams); bottom trawl data; dredge and bottom trawl data; and all other gear (mid-water trawl, purse seine, pot/trap, gillnet, hook, and pelagic hook). See Figure S.P.3.1 for an explanation of the map and symbology. Source: NOAA Office of Law Enforcement 2019

The background provided in response to Question 10 (Integrity of Habitat) offers further detailed explanation and documentation of commercial fishing activity and its consequences. The potential adverse influence of commercial fishing is of concern. However, overall fishing effort, including bottom-contact gear, has declined by around 55% since 2009, leading to divergent viewpoints among expert panelists about whether this has resulted in significantly improved benthic habitat integrity throughout the sanctuary.

Anchoring of recreational vessels in shallower areas of the sanctuary is another potential source of disturbance to benthic habitats, but is likely localized to small areas on top of Stellwagen Bank. These shallow areas are routinely disturbed by storm-generated waves, thus any anchor disturbance may be short-term. Little documentation of the potential effects of anchoring in the sanctuary is available, so the actual impact of this activity is unknown, but perhaps worthy of additional investigation.

There is also potential for localized disturbance of benthic habitats along pipeline and cable installation routes. The one existing cable in the sanctuary, the Hibernia Atlantic cable, was installed using a seaplow and was to be buried in a trench approximately 1.5 meters deep. However, immediately post-installation, the company reported that many locations were only 0.5-0.75 meters deep. Surveys conducted post-installation showed that portions of the cable remained exposed. According to the final monitoring report (Auster et al. 2013b) and ROV and side scan sonar surveys in 2010, some of the unburied sections remain exposed and natural processes have not allowed full recovery of the trenched areas. However, apart from this localized impact, sanctuary monitoring (Auster et al. 2013b) seems to suggest that recovery of the disturbed areas occurs within a few years, and therefore, is not considered a major concern (see Question 10, Integrity of Major Habitat Types, for additional information).

Although there is active commercial and recreational fishing around the cable, SBNMS staff are not aware of any instances of fishing gear or other equipment becoming caught on or entangled in the cable. In addition, despite the still-exposed cable segments and detectable trench, monitoring data indicate that cable installation did not cause any habitat injury or changes in benthic composition greater or significantly different than those caused by commercial fishing (Auster et al. 2013b).

Other habitat impacts occur in the water column, such as sediment contaminants, vertical lines from fixed fishing gear, and acoustic impacts.

With the planned deepening of channels and berths in the Port of Boston, additional disposal of large amounts of dredged material at the MBDS is a concern in the local area surrounding the MBDS. Though the disposal site was thought to have been used less frequently between 2007 and 2017, the MBDS is still considered to be an effective disposal site, because material disposed there seems to be confined to specific areas where it was deposited. Therefore, even with the relatively large volume of dredged material anticipated from the deepening project, given the testing required to ensure that materials are suitable for unconfined open water disposal and the subsequent limited mobility of material once deposited, this activity is not likely to be a major concern.

Habitat degradation from sediment contaminants is also a potential concern, but the sources of contaminants from vessel discharges, land-based sources, and wastewater outfalls are not a major concern. The available information on these human activities is discussed in greater detail in the response to Question 11 (Contaminant Concentrations in Habitats). Existing monitoring activity related to these discharges may be sufficient to alert sanctuary staff to any unanticipated changes that may raise the level of concern about contaminants in benthic habitats; however, it is insufficient to detect novel or emerging contaminants in the water column.

To better understand the impact of fixed gear on benthic habitats, researchers conducted a comprehensive evaluation of fishing gear impacts on these habitats. The goals of this evaluation were to inform managers in the northeastern US which habitats are the most susceptible to fishing, which gears cause the greatest impacts, and what the expected recovery times are for habitat features that are affected. The evaluation revealed that substrates were most vulnerable to impacts from hydraulic dredging, slightly less vulnerable to those from trawling and scallop dredging, and least vulnerable to fixed gears. Traps had a greater impact than gillnets and longlines. However, researchers also pointed out the paucity of quantitative data on fixed gear impacts on the benthos (Grabowski et al. 2014). A more recent study focused specifically on the effects of lobster traps on the benthos off the coast of Delaware and Maryland. This study concluded that the dragging of traps across the benthos during the process of hauling a 20-trap trawl, which is a typical configuration in the sanctuary, can have considerable effects on structure-forming fauna in benthic habitats (Schweitzer et al. 2018). The study did not address impacts from trap movement during storm events, which are frequent in the vicinity of SBNMS. Given the large number of traps fished in the sanctuary during the open season, and given the frequency of storm events, the impact of traps dragging across benthic habitats that are targeted in the lobster fishery is not insignificant, although likely less than that of mobile gears (based on spatial estimates of adverse effects of trawl gear and traps in the SASI model described in the Omnibus Habitat Amendment 2; NEFMC 2018).

Impacts to acoustic habitats within the sanctuary are also a concern. The acoustic environment of the sanctuary has been studied intensively, and concerns have been raised regarding the impact of human-generated underwater noise on the quality of acoustic habitats in the sanctuary. Specifically, commercial vessel traffic can interrupt behavior and communication of various species, including marine mammals and some fish species (e.g., cod spawning behavior). The acoustic environment is another significant habitat for many living resources in the sanctuary. SBNMS has been at the cutting edge of expanding our collective understanding of the acoustic environment since concerns began to be raised about the potential impacts of human-generated noise in the ocean environment. Utilizing advanced passive acoustic monitoring technology, the sanctuary has been at the forefront of raising awareness of the potential threat of noise to organisms including marine mammals, fish, and some invertebrates. SBNMS staff have worked with many partners to conduct essential research to expand our collective knowledge of the acoustic environment; the results of this research have been documented in numerous scientific publications including Hatch et al. (2012). The acoustic environment was not extensively considered when evaluating the state of the sanctuary's habitat integrity.

4. What are the levels of human activities that may adversely influence living resources and how are they changing?

Status Description: Selected activities have caused severe impacts that are either widespread or persistent.

Rationale: Fixed and mobile commercial fishing methods, shipping, and recreational activities such as fishing and whale watching are of particular concern, as they can cause negative impacts on living resources. Improvements in gear management and decreases in overall fishing effort have resulted in reduced impacts on living resources, ship strikes of whales have decreased, and efforts are underway to mitigate noise impacts on marine mammals.

SBNMS supports significant marine mammal, fish, and seabird populations. Humans are also attracted to these resources in considerable numbers, and the sanctuary's proximity to Boston makes it readily and conveniently accessible. The 2007 rating for this question was "fair/poor" and "not changing." The 2018 status rating is unchanged. Available data are, in general, limited across all activities; however, there are some efforts underway to monitor and mitigate these continuing threats. The trend is now "improving" (high confidence) due to several factors. Analysis of VTR and VMS data indicates significant reductions in fishing effort. This decreased effort combined with improvements in gear management have reduced impacts to living resources. Ship strikes to large whales have also declined, and efforts are underway to mitigate noise impacts on marine mammals.

Commercial Fishing

Commercial fishing occurs extensively throughout the sanctuary (see Figure DP.CF.2). Commercial fishing can directly impact aggregations and populations of economically and ecologically important species and their habitats, and can also result in incidental capture of associated species (bycatch) (NEFSC 2017b, Pittman 2019). In addition, commercial fishing has indirect effects on species and populations through injury and mortality associated with entanglement and the effects of underwater noise, which can mask sounds used by fish, crustaceans, and protected species (e.g., whales) in reproduction, feeding, and social interactions (e.g., Stanley et al. 2017). This section will focus on impacts by mobile and fixed gear types.

Mobile Gear

In terms of direct impacts, the average pounds landed from the sanctuary per year from 2007–2018 was around 13 million pounds (Figure S.P.4.1). During the previous 10-year period, from 1996–2005, the average pounds landed per year from the sanctuary was around 17 million pounds.

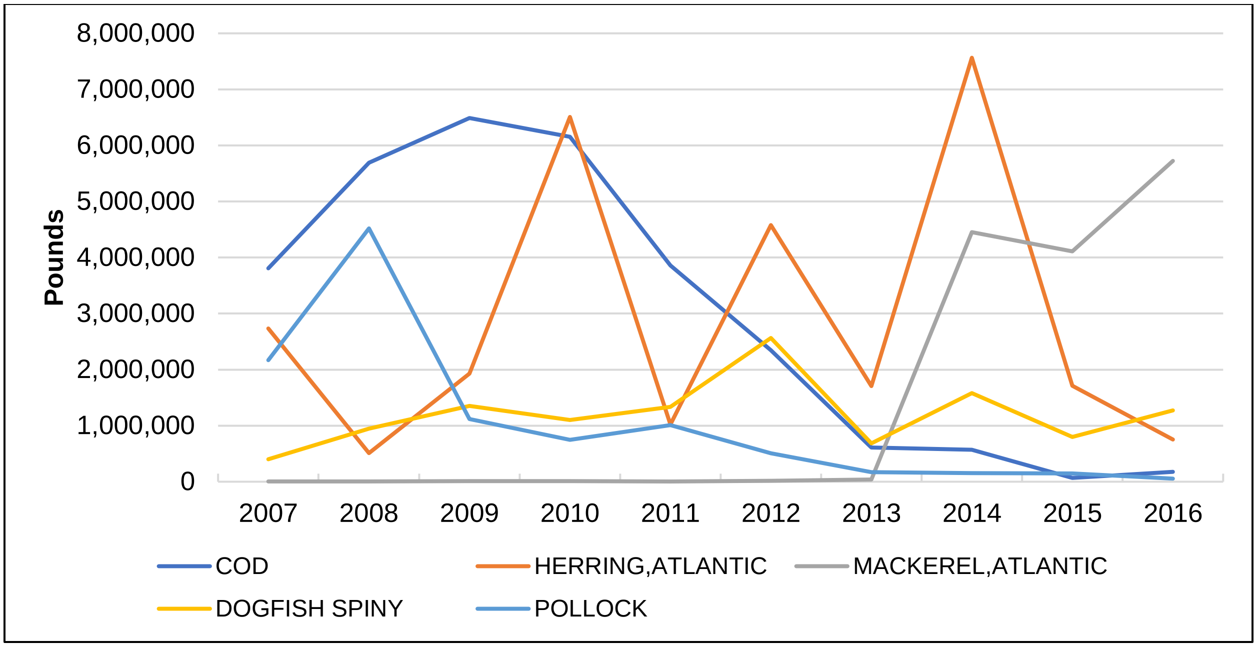


Figure S.P.4.1. Commercial landings in pounds by species in SBNMS, 2007–2016. Image: GARFO 2019b

Cod accounts for the greatest volume by species landed from the sanctuary, averaging 3.0 million pounds annually (2007–2016), with the highest single-year landings of 6.5 million pounds in 2009. The second most fished species in SBNMS was Atlantic herring, with an average of 2.9 million pounds annually (2007–2016) and the highest single-year landings totaling 7.6 million pounds in 2014. Since 2009, cod landings decreased and herring landings have been erratic, while Atlantic mackerel landings have increased dramatically since 2013 (Figure S.P.4.1). The availability of herring may be a factor in determining the local abundance of whales, dolphins, tuna, and other wildlife in the sanctuary. Although herring are currently not overfished in the Gulf of Maine, the potential for localized depletion of herring by fishing in the sanctuary is a related concern. Herring and sand lance are key prey species that constitute a major segment of the forage base underlying all ecological functions and economic and recreational activities that define the sanctuary. Catch of scallops increased dramatically after 2014 through intensive fishing in a relatively small part of the northwest corner of Stellwagen Bank, an important habitat for sand lance. In 2018, GARFO changed the Northern Gulf of Maine scallop regulations, which significantly reduced the level of effort on the northwest corner.

The transition to sector management in May 2010 for the Northeast Multispecies Fishery Management Plan is clearly reflected in effort data for commercial fishing in the sanctuary, and the effect was profound. In terms of number of vessels, there was an 11.5% increase in 2010 (from 2009), which was likely due to vessels targeting the hyperaggregation of cod (Richardson et. al. 2014) (Figure S.P.4.2). Between 2010 and 2011, the number of vessels declined about 21%. The 34% increase in the number of vessels in 2016 was likely due to the scallop fishery on the northwest corner of the bank; however, scallop boats are not included in sector management. There was, on average, a 2.5-fold increase in the number of large vessels (>70 feet) within SBNMS after 2010, likely due to the change to sector management, which removed the days-at-sea restriction for large trawlers, allowing them to target Stellwagen Bank (Figure S.P.4.2). The influx of these large trawlers resulted in rapid depletion of the concentration of Gulf of Maine cod, which were aggregated on the northwest corner of Stellwagen Bank due to an abundance of sand lance (Richardson et. al. 2014).

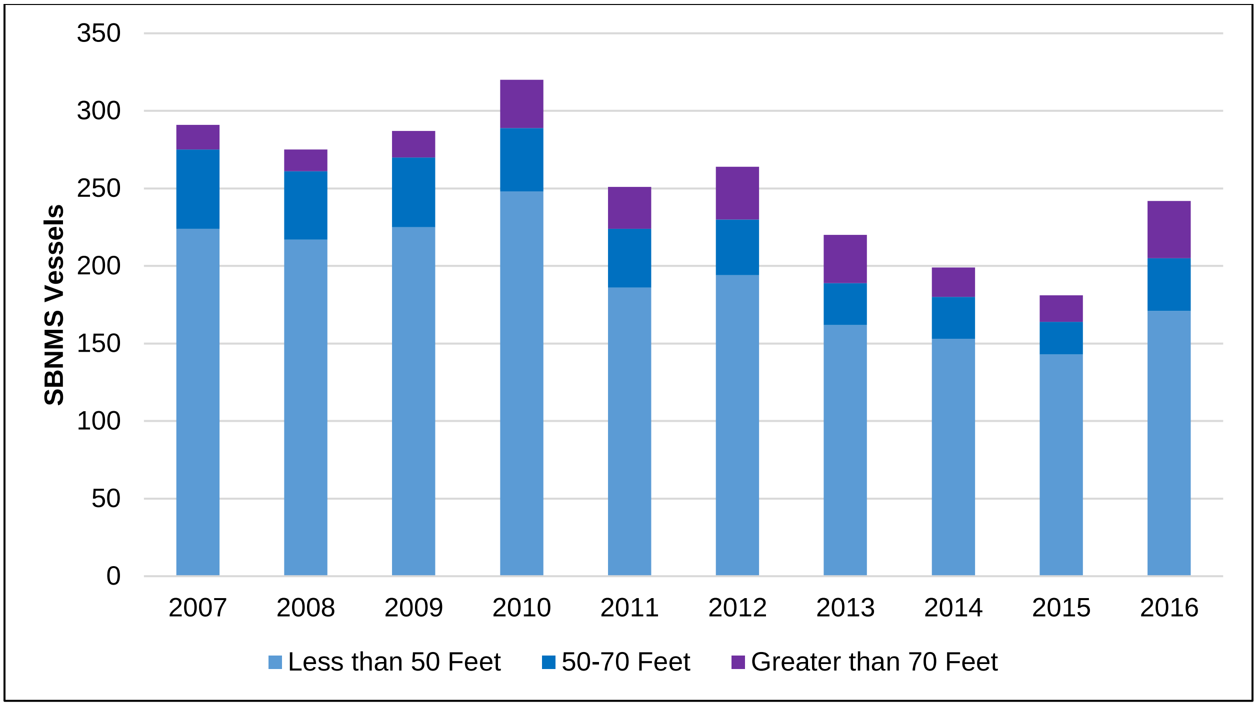


Figure S.P.4.2. Number of all commercial fishing vessels within SBNMS by year and categorical vessel length, 2007–2016. (Note: some, but not all, vessels represented in these data were affected by sectors.) Data: GARFO 2019b. Image: SBNMS 2019

In terms of fishing effort (expressed in number of vessel trips), the total number of trips decreased by 55.3% between 2009 and 2016 (Figure S.P.4.3). The number of vessel trips declined for boats less than 50 feet and those that were 50–70 feet. Trips by large vessels increased 2.2-fold from 2015 to 2016, likely due to the scallop fishery on the northwest corner of the bank.

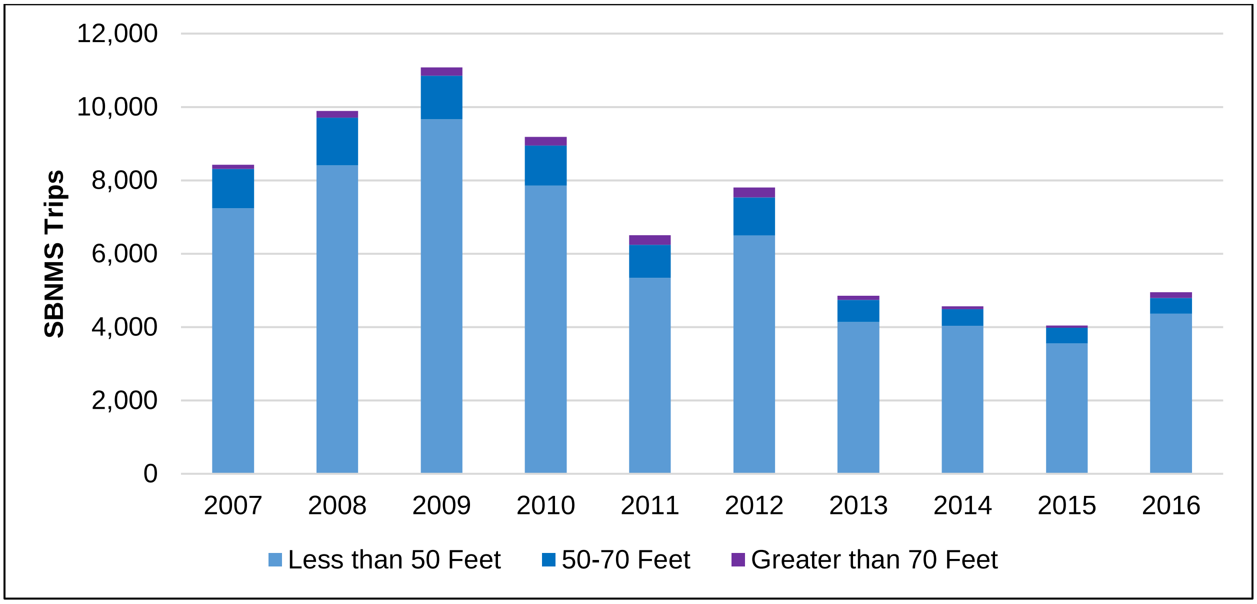


Figure S.P.4.3. Commercial fishing trips in SBNMS by vessel size, 2007–2016. (Note: some, but not all, vessels represented in these data were affected by sectors.) Data: GARFO 2019b. Image: SBNMS 2019

Based on VMS data, fishing effort (expressed in hours fished) declined 19.2% between 2009 and 2016. This is not as dramatic a decline as the number of trips (from VTR data), which is likely due to the fact that fewer vessels are required to use VMS.

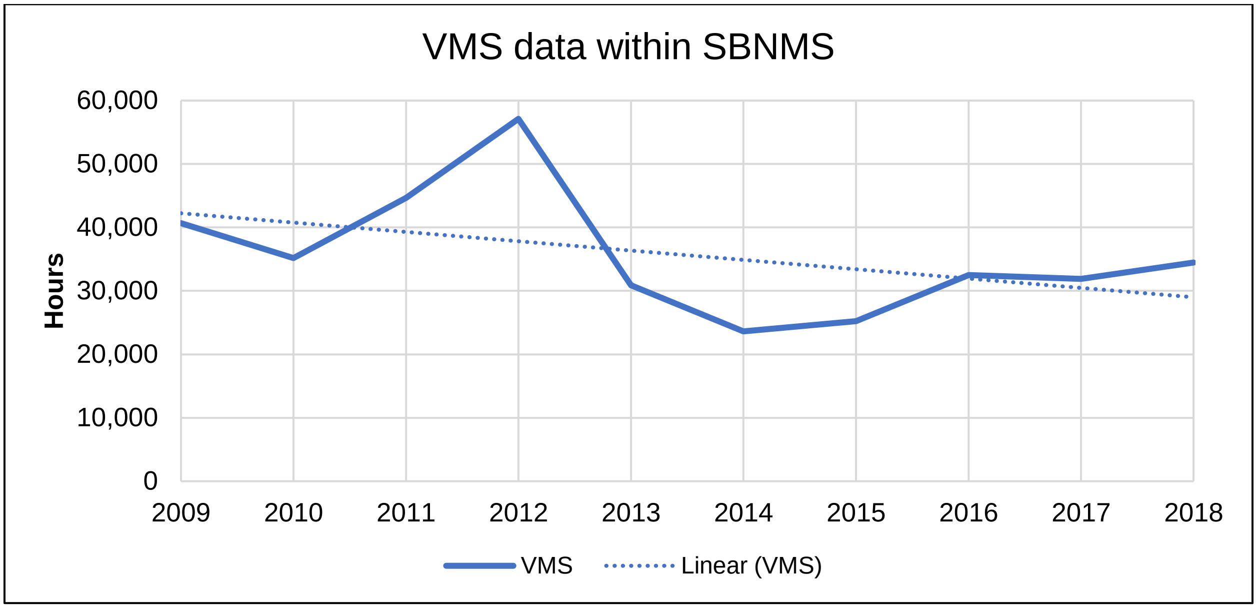


Figure S.P.4.4. Fishing effort based on VMS data, expressed as hours fished. Data: GARFO 2019b. Image: SBNMS 2019

Fixed Gear

During the time period of this report, 2007–2016, fixed gear (sink gillnets, lobster traps, and longlines) comprised 62.9% of commercial fishing, whereas mobile gear comprised 32.7%. The transition to sector management and drastic cuts in cod quota led to a ~87% decrease in gillnet fishing in the sanctuary since 2009, and a ~56% increase in the lobster fishery (Figure S.P.4.5). The decline in spatial extent and effort of mobile gear fishing since 2009 allowed the lobster fishery to expand into areas previously fished by mobile gear (the two gear types conflict with each other).

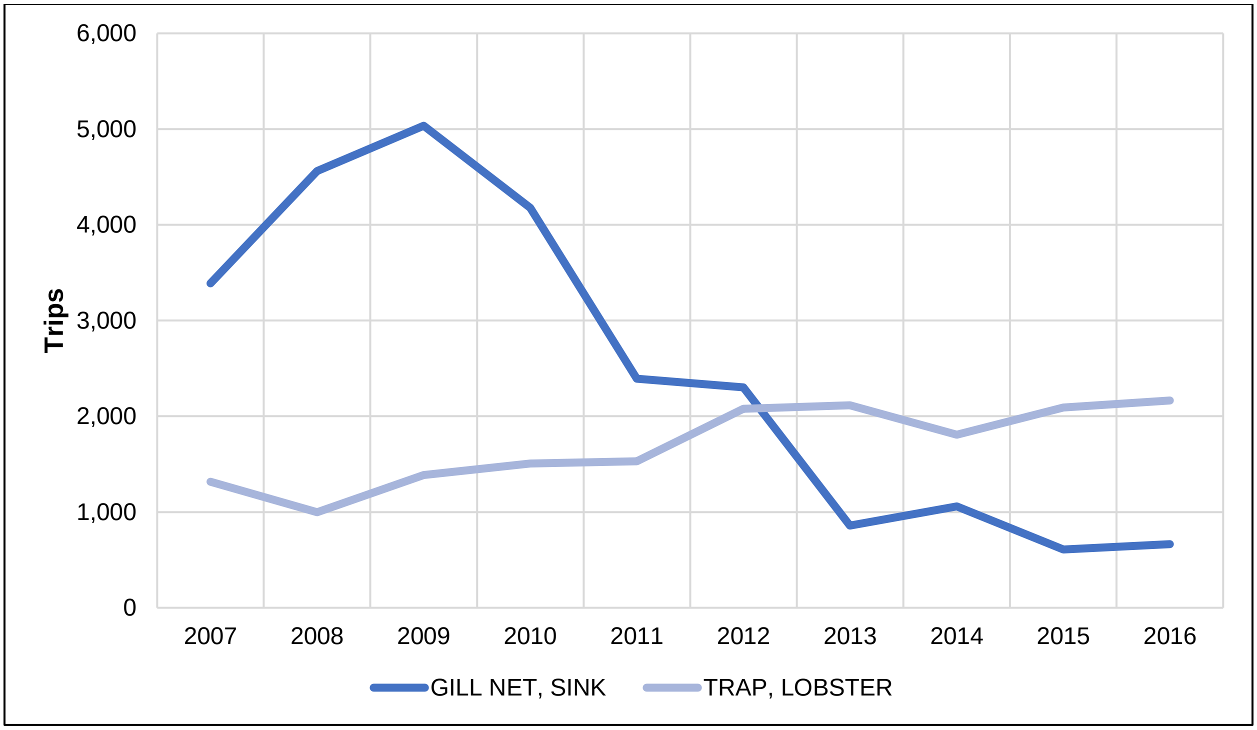


Figure S.P.4.5. Trends in effort (number of trips) for two types of fixed gear: gillnets and lobster traps, 2006–2017. Data: GARFO 2019b. Image: SBNMS 2019

Entanglement/Bycatch

Fixed gear (e.g., traps and gillnets) used in commercial fishing has the potential to bycatch or entangle marine mammals and seabirds. For marine mammals, the greatest apparent bycatch is grey seals, followed by harbor seals and harbor porpoises. For seabirds, the greatest apparent bycatch is great shearwaters, followed by common murres and northern fulmars. As identified by the number of bycaught species and the number of bycaught individuals, the gillnet fishery is the main source of bycatch (Figures S.P.4.6–S.P.4.8) (NEFSC 2017c), although this might be influenced by differences in observed trips among the fisheries. Spatially, most entanglements of pinnipeds, small cetaceans, and seabirds reported in NEFSC's Observer Program occur in the northern part of the sanctuary and along the line that delineates the western edge of the Western Gulf of Maine Closure Area, where it runs through the sanctuary (Figure S.P.4.9). Mobile gear also has the ability to incidentally catch non-targeted species. However, after the 2010 implementation of catch shares in the Northeast Multispecies Fishery Management Plan, discards of groundfish were reduced dramatically (see Figure S.P.4.7).

Figure S.P.4.6. Number of bycaught animals in SBNMS by species and year. Data are not corrected for observer effort. Data: GARFO 2019b. Image: SBNMS 2019

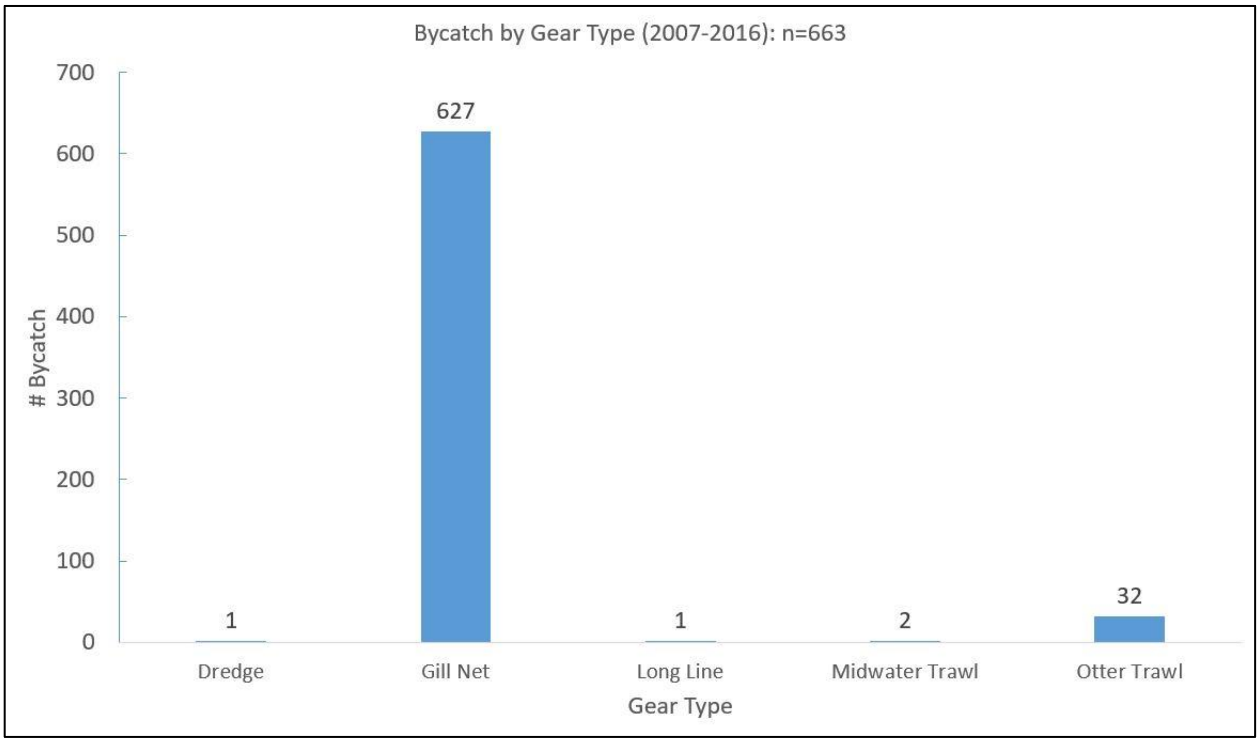


Figure S.P.4.7. Number of bycaught animals (all species) by gear type for the years 2007–2016, showing the apparent greatest level of bycatch resulting from the gillnet fishery. Data are not corrected for observer effort. Data: GARFO 2019b. Image: SBNMS 2019

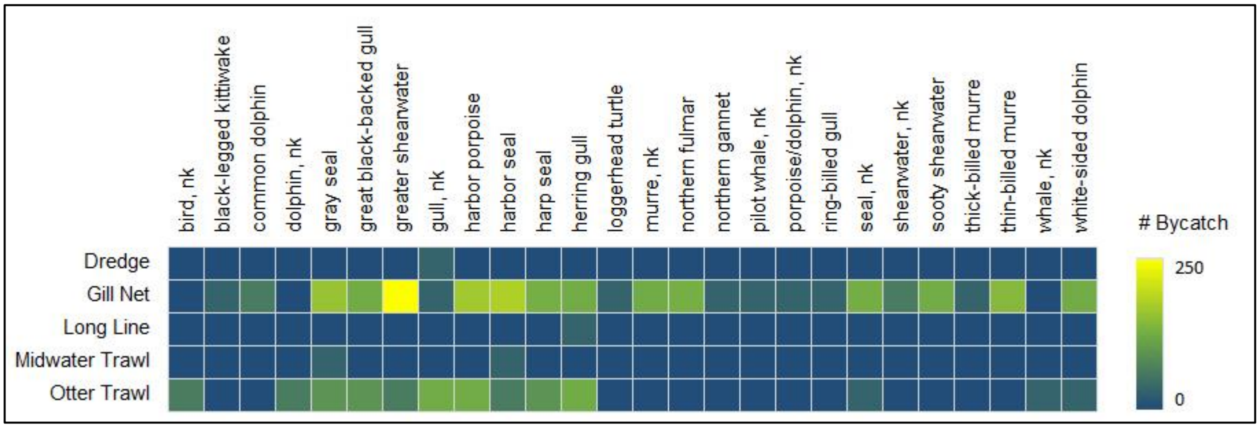


Figure S.P.4.8. Number of bycaught animals in SBNMS by species and gear type, showing the apparent greatest level of bycatch resulting from the gillnet fishery. Data are not corrected for observer effort. Data: GARFO 2019b. Image: SBNMS 2019

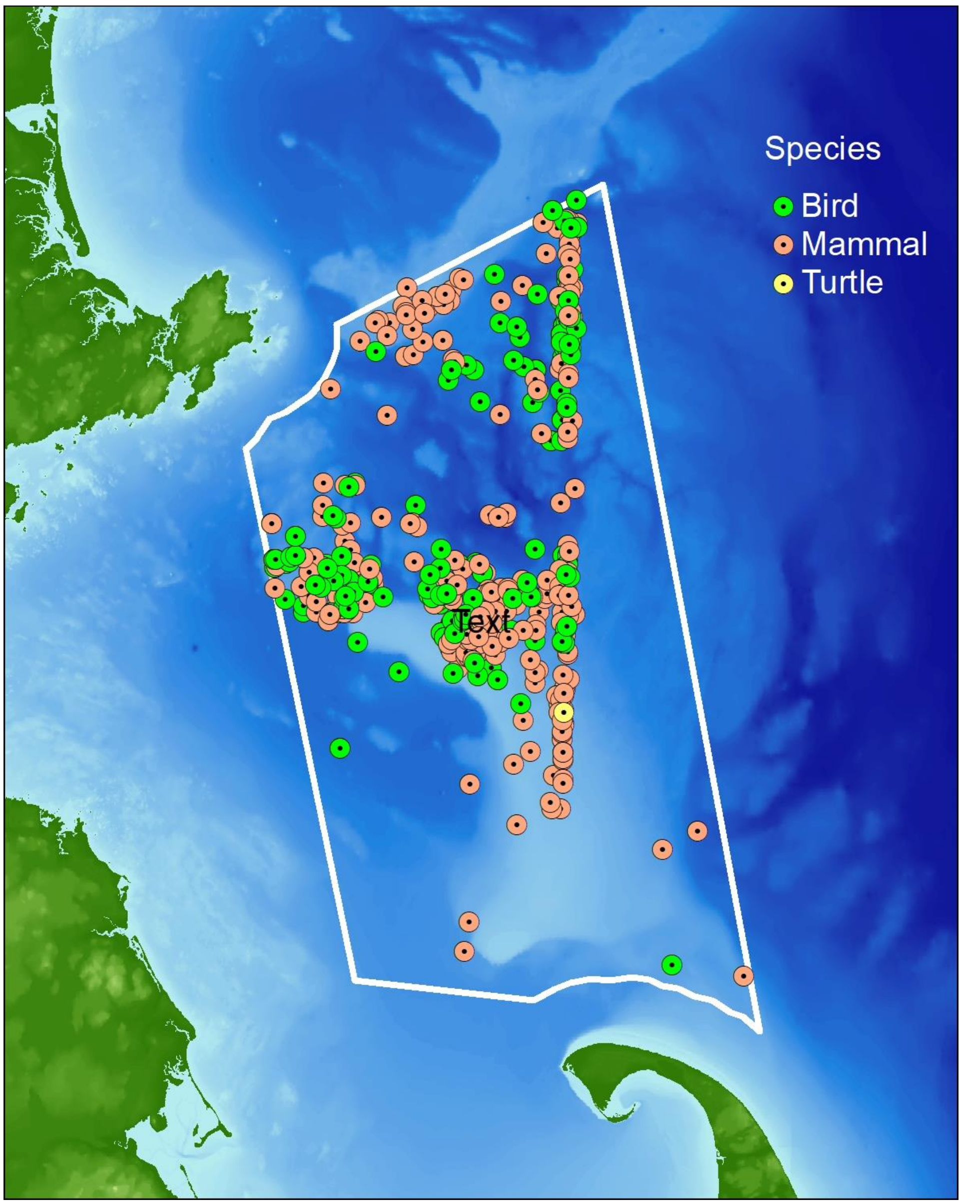


Figure S.P.4.9. Location of bird, mammal, and turtle bycatch in SBNMS (2007–2016). Data: GARFO 2019b. Image: SBNMS 2019

Summary of Commercial Fishing Impacts

Over the time period covered by this report, there has been a significant reduction in effort and spatial extent of mobile gear fishing and gillnet fishing for groundfish. At the same time, there have been increases in lobster fishing, scallop dredging, and midwater trawling for forage fish like herring and mackerel. The overall direct effects of commercial fishing have been considerable. The primary direct effects have been the collapse of the cod population around 2010 and entanglement of marine mammals and seabirds.

Shipping

Commercial vessels can impact sanctuary resources through collisions with whales and increased noise levels.

Strikes

In 2008, NOAA Fisheries mandated that from March 1–April 30, all vessels 65 feet or longer transiting in seasonal management areas (including the Off Race Point Management Area, which overlaps with the TSS portion of the sanctuary) must travel at 10 knots or less. The purpose of this regulation is to reduce the likelihood of deaths and serious injuries to North Atlantic right whales resulting from collisions with ships. In addition, this mandate may also result in reduced noise contribution from compliant vessels. However, a cause and effect relationship between reduced vessel speed and reduced noise generation has proven difficult to quantify.

While operating around seasonal populations of large marine mammals, vessels could disturb or potentially collide with whales. The shift of the TSS shipping lanes in 2007 from the southern portion of the bank to mid-bank (Figure DP.CS.1) has moved large ships away from the primary feeding area for humpback, finback, and minke whales and further away from concentrated zooplankton in Cape Cod Bay and the southern part of the sanctuary. This shift has moved large commercial traffic away from the usual whale watching area, and has thus reduced the potential for and threat of collisions between ships and whales.

Noise

The level of noise pollution in the oceans in general and in SBNMS in particular has increased dramatically during the last 50 years. Noise generated by human activities can have a detrimental effect on marine life in terms of feeding and spawning behavior.

In 2006–2007, the sanctuary conducted a year-long passive acoustic monitoring project to characterize the sanctuary’s low-frequency “noise budget” associated with large commercial vessels by using data from AIS to document the distribution and density of vessel traffic. The monitoring project quantified baseline noise conditions for the sanctuary, including intra-annual variability, providing an understanding of average conditions, loudest conditions, and quietest conditions (Hatch et al. 2008, 2009). The study also assessed spatial variability in noise conditions within the sanctuary, and demonstrated a clear correlation between sites with the highest average noise levels and sites with the highest numbers of close approaches by container ships, tankers, and cruise ships (e.g., in the TSS). With the shifting of the TSS in 2007, estimates were also made for the collateral reduced risk of peak noise exposures from close approaches of vessels in lanes that were now, on average, more distant from preferred whale feeding locations (Hatch et al. 2008).

Low-frequency noise travels efficiently underwater, and thus significant noise energy is retained over large distances. The 2006–2007 monitoring program demonstrated that despite being relatively shallow and therefore propagation-limited, waters within SBNMS retained significant regional-scale noise signatures from vessel traffic occurring within greater Massachusetts Bay. This signature was omnipresent, and is of concern because of the potential for noise to “mask” the biologically-important acoustic signals that marine animals use to survive and reproduce.

From 2007–2010, a collaborative group of researchers from SBNMS, NEFSC, Cornell University, and Marine Acoustics, Inc. worked to quantify impacts associated with masking on large whales within the sanctuary. The study showed that on average, right whales have lost 63-67% of the space over which they could detect each other’s contact calls in sanctuary waters, relative to historic conditions (Hatch et al. 2012). This study also aimed to compare current noise levels in the sanctuary to historic levels. It was concluded that historic data sets (Wenz 1964, Piggott 1964, Urick 1983, 1984) suggest that historical ambient noise levels were as much as 20 dB less than the levels measured contemporarily in SBNMS, which is indicative of lower traffic conditions in the past. However, Hatch et al. (2012) suggested 10 dB less than contemporary values as a highly conservative value for historical noise, and retained 20 dB less than contemporary values for a broader sensitivity analysis.

Subsequent work by the same team expanded the study to examine masking potential for other large whale call types that are common within SBNMS, including fin and humpback whale songs, humpback whale social sounds, minke whale pulse trains, and North Atlantic right whale gunshots. This work found that current ambient noise in SBNMS and AIS vessel activity contribute most heavily to masking these call types, with lesser impacts by both whale watching and fishing vessels. Right whale gunshots were found to suffer the least amount of masking, while fin, humpback, and minke whales experienced masking levels of 80% or more for their respective sound types. These estimates of loss of communication capability are relative, and 10 dB less than current sound levels continues to be used as a highly conservative historical reference value (Cholewiak et al. 2018).

In 2013, SBNMS and NEFSC began partnering with the Massachusetts Division of Marine Fisheries (MA DMF) to document the calling behavior of spawning Gulf of Maine cod in remnant spawning areas both within and directly west of sanctuary waters (Hernandez et al. 2013). In 2016, SBNMS and NEFSC staff began mining the 2006–2007 passive acoustic dataset to examine calling behavior by cod, haddock, and other soniferous fishes in more detail throughout sanctuary waters, and to document overlap with sources of noise. The study investigated the alteration of estimated effective communication spaces during the winter (January through March) at three spawning locations (two within and one inshore of the sanctuary) for populations of cod and haddock. Both the ambient noise levels and the estimated distance over which fish vocalizations could be heard fluctuated dramatically during the three month period at each of the recording sites. Increases in sound level appeared to be largely driven by large vessel activity, and accordingly exhibited a significant positive correlation with the number of AIS tracked vessels within a 10 nm radius of the recording site. The near constant high levels of low-frequency sound and consequential reduction in communication space observed at these recording sites during times of high vocalization activity raises concerns that communication between conspecifics may be compromised during critical biological periods, such as migration, courtship, and spawning (Stanley et al. 2017).

Recreation

Recreational Fishing

Recreational use of the sanctuary is mostly seasonal (April–October) but can be widespread and intensive, potentially resulting in adverse impacts to living marine resources. While recreational discards can outnumber landings by 2:1, mortality of discarded cod is around 15% (Capizzano et al. 2016). In addition, recreational tuna fishing frequently targets areas where whales are present and can result in lures and hooks being snagged in whales' skin. The Center for Coastal Studies documents reports of recreational fishing gear entanglements of whales. Recreational vessels can also create underwater noise that can disturb whales. Data on the number of recreational boats operating in sanctuary waters are limited, so it is challenging to derive any numerical threshold for identifying when adverse impacts are more likely to occur.

Whale Watching

Since the last condition report, the whale watching season has expanded. The season starts earlier in the spring and lasts longer into late fall. Since 2007, there is increased knowledge about sound and its effects on whale communication. No mitigation measures have been identified, and therefore, there has been no change in overall whale watching practices regarding minimization of noise. However, more companies have joined the Whale SENSE program, which increases awareness around issues such as noise. Largely due to the efforts of Whale SENSE, communication between whale watch companies and NOAA has improved dramatically, which has resulted in increased reporting of right whale sightings and entanglements.

5. What are the levels of human activities that may adversely affect maritime heritage resources and how are they changing?

Status Description: Selected activities have caused severe, persistent, and widespread impacts.

Rationale: Incidental contact from fishing gear has affected nearly every maritime heritage resource in the sanctuary and continues to negatively impact archaeological site conditions. Recreational diving has also caused some local impacts but is not considered to be causing widespread degradation of maritime archaeological sites.

In the 2007 condition report, this question was rated "poor" and "declining." Because selected activities have caused severe, persistent, and widespread impacts, the rating remains unchanged.

Commercial fishing activity continues to be the greatest source of impacts to archaeological site condition. For a non-renewable resource such as historic shipwrecks, one encounter with a scallop dredge or bottom trawl can result in catastrophic damage that diminishes both historic and economic value. Commercial fishing impacts to shipwreck sites are fairly widespread, show variability by gear type, and are considered to be the primary source of concern for site disturbance (Figure S.P.5.1). A significant increase in scalloping by large vessels in the sanctuary in 2017 was thought to be a potential issue for historic site preservation, but NOAA's Greater Atlantic Regional Fisheries Office (GARFO) closed a loophole in regulations in 2018 that alleviated the potential for another intensive fishery and impacts to historic sites.

ONMS management of maritime heritage resources has not changed significantly since 2007. As a result, human activities that have the greatest impact on maritime heritage resource integrity also remain unchanged. In the past, ONMS policy prevented disclosure of historic shipwreck locations in order to afford them protection, primarily from looting. Maritime heritage disclosure policy is currently being refined to better account for a variety of hazards. SBNMS regulations prohibit the destruction or removal of historic resources except by traditional fishing operations such as trawling and dredging. Whether non-disclosure of historic shipwrecks enhances their protection is open to debate and will be addressed in the next management plan.

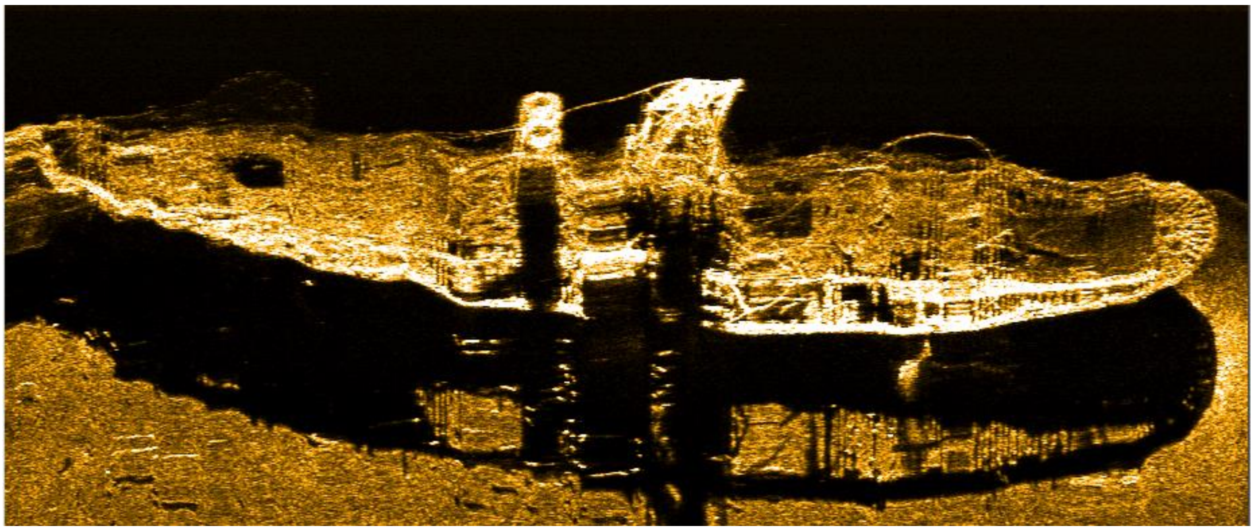


Figure S.P.5.1. A trawl net entangled on the historic steamship *Portland's* starboard bow and gillnet headropes entangled on the walking beam and aft deck. Note the aggregations of large fish off the port side that appear as white specks in the side scan image. Image: Klein Sonar

A recent example of fishing impacts on a wreck occurred in 2017 with the remains of the clam dredge vessel *North Star*. The *North Star* sank in 2003, making it a modern, non-historic vessel that became a popular dive site by local charter dive boat operators. In 2017, an intensive commercial scallop fishery targeted a dense bed of scallops on the northwest corner of Stellwagen Bank. This "derby" fishery was unexpected and involved over 40 scallop dredge vessels (a mix of smaller general category and larger limited-access boats) fishing a relatively small area for three weeks until the fishery was closed. The remains of the *North Star* (comprised of several sections) were impacted and dispersed over a wider area on the seabed. This site is no longer a worthwhile destination for recreational SCUBA divers, thus nullifying its economic value (Figure S.P.5.2).

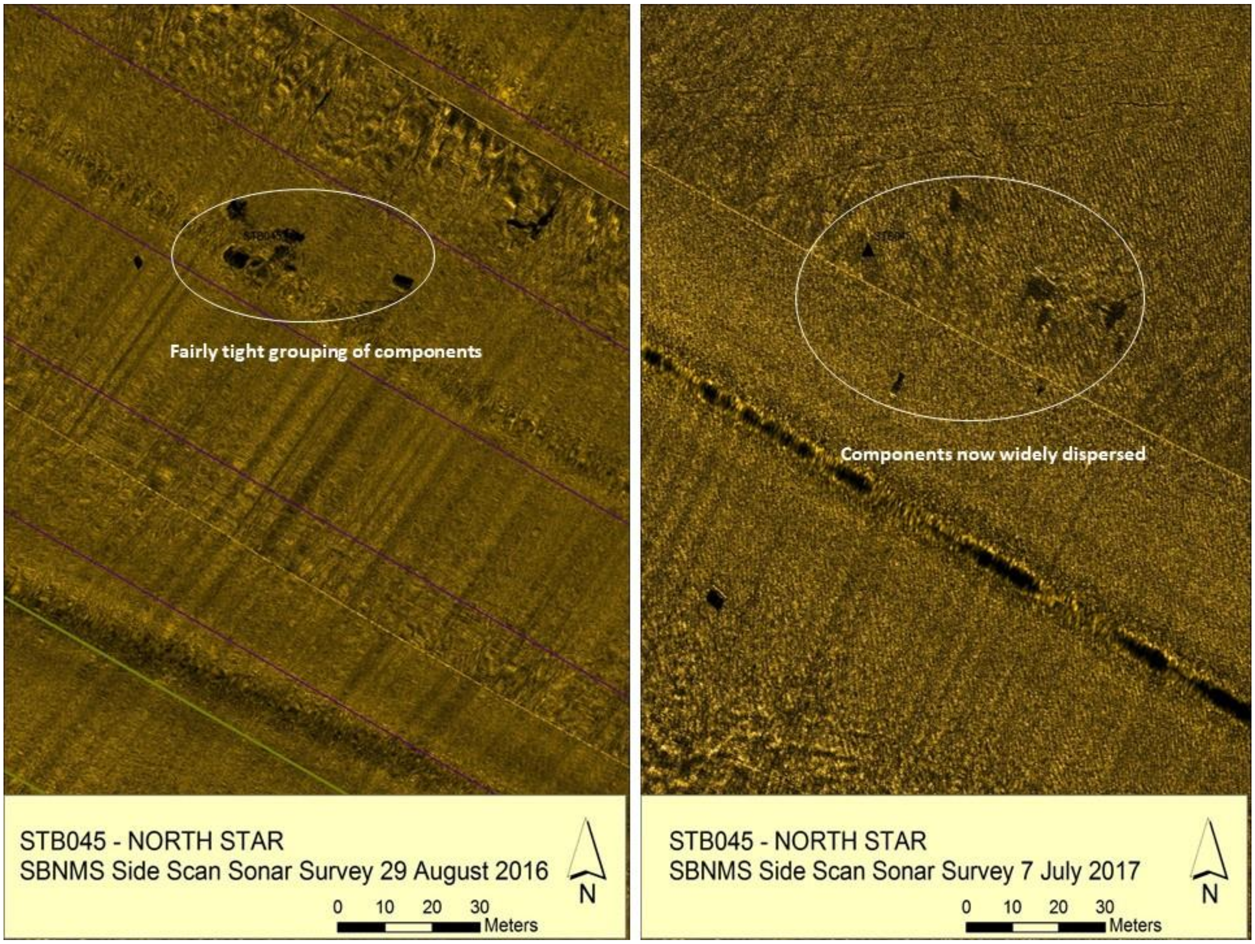


Figure S.P.5.2. Comparison of side scan sonar images of the shipwreck *North Star* acquired before the March 2017 scallop fishery and after the fishery. Note dispersion of components of wreck site over wider area. Image: NOAA

Recreational diving does not appear to produce widespread degradation of maritime archaeological sites, but disturbance has been documented at a few sites. As recreational diving has increased in SBNMS, so has the potential for impacts from this activity. Recreational diving occurs on a limited basis and, for the purposes of this report, includes technical diving (diving to depths greater than 130 feet). In rare instances, some dive charter boats have directly anchored on a historic shipwreck, risking damage to the shipwreck's structure. These rare events likely occurred when no mooring was present at the site. Although sanctuary regulations prohibit the removal of artifacts from sanctuary shipwrecks, there have been isolated cases in which divers have picked up and moved artifacts around an archaeological site. In cases where the artifact is partially buried, moving it exposes it to increased levels of oxygen and hastens degradation. This activity also diminishes the site's integrity and ability to answer research questions based upon an artifact's provenance (i.e., its relationship to other artifacts and the site in general).

STATE OF SANCTUARY RESOURCES

This section provides summaries of the status and trends within four resource areas: water quality, habitat, living resources, and maritime heritage resources. An expert workshop was convened by sanctuary staff on February 13–15, 2018 to discuss and evaluate the following series of questions about each resource area (Appendix D). Answers are supported by data and the rationale is provided at the end of each section for each resource area. Where published or additional information exists, the reader is provided with appropriate references and web links. Workshop discussions and ratings were based on data available at the time (e.g., through February 2018). However, in select instances, sanctuary staff later incorporated newly available data in order to more accurately describe the current status and trends of resources. Situations where data were used by sanctuary staff to support a rating, but were not presented or discussed during the workshop, are noted in the text.

Water Quality (Questions 6–9)

The following information provides an assessment of the status and trends of key water quality indicators in SBNMS for the period 2007–2018. Eutrophic conditions and their influence on primary production in sanctuary waters is the focus of Question 6. Eutrophication is the accelerated production of organic matter, particularly algae, usually caused by an increase in the amount of nutrients (primarily nitrogen and phosphorus) in surface waters. Eutrophication can impact the condition of sanctuary resources, for example, by promoting nuisance and toxic algal blooms or impacting dissolved oxygen levels.

Question 7 focuses on parameters affecting public health. Human health concerns can arise from water, beach, and/or seafood contamination (bacteria or chemical). Indications of health impacts may include fishery closures and seafood consumption advisories.

Question 8 focuses on shifts in water quality due to climate drivers. Climate indicators include indices of large-scale climate patterns, water temperature, acidity, upwelling intensity and timing, and dissolved oxygen. Shifts in water temperature can affect species growth rates, phenology, distribution, and susceptibility to disease. Acidification can affect organism survival, growth, and reproduction. Upwelling influences oxygen content and nutrient cycling.

Question 9 assesses other biotic and abiotic stressors, individually or in combination, that may influence sanctuary water quality, but were not addressed in other questions. Examples include non-point source contaminants, and hard-to-quantify stressors that influence the condition of habitats and living resources. Such inputs may include industry discharges and emissions, fertilizers, pesticides, heavy metals, and sewage.

6. What is the eutrophic condition of sanctuary waters and how is it changing?

Status Description: Eutrophication has not been documented, or does not appear to have the potential to negatively affect ecological integrity.

Rationale: MWRA hydrographic modelling (Zhao et al. 2017a) suggests that eutrophication is not occurring. Dissolved oxygen has not approached hypoxic or anoxic conditions over time. Background nitrogen may be decreasing regionally, which would decrease the probability of eutrophication.

The 2007 rating for this question was "good" (very high confidence) and "not changing" (very high confidence). Since 2007, regional monitoring suggests no sustained increases of key nutrient concentrations or nutrient ratios. Observed nutrient dynamics within the sanctuary and greater Massachusetts Bay are primarily driven by regional circulation and hydrodynamics of the Gulf of Maine (Townsend et al. 2015, 2010, McManus et al. 2014, Libby et al. 2017). Thus, the rating remains unchanged.

SBNMS receives nutrient and pollutant inputs from coastal point and non-point sources and via atmospheric deposition from proximate and distant inland regions. Anthropogenic nutrient sources of primary importance include wastewater treatment plants discharging into rivers or directly into Massachusetts Bay. Notably, the MWRA Deer Island Wastewater Treatment Plant sewage outfall discharges approximately 350 million gallons of effluent daily into the offshore Massachusetts Bay environment, roughly 12 nautical miles west of the SBNMS boundary (Werme et al. 2017).

MWRA conducts ongoing water quality monitoring across Boston Harbor and Massachusetts Bay to identify impacts of the Deer Island Wastewater Treatment Plant outfall within the coastal and offshore environment. The monitoring program assesses an extensive suite of physical and chemical parameters, such as temperature, salinity, dissolved oxygen, and nutrient concentrations, in addition to biological parameters, such as chlorophyll concentrations and phytoplankton community composition. Monitoring has been ongoing since 1992, with increased monitoring in SBNMS directly following outfall relocation in 2000 until 2010, when it was determined that a smaller subset of offshore stations adequately represented offshore conditions. MWRA currently maintains one monitoring station in the southwest corner of SBNMS (F29), one station slightly outside the northwest corner of SBNMS (F22), and two stations within Cape Cod Bay (F01 and F02). These stations are monitored nine months of the year. The Northeastern Regional Association of Coastal Ocean Observing Systems also maintains a monitoring buoy along the northwest boundary of the sanctuary, collecting data on water temperature, salinity, turbidity, chlorophyll concentration, density, dissolved oxygen, wind, waves, and currents on an hourly basis. These current and historical data sources provide an excellent platform from which to identify and infer long-term water quality trends within and around SBNMS.

The 2007 condition report and 2010 management plan both suggested that eutrophication was not a pressing problem in SBNMS waters. Nitrogen and phosphorus (in elevated concentrations) are the primary nutrients that may contribute to eutrophication. Ammonium and nitrate are two forms of nitrogen that may particularly contribute. Nutrient dynamics in the region are dominated by large-scale circulation of the Gulf of Maine and influx of Gulf of Maine water into Massachusetts Bay (Figure S.WQ.6.1, HydroQual 2000). Nutrient availability in surface and bottom waters is influenced by stratification and circulation patterns that are regulated by long-term climate dynamics and seasonal forcing. Surface water nutrient concentrations have remained roughly constant or declined over the course of MWRA monitoring (Figure S.WQ.6.3). Bottom water nutrient trends roughly approximate surface water results, yet bottom water reservoirs display predictably higher nutrient concentrations compared to surface waters (Figure S.WQ.6.4). Specifically, total nitrogen and total phosphorus have decreased in concentration since the early 2000s, possibly related to circulation shifts driven by the North Atlantic Oscillation (Figure S.WQ.6.4). SBNMS waters contain sustained concentrations of ammonium and nitrate, consistent with seasonal nutrient cycles observed across the region (McManus et al. 2014, Costa et al. 2017, Libby et al. 2017). Concentrations of orthophosphate and silicate, two other types of nutrients important for primary productivity, have decreased in the offshore environment since roughly 2010–2011. These nutrients typically come from terrestrial environments, so changes may reflect larger-scale shifts in circulation or precipitation altering riverine inputs or connectivity to offshore habitats (Figure S.WQ.6.3, Townsend et al. 2010, 2015, Berton et al. 2017). Overall, nutrient data from 1994–2016 suggest no evidence of increased eutrophication in sanctuary waters (Townsend et al. 2010, 2015, Costa et al. 2017, Libby et al. 2017). Modeling results support a lack of eutrophication potential in surface and bottom waters of Massachusetts Bay and SBNMS due to effluent inputs (Zhao et al. 2016, 2017a). Bottom water dissolved oxygen concentrations also do not indicate hypoxic or anoxic conditions indicative of eutrophication (Libby et al. 2017).

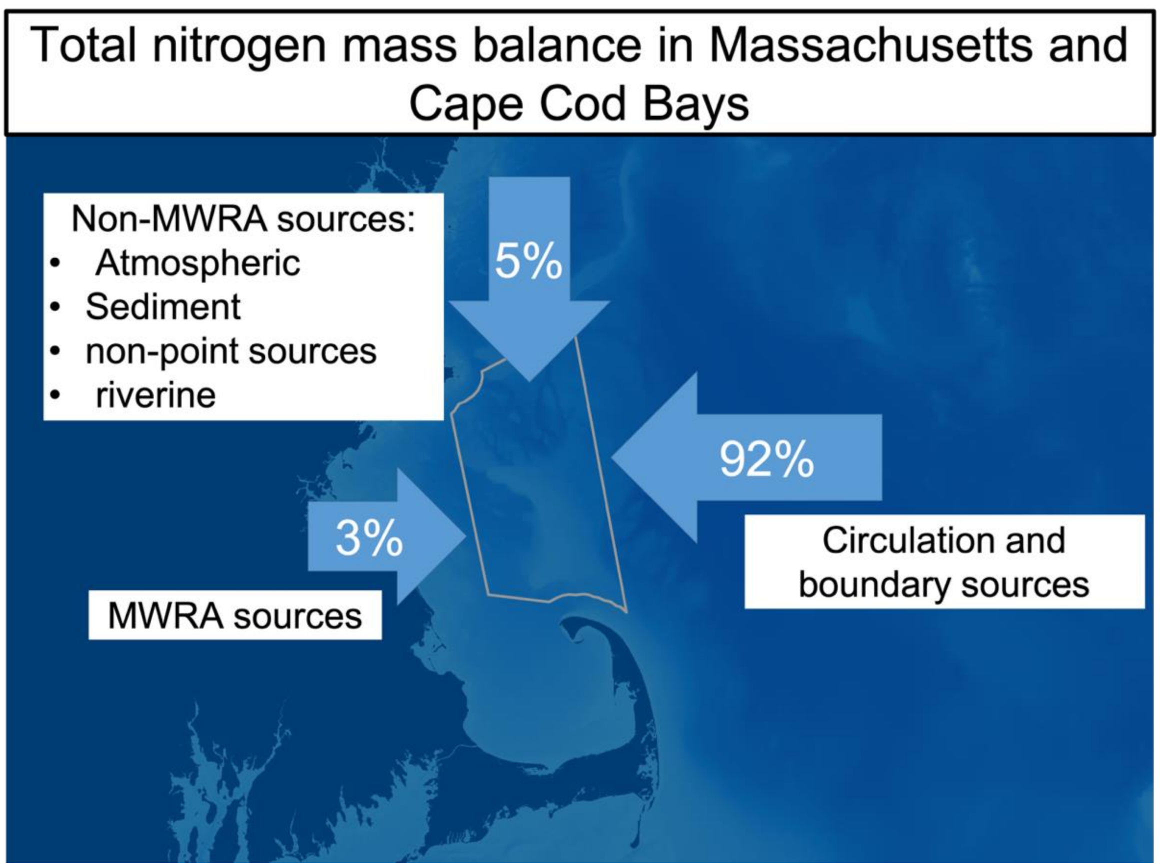
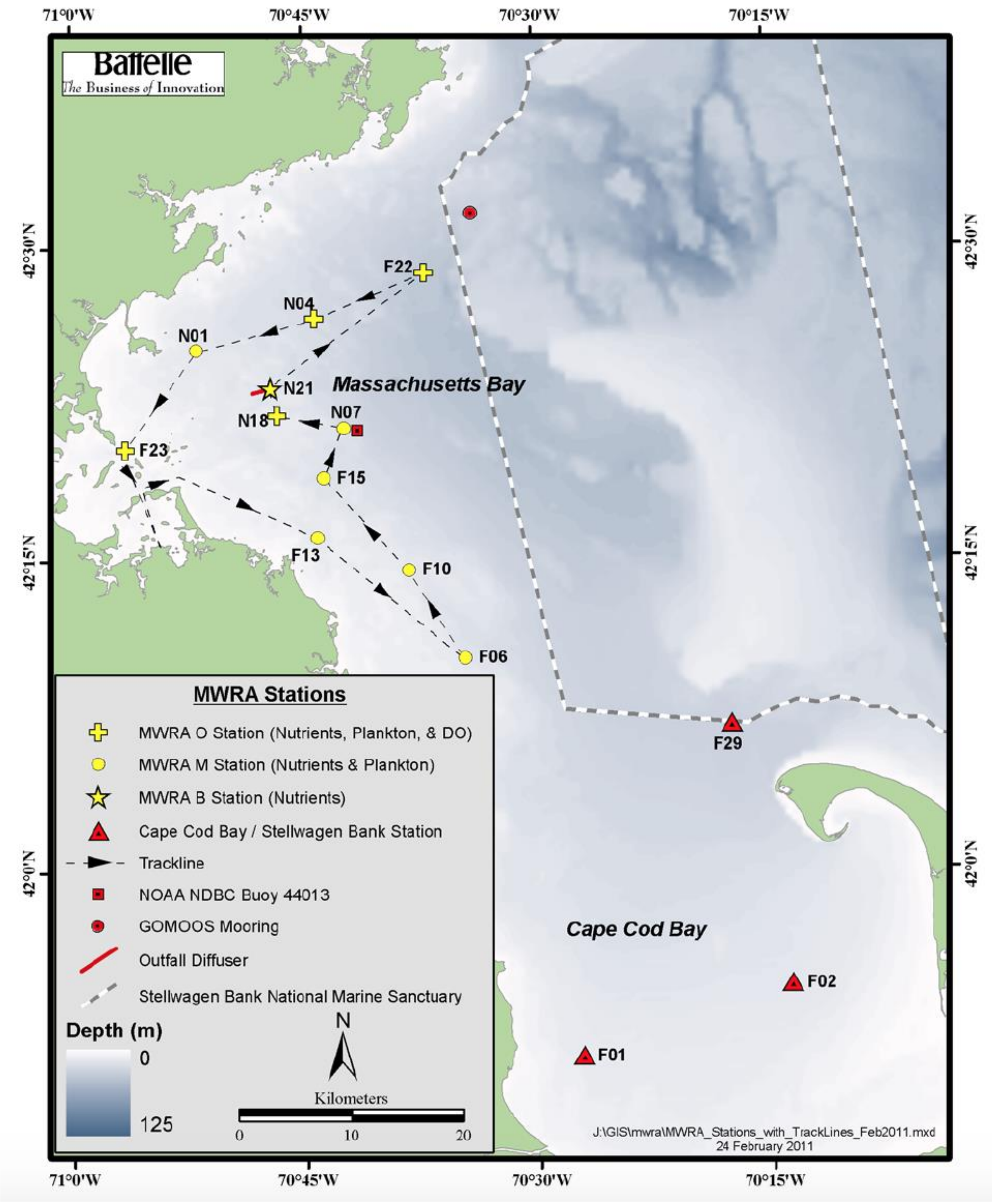


Figure S.WQ.6.1. A mass balance of nitrogen inputs into Massachusetts Bay from 1992-1994 suggests approximately 3% of the nitrogen in Massachusetts Bay originates from MWRA sources, while 92% of nitrogen in the system comes from regional circulation beyond the boundary of Massachusetts Bay. This modeling underscores the low impact of the MWRA outfall tunnel on nutrient dynamics in SBNMS and the greater Massachusetts Bay. Image: Modified from HydroQual 2000



S.WQ.6.2. Location of MWRA monitoring sites across Massachusetts Bay. Station F29 is at the southwest corner of the sanctuary, while F22 is slightly outside sanctuary boundaries to the west. These two stations were used as representations of sanctuary water quality as captured within this monitoring program. Image: Libby et al. 2017

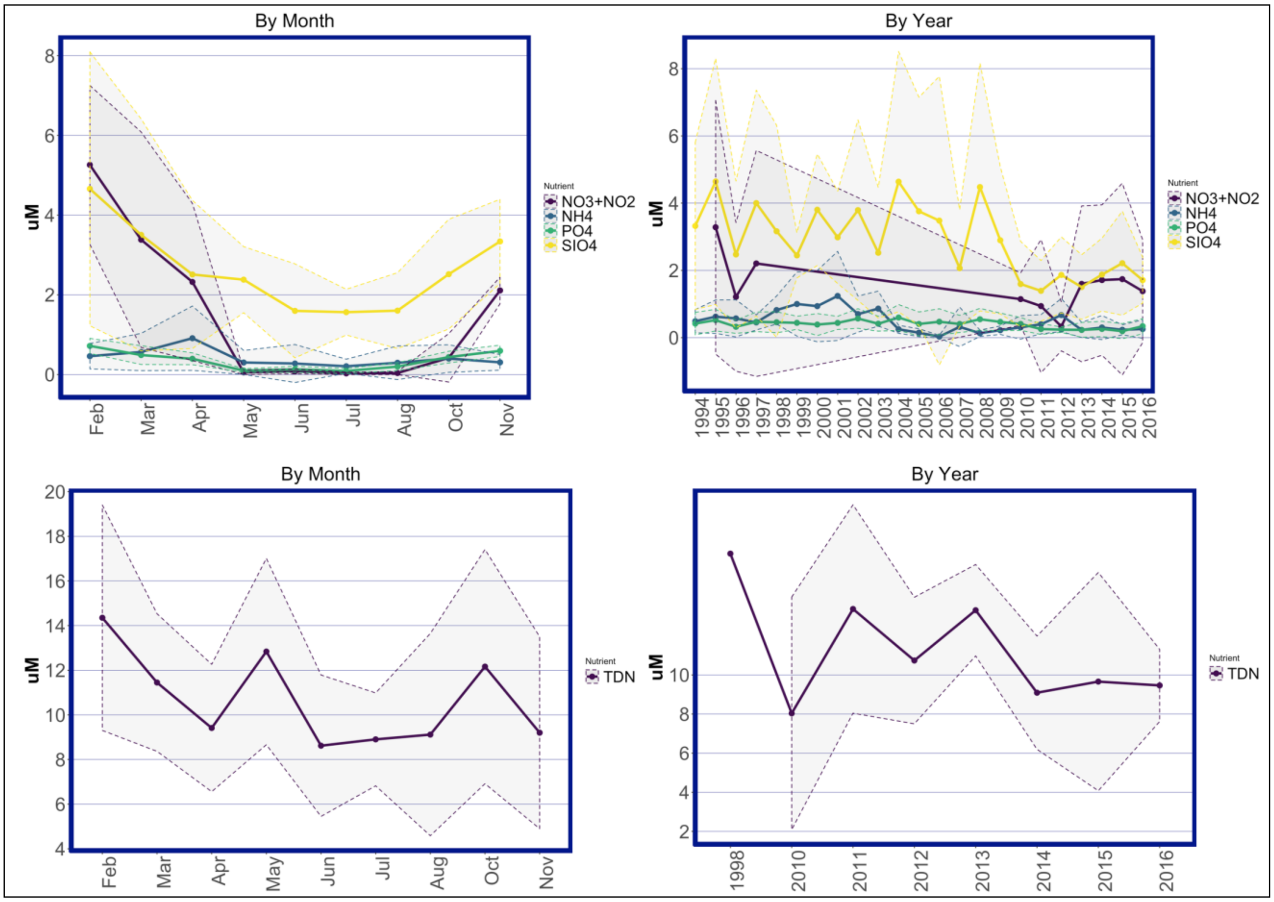


Figure S.WQ.6.3. Intra- and interannual nutrient data from F29, an MWRA monitoring station within SBNMS. Figures present monthly and yearly average concentrations of nitrate + nitrite, ammonium, orthophosphate, and silicate (top row) along with total dissolved nitrogen (TDN, bottom row). These data suggest an apparent lack of eutrophication as indicated by concentrations of key nutrients. Quasi-predictable seasonal fluctuations coupled with regional biogeochemical and hydrological dynamics drive observed nutrient concentrations and subsequent primary productivity in SBNMS and Massachusetts Bay. Gaps in nitrogen data reflect gaps in measurement of these parameters at station F29. Image: MWRA yearly average nutrient data, stations F02, F06, F29, F22, and N20. MWRA data courtesy of Kenneth Keay and Douglas Hersh

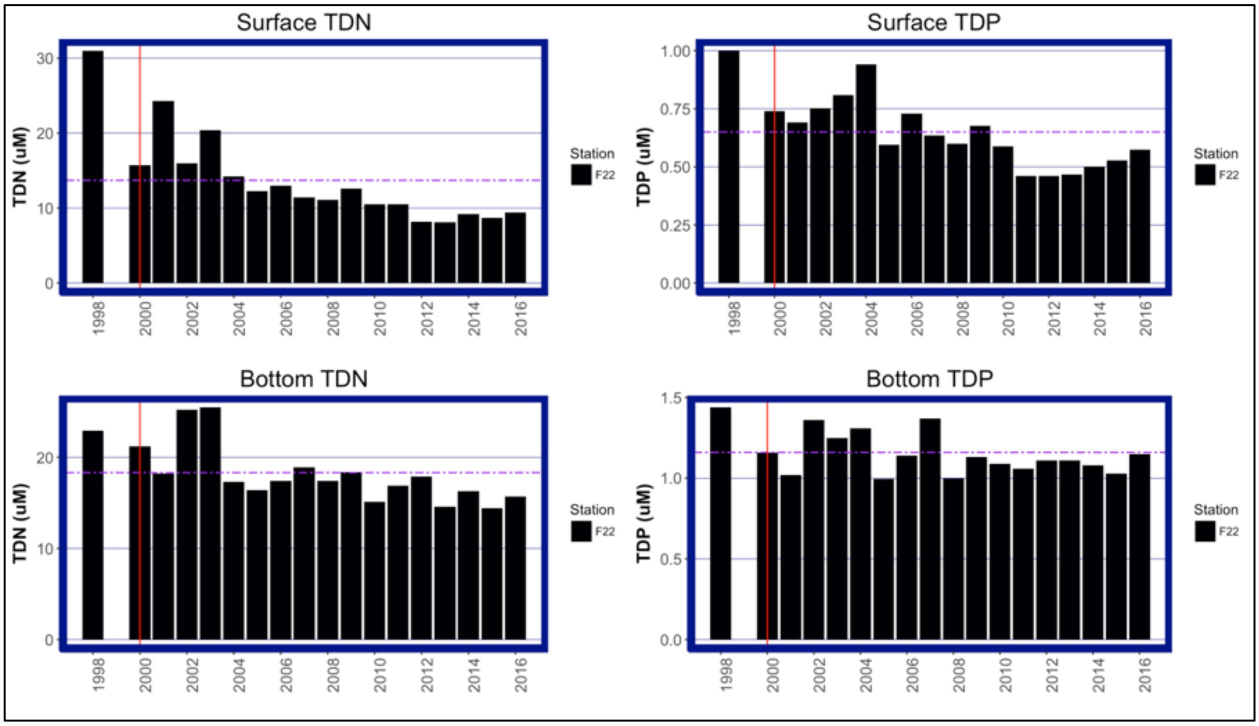


Figure S.WQ.6.4. Data from F22, an MWRA monitoring station directly adjacent to SBNMS boundaries, also suggest that eutrophication is not a pressing problem in SBNMS surface or bottom waters, or the surrounding far-field environment. Dashed purple lines indicate mean parameter concentration across time series, while red vertical lines demarcate MWRA outfall introduction in 2000. Note: F22 was used to denote total dissolved nitrogen (TDN) and total dissolved phosphorus (TPP) in the absence of identical data at F29. Image: MWRA yearly average nutrient data, stations F02, F06, F29, F22, and N20. MWRA data courtesy of Kenneth Keay and Douglas Hersh

Further evidence against eutrophication includes constant or declining regional primary production (Figure S.WQ.6.5, NEFSC 2017b, Libby et al. 2017, Oviatt et al. 2007). Notably, phytoplankton and zooplankton abundance and community makeup show significant seasonal and annual variation since MWRA monitoring began in 1992; however, these changes are likely driven by regional, decadal scale processes in the Gulf of Maine rather than eutrophication-related drivers (Oviatt et al. 2007, McManus et al. 2014, Costa et al. 2017, Libby et al. 2017).

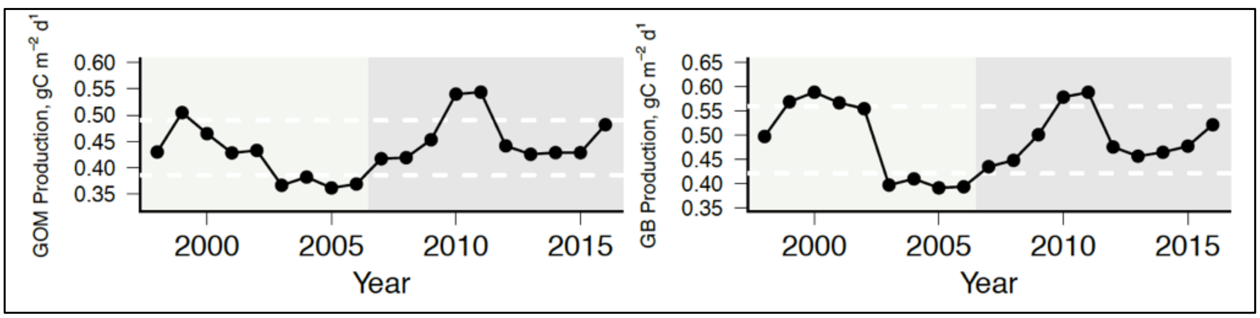


Figure S.WQ.6.5. Primary production in the Gulf of Maine, left, and Georges Bank, right, has fluctuated over time, with current conditions suggesting stable and average overall system production. Dashed lines indicate +/- 1 standard deviation. Image: NEFSC 2017b

7. Do sanctuary waters pose risks to human health and how are they changing?

Status Description: One or more water quality indicators suggest the potential for human health impacts, but human health impacts have not been reported.

Rationale: Toxigenic algae are present but not observed to cause demonstrable threats to human health. Observed water quality changes over the last 12 years may be related to changes in the North Atlantic Oscillation.

In the 2007 condition report, this question was rated "good" and "not changing." The status has now been downgraded to "good/fair." Ongoing bacterial monitoring suggests bacteria are rarely detectable. The downgraded rating stems from the documented occurrence of several toxigenic phytoplankton species with varying degrees of predictability; this suggests the potential for human health impacts, though these impacts have not been reported. Harmful algal bloom dynamics in SBNMS and the wider Gulf of Maine are thought to be mediated by large-scale circulation and climatic dynamics.

At present, SBNMS waters likely pose low risk to human health. Bacterial monitoring has been ongoing across the region by MWRA related to the Deer Island Wastewater Treatment Plant outfall, and indicates that water column bacterial counts consistently remain below detection limits, with a very low likelihood of exceeding thresholds protective of public health and resource use (Codiga et al. 2016).

The most likely source of possible human health effects in the region stems from the presence of toxigenic phytoplankton species (Figure S.WQ.7.1). Identified species of note include *Pseudo-nitzschia* spp., *Alexandrium* spp. (Pittman 2019), and *Dinophysis* spp., which have all been documented in SBNMS, Massachusetts Bay, and the greater Gulf of Maine. *Pseudo-nitzschia* spp. are classified as diatoms, while the latter two species are dinoflagellates; all produce toxins that may bioaccumulate, particularly in shellfish, and can cause widespread economic loss or health effects in humans (Anderson et al. 2000, Etheridge 2010, Lefebvre and Robertson 2010).

There is no definitive understanding regarding the risk of harmful algal blooms (HABs) to humans or wildlife that utilize the sanctuary, although risk from these or other toxigenic algae may be changing due to evolving HAB dynamics in the greater Gulf of Maine. *Alexandrium* spp. and *Dinophysis* spp. have been irregularly identified at low numbers within SBNMS and surrounding waters as measured via MWRA whole water phytoplankton assessments and regional research (Figure S.WQ.7.1, Anderson et al. 2014a, Gobler et al. 2017, Libby et al. 2017). *Alexandrium* spp. blooms are frequently a health concern in waters further north of the sanctuary (Anderson et al. 2014a, 2014b). Literature review and regional monitoring suggest *Alexandrium* spp. concentrations in excess of 1000 cells/L require increased monitoring for shellfish toxicity; MWRA maintains a caution threshold of 100 cells/L for the same taxa. Concentrations of *Alexandrium* spp. have infrequently surpassed either threshold, with notable occurrence of *Alexandrium* in the sanctuary only in 2005 according to MWRA cell count data.

Over 14 *Pseudo-nitzschia* species have been identified in the Gulf of Maine, seven of which are known to produce domoic acid, a neurotoxin. *Pseudo-nitzschia* spp. has been regularly documented in SBNMS according to MWRA survey data, with notable occurrences in sanctuary waters in the autumns of 2012, 2013, and 2016 (Figure S.WQ.7.1). Literature review, regional monitoring, and safety thresholds established by states in the region suggest *Pseudo-nitzschia* cell counts in excess of 20,000 cells/L merit increased monitoring for potential adverse effects in shellfish. Data exist regarding the relationship between cell count and domoic acid production or bioaccumulation specific to the offshore environment (Fernandes et al. 2014), which makes understanding risks associated with cell count thresholds challenging. It is also unclear if or to what extent the presence of this toxigenic diatom may translate to domoic acid exposure in the sanctuary food web. Blooms of toxigenic *Pseudo-nitzchia* spp. have been implicated in marine mammal and bird deaths around the globe, yet no SBNMS-specific mortality events have been documented (Lefebvre and Robertson 2010, D'Agostino et al. 2017).

Climate change likely plays a pivotal role in local and regional HAB dynamics. Recent research examining the relationship between sea surface temperature and HAB dynamics across the greater Northwest Atlantic from 1982–2016 found that bloom season and growth rate of *Alexandrium* spp. and *Dinophysis* spp. were positively correlated with increasing sea surface temperature, suggesting that climate change may have already exacerbated these or other HAB species dynamics in the region (O'Neil et al. 2012, Gobler et al. 2017). Modeling work considering the greater Gulf of Maine also suggests that climatically-mediated variables, such as river discharge, wind patterns, and cross-shore transport, are specifically associated with paralytic shellfish poisoning toxicity events caused by *Alexandrium fundyense* in a given year; it is uncertain if or how these variables may be shifting within SBNMS and how this may translate to increased risk for toxic HAB events (Nair et al. 2013). Phytoplankton cell counts obtained via MWRA monthly monitoring data from F22 and F29 do not indicate an explicit association between HAB species occurrence and warming SBNMS surface water temperatures or repositioning of the outfall. Although this may be a function of sampling frequency or a similar artifact, substantial regional evidence of decadal variation modulating HAB dynamics suggests the same factors are moderating HAB occurrence locally in SBNMS (Anderson et al. 2014a, 2014b, Libby et al. 2017, Nair et al. 2013). Note that MWRA cell count and monitoring data, taken monthly from February until December, can only be used to moderately comment on the occurrence or risk of quickly evolving HAB blooms, as blooms may develop and dissipate over the course of a few days or weeks. Further study of phytoplankton communities and toxigenic algae dynamics in the face of changing regional dynamics is warranted.

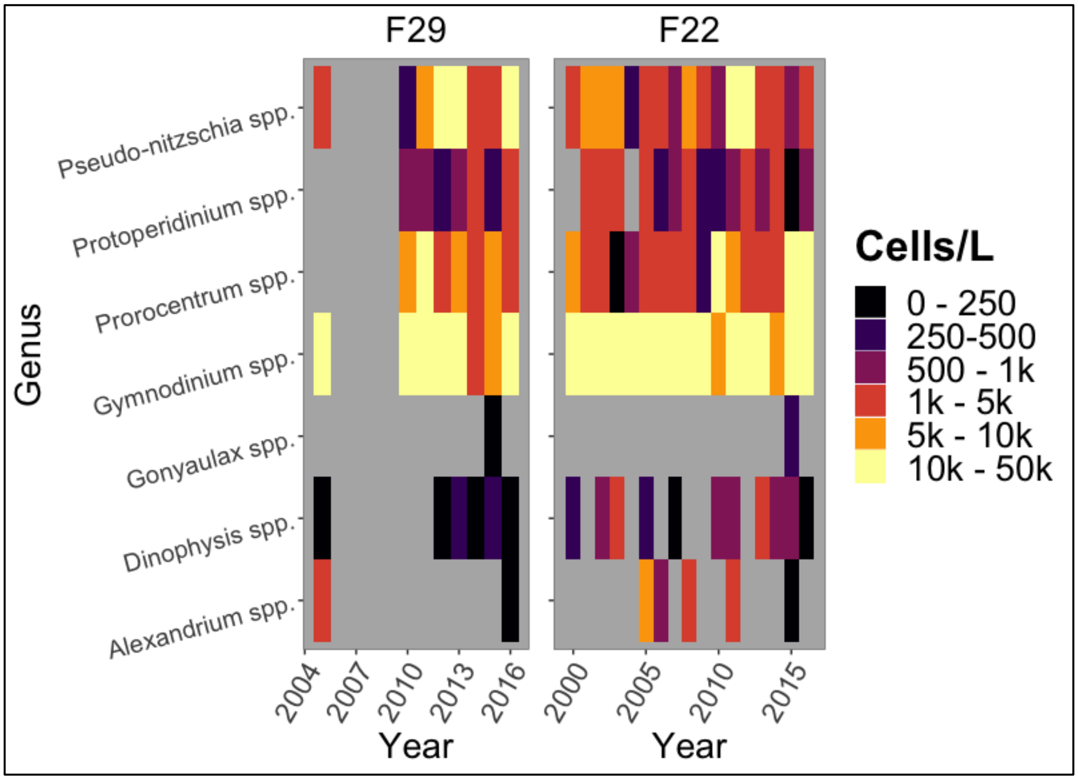


Figure S.WQ.7.1. Yearly average cell counts of toxigenic algae genera at two MWRA ambient monitoring stations. Grey area indicates the species was not observed. While there is no clear trend associated with cell counts of toxigenic algae species over time, several types of toxigenic algae occur regularly or semi-regularly in cell count surveys conducted at MWRA stations F29 and F22, in or directly adjacent to SBNMS waters. Image: MWRA monthly surface phytoplankton count data, stations F29 and F22. MWRA data courtesy of Kenneth Keay and Douglas Hersh

8. Have recent changes in climate altered water conditions and how are they changing?

Status Description: Climate-related changes have caused measurable, but not severe, degradation in some attributes of ecological integrity.

Rationale: Climate change is influencing the primary production cycle in the region, and has the demonstrated capacity to produce cascading effects within the ecosystem. Additional changes in water temperature, dissolved oxygen, stratification, sea level, precipitation, and storm activity have been documented or modeled, with some suggestion of changes in pH, though more monitoring is needed to more robustly identify acidification trends and effects.

This question is new and was not assessed in the 2007 condition report. SBNMS, as part of the Gulf of Maine, is one of the fastest warming regions around the globe. The current rating is based on changes in the phenology and distribution of fish, plankton, and other organisms that are being observed and attributed to climate change (Staudinger et al. 2019, Pershing et al. 2015, Nye et al. 2009), all of which are affecting production and food web dynamics within the ecosystem.

Climate change impacts have manifested regionally in remarkable and dramatic ways. Overall, the Gulf of Maine is warming 99% faster than the global ocean. This 1.5°C/decade temperature increase is likely due to the influence of decadal-scale cycles and the northward shift of the Gulf Stream (Pershing et al.

2015, Thomas et al. 2017). The Gulf of Maine is experiencing areas of increasingly warmer surface water and decreases in areas of cold water since 1980 (Figure S.WQ.8.1, NEFSC 2017a). Using monitoring data from the MWRA monitoring site in SBNMS, linear regression of yearly average water temperature data suggests increases in both surface water and bottom water commensurate with regional trends (Figure S.WQ.8.2). Seasonal water temperature changes have also been documented in the Gulf of Maine, with recent research suggesting an earlier summer start date, a later summer end date, and longer summer length based on data from a 33-year period (Thomas et al. 2017). Recent national predictions also suggest average annual air temperatures in the northeast may increase between 3.98 and 5.09°F as early as 2036 (Wuebbles et al. 2017).

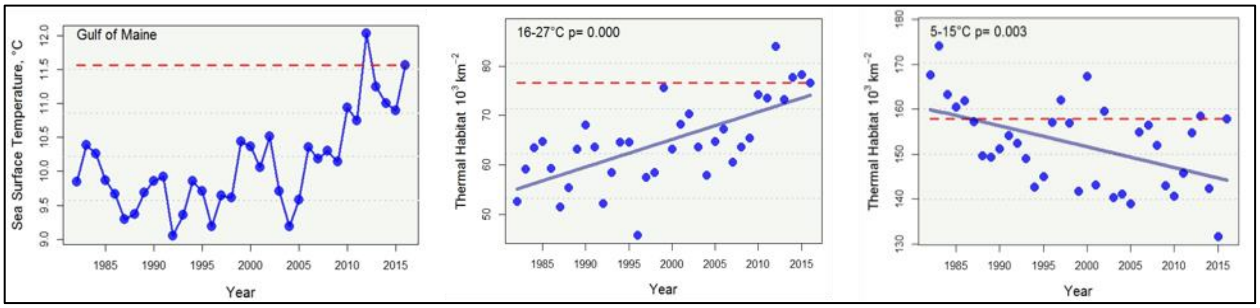


Figure S.WQ.8.1. Changes in sea surface temperature and thermal habitat area over time. Red dashed line indicates 2016 data. Image: NEFSC 2017b

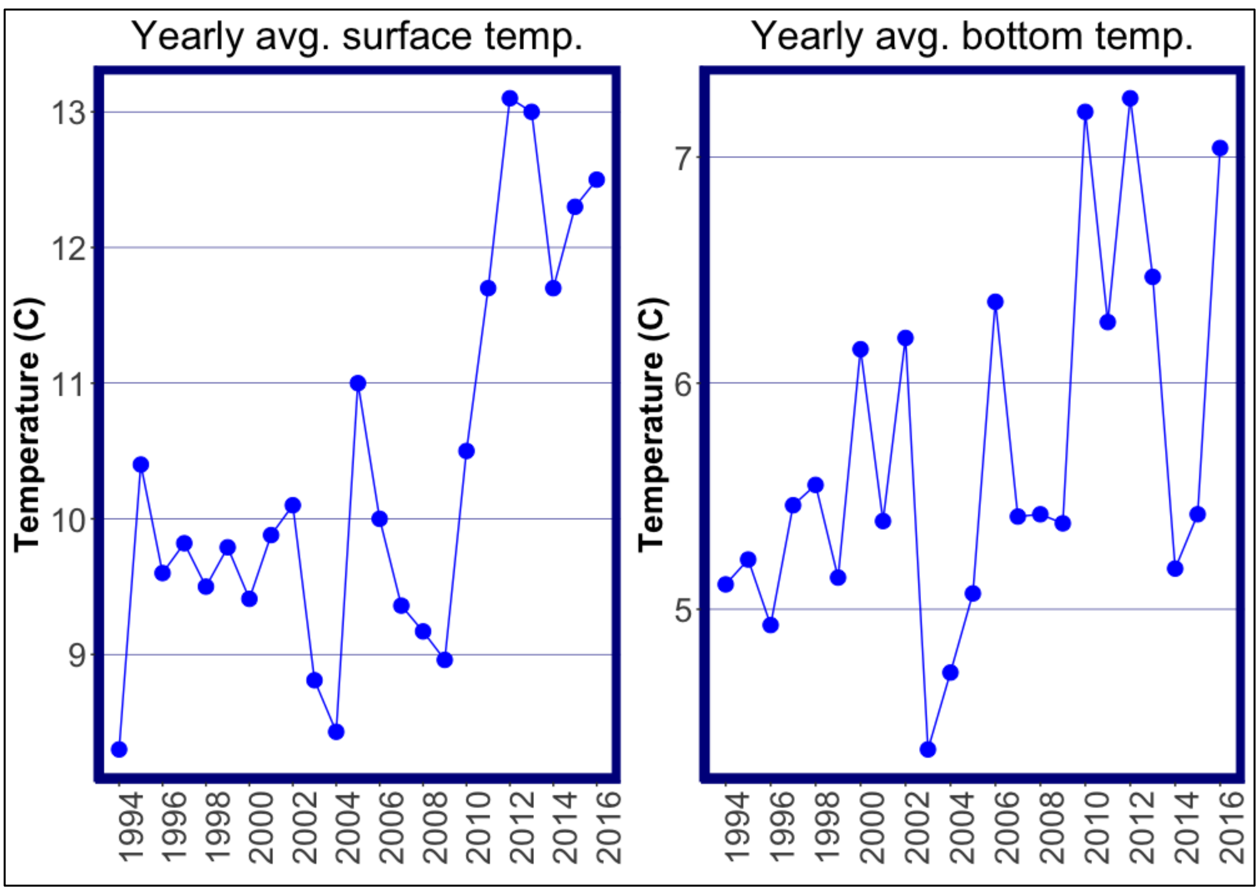


Figure S.WQ.8.2. Plot displaying average yearly surface water (left panel) and bottom water (right panel) temperatures observed at F29, the MWRA monitoring station on the southern boundary of SBNMS. Image: MWRA yearly average nutrient data, stations F02, F06, F29, F22, and N20. MWRA data courtesy of Kenneth Keay and Douglas Hersh

Dissolved oxygen concentrations have decreased over time in SBNMS and Massachusetts Bay according to MWRA monitoring data. This may be due to sampling artifacts or related to the reduced capacity of warmer water for oxygen. Note that decreased oxygen concentrations are likely not yet ecologically relevant, as bottom water consistently maintains saturation levels above 80% based on MWRA monitoring data (Libby et al. 2017).

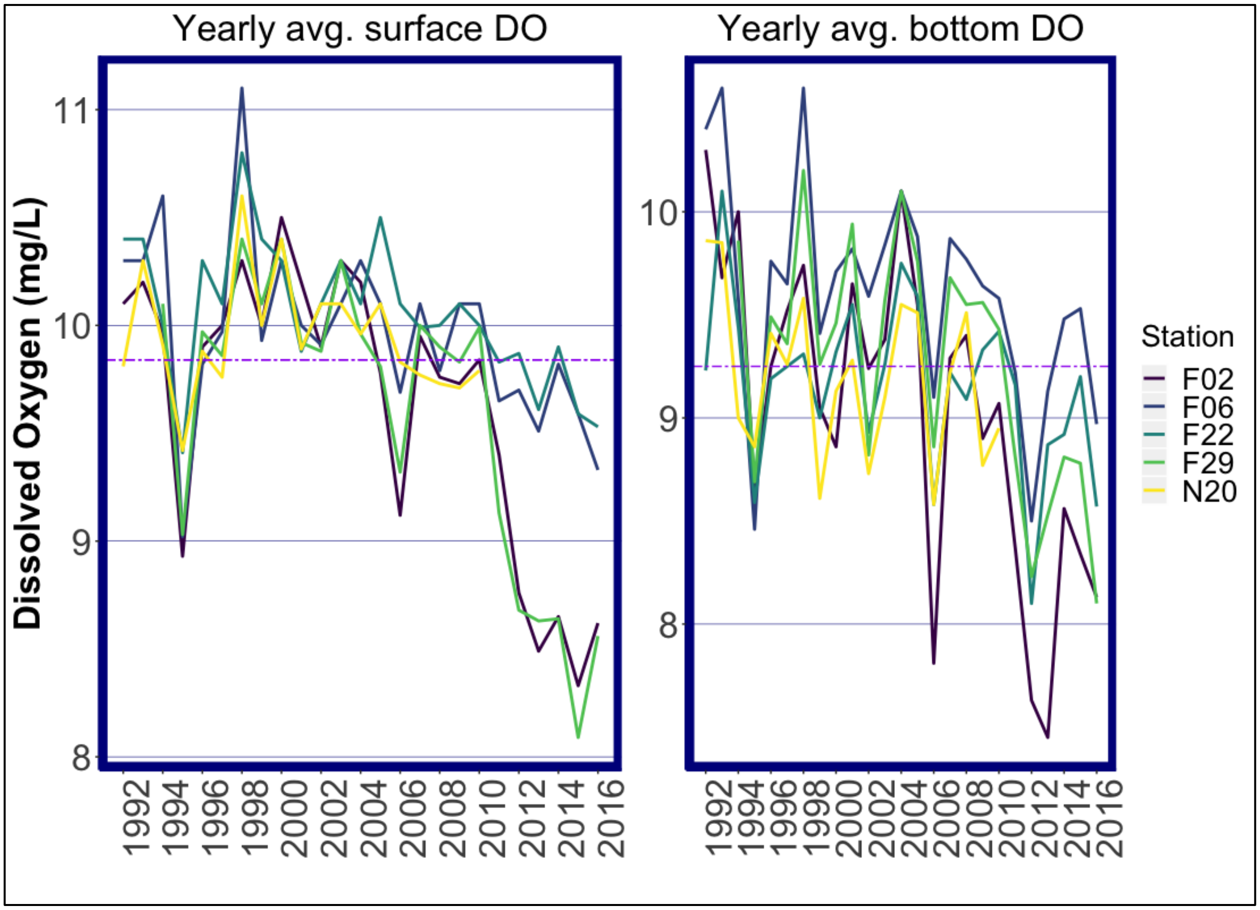


Figure S.WQ.8.3. Plot displaying average annual surface (left panel) and bottom water dissolved oxygen (DO) concentrations (right panel) observed at five MWRA monitoring stations in Massachusetts Bay, with the purple line depicting the mean dissolved oxygen level observed over the time series. Image: MWRA yearly average nutrient data, stations F02, F06, F29, F22, and N20. MWRA data courtesy of Kenneth Keay and Douglas Hersh

Climate change is also likely affecting primary production within SBNMS and the surrounding offshore environment, with uncertain cascading effects within the regional food web (McManus et al. 2014, Costa et al. 2017, Libby et al. 2017). Discharge from the Merrimack River has been demonstrated to strongly correlate with conditions associated with key climate indices, the Atlantic Multidecadal Oscillation, and the North Atlantic Oscillation, with greater than average river discharge anticipated in future (Berton et al. 2017). Climatically-mediated river discharge from the Merrimack and other coastal rivers, Western Maine Coastal Current intrusion, wind stress, and inflow contributions to the greater region from low-salinity Scotian Shelf waters act to freshen the surface layer and increase stratification, producing variable and dynamic levels of primary production and nutrients (McManus et al. 2014, Townsend et al. 2015).

The Northeast is expected to experience higher rates of sea level rise by 2100 compared to the global average (NEFSC 2017b, Wuebbles et al. 2017). Massachusetts coastlines are projected to experience an average sea level rise of 2.83 mm/year. Cape Cod and outlying islands are particularly at risk in terms of sea level rise (NOAA 2019b). The offshore location of SBNMS insulates it from direct effects of sea level rise. It is unclear how inundation of coastal areas and changing sediment sources/transport may impact offshore environments in Massachusetts Bay.

The Gulf of Maine region is particularly susceptible to ocean acidification, due to poor buffering capacity and existing low calcium carbonate concentrations as a result of substantial freshwater and low-salinity inputs from coastal rivers and Scotian Shelf flow (Gledhill et al. 2015, Townsend et al. 2015, Wang et al. 2017). However, recent increases in the temperature and salinity of the Gulf of Maine as a result of the northward shift in the Gulf Stream appear to be buffering against the impacts of ocean acidification on pH and aragonite saturation state (Salisbury and Jönsson 2018). Regional work has demonstrated that inorganic carbon concentrations are determined by seasonal cycles driven by primary production-respiration dynamics, with apparent $CaCO_3$ dissolution in bottom water during fall and winter (Wang et al. 2017). A pilot study in SBNMS from December 2011–June 2012 indicated decoupling of surface and bottom water pCO_2 in response to the spring bloom, with corresponding decreases in bottom water pH and calcium carbonate saturation state, a derived index of carbonate ion availability (SBNMS 2013). Sustained ocean acidification may result in sustained subsurface aragonite undersaturation across the region in 30–40 years, with variable and uncertain consequences for water quality or shell-forming invertebrates in SBNMS and the greater Gulf of Maine (Gledhill et al. 2015, Ekstrom et al. 2015, Wang et al. 2017). More robust monitoring incorporating both surface and bottom water measurements is necessary across SBNMS and the wider region to understand acidification trends, seasonal fluctuations, and possible ramifications for shellfish and the larger ecosystem.

A warming atmosphere and ocean also translates to increased water vapor in the atmosphere, impacting precipitation and tropical cyclone activity. In the northeast, the annual maximum daily precipitation was 17% higher between 1981 and 2015 than it was in the years between 1901 and 1960, while extreme precipitation from 1996-2014 was 53% higher than 1901-1995 (Figure S.WQ.8.5, Huang et al. 2017, Wuebbles et al. 2017). Though numbers of tropical cyclones are predicted to remain the same or even decrease globally, tropical cyclone intensity has increased over the past 40 years as illustrated by the doubling of the number of category 4 and 5 tropical cyclones since the 1970s. Moreover, more storms are predicted to track poleward under current emission and temperature change scenarios, likely translating to increased tropical activity reaching SBNMS and the greater North Atlantic (Tamarin-Brodsky and Kaspi 2017, Wuebbles et al. 2017). It is uncertain how increased hurricane and tropical storm exposure may impact local resources and processes.

9: Are other stressors, individually or in combination, affecting water quality, and how are they changing?

Status Description: Undetermined

Rationale: Ongoing contaminant monitoring has focused on a handful of legacy contaminants, leaving the majority of emerging organic contaminants unmeasured. No data exists to determine changes over time, which is the primary factor driving the rating and trend. More monitoring is needed in this area.

In the 2007 condition report, this question was rated “good/fair” and “not changing.” Since that report, limited data has emerged to document other water quality stressors. Sediment monitoring has indicated concentrations of man-made organic contaminants and metals have decreased or remained steady in the SBNMS region. Both modeling and observational work indicate that dredge material and any associated contaminants remain confined within disposal sites, and are not likely to impact water quality. However, ongoing contaminant monitoring has focused on only a handful of legacy contaminants, leaving the majority of emerging organic contaminants unmeasured, with no indication of how they may be changing in the system, which is the primary uncertainty driving the “undetermined” rating for status and trend for this question.

As an offshore region adjacent to urbanized margins, SBNMS is subjected to a variety of stressors with variable influence on observed water quality. Anthropogenic contaminants, wastewater discharges, and vessel discharges are stressors of particular relevance that may impact water quality within the sanctuary.

Current organic pollutant monitoring by MWRA within the region entails sediment sampling and measuring legacy hydrophobic chemicals that readily adsorb to particles and prefer to remain particle-bound (versus dissolved). Few data exist on concentrations of dissolved or suspended, particulate-associated hydrophobic pollutants within SBNMS or greater Massachusetts Bay (Dahlen et al. 2006, Nestler et al. 2017). Based on existing sediment monitoring and well-established partitioning behavior of these hydrophobic chemicals, dissolved concentrations of legacy organic contaminants are likely very low and not a significant stressor of water quality within SBNMS (Nestler et al. 2015).

However, there are no data describing dissolved concentrations of emerging contaminants with water-loving or hydrophilic chemistries, such as water repellents (PFASs) or personal care products (Wang et al. 2011, 2017), whose partitioning behavior is poorly understood. Microplastics and nanomaterials are also poorly described in the region. These emerging pollutants have been identified in water samples and biotic tissues regionally and are likely present in SBNMS due to its proximity to urban source areas (Shaw et al. 2009b, Costa 2012, Cantwell et al. 2016a, 2016b). Dissolved concentrations of emerging contaminants are likely below levels associated with acute impacts due to vigorous flushing mechanisms within Massachusetts Bay or possible degradation, but this has yet to be demonstrated empirically (Jones et al. 2005, Corcoran et al. 2010, Zhao et al. 2016). Testing for emerging contaminants by the EPA and the University of Rhode Island will occur in 2019. There are also no data informing how dissolved emerging organic contaminants may be changing over time.

SBNMS receives continued inputs of dissolved trace metals via offshore circulation, the MWRA outfall and other wastewater streams, and seasonally-mediated resuspension from local sediments (Kalnejais et al. 2015). While sediment metal concentrations are characterized within Massachusetts Bay via ongoing

MWRA monitoring, dissolved concentrations are less clearly documented. Modeling work suggests differential distributions of dissolved metals between surface and bottom water, while existing sediment monitoring implies that dissolved concentrations are likely below biologically meaningful thresholds due to generally low sediment concentrations (Li et al. 2010, Nestler et al. 2017, Werme et al. 2015). However, it is unclear how seasonal and climatic cycles impacting relevant physicochemical water column parameters may change the availability of dissolved metals over time (Atkinson et al. 2007).

Effluent volume from the MWRA Deer Island Wastewater Treatment Plant is not significantly increasing over time. Discharge volume mirrors regional rainfall trends, with an increasing percentage of effluent receiving full secondary treatment (Figure S.WQ.9.1, Werme et al. 2017). Additionally, the Merrimack River brings significant and rain-dependent flow to the northern area of the sanctuary; its discharge has the capacity to carry point and non-point source pollution from the large Merrimack watershed, which could threaten SBNMS water quality.

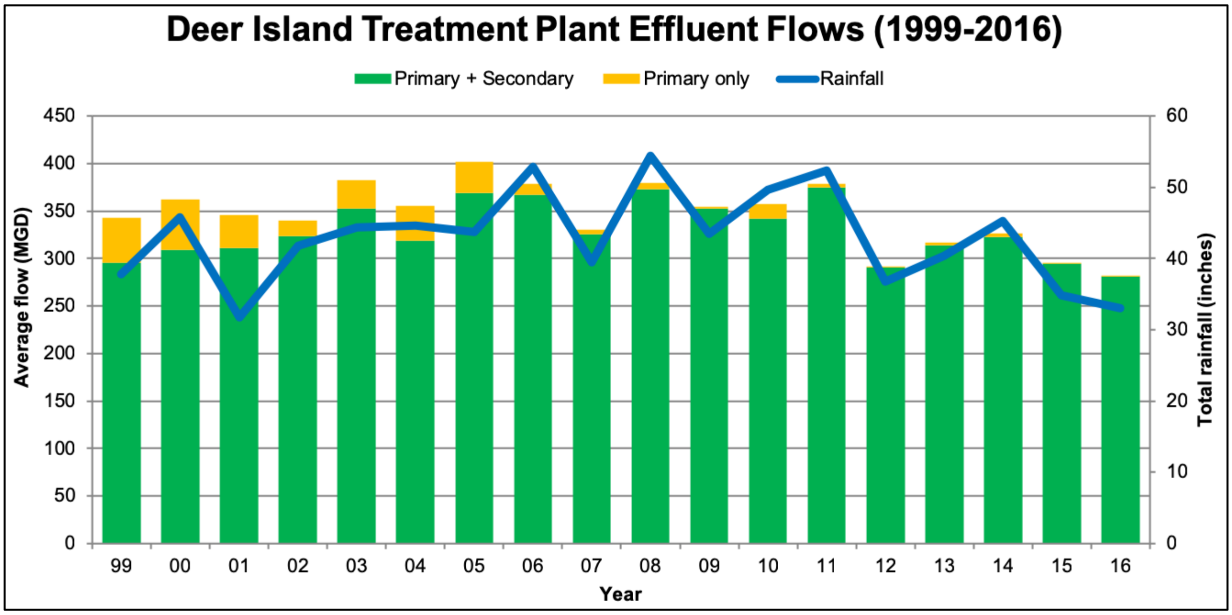


Figure S.WQ.9.1. Average annual effluent discharge volume, in green and yellow, is associated with regional precipitation, tracked in blue. Effluent discharge from the Deer Island Wastewater Treatment Plant has not increased over time. Image: Werme et al. 2017

Disposal of dredge material likely does not pose a threat to water quality, as modeling indicates that disposed sediment remains confined in the disposal area, and only sediment deemed safe for offshore deposition is considered for disposal (USACE 2015). While large commercial and cruise ship discharges have the potential to adversely influence water quality in the sanctuary, there is no data available on the levels of discharges that may be occurring in the sanctuary.

Habitat (Questions 10–11)

The following information provides an assessment of the status and trends of key habitat indicators in SBNMS for the period 2007–2018. Question 10 focuses on the integrity of major habitats within the sanctuary, including biologically (biogenic) and abiotically (physical) structured habitats. Physical habitats are abiotic structures, such as sand waves, mud-draped gravel, and piled boulders. Biogenic habitats are structure-forming species, which create habitat structures used by other living marine resources, including hydroids, anemones, and sponges. Biogenic habitats are layered on top of, and are often determined by, the coincident physical habitat. Changes to both biotic and abiotic habitat can significantly alter the diversity of living marine resources and ecosystem services. Question 11 examines concentrations and variability of contaminants in major sanctuary habitats.

10. What is the integrity of major habitat types and how is it changing?

Status Description: Selected habitat loss or alteration has caused measurable but not severe degradation in some attributes of ecological integrity.

Rationale: Data suggest measurable changes in habitat quality, likely due to the use of bottom-contact commercial fishing gear. Some habitat attributes show degradation, while others show improvement. Significant habitat degradation is observed in isolated areas due to chronic disturbance. Use of bottom-contact gear is intensive in SBNMS, but diminishing due to regulatory controls and fleet consolidation. An increase in scallop dredging started in 2017 and will continue. Seabed disturbance from anchoring and other activities might also be locally important and should be evaluated.

In the 2007 condition report, this question was addressed differently, with abiotic and biotic habitat types assessed separately. Here, major habitat types are assessed collectively.

The sanctuary has a variety of habitats that have been characterized by both geologic attributes and dominant structure-forming species, including sand waves with dense hydroids, shell deposits over sand, mud-gravel with burrowing anemones, gravel with sponges, and piled boulders with dense invertebrates. The organisms that contribute to elements of habitat complexity are vulnerable and sensitive to direct disturbance (Figure S.H.10.1).

The condition of major habitat types within the sanctuary is widely affected by human activities, with lower levels of direct impacts in the Western Gulf of Maine (WGOM) Closure Area, which overlaps the sanctuary. Information suggests measurable changes in habitat quality over the past ten years (see below), primarily due to bottom-contact gear used in commercial fishing. Impacts to habitat are both direct (from disturbance by fishing gear) and indirect (from shifts in trophic and competitive interactions that affect populations of structure-forming species). Fishing effort is not uniform across the sanctuary and is more intensive in certain productive areas. Overall fishing effort in the sanctuary has decreased since 2009, partly as a result of sector management implementation in 2010 as part of the Northeast Multispecies Fishery Management Plan (see Figs. S.P.3.1 and S.P.3.2). There was a significant increase in scallop dredging in the northern end of the sanctuary in 2017 but, as a result of actions taken by the NEFMC and GARFO, this effort was significantly reduced in 2018. Seabed disturbance from anchoring of recreational fishing vessels might also produce locally important impacts and should be evaluated. Also, evidence of disturbance in the WGOM Closure Area suggests that impacts from bottom-tending mobile gear (Auster 2015 and see discussion below) have resulted in some habitat degradation there.

Effects from the installation of the Hibernia Atlantic fiber-optic cable in 2000 appear to be minimal. Changes to local topography persist along deeper, coarser-grained parts of the cable route, but burial was complete in shallower, finer-grained sediments, and community structure in habitats on and off the cable is similar.

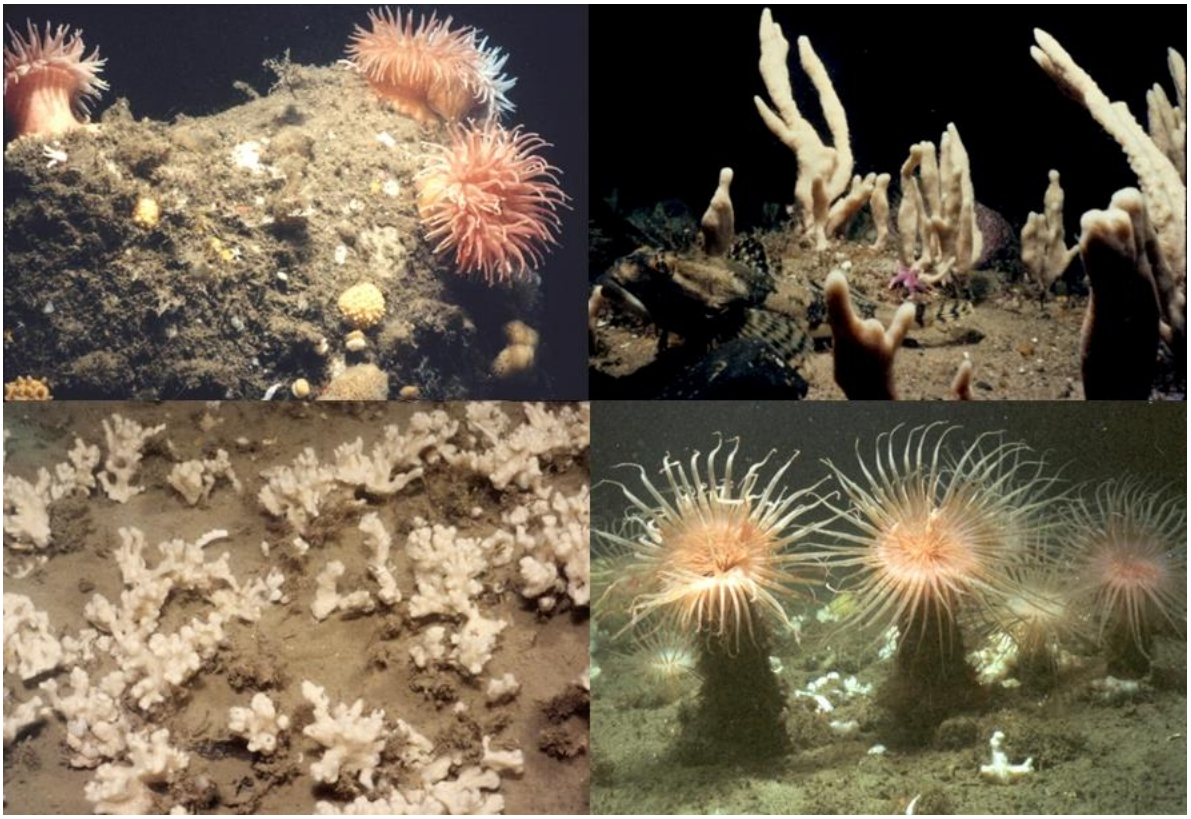


Figure S.H.10.1. Examples of biogenic habitats in SBNMS. Clockwise from top left: boulder with attached epifauna, sponge community on sand-gravel ridge, burrowing anemones in mud-draped gravel, sponge attached to hydroid skeletons on mud-draped gravel. Photos: P. Auster/University of Connecticut and Seafloor Habitat Recovery and Monitoring Project Science Team

Fishing gears in aggregate demonstrably alter the structure of marine habitats and influence the diversity, composition, biomass, and productivity of the associated organisms in the SBNMS region (Auster et al. 1996, NRC 2002, Collie et al. 2017). These and other studies have found that chronic and widespread use of bottom-contact fishing gear significantly impacts all habitat types and reduces vertical relief and structure. The structure of shallow, mobile sand habitats tends to recover faster than deep boulder and mud areas (i.e., months versus years to decades). However, during recovery from disturbance, the functional role of even highly resilient habitats may be diminished (Auster and Langton 1999). Further, indirect effects from removal of predators by fishing (e.g., cod, wolffish, cusk, haddock, flounders) have a potential to alter top-down controls of species (e.g., predatory sea stars, urchins, crustaceans) that affect structure-forming invertebrate species (e.g., sponges, hydroids, bivalves).

Fishing effort across the northeast U.S. continental shelf has declined for over a decade (NEFMC 2014b). However, fishing affects nearly all areas of the sanctuary and makes all habitats vulnerable to direct and indirect impacts. Fishing effort persists within the sanctuary where bottom-tending mobile gear is allowed and exceeds habitat-specific recovery rates based on a gear-impact model, precluding full recovery (NEFMC 2014b). Some research suggests that even habitats that can rapidly recover from fishing impacts cannot sufficiently meet the ecological requirements needed by early demersal fish after they settle to the seafloor, which may suggest long-term impacts of fishing on sanctuary habitats (Auster and Langton 1999).

The Seafloor Habitat Recovery and Monitoring Project was designed to investigate and compare the recovery rates of seafloor habitat (both physical and biogenic) and associated taxa (such as fish) following natural and anthropogenic disturbance (e.g., a single acute impact from a fiber-optic cable installation and chronic impacts from a range of fishing activities) (Auster et al. 2013b). This program was initiated in 1998 following the designation of the WGOM Closure Area by the NEFMC. Seafloor Habitat Recovery and Monitoring Project results indicated that a complex system of natural and human-caused drivers of habitat change are at play (Auster et al. 2013b). Of significance, the study found that communities of epi- and emergent fauna were dynamic over the 1998–2010 sampling period (Figure S.H.10.2), and while communities both inside and outside the WGOM Closure Area changed over time, there was still a clear and significant effect of the closure on species abundance and community structure across all major habitat types (sand, mud, gravel, and piled boulder). Also, in the twelve years following closure, communities inside the closed area had not reached a stable climax state, suggesting that these communities do not exhibit successional change (i.e., recovery without resilience). Finally, infaunal communities in deep mud habitat exhibited a clear response to closure, while those in shallow sand were more stochastic.

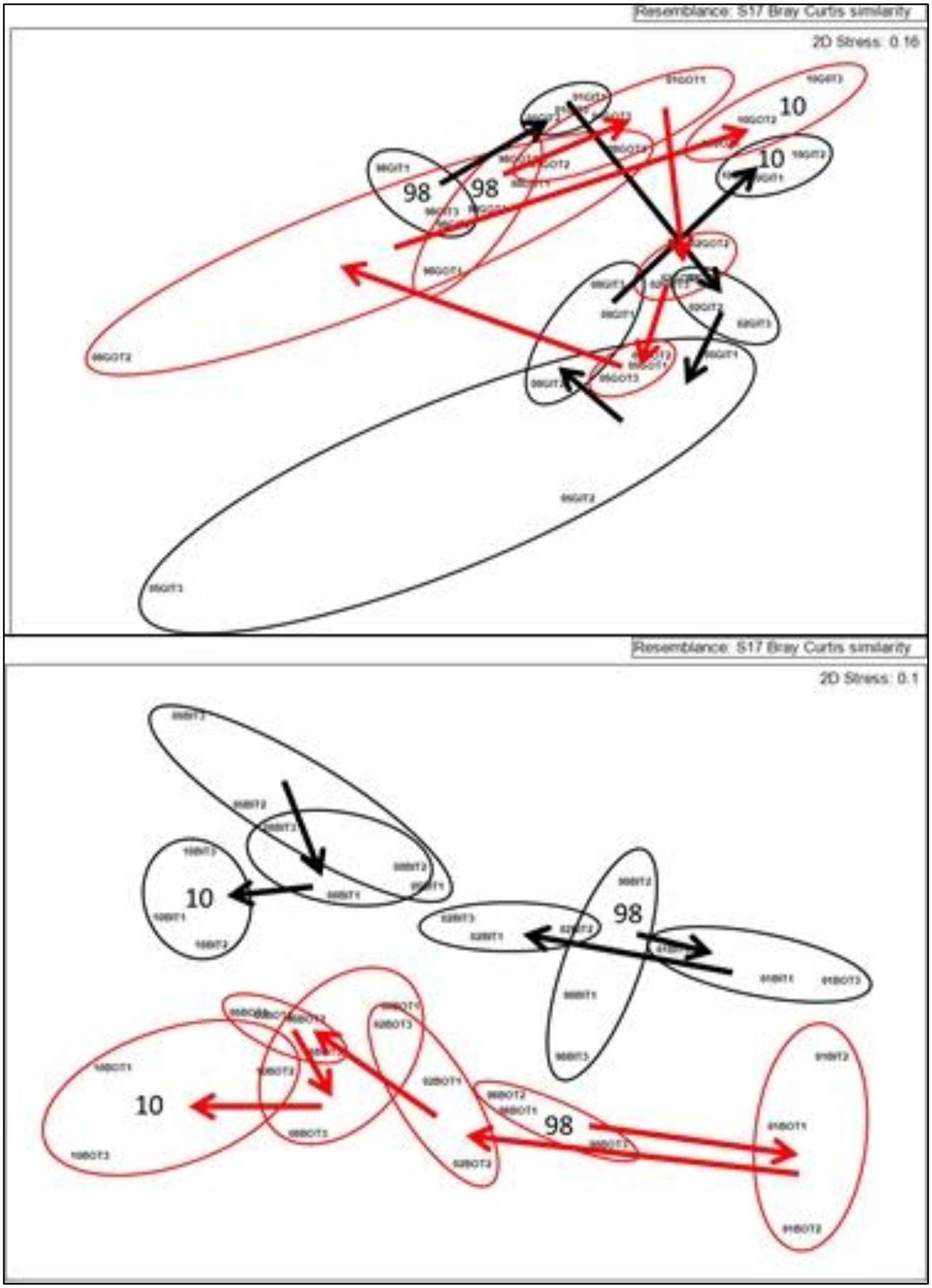


Figure S.H.10.2. Non-metric multidimensional scaling plots based on community structure from 1998–2010 in gravel habitats (top) and boulder habitats (bottom). These plots visualize similarity-dissimilarity in species composition based on relative distances in two-dimensional space. Stations from each year and inside or outside the WGOM Closure Area are grouped in circles, with trajectories tracked by red (outside) and black (inside) arrows. Differences between years as well as between inside outside are notable over time. Image: Auster et al. 2013b

Auster et al. (2013b) also identified trends in composition and distribution of particular structure-forming species and groups relative to the closed area, further suggesting differential impacts due to fishing levels (Figure S.H.10.3). For example, structure-forming taxa recovered both inside and outside the closed area, although different taxa were dominant in each. Increases in species diversity at stations within the WGOM Closure Area were not observed by the end of the study period, suggesting that community recovery draws from a regional species pool and patterns of abundance vary based on local patterns of disturbance.

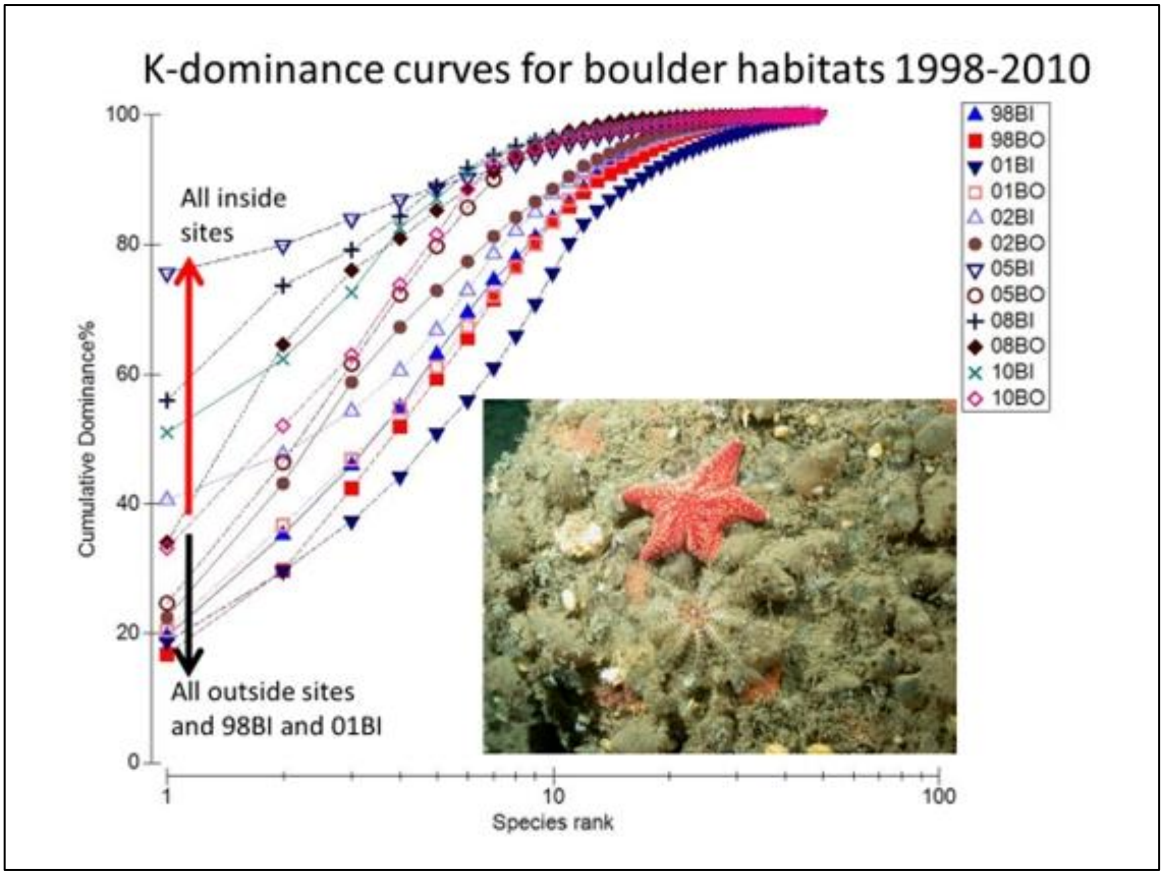


Figure S.H.10.3. Patterns of numerical dominance for invertebrate species in boulder habitats over time (1998–2010) for sites inside and outside the WGOM Closure Area (ordered most to least abundant from left to right). It is notable that some species inside the closed area increased in dominance (abundance) over time since closure, indicative of small-scale processes of competition and predation as drivers of community structure, while physical disturbance remains a driver for communities outside the closure. Image: Auster et al. 2013b

Subsequent imaging surveys from 2013–2015 (Figure S.H.10.4) revealed that while the seafloor community of habitat-forming species has been dynamic, the condition of the community in 2015 essentially mirrored that found at the time of closure in 1998 (i.e., a gravel pavement with virtually no biological structure; Auster 2015). The large-scale nature of this disturbance suggests intermittent impacts from bottom-contact fishing gear.

Other more northerly, deeper sites within WGOM Closure Area and just east of the sanctuary boundary were surveyed in 2015 to assess changes in sea pen density following the closure in 1998. Seafloor communities appeared to have been impacted recently based on sector-scanning sonar records of gear marks on the seafloor and the species observed (Auster 2015). These sites may have been fished after the initial closure, but estimating the times of those impacts is difficult.

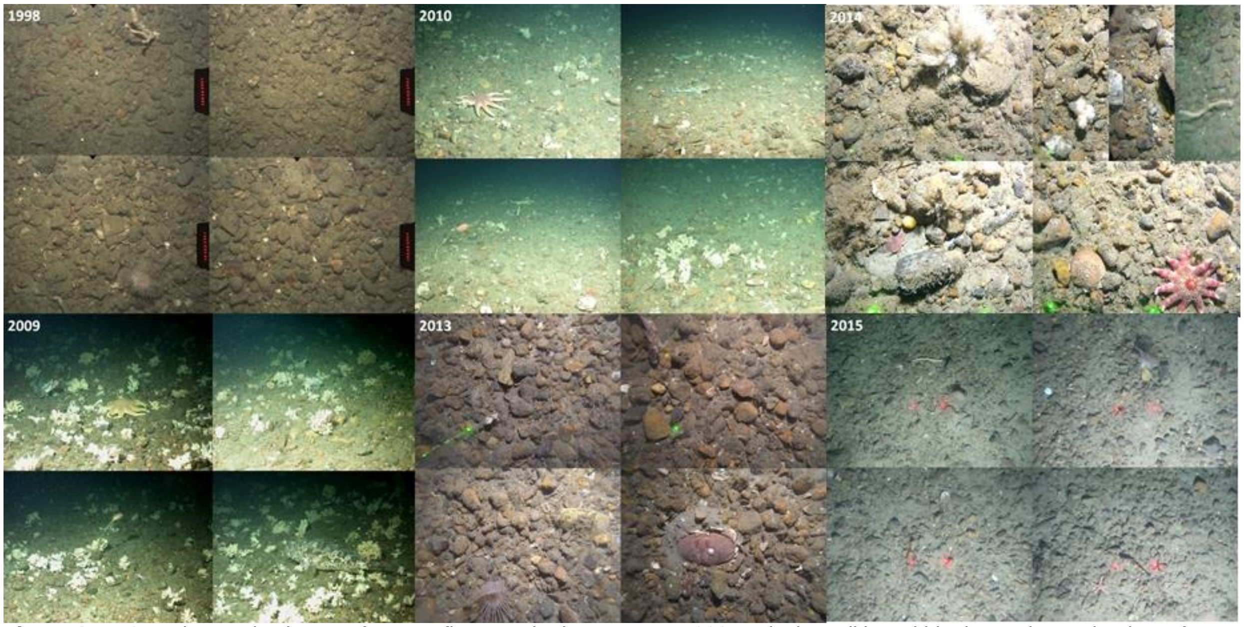


Figure S.H.10.4. Time series images from seafloor monitoring surveys. 1998: typical condition within the station at the time of closure. 2009: state of recovery in the seafloor invertebrate community eleven years after closure with high coverage of emergent and structure-forming fauna. 2010: apparent impacts to the community; it is unclear whether this represents ecological versus anthropogenic effects. 2013-2014: structure-forming fauna generally absent with some coverage of early recruits. 2015: the community was highly disturbed, but with conditions comparable to maximal fishing effects from 1998 at time of closure. No obvious ecological process would produce this pattern. Photos: Auster 2015

11. What are contaminant concentrations in sanctuary habitats and how are they changing?

Status Description: Undetermined

Rationale: Legacy contaminants have been reported in benthic habitats. However, they infrequently exceed thresholds of concern, do not appear to remobilize beyond sites where they have been identified (e.g., MBDS), and no indications of acute life history or population effects have been observed. Compounds of emerging concern are present, but poorly documented or monitored; thus, their status and trends could not be assessed. More monitoring is needed in this area.

In the 2007 condition report, this question was rated “good/fair” and “not changing”. The current undetermined ratings primarily stem from the abundance of unknowns surrounding contaminant occurrence, trends, and biological effects. MWRA and other regional monitoring has demonstrated the continued, low-level presence of legacy contaminants in benthic habitats, occasionally at concentrations above established regulatory thresholds of low concern. Legacy contaminants in sediments do not appear to be subject to remobilization or transport beyond sites where they have been identified (e.g., MBDS), and there are currently no indications of acute life history or population effects related to legacy contaminant exposures despite demonstrated bioaccumulation in regional fauna. However, biological impacts of contaminants are particularly difficult to parse out in wildlife and marine systems given the abundance of other abiotic and biotic stressors, compounding uncertainty related to assessing contaminant degradation in the sanctuary habitat. Compounds of emerging concern are also present in sanctuary habitats and biota, but are not well-documented or effectively monitored; limited information suggests that emerging contaminant concentrations may be shifting or increasing with continued introduction of new chemicals to replace regulated compounds. Therefore, status and trends of these emerging compounds could not be assessed with the limited information available.

Contaminant concentrations in SBNMS sedimentary habitats are dynamic. Observed concentrations reflect the influence of local, regional, and global processes that distribute pollutants via atmospheric, particulate, or water-based transport at different time scales. Compound-specific partitioning and degradation pathways also determine environmental distribution and possible biological activity.

MWRA monitors locations across the nearshore-offshore continuum for sediment condition and infauna community structure annually, and sediment contaminant levels are determined every three years (Rutecki et al. 2017). This ongoing program, in combination with additional regional monitoring of sediments and biota, provides a relevant dataset describing concentrations of metals and selected organic contaminants. Regional monitoring of sediments indicates low yet persistent concentrations of metals, such as mercury, and legacy persistent organic pollutants (POPs), such as PAHs, PCBs, and organochlorine pesticides (OCPs) (Figures S.H.11.1—S.H.11.2, Nestler et al. 2015, Sunderland et al. 2012, Kimbrough et al. 2009). Most metals and legacy POPs continue to decrease or remain steady within SBNMS, as documented at one current MWRA monitoring site within sanctuary boundaries. These local trends are commensurate with declines seen regionally and worldwide, as stringent regulation translates to decreased or negligible environmental inputs of many metals and legacy POPs (Zhao et al. 2017b, Werme et al. 2015, Nestler et al. 2015).

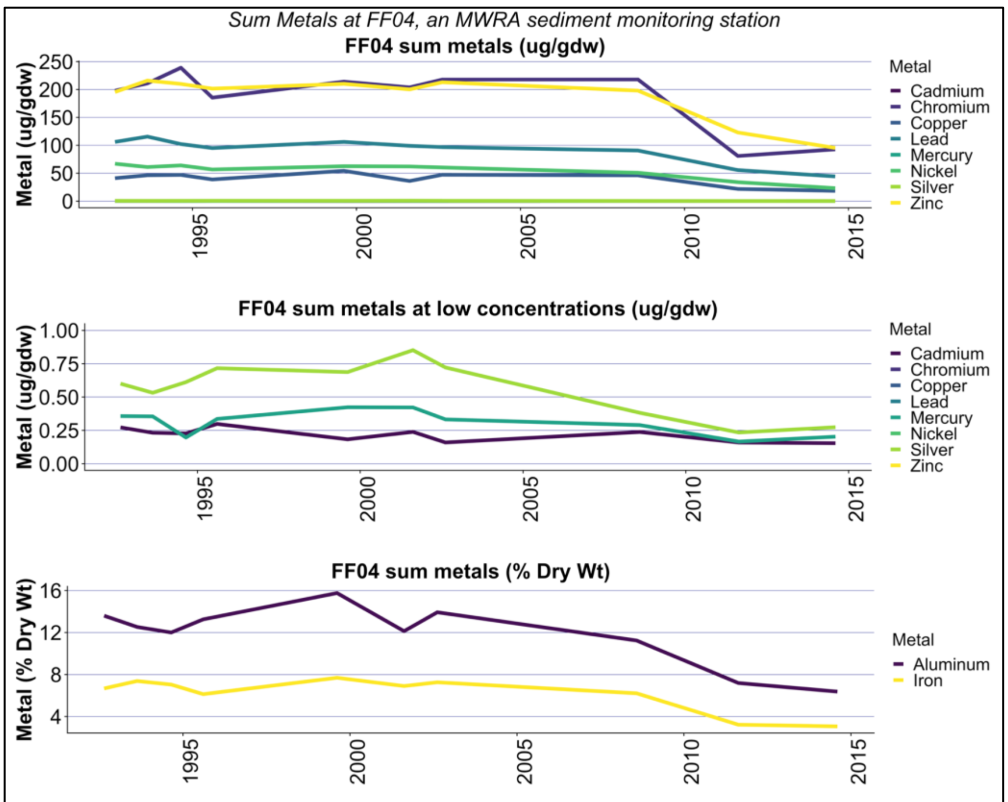


Figure S.H.11.1. Sum metal concentrations have decreased over time at the MWRA monitoring station in SBNMS (FF04), according to MWRA monitoring data. Images: MWRA sediment chemistry data, stations FF04, FF09, FF01A, NF12. MWRA data courtesy of Kenneth Keay and Douglas Hersh

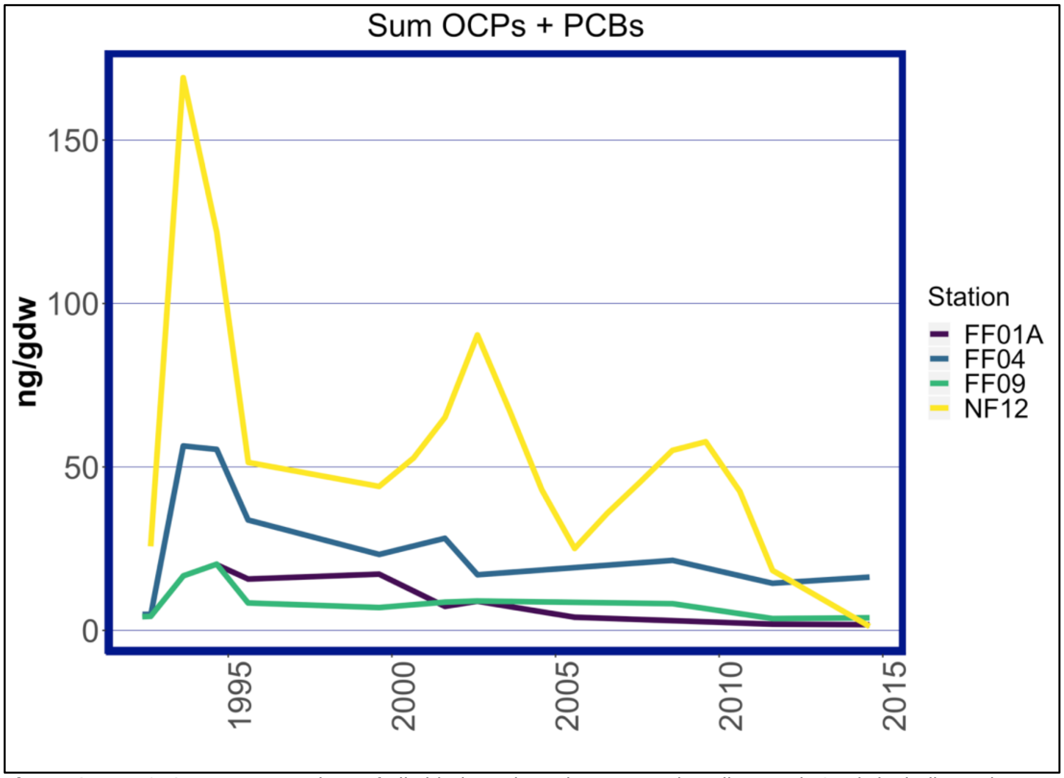


Figure S.H.11.2. Sum concentrations of all chlorinated persistent organic pollutants (POPs), including select organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs), in sediment at four MWRA benthic monitoring stations across Massachusetts Bay; FF04 is the station within SBNMS. Image: MWRA sediment chemistry data, stations FF04, FF09, FF01A, NF12. MWRA data courtesy of Kenneth Keay and Douglas Hersh

Biotic monitoring also indicates sustained concentrations of metals and legacy POPs. Some regional studies of mussels, fish, pinnipeds, and cetaceans indicate significant tissue burdens of metals and/or legacy POPs, suggesting these compounds remain relevant in the offshore food web, are capable of bioaccumulation, and, in some cases, exceed estimated immunotoxicity thresholds (Nestler et al. 2016, Shaw et al. 2014, 2009b, 2005, Sunderland et al. 2012, Elfes et al. 2010, Kimbrough et al. 2009).

Additionally, a plethora of emerging contaminants remain uncharacterized within the Massachusetts Bay environment and food web, including per- and polyfluorinated substances, novel flame retardants, plasticizers, pharmaceuticals and personal care products, endocrine disrupting compounds, currently used biocides, and more. Few studies have documented various compounds regionally in water, sediment, or biota, and there is no substantial understanding regarding their presence, risk, or trends in SBNMS (Cantwell et al. 2016a, Costa 2012, Kimbrough et al. 2009, Shaw et al. 2009a, 2009b, Kolpin et al. 2002). Limited existing data suggest emerging contaminants are probably present within the overall Massachusetts Bay habitat, likely at low concentrations, with uncertain biological ramifications.

No data were found detailing concentrations of microplastic particles or fibers in SBNMS sediments, or how plastic levels may be changing over time; this is a major data gap, considering marine sediments are a major sink for microplastic pieces (Woodall et al. 2014). Surface water concentrations confirm the presence of microplastic contamination in the region. Surface tows between 1986–2008 suggest Gulf of Maine surface water concentrations of 1534 +/- 200 plastic pieces per square kilometer, an order of magnitude lower than concentrations observed in the North Atlantic subtropical gyre (Law et al. 2010, Eriksen et al. 2014).

Concentrations of *Clostridium perfringens*, an anaerobic bacterium that acts as a tracer of wastewater effluent influence in sediments, have remained low or declined within SBNMS and at other offshore locations since outfall diversion. Observed concentrations are comparable to baseline levels at MWRA monitoring sites in and around SBNMS following the relocation of the outfall in 2000, suggesting that discharge from the outfall has minimal impact on bacterial loads in SBNMS sediments (Nestler et al. 2015, 2017).

Living Resources (Questions 12 –15)

The following information provides an assessment of the status and trends of key living resource indicators in SBNMS for the period 2007–2018. Most benthic invertebrate species are not included in the living resources section because they are covered in the habitat section of this report (Questions 10 and 11). However, major species groups that function as structure formers are considered here as foundation species. Rare invertebrates are considered under the topic of biodiversity.

Keystone species and foundation species are the focus of Question 12. Both are important components of the ecosystem, as the persistence of a large number of other species depends on them. They are differentiated by their numerical abundance or biomass.

- A "keystone" species has a disproportionately large effect on its environment relative to its abundance (Cottee-Jones and Whittaker 2012). It plays a critical role in maintaining the structure of its ecological community and helping to determine the types and numbers of various other species in the community. As such, keystone species are often called "ecosystem engineers" and can include habitat creators (e.g., corals, kelp), predators that control food web structure (e.g., Humboldt squid, sea otters), herbivores that regulate benthic recruitment (e.g., certain sea urchins), and those involved in critical symbiotic relationships (e.g., cleaning or cohabitating species). In the 2007 condition report, cod was considered a keystone species at SBNMS; however, based on the findings of Link et al. (2009), it is not considered a keystone species in this report. Cod are, nevertheless, focal species (see Question 13), as they have tremendous cultural value, have historically played an important role in the Gulf of Maine ecosystem, and remain an important species in fisheries management. There has been some scholarly debate about the role of American lobster (*Homarus americanus*) as a keystone predator in the coastal regions of the Gulf of Maine, but ultimately the evidence for such a role is inconclusive (Elner and Vadas 1990). However, local context in terms of community composition and associated species interactions is important for identifying such roles (Power et al. 1996).
- "Foundation" species are those that define much of the structure of a community by creating locally stable conditions, such as providing primary prey for local predators or serving as biogenic habitat (sensu Dayton 1972). The loss of foundation species will acutely and chronically impact food webs, fluxes of energy and nutrients, and biodiversity. In this report, calanoid copepods, Atlantic herring, sand lance, sponges, and anemones are identified as foundation taxa within the greater SBNMS ecosystem.

"Other focal species" are the focus of Question 13. SBNMS staff selected a set of indicator species that are described in the response for this question — North Atlantic right whales, humpback whales, harbor porpoises, Atlantic white sided dolphins, great shearwaters, lobsters, tuna, and Atlantic cod.

Question 14 focuses on assessing the impacts of non-indigenous species. Also called alien, exotic, non-native, invasive, or introduced species, these are animals or plants living outside their endemic geographical range. Often having arrived in the sanctuary by human activity, either deliberately or accidentally, their abundance in sanctuary habitats along with any known ecological impacts will be discussed.

Question 15 addresses the status of biodiversity, which is defined as variation of life at all levels of biological organization, and commonly encompasses diversity within species (genetic diversity), among species (species diversity), and comparative diversity among ecosystems (ecosystem diversity). Biodiversity can be measured in many ways. The simplest measure is to count the number of species found in a certain habitat or ecosystem, termed species richness. Other indices of biodiversity couple species richness with relative abundance to provide a measure of evenness and heterogeneity. When discussing "biodiversity" in response to Question 15, the report primarily refers to species richness (simply the total number of species) and diversity indices (based on the relationship between the number of species and their abundances). Non-indigenous species were not included in estimates of native biodiversity.

12. What is the status of keystone and foundation species and how is it changing?

Status Description: The status of keystone or foundation species may preclude full community development and function, but has not yet led to measurable degradation.

Rationale: Foundation species considered include Calanoid copepods, Atlantic herring, sand lance, sponges, and anemones. Calanoid copepods have persisted in the western Gulf of Maine despite recent warming. Atlantic herring have recovered from overfishing, but poor recruitment may result in a future decline in biomass. Sand lance are tightly linked to isolated shallow sand habitat on top of Stellwagen Bank and exhibit variable, unpredictable local abundance. The status of sponges and anemones is uncertain.

A direct comparison between the 2018 rating and the 2007 condition report is not possible because this specific question was not previously addressed. However, there were two questions in the 2007 condition report that assessed the status and condition of key species. The status of key species was rated "fair/poor" and "not changing" in 2007 and the health of key species was rated "fair" and "not changing." The ratings in the current report integrate the status and trends for numerous foundation species, but did not include data for cod, as discussed above. This explains, to a large extent, the difference in ratings from the question on key species in the 2007 report. Among the foundation species, data for some taxa are limited, particularly for ecologically important copepods. Sand lance is being monitored, but data are currently insufficient to offer a definitive sense of state and multi-year trends. However, sand lance may be particularly vulnerable to climate change due to their dependence on sand habitat and their potential inability to move into areas with favorable conditions. Sensitivity of Atlantic herring to fishing and spatial restriction of sand lance to sand habitat may both be emerging concerns.

Calanoid Copepods

The copepod *Calanus finmarchicus* is a crucial primary consumer in the Gulf of Maine and a lipid-rich food source for a diversity of ecologically and economically important species. It is one of the most abundant copepod species in the region, and is of special importance in SBNMS as it serves as a vital food source for larval cod and haddock, herring, and sand lance (Figure S.LR.12.1). Dense concentrations of copepods are particularly important for bioenergetics of North Atlantic right whales and have been linked to calving success (Meyer-Gutbrod et al. 2015).

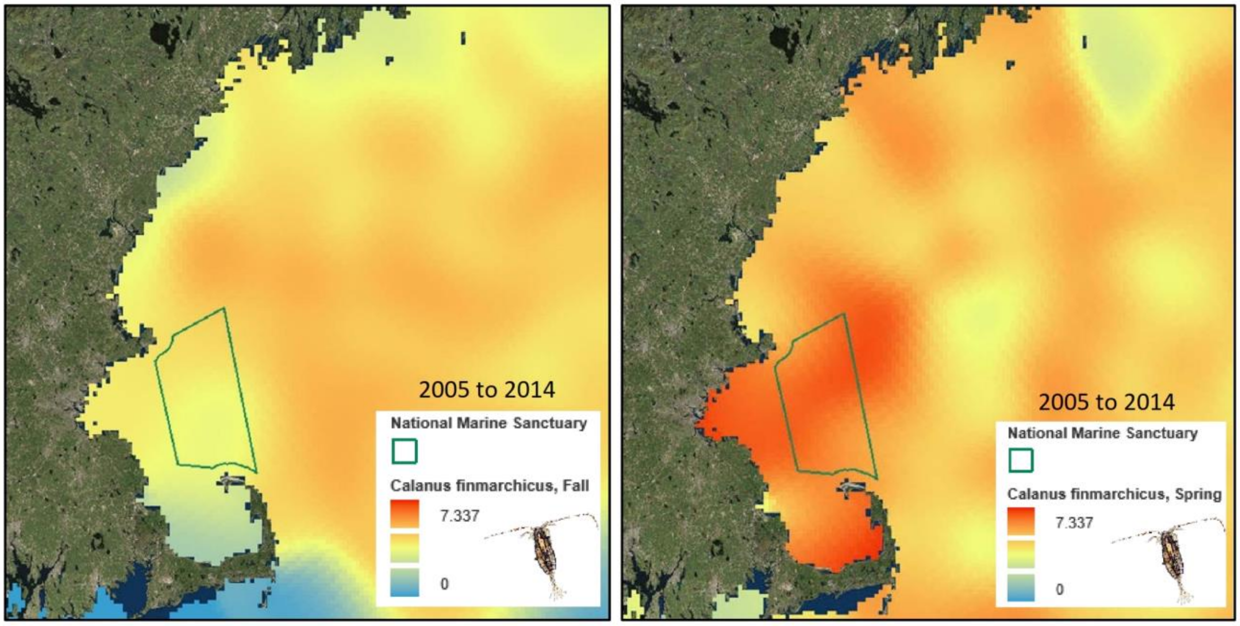


Figure S.LR.12.1. *Calanus finmarchicus* abundance (per cubic meter log-transformed) in fall and spring surveys in the southern Gulf of Maine (2005 – 2014). Images: NEFSC and TNC Northeast ocean data, Pittman 2019

C. finmarchicus undergoes a complex life cycle consisting of six nauplii stages and five copepodite stages before reaching maturity (Marshall and Orr 1972). Each stage relies on multiple habitats, potentially leaving *C. finmarchicus* particularly vulnerable to the effects of climate change. Grieve et al. (2017) demonstrated a general downward trend in *C. finmarchicus* abundance from the early 2000s through 2013 (last year of the time series) and predicted that by 2081–2100 average *C. finmarchicus* density will decrease by as much as 50% under a high greenhouse gas emissions scenario. Results showed these decreases could be particularly pronounced in the Gulf of Maine during spring and summer. Reygondeau and Beaugrand (2011) projected that *C. finmarchicus* would be absent in the Gulf of Maine by 2050–2059. However, Ji et al. (2017) predicted that *C. finmarchicus* could persist in Wilkinson basin (located northeast of the sanctuary) and moderate the effect in SBNMS. Recent warming since the 1980s in the Gulf of Maine and subsequent population responses, including a record spring cohort in 2013 despite record high water temperatures, suggests other mechanisms can maintain persistence (Runge et al. 2014). It is also possible that water temperature-induced changes in the phenology of *C. finmarchicus* development could put the phytoplankton/zooplankton/larval fish production chain out of phase before the copepod becomes absent or severely reduced (Friedland et al. 2015).

Atlantic Herring

Atlantic herring (*Clupea harengus*) is one of the most numerous fish species in the ocean. This species generally occurs in large pelagic schools during the daytime and can reach 45 centimeters (1.1 kilogram) in size. Herring have an important functional role in the northeast U.S. large marine ecosystem as prey (forage) for a diversity of piscivorous species (marine mammals, birds, fish), and as a primary target species in the regional fishery (Applegate et al. 2015). Multiple forage species occur across the northeast

U.S. large marine ecosystem (including sand lance, Atlantic mackerel, squids, and hakes), although herring, sand lance, and mackerel have higher energy content than most other forage species. The ecological role of forage species in general, including Atlantic herring, depends on fish size, density, and school (patch) size, as well as the size, number, and behavior of their predators.

Atlantic herring landings in mobile gear fisheries (trawls and purse seines) peaked in the late 1960s and early 1970s, largely due to efforts from foreign fleets, resulting in severely depleted populations. However, since the implementation of the Magnuson-Stevens Fishery Conservation and Management Act in 1976, Atlantic herring populations recovered at the scale of the northeast U.S. large marine ecosystem. Catch in this fishery was relatively stable during the 2000s, and has accounted for most Atlantic herring catches in recent years, although the contribution has declined from 2010–2015 (Deroba 2015, NEFSC 2018b). Recruitment of juvenile herring (age one) declined dramatically in 2016 and 2017. Four of the six lowest recruitment estimates have occurred since 2013 (Figure S.LR.12.2, NEFSC 2018b).[11] If these estimates of poor recruitment are confirmed and continue into the future, projected stock status will continue to decline (NEFSC 2018b).

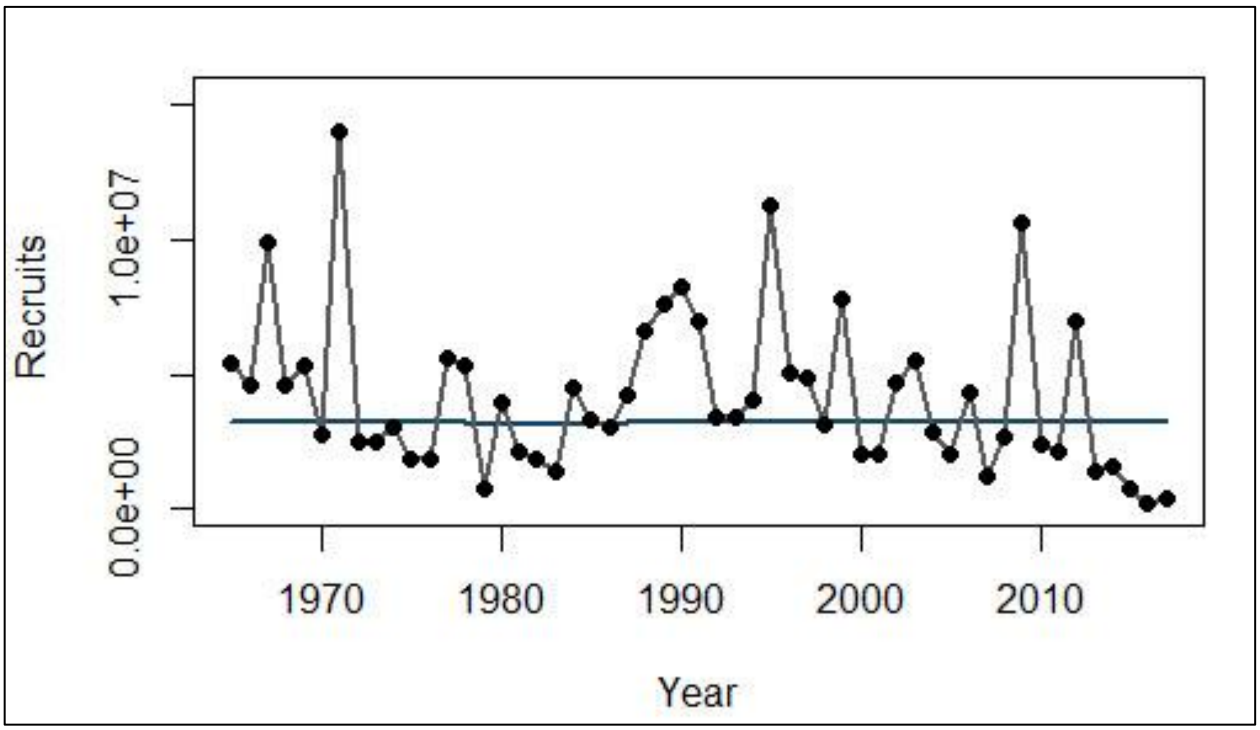


Figure S.LR.12.2. Data from the 2018 stock assessment (post-expert Workshop). Atlantic herring annual recruit time series, 1965–2017 (in 000s). The horizontal line is the average over the time series. Source: NEFSC 2018b

Recent trawl survey data show that the distribution of Atlantic herring within SBNMS is highly patchy and abundance is quite variable (Auster and Conroy 2019). This variability at the spatial scale of SBNMS contributes to the variable functional role that herring plays within the local food web over time. For example, Richardson et al. (2014) demonstrated that Atlantic cod preyed on herring along the edges of

[11] Following the February 2018 workshop where subject matter experts gathered to discuss status and trends of important ecosystem indicators, a new stock assessment for Atlantic herring was completed. Although this assessment was not considered by the subject matter experts during the workshop, sanctuary staff reviewed the findings and have determined it does not change the rating for this question.

Stellwagen Bank and in surrounding deeper waters, but in shallow waters on top of the bank, sand lance were the primary prey. Notably, herring and sand lance populations in the SBNMS region typically oscillate out of phase (see Fig. S.LR.12.3, Sherman et al. 1981, Richardson et al. 2014) and, given their role as primary prey of Atlantic cod, can serve as alternate high-calorie prey (e.g., Steimle and Terranova 1985, Lawson et al. 1998) that occur in dense aggregations.

The patchiness of herring is a key factor in their ecological role at SBNMS. A recent study found that the number of schools of prey species (including herring) is proportional to the biomass of the species; however, the size of the schools remains constant (Jech and Stroman 2012). The number of schools of prey is a critical bioenergetic issue for predators such as cod and whales. Predators that either need to search more widely for prey or switch to alternative prey may experience changes in growth (Hazen et al. 2009, Rennie et al. 2005) and fecundity (Lambert 2008).

Sand Lance

Sand lance (*Ammodytes* spp.) are small (<20 cm) pelagic fish that function as zooplanktivores, forming a vital link for flow from lower to higher trophic levels. Like many short-lived forage species, sand lance exhibit dramatic fluctuations in spatial and temporal abundance. Sand lance are restricted to shallow sand habitats and are non-migratory as juveniles and adults (Nelson and Ross 1991). Sand lance typically feed in the water column during daylight periods and move to the bottom at night or bury themselves in coarse, well-ventilated sand (Meyer et al. 1979, Nelson and Ross 1991). Thus, sand lance are extremely place-based. Fluctuations in abundance of humpback whales (Payne et al. 1990) and cod (Richardson et al. 2014) within SBNMS have been correlated with sand lance abundance. Further, sand lance abundance is negatively correlated with Atlantic herring (Richardson et al. 2014) based on time series data from 1963–2011, with sand lance at low population levels between 1963–1975 and 1992–2005, while Atlantic herring abundance was high. The opposite trend occurred for these species between 1977–1991 and 2006–2010 (Fig. S.LR.12.3).

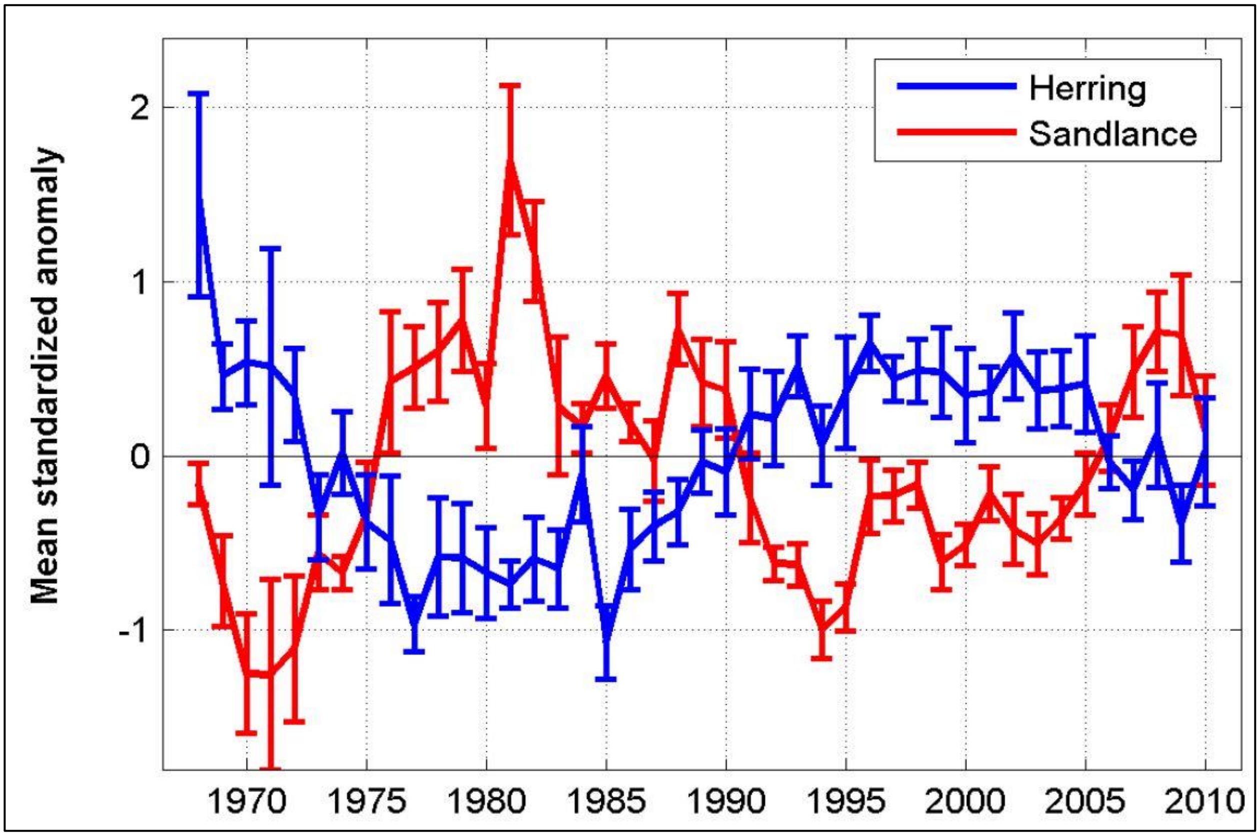


Figure S.LR.12.3. Relative abundance of sand lance and herring from 1963–2010. Image: Richardson et al. 2014

Sand lance are also key prey for endangered roseate terns (U.S. Fish and Wildlife Service 1998), which frequent the sanctuary. Recent research by SBNMS staff and colleagues (Powers et al. unpublished data, Silva et al. unpublished data) indicates that distribution of sand lance influences the distribution of great shearwaters and humpback whales.

Despite their importance, little is known about the ecology of sand lance and what drives observed temporal and spatial variability within SBNMS. That sand lance and Atlantic herring exhibit out-of-phase population cycles in the Gulf of Maine (Richardson et al. 2014) suggests either bottom-up forcing of such patterns, or an effect of direct species interactions (predation or competition). SBNMS and colleagues (Silva et al. unpublished data) observed sand lance spawning during a short time period in late November. The resulting eggs are demersal, and subsequent larvae are pelagic for several months (Dalley and Winters 1987). This long pelagic period prior to settlement, combined with prevailing currents, suggests that sand lance hatched on Stellwagen Bank could have low retention and that sand lance might recruit to the sanctuary from unknown sources to the north.

Hare et al. (2016) found that sand lance are highly exposed to, but at moderate risk from, detrimental effects of climate change (although uncertainty was high). This is due to their exposure to increased ocean temperature and ocean acidification at all life stages, limited mobility as adults, specific sand habitat requirements, winter dormancy, and possible water temperature-induced spawning. While this combination of factors might make sand lance in the Northeast only moderately susceptible to climate change, the more spatially isolated shallow sand habitat in the sanctuary would suggest that abundance and distribution of sand lance in SBNMS could be significantly impacted.

Sponges and Anemones

Structure-forming species have important ecological roles related to provision of shelter (e.g., settlement sites and cover from predators, refugia from flow, focal sites for predation) for a diversity of associated species (e.g., crustaceans, echinoderms, fishes). This role enhances patterns of local diversity and contributes to the patchiness of environmental conditions across the seafloor landscape that enable competing species to coexist. Two major taxonomic groups, Porifera (sponges) and Cnidaria (hydroids and anemones), fulfill this role and are physically fragile, have species with highly variable life histories, and can serve as indicator species for the state of diverse seafloor communities.

Structure-forming sponges and cnidarians are sensitive to disturbance (Auster and Langton 1999). In SBNMS, these species have important roles as structure-forming organisms (Auster et al. 1996, 2003, Auster and Lindholm 2005). Both taxa principally occur in hard substratum habitats, small patches of hard substratum nested within fine-grained sediment habitats (such as in the troughs of sand waves), and mud- and sand-draped gravel buried to a minimal depth (i.e., ca. 1–2 cm). However, sponges also attach to and grow on other features, such as the dead skeletal remains of bryozoans and hydroids (Auster et al. 1998). Hydrozoans, like *Corymorpha pendula*, occur in very dense patches anchored in fine-grained sediments (e.g., Auster et al. 1996, 1998). Burrowing anemones also occur in fine-grained sediments and appear to have high survival in areas with a gravel-fine-grain sediment matrix, with tubes extending deep below the sediment-water interface (Auster et al. 2003, Shepard et al. 1987).

Changes in the abundance and distribution of these taxa over time correspond both to larger regional (e.g., water temperature, primary production) and local (e.g., predation, competition) processes as well as effects of fishing and other uses inside and outside the WGOM Closure Area (e.g., Tamsett et al. 2010). Monitoring studies conducted at various boulder habitat stations in SBNMS (see Tamsett et al. 2010 for locations) have demonstrated general trends of initial decline and then increasing density of sponges from 1998–2010, occurring both inside and outside the closed area (Figure S.LR.12.4). However, patterns for cnidarians are different, with declining density since the time of closure, both inside and outside the closed area, but with an increase in 2010 at both protected and open stations (Figure S.LR.12.4). The status of these foundational species across monitoring sites within SBNMS from 2011–2017 remains unknown.

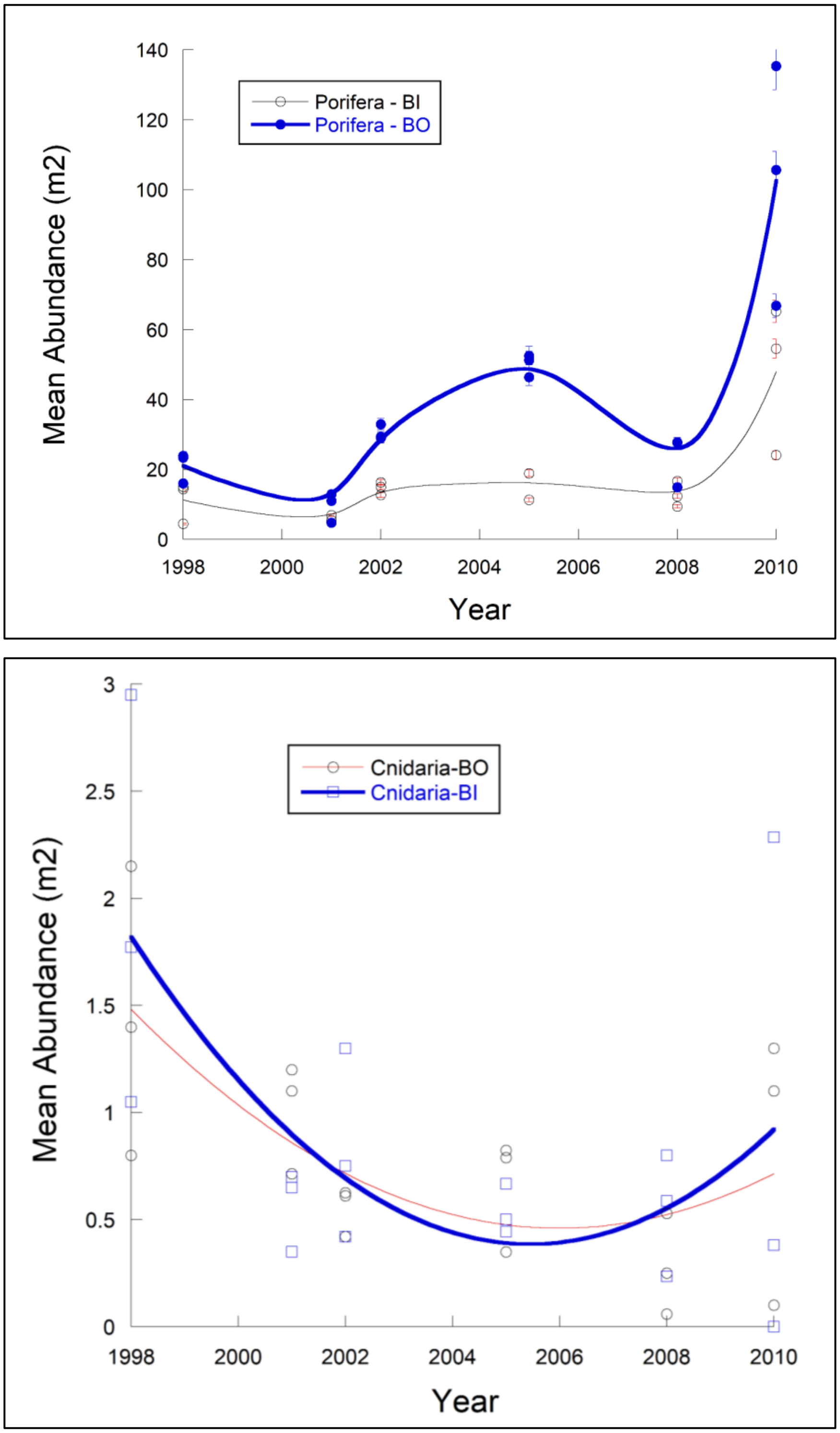


Figure S.LR.12.4. Patterns in the abundance of aggregate Porifera (sponge) species (top) and Cnidaria (hydroids, anemones) species (bottom) from boulder habitat stations inside (BI) and outside (BO) the WGOM Closure Area from 1998–2010. Image: Auster et al. 2013b

In summary, the rating for this question, “good/fair” and “not changing,” integrates the status and trends for numerous foundation species that exhibit variable states and trends based on multiple pressures. *Calanus* has demonstrably persisted in the western Gulf of Maine despite recent warming, although longer-term climate change effects could have significant impacts. Atlantic herring have recovered from overfishing that occurred decades ago, but patch dynamics are linked to their ecological role as prey species. Sand lance, another important forage species, are tightly linked to the isolated shallow sand habitat on top of Stellwagen Bank and exhibit variable local abundance that is not predictable at our current level of ecological understanding. Finally, the status and trends in abundance of structure-forming species and their responses to both regional population processes and local ecological and human-caused effects creates difficulty in determining the causes of trends. Identifying local-scale versus regional-scale drivers that can aid in interpretation of data on the state of foundation species within SBNMS remains a significant challenge.

13. What is the status of other focal species and how is it changing?

Status Description: Selected key species are at reduced levels, but recovery is possible.

Rationale: The eight focal species considered include North Atlantic right whale (poor and worsening), humpback whale (poor and improving), harbor porpoises (fair and undetermined), Atlantic white-sided dolphins (good and undetermined), great shearwaters (good/fair and undetermined), Atlantic cod (fair/poor and worsening), lobster (good and improving), and bluefin tuna (undetermined and improving). The overall rating is driven by the precarious status of North Atlantic right whales, whose recovery is dependent on additional management intervention, and humpback whales, which have been experiencing an unusual mortality event since 2017.

As with Question 12, direct comparison of the 2018 rating with the 2007 condition report is not possible for this question because it was changed after 2007. However, two separate questions in the 2007 condition report assessed the status and condition of key species. The status of key species was rated “fair/poor” and “not changing” in 2007 and the health of key species was rated “fair” and “not changing.” In the current report, this question involved an assessment of the status of eight specific, but very different, focal species, and thus it is challenging to arrive at an integrated rating that is illustrative of the collective state and trends. To summarize, the condition for focal species in SBNMS is mixed. North Atlantic right whales are declining and potentially at risk of extinction (Pace et al. 2017). SBNMS is a hot spot for reports of entangled humpback whales; however, locations of entanglement reports are not necessarily the same locations of entanglement origin. SBNMS remains an area of entanglement risk for great shearwaters and other seabirds. Small odontocetes, such as harbor porpoises and Atlantic white-sided dolphins, also remain at risk, though not at a level which would impact populations. Large whales are most at risk from trap/pot fisheries, while small cetaceans, seals, and seabirds are most at risk from gillnet fisheries. The current rating is largely driven by the decline and status of right whales with an undetermined trend for all species because there is no consistent trend across all species.

This question targets focal species of particular interest from the perspective of sanctuary management. These other species may not be abundant or provide high value to ecosystem function, but their presence and health is important for the provision of other conservation-related or economic services. The focal species evaluated in this report were identified during a workshop at SBNMS in March 2017, during which participants developed a conceptual model for the SBNMS ecosystem by identifying key components of the ecosystem and the drivers, pressures, and links between them. In February 2018, the focal species identified during the 2017 workshop were presented to the expert panel, who agreed with the selections. Focal species considered in this discussion include North Atlantic right whales, humpback whales, harbor porpoises, Atlantic white-sided dolphins, great shearwaters, lobster, bluefin tuna, and Atlantic cod.

North Atlantic Right Whales

North Atlantic right whales are critically endangered. Serious injury and mortality from ship strikes and entanglement have resulted in a decreasing population since 2010 (Pace et al. 2017). Within the sanctuary, the TSS shipping lane shift in 2007, implementation of seasonal speed restrictions in 2008, a sanctuary-led campaign to increase mariner compliance with NOAA's Right Whale Ship Strike Rule, the creation of a near real-time passive acoustic detection system for right whales, and the development of Whale Alert (a mobile app) have likely contributed to reducing the risk of ship strikes in SBNMS. From 2007–2017, two right whales were sighted as entangled, and possibly became entangled, in the sanctuary. Implementation of NOAA's Atlantic Large Whale Take Reduction Plan, including attempts to reduce vertical lines and changes to closures, may have reduced entanglement risk in the sanctuary. Given declines in the population, the Atlantic Large Whale Take Reduction Team, which includes SBNMS, recommended modifications to the plan to further reduce the risk of right whale entanglement-related serious injury and mortality.

Research on right whales in the Bay of Fundy using fecal hormones showed that cortical steroids (an indicator of stress) dropped significantly during a period with less vessel traffic and its accompanying noise (Rolland et al. 2012). Additional research in the sanctuary showed that noise from large ships can completely mask the social upcalls of right whales, and that this species has, in the last 50 years, lost about two-thirds of its communication space (i.e., their opportunity to communicate). Because right whales, humpback whales, and other whales use sound for many purposes, extra noise may have significant effects on these species. Since June 7, 2017, elevated North Atlantic right whale mortalities have been documented (primarily in Canada) and were declared an unusual mortality event by NOAA. In 2017, there was a total of 17 confirmed dead, stranded whales (12 in Canada and 5 in the United States) and in 2018, three whales stranded dead in the United States. In 2019, nine whales died in Canada and one, last seen entangled in the Gulf of St. Lawrence, stranded dead in the U.S. Thirty total mortalities are associated with the unusual mortality event at present (21 in Canada and 9 in the United States). Necropsy results are pending, however, preliminary findings support human interactions, specifically vessel strikes or rope entanglements, as the cause of death for the majority of whales.

Humpback Whales

The humpback whales that frequent SBNMS are part of the West Indies distinct population segment, which is one of 14 distinct population segments around the world. After careful review of available data on population status and threats, NOAA Fisheries removed the West Indies distinct population segment from the list of endangered and threatened species in 2016. The Gulf of Maine supports a population of approximately 900 humpback whales, some portion of which rely on the productive waters of the sanctuary to feed and to rear their calves.

Humpback whales have been aided by the TSS shift; however, whales continue to be observed in the sanctuary entangled in fixed fishing gear (trap/pot and gillnet) and struck by small boaters. Numerically, large whales (e.g., right, humpback, fin, and minke) are poorly represented in the database collected by onboard fishery observers because the animals frequently swim away from the site of original entanglement, and observers in trap/pot fisheries are rare. These challenges make it difficult to reliably identify where large whale entanglement occurs. Research based on acoustic recordings in the sanctuary indicates that the detection range of sounds produced by humpback whales during feeding activity are significantly reduced in the presence of vessel traffic (both large commercial ships and smaller vessels, such as whale watching and fishing vessels) (Cholewiak et al. 2018). Sanctuary research has found sounds produced by humpback whales during feeding have key roles in prey manipulation and social coordination (Stimpert et al. 2007). Additionally, louder sounds, such as those generated by close passage of larger vessels, have been shown to disrupt humpback whale feeding activity in the sanctuary (Blair et al. 2016). Therefore, vessel traffic influences on communication as well as behavioral aspects of feeding have been shown to be of concern for humpbacks in sanctuary waters. An additional confounding variable is that entangled whales are most frequently reported by commercial whale watching vessels, which have disproportionately high occurrence within SBNMS. Still, large whales are observed entangled in SBNMS, particularly in the southern part of the sanctuary (Figure S.LR.13.1), where an economically valuable trap/pot fishery operates. Humpback whales are the most frequently observed entangled species, followed by minke, right, and fin whales. Since January 2016, elevated humpback whale mortalities have occurred along the Atlantic coast from Maine through Florida (primarily in the Mid-Atlantic and about half due to vessel strikes), prompting NOAA to declare an unusual mortality event (an unusual mortality event was also declared for minke whales in 2017).

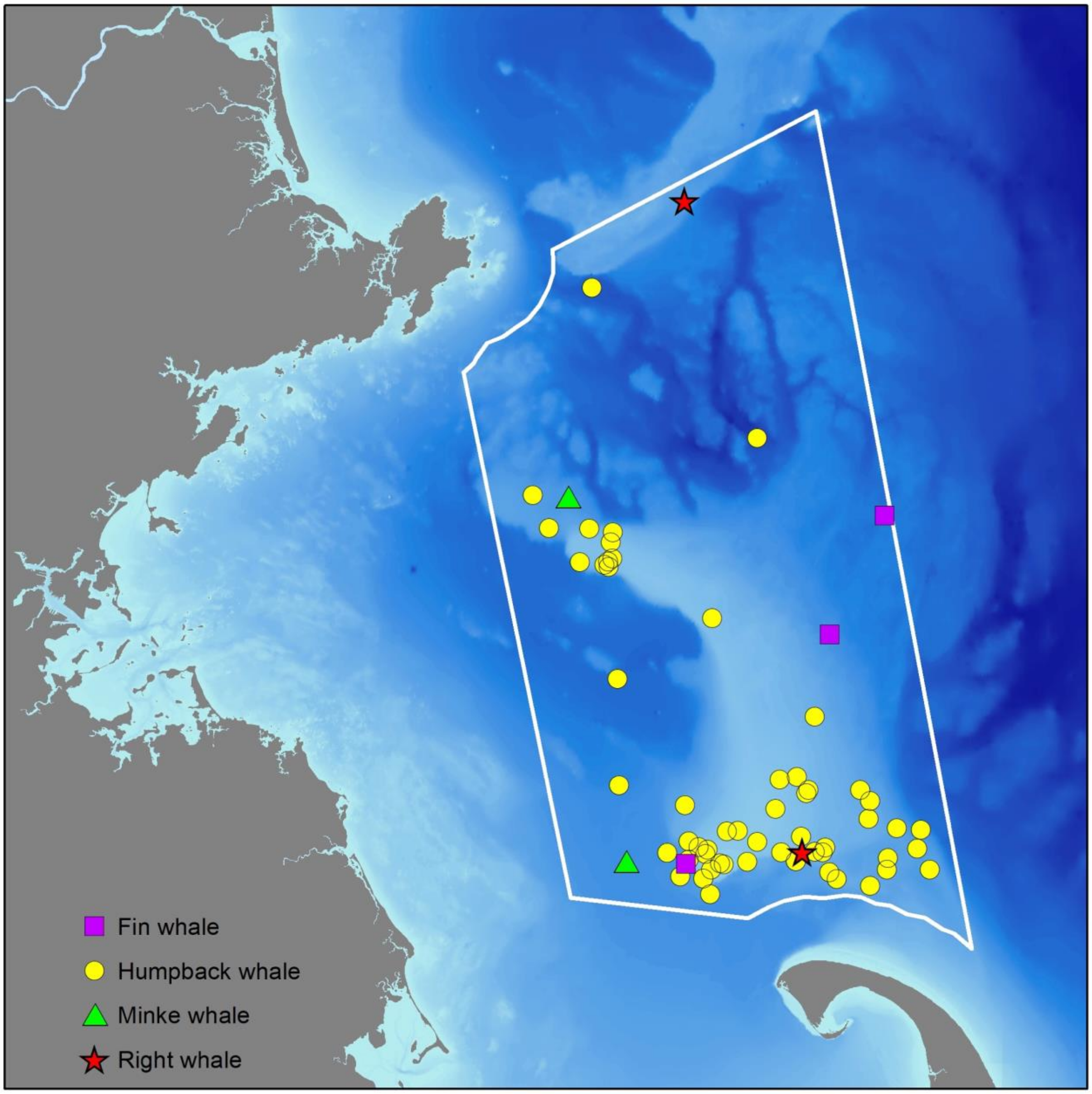


Figure S.LR.13.1. Location and species of large whales observed to be entangled within SBNMS. Large whales can carry entangling gear for many miles, and the site of observation is not necessarily the site of original entanglement. Image: Center for Coastal Studies and the Atlantic Large Whale Disentanglement Network

Harbor Porpoises

SBNMS is also a member of the Harbor Porpoise Take Reduction Team, which is tasked with reducing serious injury and mortality of harbor porpoises in the gillnet fishery. Harbor porpoise take exceeded potential biological removal[12] (PBR) from 2008–2013 and was below PBR from 2014–2016. Observer data provided by NEFSC indicate that gillnets pose a major danger to marine mammals (Figure S.LR.13.2), and harbor porpoises are the second most frequently observed marine mammal species in bycatch (90 observed bycatch incidents, Figure S.LR.13.3).

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[12] Potential biological removal is the maximum number of animals, not including in natural mortalities that may be removed annually from a marine mammal stock while allowing that stock to reach or maintain its optimal sustainable population level.

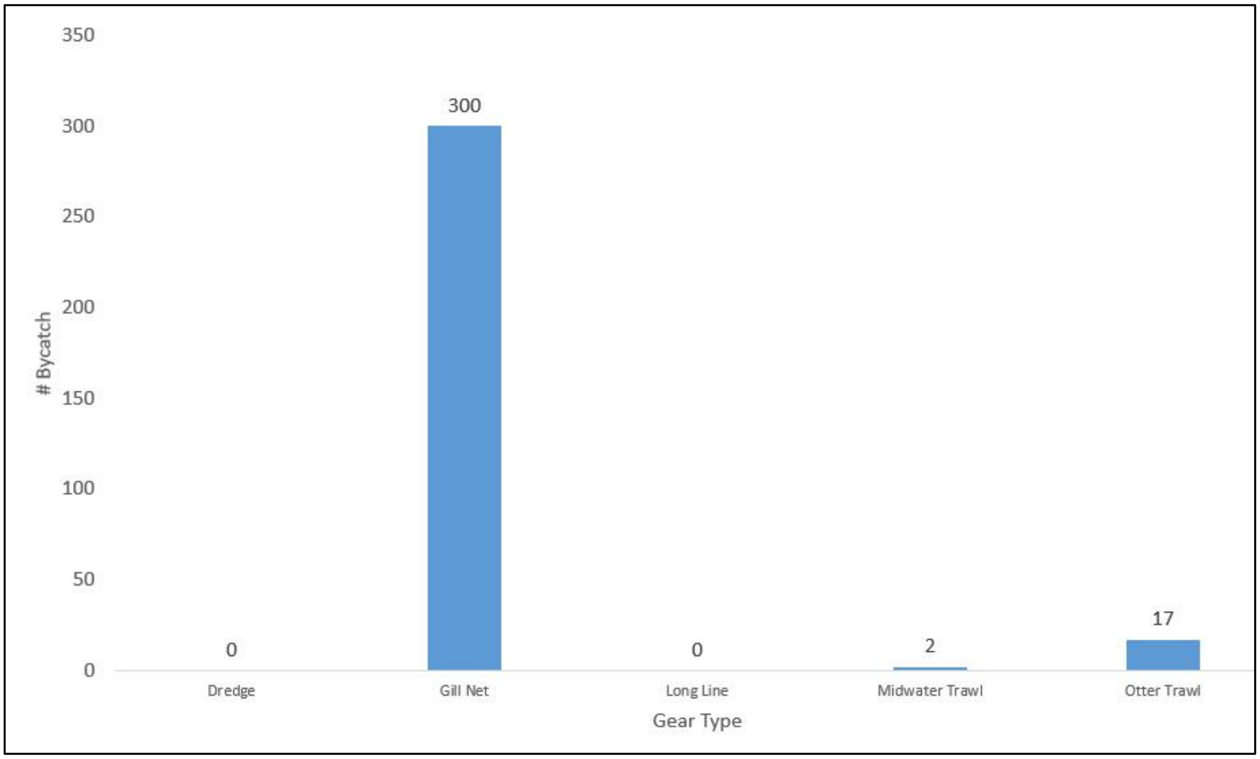

Figure S.LR.13.2. Observed bycatch of marine mammals (excluding large whales) in SBNMS by gear type for the years 2007–2016 (n = 319). Gillnets were the largest source of bycatch. Numbers are not corrected for effort. Source: NEFSC 2017c

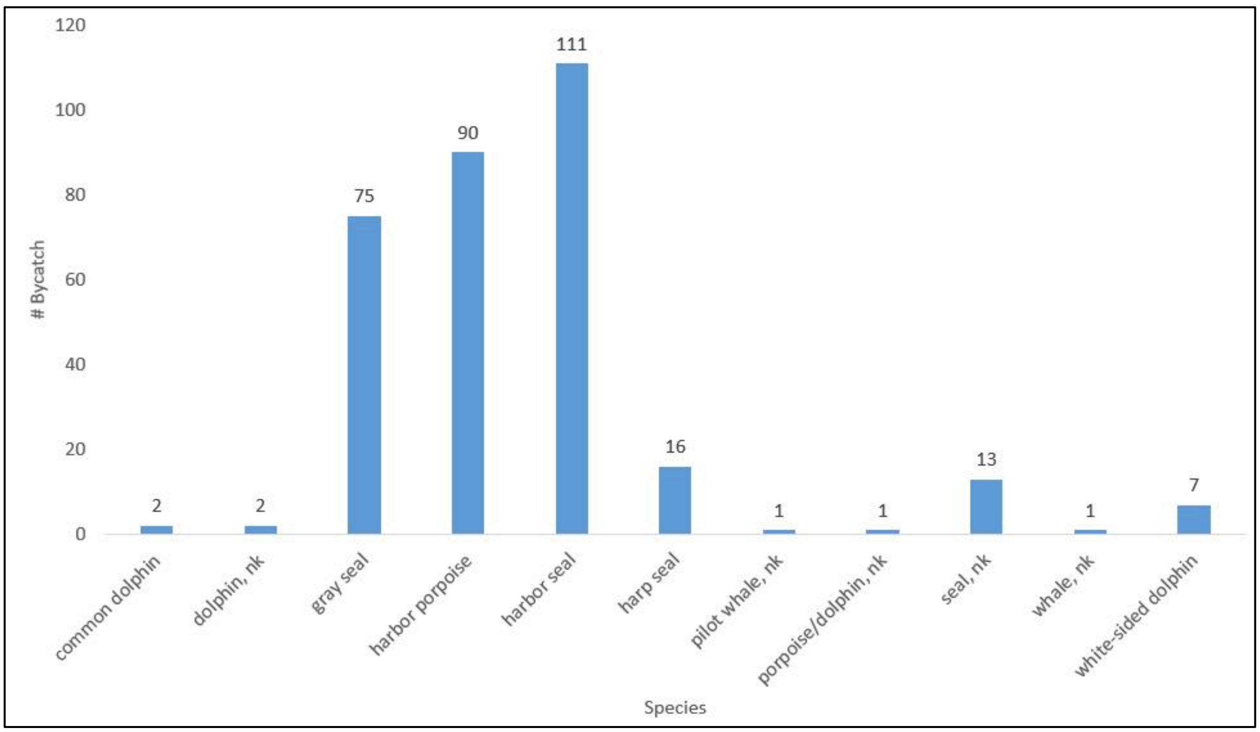

Figure S.LR.13.3. Observed marine mammal bycatch in SBNMS for the years 2007–2016 (n = 313). Observations indicate that harbor seals, harbor porpoise and gray seals were at greatest risk. Data are not corrected for effort. Source: NEFSC 2017c

Atlantic White-Sided Dolphins

Opportunistic sightings data shows that Atlantic white-sided dolphins are the most commonly sighted toothed whale species in SBNMS and are seen most frequently April-May and in August (Silva 2018). Standardized surveys (Wiley et al. 2003, NOAA Office of National Marine Sanctuaries 2010), stranding data (Hayes et al. 2017), and recent passive acoustic data (Silva 2018) suggest a frequent winter presence in SBNMS and surrounding waters. Habitat models indicate that Atlantic white-sided dolphins associate most strongly with shallow, sandy habitats in Stellwagen Bank, suggesting that sand lance may be an important prey item (Silva et al. 2019).

Primary potential threats to Atlantic white-sided dolphins in SBNMS include bycatch and ocean noise. Seven animals were bycaught in SBNMS from 2007—2016 (see Figure S.LR.13.3). The presence of boats and associated ocean noise is known to influence toothed whale behavior (Nowacek et al. 2001, Buckstaff 2004, Jensen et al. 2009, Pirotta et al. 2015). However, ocean noise at delphinid communication frequencies has not been characterized in SBNMS and potential impacts on toothed whales are unknown.

Great Shearwaters

Since 2013, SBNMS has led a large collaboration involving government agencies (U.S. Fish and Wildlife Service and U.S. Geological Survey) and academic institutions (Boston University, Long Island University, University of Rhode Island, and Massachusetts Institute of Technology) to investigate the habitat use, foraging habits, and health of great shearwaters in and around the sanctuary. This research identified SBNMS as a high-use foraging area for shearwaters (Powers et al. 2017). It also found that the areas of highest great shearwater bycatch in the Gulf of Maine were located outside SBNMS (Hatch et al. 2015). However, great shearwaters have the highest rate of bycatch of any animal in the sanctuary, with gillnets accounting for the vast majority of mortalities in seabirds (Figures S.LR.13.4—S.LR.13.5). The sanctuary-led research team also identified that great shearwaters are not a reservoir for avian influenza virus. The team is also leading an investigation into the recent mass mortality of great shearwaters along the eastern seaboard of the U.S., including Cape Cod (the landmass nearest to SBNMS). SBNMS and the Massachusetts Audubon Society are also collaborating on seasonal standardized seabird surveys of the sanctuary. These surveys have occurred since 2014, and the sanctuary's long-term commitment to the project will provide key data about changes to this important living resource. SBNMS is also collaborating with commercial whale watching vessels as platforms of opportunity, with trained SBNMS seabird volunteers joining whale watching trips to record seabird observations.

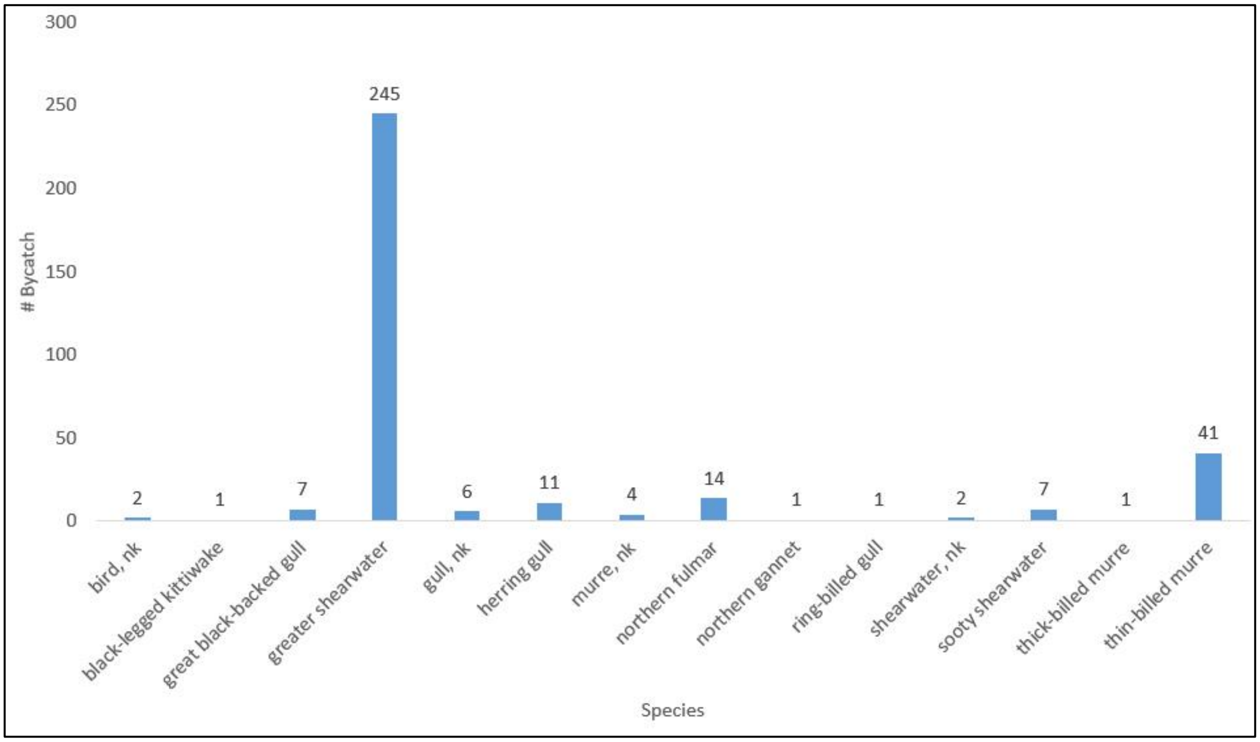

Figure S.LR.13.4. Observed seabird bycatch in SBNMS for the years 2007–2016 (n = 343). Observations indicate that great shearwaters, common murres, and northern fulmars were at greatest risk. Data are not corrected for effort. Source: NEFSC 2017c

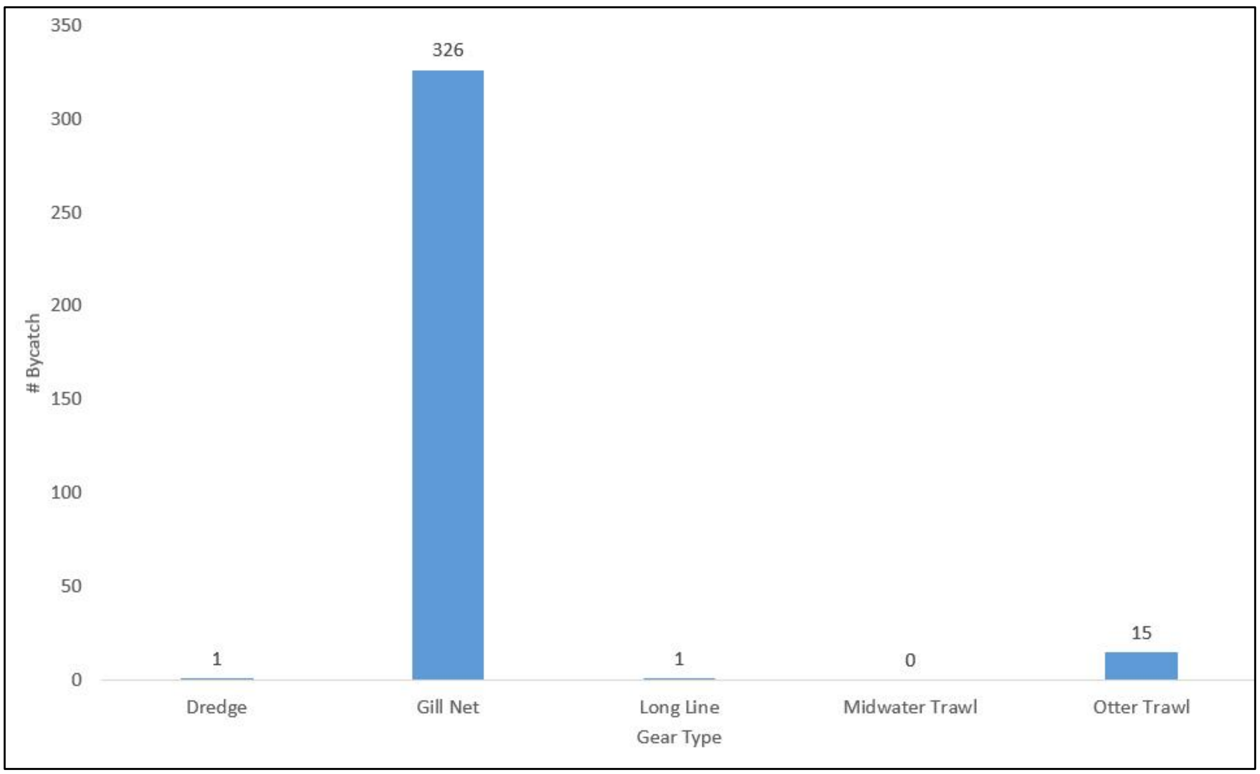

Figure S.LR.13.5. Observed bycatch of seabirds in SBNMS by gear type for the years 2007–2016 (n = 343). Gillnets were the largest source of bycatch. Data are not corrected for effort. Source: NEFSC 2017c

Atlantic Cod

Atlantic cod is a culturally, ecologically, and economically important species in the Gulf of Maine and SBNMS, where it historically has been the focus of commercial and recreational fishing. Research indicates that the population is at historic lows. The remaining population is heavily centered on, or contracted into, SBNMS, where Atlantic cod feed on sand lance and Atlantic herring (Richardson et al. 2014). Since 2011, SBNMS scientists and collaborators (MA DMF, NOAA Fisheries, Cornell University Bio-Acoustic Research Program, UMass Dartmouth, and The Nature Conservancy) have used marine autonomous recording units to investigate the occurrence, spatial extent, and duration of spawning cod aggregations (Zemeckis et al. 2019). Since 2013, the group has also worked with scientists from Woods Hole Oceanographic Institution using gliders equipped with passive acoustic detectors to map wider areas for sounds made by cod and other fishes. Numerous cod detections were documented in sanctuary waters (Figure S.LR.13.6). While these and other efforts will provide important information on cod in SBNMS and elsewhere, a combination of fishing pressure, species interactions (e.g., predation, competition), and environmental change have led to a continued decline in the Gulf of Maine cod stock (NEFSC 2017a). The western Gulf of Maine, including SBNMS, is possibly the last area with consistent aggregations of cod in the Gulf of Maine stock.

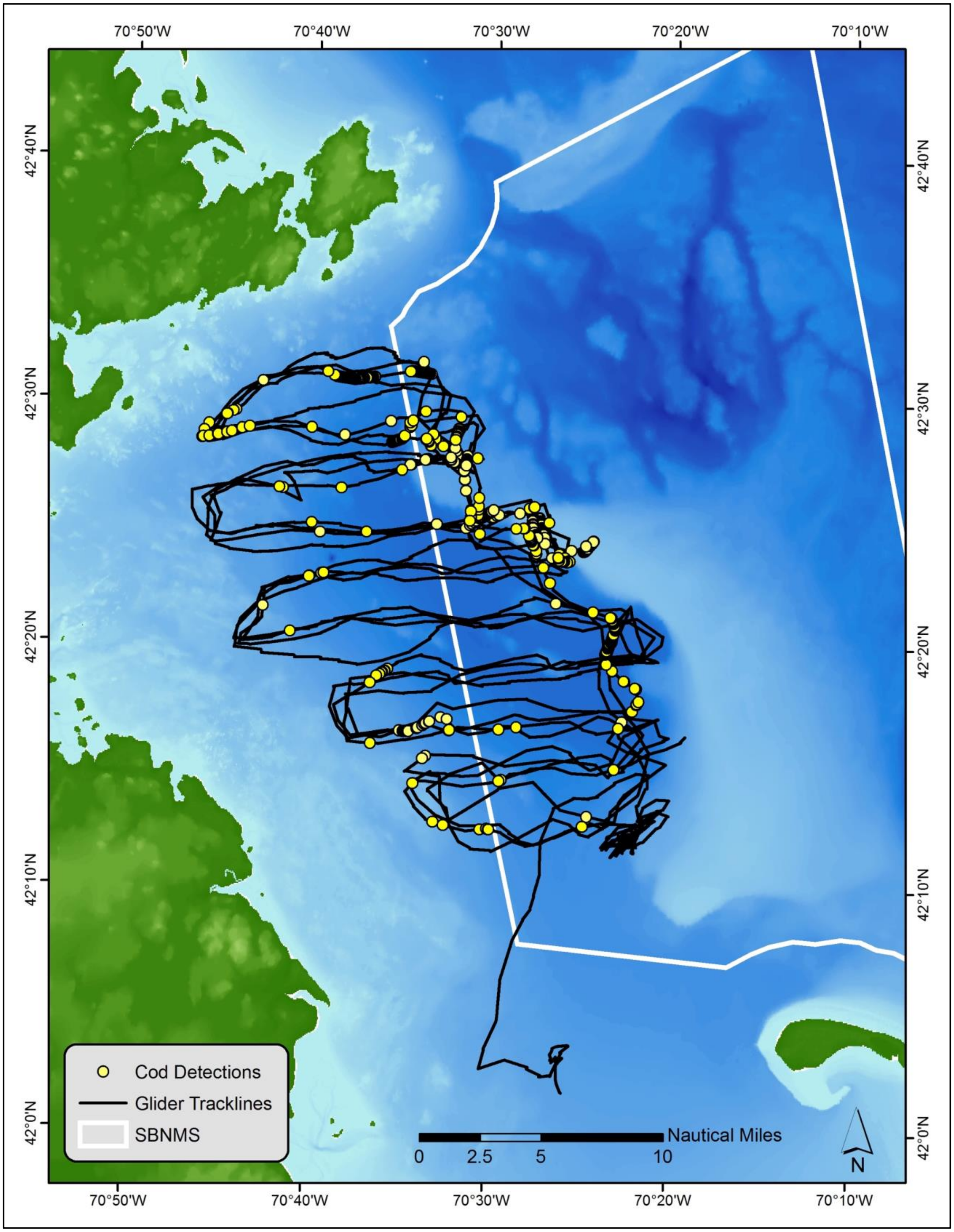

Figure S.LR.13.6. Daily presence of cod grunts (yellow dots) from three gliders (November 2015-March 2016), showing high levels of activity in SBNMS. Image: NEFSC Passive Acoustics Research Group

Atlantic cod were once a dominant piscivore in the Gulf of Maine ecosystem. Now, the Gulf of Maine cod population is at historic lows for both spawning stock biomass and recruitment for the period from 2010–2016, and even below the low population status from 2000–2009 (Figure S.LR.13.7, NEFSC 2017a, MA DMF 2017). The distribution of cod has also shifted. While once distributed throughout the Gulf of Maine region, cod now occur primarily in the western Gulf of Maine (Figure S.LR.13.8), with declining populations resulting in spatially limited hyper-aggregations (Richardson et al. 2014). Such aggregations make this species vulnerable to exploitation. Notably, significant percentages of both commercial and recreational catches of cod are taken from a small percentage of the Gulf of Maine region, and those areas significantly overlap with SBNMS (NEFSC 2013). Within SBNMS, mean spring cod abundance per survey tow has increased from the 1970s–2000s, reflecting the general trend of high concentrations of cod in the western Gulf of Maine over time. However, abundance declined during the 2000s and 2010s (Auster and Conroy 2019).

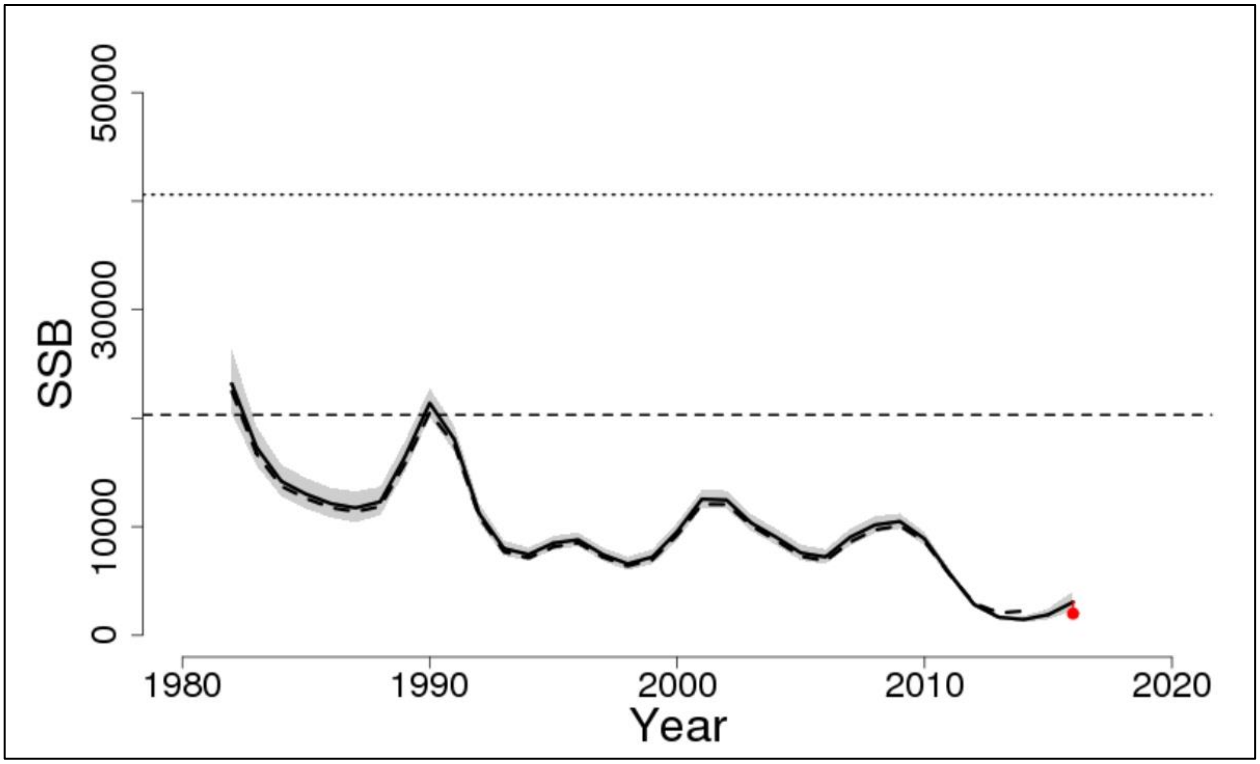

Figure S.LR.13.7. Estimated trends in the spawning stock biomass (SSB) of Gulf of Maine Atlantic cod between 1982 and 2016 from the current (2017 — solid line) and earlier (2015 — dashed line) population assessments. Estimates were made using the M = 0.2 assessment model. Image: NEFSC 2017a

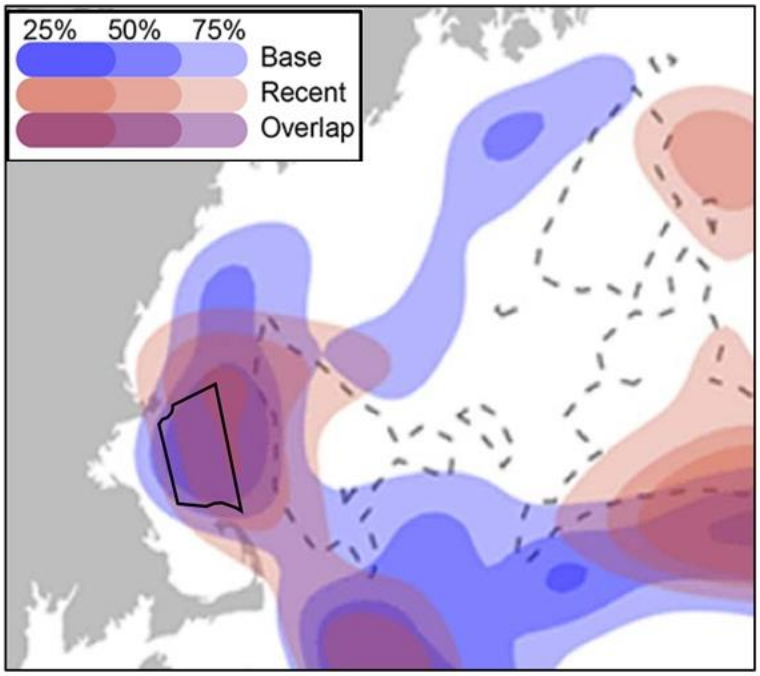

Figure S.LR.13.8. Kernel density plot of Atlantic cod distribution. Three levels of probability contours were mapped (25%, 50%, and 75%) for species distributions recorded in 1970s trawl data (blue shading, base) and in 2013–2015 data (orange, recent), whereby the 25% kernel defines the core area of the distribution and the 75% kernel defines the broader outlying extent of the distribution. Overlap between the 1970s and recent years is shaded purple. Image: Pittman 2019

Atlantic cod generally eat the same types of food across the Gulf of Maine despite local changes in habitat (Link and Garrison 2002). Diets are representative of local organisms and depend on seasonal and year-round availability of small pelagic forage species (e.g., Atlantic herring, Atlantic mackerel, and sand lance species). Over the past two decades, the diet of cod shifted, reflecting changes in the availability of forage species (Link and Garrison 2002). Both herring and mackerel abundance declined in the 1970s, while sand lance (*Ammodytes* spp.) increased and replaced those once dominant small pelagic species in the Atlantic cod diet (Fogarty et al. 1991). In the SBNMS region, cod predation on small pelagic forage species is linked to landscape attributes and the variable distribution of prey fish linked to such changes. For example, sand lance are primary prey for cod on top of Stellwagen Bank, where they occur in high abundance, in part due to the availability of shallow sand habitats, while Atlantic herring are the primary prey along the edges of the bank and in deeper surrounding waters (Richardson et al. 2014).

While some predators of cod have increased over past decades (e.g., sea raven), most have declined or are at low abundance (e.g., sharks, Atlantic halibut, large cod, large hakes) since the 1970s (Link et al. 2009). There is no strong relationship between predator population declines and the decline of cod as a prey species, as cod did not make up a significant percentage of predator diets. Even for species that have increased in abundance, such as sea raven, cod is not a large portion of their diet. However, some have hypothesized that cod populations may be stuck in a “predator pit,” (a situation in which predation increases when a prey population increases), precluding population recovery (Link et al. 2009). There has been much speculation about the role of abundant elasmobranchs, such as spiny dogfish or winter skate, as predators of cod but this has been refuted (Link et al. 2002). However, predation by planktivorous fish on cod larvae may play a role in suppression of cod populations (Collie et al. 2013), although the magnitude of this interaction remains unresolved. Predation on post-settlement juveniles in nursery habitats may also limit year class success. Ambush predators, like longhorn and shorthorn sculpin, have increased over time in the Gulf of Maine-Georges Bank ecosystem, and densities have been highly variable in both trawl and visual surveys in gravel habitats at SBNMS (Auster et al. 2013a). The co-occurrence of ambush predators in gravel habitats that function as nursery areas for early benthic phase cod (and where juvenile cod have been observed directly) suggests that recruitment variability, at least at some places and times, could be linked to local predator abundance. These processes are consistent with the general pattern in which early life history phases of fish are subject to the greatest degree of mortality. Understanding how and where such mortality occurs is one key element for developing interventions to enhance recovery of previously abundant fish populations like Atlantic cod.

At the spatial scale of large marine ecosystems, compensation in trophic role, where one species declines and another increases to serve the same trophic function, can occur. Auster and Link (2009) found that five of seven trophic guilds on the northeast shelf exhibited compensation in numbers over multiple decades. In the present case, while numbers of Atlantic cod declined, other predator species increased in abundance so the trophic role of predation was maintained over time. However, at smaller spatial scales of habitats and landscapes, such as SBNMS, such compensation was not always apparent. Further work is needed to tease out such trophic relationships at the sanctuary scale.

The issue of competitive interactions hampering recovery of cod is also a concern (Link et al. 2009, Link and Auster 2013). Whether prey or habitat is a limiting resource, or whether prey switching can reduce competitive interactions in the Gulf of Maine and SBNMS is unclear. In Newfoundland and Labrador, growth, condition, and reproductive capacity of cod were significantly influenced by prey quality (Sherwood et al. 2007). Switching from capelin, once the primary prey species, to pandalid shrimp resulted in physiological limitations. While cod can eat a wide variety and size range of prey (within the limits of gape), in order to grow and reproduce they need to eat optimal-sized and high-quality prey. Rebuilding depleted cod populations will likely require a return of prey with higher nutrient quality, such as capelin, herring, or sand lance (Sherwood et al. 2007). How cod, and related predators, interact and compete (through direct or interference competition) for discrete patches of high-quality schooling prey remains unknown.

Despite a limited knowledge of interactions that could limit cod population size and recovery in the Gulf of Maine and SBNMS, their status is currently poor in relation to their status in the last condition report.

Lobster

Lobster are iconic species in the Gulf of Maine and SBNMS and are subject to an intensive and lucrative fishery. Two stock units have been identified based on regional differences in life history parameters: the Gulf of Maine/Georges Bank (GOM/GBK) and Southern New England (SNE). Warming waters have led to increased growth and reproduction of lobsters in the GOM/GBK stock. Also, commercial catch and assumed population have been increasing annually (ASMFC 2019). Lobster in SBNMS are part of the GOM/GBK stock and the Massachusetts Statistical Reporting Area 19 shown in Figure S.LR.13.9.

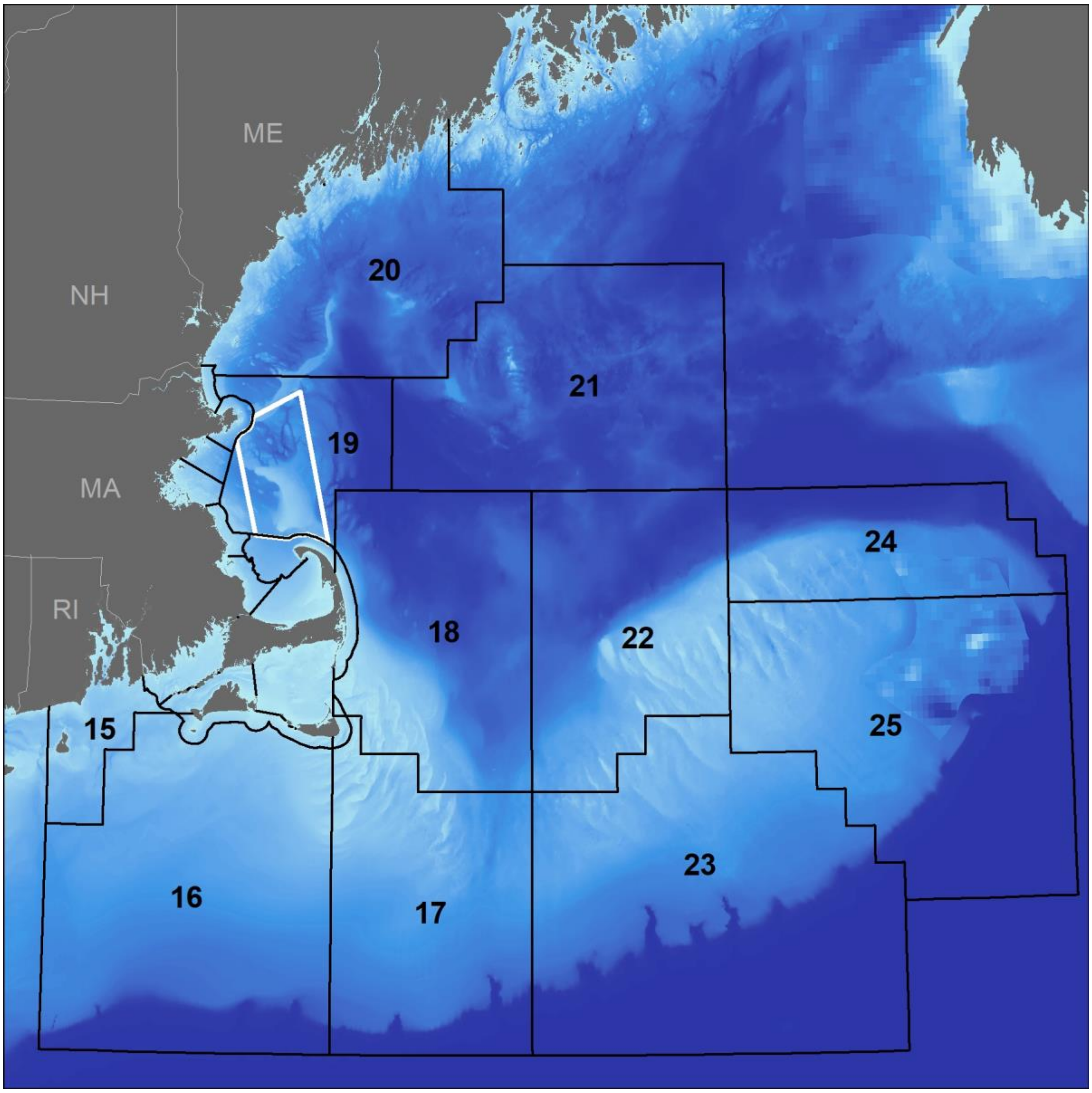

Figure S.LR.13.9. Map of MA DMF Statistical Reporting Areas. SBNMS is part of statistical reporting area 19. Image: MA DMF

GOM/GBK stock abundance has increased since 1979 and at an accelerated pace since 2007 (Figure S.LR.13.10). Landings of lobster from ports in Massachusetts also increased from 2007–2016 (Figure S.LR.13.11). Current stock abundance is at an all-time high and recruitment has remained high between 2008 and 2013. Warming waters have evidently aided reproduction and growth, increasing biomass and supporting larger catches. Importantly, since 2012, there have been consistent declines in abundance of young-of-year lobsters in the GOM/GBK stock. This may indicate future declines in recruitment and landings. The SNE stock is in poor condition and factors associated with that condition may be of future importance to the GOM/GBK stock, and therefore SBNMS. The SNE stock is severely depleted, with record low abundance and recruitment failure. This poor stock condition is thought to be the result of several factors, including changing environmental conditions, such as warming waters and increased predation, and continued fishing mortality (ASMFC 2019). Epizootic shell disease, which eats away at animals' shells, causing deep body lesions, occurs at warmer temperatures. These lesions are extremely unattractive, making infected lobsters unmarketable, and can be fatal. The MA DMF found that the disease was present in 20% of 716 lobsters sampled south of Cape Cod, but less than 1% of lobsters sampled along the outer Cape area were affected (MA DMF 2019). While warming temperatures seem to have benefited the GOM/GBK stock to date, a temperature threshold (prolonged temperatures above ~68° F) appears to have been exceeded in southern New England, negatively impacting the SNE stock. If climate change continues to warm sanctuary waters, lobsters could be negatively affected.

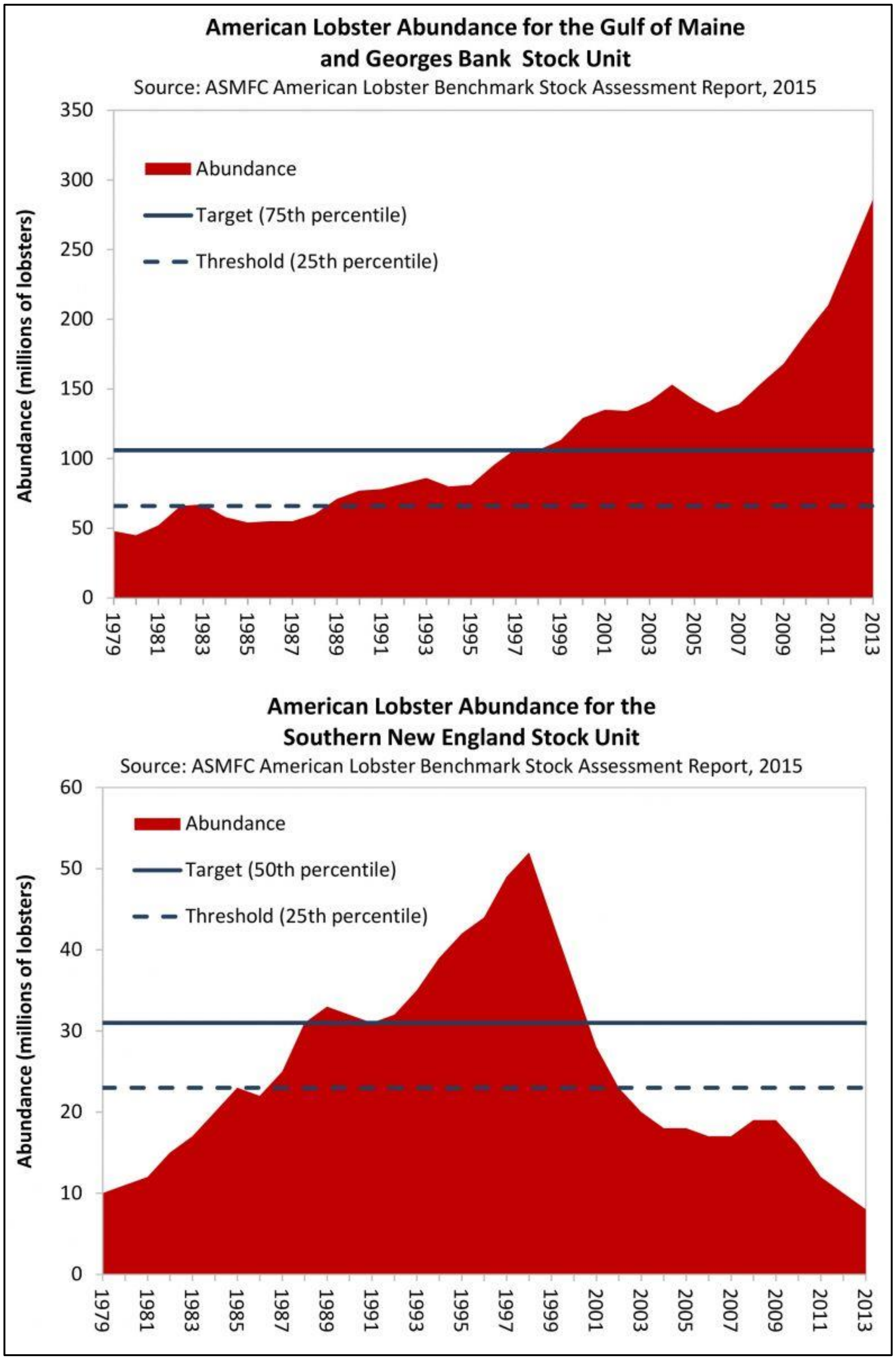

Figure S.LR.13.10. Trends in lobster abundance for the GOM/GBK and SNE stocks, 1979–2013. GOM/GBK stock is increasing, while the SNE stock is decreasing. Warming waters, increased predation, and shell disease are suspected causes of the SNE stock decline. Image: ASMFC 2019

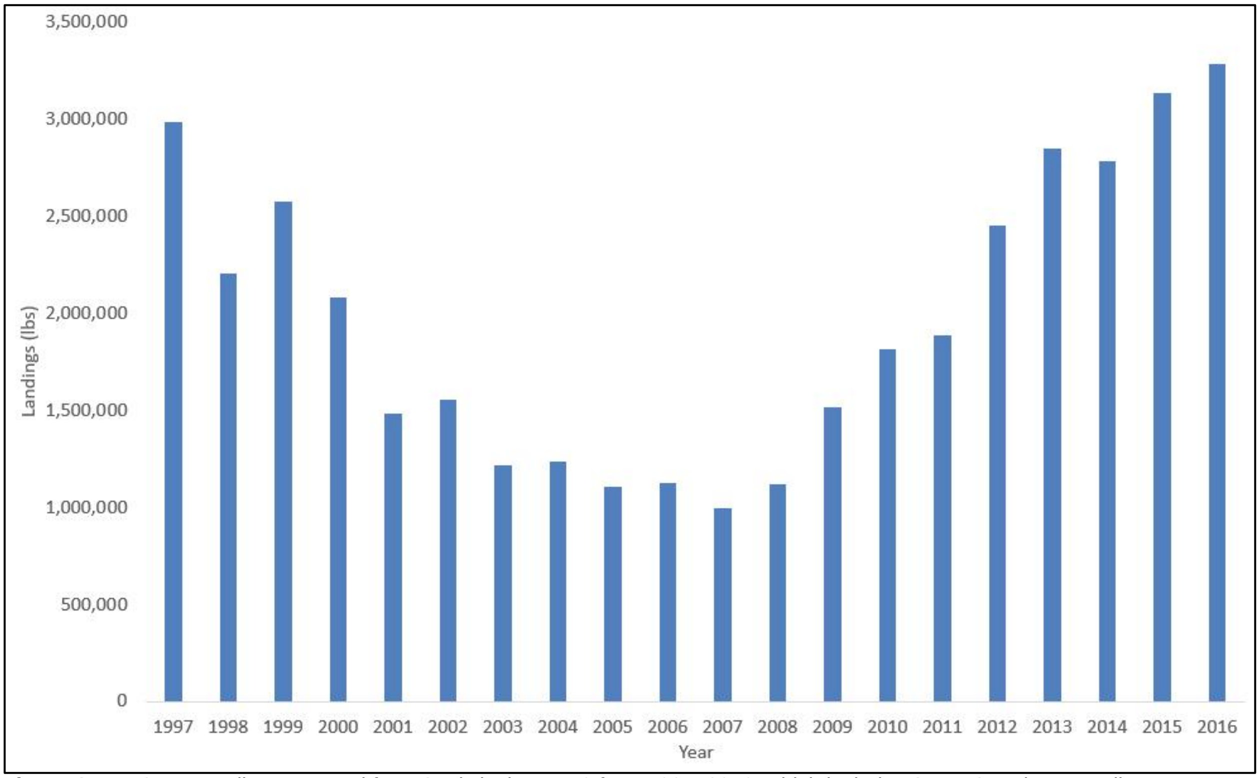

Figure S.LR.13.11. Landings reported from Statistical Area 19 from 1997–2016, which includes SBNMS and surrounding waters. The number of fished traps reported has increased from 2007–2016. Image: MA DMF

Bluefin Tuna

The status of bluefin tuna is complex, but abundance in the region has been increasing over the past decade. Bluefin tuna (*Thunnus thynnus*) are large, higher trophic level predators in the family Scombridae. This species can exceed 300 cm in size and 680 kg in weight, and can swim at speeds up to 70 km/h (43 mph). Bluefin tuna nominally dive to depths encompassing the entire water column on the continental shelf, but can dive to depths >1000 m in deep sea regions (Block et al. 2001). The species occurs from the tropics to the arctic in both the western and eastern Atlantic Ocean, and tagged individuals have crossed ocean basins (Block et al. 2001). For example, one fish traveled from the Bahamas to Norway in 54 days.

Off the northeast U.S., there are oceanographic and topographical features where bluefin tuna aggregate and hunt for prey during annual migrations, including Stellwagen Bank. A study of the diets of bluefin tuna caught at five principal foraging grounds off the northeast U.S. shelf (Jeffreys Ledge, Stellwagen Bank, Cape Cod Bay, Great South Channel, and south of Martha's Vineyard) found sand lance, Atlantic herring, Atlantic mackerel, squid, and bluefish had the highest frequency of occurrence and weight (Chase 2002). Notably, prey composition was generally not correlated with bathymetric features except for significant associations with Stellwagen Bank and Great South Channel, where sand lance and Atlantic herring occurred most frequently in sampled stomachs.

Bluefin tuna distribution and abundance varies dramatically by area, by year, and within a given year. Shifts in tuna abundance and distribution may be attributed to shifts in the abundance and distribution of prey resources. Spatial linkages between tuna and herring distributions in the Gulf of Maine have been documented (Golet et al. 2013). Movement tracks of tagged tuna indicate that fish respond to a prey patch on average every 2 h, that patches have an average radius of 0.7–1.2 km, and that there are at most only 5–9 patches per 100 km^2 to which they respond (Gutenkunst et al. 2007). These results imply that not just prey abundance, but characteristics of patchiness are important for sustaining bluefin tuna populations on foraging grounds.

Recent increases in bluefin tuna abundance observed in the Gulf of Maine support the overall trend for the western Atlantic. However, uncertainty remains with regard to changes in distribution, management regulations, fishing behavior, and the environment. NOAA Fisheries increased the baseline annual U.S. bluefin tuna quota from 1,058.79 to 1,247.86 metric tons (mt), the level recommended for 2018 through 2020 by the International Commission for the Conservation of Atlantic Tunas at its 2017 annual meeting.

Summary

While this report is focused on SBNMS, it is informed by the condition of species at large. For commercial species, Gulf of Maine cod are at historic lows, but local abundance and commercial catch per unit effort in SBNMS are relatively high as the remaining cod have apparently constricted into SBNMS to feed on sand lance. SBNMS lobster are healthy and increasing. Bluefin tuna are increasing from past low abundances.

Given that this question involved an assessment of the status of eight specific, but very different, focal species, it is challenging to arrive at an integrated rating that is illustrative of the status and trends identified. Therefore, SBNMS used a simple scoring metric for the ratings of the eight focal species as identified below (Good = 3, Fair = 2, and Poor = 1), and attempted to estimate an “average” collective status and trend; the average score is 2, or Fair. The large number of undetermined trends makes an overall assessment difficult.

Table S.LR.13.1. Status, trend, and confidence ratings for individual focal species.

Focal Spp.	Status[13]	Trend	Trend Confidence
North Atlantic right whale	Poor	Worsening	Very High
Humpback whale	Poor	Improving	High
Harbor porpoise	Fair	Undetermined	High
Atlantic white-sided dolphin	Good	Undetermined	Low
Great shearwater	Good/Fair	Undetermined	High
Atlantic cod	Fair/Poor	Worsening	Medium
Lobster	Good	Improving	Very High
Bluefin tuna	Undetermined	Improving	Low

[13] Definitions for each status rating are provided in Appendix A, which describes the specific considerations and thresholds to rate each question.

The state of large whale populations in the sanctuary are poor, with unusual mortality events declared for three species in the northeast region: right, humpback, and minke (NOAA Fisheries 2019a). The most recent information on right whales suggests that the situation is worsening, with only 12 births since 2017, a period in which 30 mortalities have been documented. Despite the fact that right whale abundance in Massachusetts Bay and Cape Cod Bay, including the sanctuary area, has been steady or slightly increasing, the poor condition of right whales is due to the declining trend in their overall population combined with elevated mortalities caused by ship strikes and entanglement throughout their range. Similarly, despite a positive growth trend for humpback whales in the Gulf of Maine (NOAA Fisheries 2019c), their co-occurrence with entangling fishing gears in the sanctuary (Wiley et al. 2003) and the relatively frequent sightings of entangled whales in the sanctuary leads to the poor status rating. Odontocete populations have been estimated to be in fair condition, with insufficient data to determine trends in some species. Conservation measures, such as the use of pingers in the gillnet fishery, seems to have resulted in reduced bycatch of harbor porpoises. Great shearwater populations in the sanctuary are in good/fair condition. The trend for these populations is unknown as bycatch in fishing gear is considered to be a threat, but gillnet fishery effort appears to be declining. Lobster populations appear to be increasing, and fishing effort is also increasing. SBNMS remains an important tuna fishing ground, but the status of the bluefin tuna population is unknown, as available data are limited. Atlantic cod are at historic lows in the Gulf of Maine region, but local abundance and commercial catch per unit effort in SBNMS are relatively high, which is attributed to the stock contracting to feed on sand lance within the sanctuary.

14. What is the status of non-indigenous species and how is it changing

Status Description: Non-indigenous species are present and may preclude full community development and function, but have not yet caused measurable degradation.

Rationale: Invasive species exist in the sanctuary and have for many decades; however, their abundance and distribution are poorly documented. The invasive tunicate, *Didemnum vexillum* has been found in isolated, small areas dominated by hard bottom habitats.

The 2007 rating for the status of non-indigenous species was “good/fair” with a “declining” trend. Unfortunately, little information is available on non-indigenous species in the sanctuary. Nevertheless, as changes water temperature and other regional conditions are underway, species distributions are changing. The arrival of non-indigenous species through range extensions and related processes poses an uncertain threat to sanctuary ecosystems.

Non-indigenous species exist in the sanctuary and have for many decades; however, their abundance and distribution is poorly documented. Human activity is likely the largest cause of species introduction, but the exact means are not well understood. High levels of vessel traffic in and around the sanctuary may introduce species through ballast water or fouling on hulls or other equipment (e.g., fishing nets). In addition, climate change may result in increased introductions due to altered habitats, warming waters, and changes in ocean circulation patterns.

The invasive tunicate *Didemnum vexillum* (Figure S.LR.14.1) has been observed in the sanctuary for the past decade, and is typically found in isolated, small areas dominated by hard bottom habitats, such as boulders, rock, gravel, or cobble substrates. It has also been observed on at least two sanctuary shipwrecks, the *Paul Palmer* and the *Portland* (A. Stratton, personal observation, January 19, 2018). Systematic monitoring has not occurred to determine its abundance and distribution. *D. vexillum* is a colonial ascidian (sea squirt or tunicate) with rapidly expanding populations on the east and west coasts of North America (Bullard et al. 2007). *D. vexillum* can degrade habitats through smothering; however, *D. vexillum* requires hard bottom habitat, which is not abundant in SBNMS; thus it is likely that any impacts will be limited to small, localized areas.

Figure S.LR.14.1. The tunicate *D. vexillum* is invasive in SBNMS. This photo was taken in sanctuary waters in 2010. Photo: D. Costa

15. What is the status of biodiversity and how is it changing?

Status Description: Selected biodiversity loss or change is suspected and may preclude full community development and function, but has not yet caused measurable degradation.

Rationale: Changes in sanctuary biodiversity are likely driven by variability in multiple factors at local and regional scales. At a local scale, fishing activities focused on species with high residency may impact biodiversity. Regional-scale factors include fishing of highly mobile species and climate change. The resulting shifts in species interactions at both spatial scales may also influence biodiversity in SBNMS.

In the 2007 condition report, the status of biodiversity was rated “fair/poor” with an “increasing” trend. The status of biodiversity has now improved largely due to increases in abundance of several fish species and the discovery of three rare invertebrate species.

Broadly defined, biodiversity refers to the variety of life on Earth, and includes diversity of communities, species, and genetic characteristics within populations, as well as the ecological processes that support them. Information to assess the status of biodiversity at SBNMS at multiple levels of organization is limited, but time series data for fish, marine birds, and invertebrates can be useful to infer status and trends.

Observed changes in biodiversity are thought to be driven by human activities (i.e., fishing effects) and climate change (i.e., principally temperature), but determining causality is challenging. New rare species are being identified, but these findings could be a function of increased sampling for some species and range expansion due to climate change for others. New surveys are needed to detect change at low levels of abundance. Time series data for fish are most comprehensive compared to other species groups, while marine invertebrates and marine birds are only sampled at selected stations over limited time periods.

Fish

Systematic seasonal trawl surveys conducted since 1970 provide a time series dataset that can be used to assess patterns and dynamics in diversity of marine fishes in SBNMS, as well as the surrounding Gulf of Maine ecosystem (Auster and Conroy 2019). Mean species richness per sample tow across the nearly 48-year time series (1970—2017), for both spring and fall surveys, has a distinct and upward trend since 2006 (Figure S.LR.15.1). Sample-based rarefaction curves and diversity estimation by decade also indicate that the last decade of the time series (2010 onwards) is different than earlier decades. Multivariate analyses of community composition from fall surveys across decades indicate that the fish community in the 1970s, 1990s, and 2000s differed significantly from the 2010s. Based on changes in species dominance, variation in community composition was principally driven by changes in species that are exploited in fisheries and, for the most recent two decades, include ocean pout, silver hake, haddock, American plaice, spiny dogfish, and Atlantic herring, among others. For spring surveys, community composition in the 1980s and 1990s was significantly different than the 2010s, again based on changes in dominance, with Acadian redfish, yellowtail founder, longhorn sculpin, and Atlantic cod, along with the same species listed above, contributing to decadal differences (see Auster and Conroy 2019 for details).

To address changes in community composition across the larger Gulf of Maine, multivariate regression tree analyses were used to link changes to factors beyond decadal period (e.g., geographic location, depth, season, and temperature over time). These analyses revealed seasonal, geographic, depth, and decadal differences, with notable differences in species composition and abundance before and after the year 2010. The same approach was used for the smaller SBNMS region. Similar to the larger region, there was a split in community composition before and after 2010. Differences in abundance of silver hake, haddock, red hake, Atlantic herring, Acadian redfish, and alewife were associated with the shift in 2010 at the Gulf of Maine scale, while haddock, silver hake, winter flounder, yellowtail flounder, Acadian redfish, alewife, and spiny dogfish were the principal species linked to changes in dominance and abundance in the SBNMS region. Notably, most species linked to significant changes in community composition have increased in abundance over time in the SBNMS region (i.e., haddock, silver hake, alewife, Acadian redfish, winter flounder, yellowtail founder, spiny dogfish); whether this is a function of fisheries management or species response to climate change (Hare et al. 2016), or a synergy of both, remains unclear.

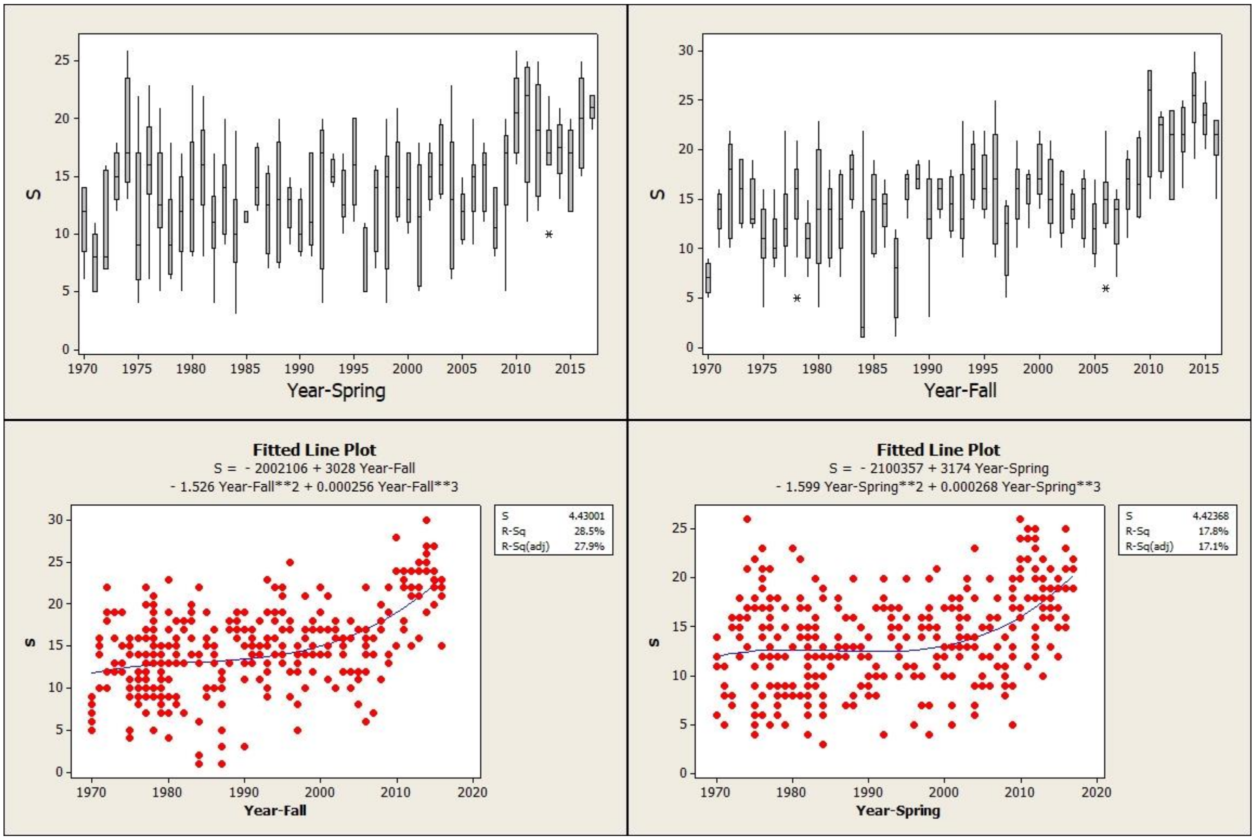

Figure S.LR.15.1. Spring (left) and fall (right) patterns in species richness (S) per tow in the region of SBNMS (see Auster and Conroy 2019 for details of sample boundaries). Top panels are box-and-whisker plots to compare distributions of S by year and season. The central line denotes the median value. The top of each box is the upper value of the third quartile (75% of data less than or equal to this value) and bottom is the upper value of the first quartile (25% of the data are less than or equal to this value). The tip of the upper whisker is the highest data value within the limit of Q3 + 1.5 (Q3–Q1) while the tip of the lower whisker is the lowest value within the limit of Q1–1.5 (Q3–Q1). Stars represent outliers of unusually high or low values outside the limits of the whiskers. The lower panels are fitted line plots of the raw data, with regressions and models illustrating upward trends in years beyond 2009. Images: (top) Auster and Conroy 2019, (bottom) Auster and Conroy unpublished.

While fish species that drive shifts in community composition are, due to sheer statistical force, dominant species, the status of rare species is also of conservation concern. Besides Atlantic and shortnose sturgeon, which are listed as threatened or endangered under the authority of the ESA, there are a number of species of concern that have been identified based on general population status and threats, but for which insufficient information is available to justify listing the species under the ESA (GARFO 2017b). Species of concern known to occur in SBNMS include: Atlantic bluefin tuna (*Thunnus thynnus*), dusky shark (*Carcharhinus obscurus*), sand tiger shark (*Carcharias taurus*), rainbow smelt (*Osmerus mordax*), cusk (*Brosme brosme*), Atlantic wolffish (*Anarhichas lupus*), Atlantic halibut (*Hippoglossus hippoglossus*), and river herring (alewife — *Alosa pseudoharengus* and blueback herring — *Alosa aestivalis*). While most of these species are transient through SBNMS, cusk has been classified as a year-round resident, and Atlantic wolffish as a seasonal resident (Auster and Lindholm 2005). While the status of these populations at both regional and local scales is uncertain, modeling studies can aid in inferring status and explaining spatial trends in data. For example, cusk have suffered dramatic declines, principally because of fishing (Hare et al. 2012). As many species are reacting to variation in temperature and related ecosystem changes due to climate variability, it is likely that both fishing and climate change will affect population status (Hare et al. 2016). Hare et al. (2012) linked a species niche model with output from an ensemble of climate models to project future distributions of cusk in the Gulf of Maine region. The results suggest that cusk habitat will both shrink and fragment because of a spatial mismatch between high-complexity seafloor habitat and suitable temperature regimes. Further, the SBNMS region functions as one of the refuge fragments under most climate model scenarios. While the importance of habitat connectivity is poorly understood, SBNMS could serve as one important element for sustaining population persistence.

Marine Birds

SBNMS conducted standardized seabird surveys from 2012–2016. Fifty-two species of marine birds have been observed during 20 standardized surveys. Herring gull, great black-backed gull, northern gannet, great shearwater, sooty shearwater, and Cory’s shearwater are the principal species in the SBNMS marine bird community.

The National Audubon Society’s Christmas Bird Count provides a regional perspective on changes in diversity of marine birds in the greater SBNMS region. An exploratory examination of ten decades of Christmas Bird Count data comparing winter avifauna along the coasts of Delaware Bay, Long Island Sound, and Cape Cod-Massachusetts Bay was conducted from 1920–2014 (Auster et al. 2017, Auster unpublished data). Species composition from each large estuary was generally distinct based on species and abundance. While most census areas are coastal and SBNMS has only recently been included in the Christmas Bird Count, general patterns over time from Cape Cod-Massachusetts Bay are useful for assessing the status of avifauna diversity in the general area. While there were significant differences in species composition from earlier decades to the present, the differences from the 1990s and 2000s to the 2010s are small. Differences from the 1950s to the 1980s compared to the 2000s and 2010s were significant. For example, differences between the 1980s and 2010s include reduced abundances of herring gull, great black-backed gull, and black-legged kittiwake and increases in razorbill and northern gannet. Overall, the analysis illustrated that community structure varied over a century at decadal time scales as well as between count locations. However, changes due to variation in breeding colony conditions, local prey resources, local human disturbances, or cascading effects from changes to oceanographic conditions are unknown.

Invertebrates

Seafloor invertebrate communities were assessed from 1998–2010 to assess changes inside and outside of the WGOM Closure Area implemented by the NEFMC. Overall, results from multivariate analyses indicate that community structure within each macrohabitat type (piled boulder, gravel, sand, mud) has been dynamic across time (years) and fishing treatment (i.e., inside and outside the WGOM Closure Area) despite the high degree of similarity between paired habitat stations at the time of closure (Auster et al. 2013b). Notably, closure effects persisted across time. Despite this pattern, changes in similarity between replicate transects within macrohabitats and between years were dynamic. This pattern suggests that dominance of local processes, such as predation and competition, may be driving community composition during some periods (i.e., contributing to greater patchiness in the distributions of taxa within stations), while larger spatial scale disturbance processes, produced either by natural events (e.g., storms, disease) or fishing activities are dominant during other periods. Species populations and community structure within the closed area have yet to reach any stable configuration, suggesting, at least to-date, recovery without resilience. Multivariate and univariate comparisons of each habitat type inside and outside the closure across years, with regard to community composition, population responses of component taxa, and patterns of diversity, all demonstrated a response to the closure, but not for all habitats or all species at all times, or in ways that are normally predicted from previous closed areas studies. For example, structure-forming taxa recovered both inside and outside the closed area, although different taxa were dominant. Differences in taxa such as *Iophon* spp. (sponge), *Molgula* spp. (tunicate), *Terebratulina septentrionalis* (stalked brachiopod), *Cerianthus borealis* (stalked anemone), among many structure-forming species, all exhibited significant differences in abundance over time and due to closure status. Notably, aggregated abundance based on functional role was significantly different across years and between habitats, but a closure effect was only found for emergent fauna in gravel habitats. Expected increases in invertebrate species diversity at stations within the WGOM Closure Area were not observed by the end of the study period, suggesting that community recovery draws from a regional species pool, and patterns of abundance vary based on local patterns of disturbance.

Rare invertebrate species have been identified in several discrete places within SBNMS. Pom pom anemones (*Liponema multicornis*) have been observed in extremely small numbers and in a small patch in the northern part of the sanctuary (Figure S.LR.15.2, Auster et al. 2011). This species occurs in sand and mud habitats and is extremely sensitive to disturbance. A glass sponge, tentatively identified as *Vazella pourtalesii*, has been identified on the wreck of the *Portland* in the deep water of Stellwagen Basin (Figure S.LR.15.3, Stratton and Auster 2015). The shipwreck likely serves as a refuge from disturbance.

Figure S.LR.15.2. A pom pom anemone *Liponema multicornis* on fine-grain sediment seafloor. This species occurs on unconsolidated sediments and does not attach to hard substratum like most other anemones. Photo: NOAA

Finally, near the western boundary of the sanctuary, the stalked sponge *Stylocordyla borealis* was observed in 2014 and 2015 in extensive patches. Interestingly, these species have rarely been observed or reported from the Gulf of Maine; however, they have been observed across larger ranges both north and south of the Gulf of Maine. Those individuals observed in SBNMS are remnants of previously widespread populations or are re-occupying former parts of their range due to changing conditions (e.g., regional oceanographic conditions or local changes in disturbance). There are diverse communities of seafloor invertebrates within SBNMS, including three species considered rare within the Gulf of Maine region. However, it is difficult to assess the status of seafloor communities during the current period, as fishing activities within the WGOM Closure Area may have impacted a long-term monitoring station, compromising the ability to assess change over time (Auster 2015).

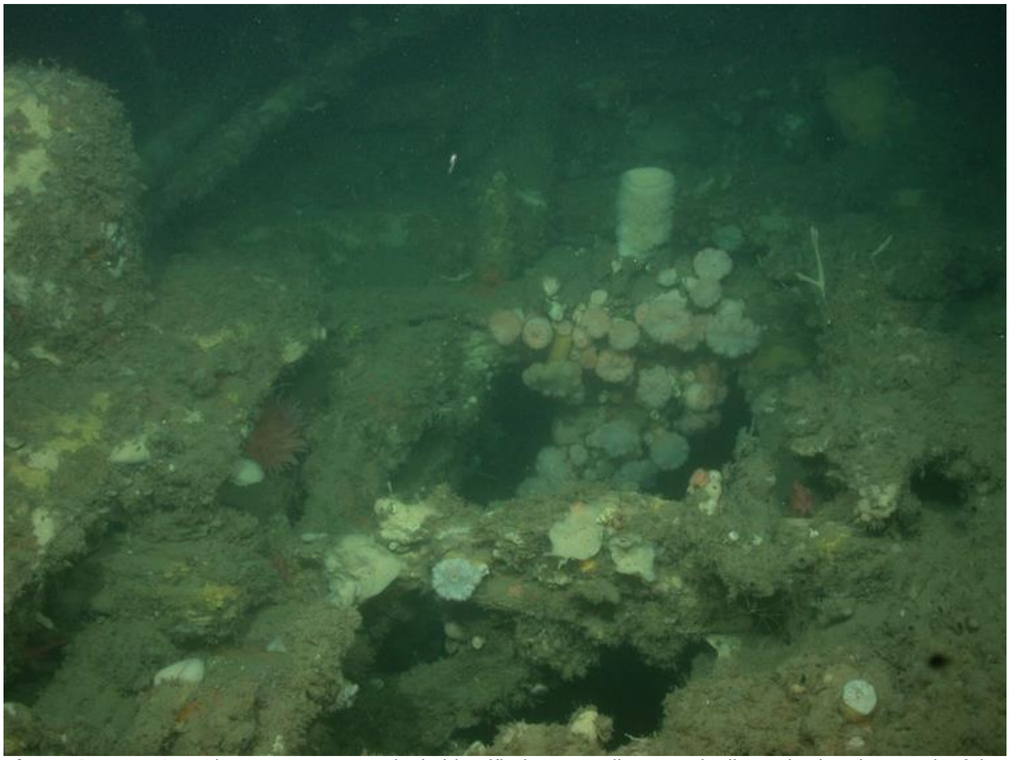

Figure S.LR.15.3. A glass sponge, tentatively identified as *Vazella pourtalesii* attached to the wreck of the steamship *Portland*. Photo: NOAA

Overall, the status of biodiversity within SBNMS has changed since the last condition report. Direct and indirect effects at regional and local scales have likely influenced biodiversity of fish, birds, and seafloor invertebrates. Direct effects include fishing of highly migratory and highly resident species at regional and local scales, respectively, and climate change. Indirect effects include changes in species interactions (predation, competition, parasitism, and facilitative interactions). The ability to parse regional- versus local-scale effects is critical for understanding how sanctuary-scale versus regional-scale interventions might be used to sustain future biodiversity.

Maritime Heritage Resources (Question 16)

The Maritime Heritage Resources section of this report addresses the condition and threats to heritage resources in the sanctuary. These include shipwrecks and other submerged archaeological sites, which are a subset of a larger category of maritime heritage resources that may include other cultural themes, such as traditions, histories, and values; the latter are not the subject of this report. Archaeological resources are material evidence of past human activities and include vessels, aircraft, structures, habitation sites, and objects created or modified by humans. Question 16 assesses the integrity of known maritime heritage resources in the sanctuary. The integrity of a heritage resource refers to its ability to convey information about the past, and can be impacted by both natural events and human activities.

16. What is the condition of known maritime heritage resources and how is it changing?

Status Description: The diminished condition of selected maritime heritage resources has reduced, to some extent, their aesthetic, cultural, historical, archaeological, scientific, or educational value, and may affect the eligibility of some sites for listing in the National Register of Historic Places.

Rationale: Shipwreck sites are known to experience damage from mobile and fixed fishing gear, as these sites create structure on the seabed that can attract commercially important fish species, and thus fishing effort. Damage to shipwreck sites from fishing gear has been documented. Shipwreck sites are also visited by scuba divers. Scuba diving in the sanctuary has increased since 2007, but seems to be well-managed by dive operators to avoid site disturbance.

In the 2007 condition report, the integrity of known maritime heritage resources was rated “fair” and “declining.” These ratings remain unchanged in this report. Human activities, such as commercial fishing, continue to affect shipwreck structures, causing fragmentation and scattering of artifacts, reducing the site’s value as a source for archaeological and historical knowledge. The declining trend is maintained because maritime heritage resources are non-renewable and do not recover once impacted.

Assessments of archaeological condition seek to determine if the sanctuary’s heritage resources have the potential to yield information that addresses important research questions relating to past human activity. Based on the condition of the archaeological remains at the site and the influences of post-depositional environmental deterioration and human activities, SBNMS’s heritage resources are in varying levels of condition, and every shipwreck shows signs of interaction with fishing gear. In general, the sanctuary’s largest historic shipwrecks are in better condition than smaller shipwrecks. Shipwrecks dating to the 18th century and older are generally less intact than more recent shipwrecks. Archaeological surveys have yet to locate a shipwreck believed to date prior to 1800.

The condition of the sanctuary’s shipwrecks is also influenced by their depth. The shipwrecks found on top of Stellwagen Bank have fewer hull remains compared to similarly-sized shipwrecks in deeper water. Strong currents and wave activity reach an estimated depth of 50 meters or more, creating an erosional environment that leads to greater physical deterioration. This environmental deterioration coupled with the likelihood of interactions with fishing gear has reduced the condition of some sites. Only six of the shipwreck sites located to date have been found at depths less than 50 meters. The remaining vessels lie in a depositional environment that is conducive to archaeological preservation.

For a non-renewable resource such as historic shipwrecks, one encounter with a scallop dredge or bottom trawl can result in catastrophic damage that diminishes its historical, archaeological, cultural, and economic value. A recent example of this is damage to the modern wreck *North Star* associated with scallop fishing (see the explanation to the response for Question 5).

Despite increased degradation and worsening condition of SBNMS shipwrecks from environmental (e.g., storm wave action or bacteriological consumption) and anthropogenic (fishing gear interactions) impacts, SBNMS sites are revealing novel historical information. For example, archaeologists have located four shipwrecks containing granite cargoes. Each cargo is a different variety of granite, and the position of stones within each hull reveal how it was stowed. The spatial distribution of wrecks also suggests sailing routes and links to quarries and ports. The identification of the *Lamartine*, a Maine-built, two-masted schooner constructed before the Civil War, reveals adaptive use patterns, or ways that shipowners changed the vessel's trade. Interpretation of these granite wrecks as part of a broader maritime cultural landscape connects them to the New England maritime community.

Most shipwreck sites are only surveyed once every fifteen years. While survey data and some site documentation are available, more frequent inventory and monitoring of these sites would be valuable, as wrecks continue to degrade over time. Most information about these wrecks is anecdotal. Seabed disturbance on top of Stellwagen Bank from storms redistributes surficial sediments. Surveying wrecks before and after storms may be important for determining whether site conditions have changed (i.e., if sites are buried or uncovered). Documentation indicates that sites have experienced damage from mobile and fixed fishing gear, as these sites create structure on the seabed that can attract commercially important fish species. Scuba diving in the sanctuary has increased since 2007, and shipwreck sites are visited by divers. However, dive operations (about a dozen dive charters each year) seem to be well-managed by operators to avoid disturbing these sites, though some incidences of disturbance have been documented. In addition, organized groups of divers have partnered with the sanctuary to research and promote stewardship of maritime heritage resources.

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STATE OF ECOSYSTEM SERVICES

Ecosystem services are the benefits that humans receive from natural and cultural resources. Generally, the taxonomy of the Millennium Ecosystem Assessment (MEA 2005) is used in ONMS condition reports. MEA (2005) was an initiative of the United Nations to assess ecosystem services, including cultural, provisioning, regulating, and supporting services. Categories of ecosystem services include "final" services, which are directly valued by people, and "intermediate" services, which are ecological functions that support final services (Boyd and Banzhaf 2007). In ONMS condition reports, only final ecosystem services are rated, which is consistent with the anthropogenic focus of the reports and highlights priority management successes and challenges in sanctuaries. The complete definitions of ecosystem services considered by ONMS are included in Appendix B.

Final vs Intermediate Ecosystem Services

There are intermediate and final ecosystem services. Ecosystem services that are evaluated in condition reports are final ecosystem services. Intermediate services support other ecosystem services, whereas a good/service must be directly enjoyed by a person to be considered a final ecosystem service. For example, nutrient balance leads to clearer water and higher visibility for snorkeling and scuba diving. Nutrient balance is an intermediate service that supports the final ecosystem service of non-consumptive recreation via snorkeling and scuba diving.

Twelve final ecosystem services may be rated in ONMS condition reports

Cultural (non-material benefits)

1. Heritage — Recognition of historical or heritage legacy
2. Consumptive recreation — Experiential opportunities that result in resource removal
3. Non-consumptive recreation — Experiential opportunities that include recreation and community activities
4. Sense of place — Aesthetic and spiritual attraction, and the level of recognition and appreciation given to efforts to protect a place's iconic elements
5. Science — The capacity to acquire information and knowledge
6. Education — The capacity to provide intellectual enrichment

Provisioning (material benefits)

7. Food supply — The capacity to support market demands for nutrition-related commodities through various fisheries
8. Water — Filtration for drinking water that minimizes pollutants, including trash, nutrients, sediments, pathogens, and chemicals
9. Ornamentals — Resources collected for decorative or aesthetic purposes
10. Biotechnology — Medicine and other chemicals found in sanctuary animals or plants, or manufactured from them
11. Energy — Use of renewable materials or processes to supply energy

Regulating (buffers to change)

12. Coastal protection — Flow regulation that protects habitats, property, coastlines, and other features

Notably**,** some consider consumptive recreational fishing as a provisioning service, but it is included here as a cultural ecosystem service. Also, even though biodiversity was listed as an ecosystem service by both MEA (2005) and ONMS (2015), ONMS decided to remove it, recognizing that biodiversity is an attribute of the ecosystem for which many "final" ecosystem services depend (e.g., recreation and food supply); therefore, it is addressed in the State section of this report. Lastly, although ONMS listed climate stability as an ecosystem service in 2015, it is no longer considered an ecosystem service in ONMS condition reports, because national marine sanctuaries are not large enough to influence climate stability (Fisher et al. 2008, Fisher et al. 2011).

For SBNMS, only seven of the 12 "final" ecosystem services were rated during the February 15, 2018 workshop (see Appendix B for a more detailed description of content and methods). Specifically, all of the cultural services are rated, including heritage, consumptive recreation, non-consumptive recreation, sense of place, science, and education. There is only one provisioning service rated for SBNMS, which is food supply via commercial fisheries. The sanctuary does not provide "final" ecosystem services for other provisioning services: ornamentals used by the aquarium trade, biotechnology, alternative energy, or clean water. Similarly, sanctuary resources do not significantly influence coastal protection (a regulating ecosystem service that involves protection of property values from damaging storms).

Ecosystem Services Indicators

The status and trends of ecosystem services are best evaluated using a combination of economic and non-economic human dimension indicators, as well as relevant ecological/resource indicators evaluated in the State section of this report, to assess the compatibility and sustainability of services relative to the condition of impacted resources.

Economic Indicators

Economic indicators may include direct measures of use (e.g., person/days of recreation or catch levels) that result in spending, income, jobs, gross regional product, and tax revenues, or non-market economic values (the difference between what people pay to use a good/service and what they would be willing to pay).

There are other measures, often referred to as indirect measures, that can impact resources in and around the sanctuary, but are not a measurement of the direct use of resources. For example, as populations and per capita incomes increase in the U.S., Massachusetts, and counties surrounding SBNMS, demand for recreation and commercial fisheries' products would be expected to increase (Bell 1978). In addition, demand in China for seafood products originating off the U.S. East Coast is so high that population and per capita incomes in China can similarly serve as good indicators of the status and trends for this provisioning service (Bell 1978). The status and trends for science (Sobel 1996, Dixon and Sherman 2009), education (Sobel 1996, Parsons 1997, Dixon and Sherman 2009), and heritage (Mires 2014) services may also correlate with changes in populations and per capita income in the U.S., Massachusetts, and local areas surrounding SBNMS. In short, people create demand for goods and services, and higher incomes can lead to investments, making these useful indicators for these services.

In addition to population and per capita income, fuel prices can serve as indirect measures of recreational demand at SBNMS because the only way to gain access to the sanctuary's offshore location for recreational purposes is by boat (Gornik et al. 2013). Thus, fuel prices can be a predictor of recreational use by boaters. For example, decreasing or stable fuel prices could support increasing use of SBNMS by recreational boaters.

Fuel prices also affect the cost of production in commercial fisheries, thus impacting distribution of effort and food supply. Higher fuel prices can cause fishers to alter fishing patterns to minimize fuel consumption; they may, for example, choose to fish closer to shore than their preferred fishing grounds. Redistribution of fishing in SBNMS could result from either fishers moving out of the sanctuary and closer to shore or into the sanctuary from offshore fishing grounds. Depending on the change in levels of effort, either could affect targeted species within and around the sanctuary.

In evaluating the above types of economic indicators, it is also important to consider "passive economic use value" (also called "non-use value"), which is an important element in evaluating sense of place. Passive economic value is the value people would be willing to pay for resources to stay in a certain condition, even though they may never actually directly use them. Estimating these values requires the use of surveys that integrate social science information with physical and natural science information in defining changes in goods or services of value to people. Economic valuation methods (Louviere et al. 2009, Bishop et al. 2011) can be used to estimate passive economic use value. This kind of data, however, is rarely available and can be expensive and time-consuming to collect. Scientifically designed public polls on peoples' preferences for environmental protection and restoration can serve as a proxy indicator for this value.

Non-Economic Indicators

Human dimension, non-economic indicators can be used to complement the economic indicators discussed above. These include importance-satisfaction ratings for natural and cultural resources, facilities and services for recreation uses, limits of acceptable change for resource conditions, social values and preferences (measured by polls), social vulnerability indicators, perceptions of resource conditions in the present and expectations for the future, and access to resources. For SBNMS, few studies have measured most of these non-economic indicators, representing a major gap in socioeconomic research and understanding. Nevertheless, some non-economic human dimensions indicators are available. For example, to rate the status and trends of science and education, the indicators used in this report include the number of vessel hours on NOAA boats, research permits, number of publications, and number of volunteers and hours.

Resource Indicators

Ecological/resource indicators are also considered in determining status and trend ratings for each ecosystem service. For each ecosystem service, a matrix was developed mapping relevant ecological/resource indicators to each ecosystem service. To rate the status of each ecosystem service, ecological/resource indicators might be used to downgrade a rating based on economic and human dimension non-economic indicators; this is because the ecological/resource indicators suggest that humans are using a stock of natural or cultural resources to get short-term economic gains that are not sustainable. For example, during periods of high interest in whale watching, both economic (e.g., spending or profit) and non-economic (e.g., visitation) data typically indicate favorable status and trends for this non-consumptive recreation activity. But if the number of ship strikes on whales is shown to be increasing, or whale feeding behaviors are negatively altered by high levels of disturbance, the activity could be deemed unsustainable at the current level, and the rating downgraded accordingly.

Cultural (Non-Material Benefits)

Heritage

Status Description: Unable to fully provide the ecosystem service due to prior or existing human activity, but performance is acceptable.

Rationale: Indicators show that historic SBNMS shipwreck stories are told in newspapers, magazines, and museums in New England. The dissemination of historic shipwreck information and stories indicates there is economic value for this resource. The resource indicators show that in-water shipwreck resources are fair and worsening.

The status of maritime heritage is rated as “good/fair” (medium confidence) and the trend is “improving” (high confidence). The maritime heritage ecosystem service recognizes the sanctuary’s ability to convey its historical or heritage legacy. For SBNMS, efforts are needed to understand the socioeconomic (direct and indirect) impacts of its activities. One option could be to conduct a cultural landscape analysis for shipwrecks and cultural resources to better understand cultural identity[14] (MPAFAC 2011). Cultural landscape analysis tells the story of how a place has developed its character and cultural identity. In addition, economic valuation work, discussed in Claesson (2011) and similar to that in Mires (2014), explained below, could be conducted along with non-economic measures, such as importance and satisfaction with cultural resource attributes and knowledge, attitudes and perceptions of management strategies, regulations, and condition of the cultural resources. Additional information on diving and museum visitation and the economic effects of this use on local economies would provide valuable information on this service for future evaluations.

Economic Indicators

There have not been any studies identifying the use or economic value of cultural resources supporting the maritime heritage service for SBNMS. However, a study done on the Graveyard of the Atlantic (Mires 2014), which includes Monitor National Marine Sanctuary, found that people’s willingness to pay for maritime heritage increased with:

- expansion of the number of shipwrecks protected;
- the level of investments in museum exhibits;
- maritime heritage trails, including virtual trails using video and mobile phone technology; and
- educational workshops on maritime heritage and training in maritime archaeology.

Similar research could be applied to SBNMS to help understand what aspects people value from maritime heritage resources. The shipwrecks in SBNMS reflect the diverse range of activities and nationalities that have traversed the New England area. Coal transport, granite trade, vessels engaged in commerce, and commercial fishing vessels have all been lost in sanctuary waters. Researchers have located more than 47

[14] Cultural identity is the way in which a person identifies or feels they belong to a group. “As identified by oral or written record, indigenous stories, knowledge, people, places, structures, objects, and traditional practices contribute to maintaining cultural identity” (MPAFAC 2011). Further, “The broad array of stories, knowledge, people, places, structures, and objects, together with the associated environment, that contribute to the maintenance of cultural identity and/or reveal the historic and contemporary human interactions with an ecosystem” is defined as (marine) cultural resources (MPAFAC 2011).

historic shipwrecks in SBNMS, and archival data indicates there may be 200 more historic wrecks still to be located (Lawrence et al. 2015).

The number of news stories appearing in newspapers and magazines is another indicator of the economic value of historic shipwrecks. From 2007 to 2016, 28 stories on historic SBNMS shipwrecks were reported in local, regional, and national newspapers and magazines (B. Barr, personal communication, January 17, 2018). A documentary on the *Portland* aired on the Science Channel in 2003 and continues to be aired 10 years later.

One workshop expert and dive shop operator noted that since 2007, diving on shipwrecks in SBNMS has been an important part of the business, which, while currently small (three boats doing a dozen trips per year), is increasing. This activity would usually be captured in the non-consumptive recreation ecosystem service, but it is noted here because learning the story of a historic shipwreck adds value to the dive, as does seeing marine life that use the site.

Non-Economic Indicators

In New England, there are nine museums/visitor centers that have exhibits, artifacts, or tell stories of the sanctuary's maritime heritage:

- Provincetown Lands Visitor Center — shipwreck interpretive panel
- Provincetown Museum — *Portland* Gale artifacts
- Maine Maritime Museum — Maine-built shipwrecks kiosk
- Mystic Seaport Museum — general regional maritime heritage information
- Essex Shipbuilding Museum — general regional maritime heritage information
- Highland House Museum — *Portland* artifacts
- Penobscot Marine Museum — Maine-built shipwrecks kiosk
- Maritime Gloucester (largest) — kiosks, videos, interpretive displays
- Scituate Maritime and Irish Mossing Museum — *Portland* Gale artifacts

One workshop expert noted that there are also 25 different historical societies, museums, and historical ships, such as the schooner *Adventure* in Gloucester, MA, that provide the public with a wealth of cultural heritage resources that do not exist anywhere else in the U.S. Another noted that, through the Preserve America Grant Program, four SBNMS partner organizations have made maritime heritage kits to help educate the public.

There are currently 47 known historic shipwrecks located within SBNMS in various stages of survey. As more is learned and discovered about other maritime heritage resources in the sanctuary, there is an expectation of future benefits from educational opportunities, development of trails (including virtual), museum exhibits, and the protection of maritime heritage resources.

Resource Indicators

As noted in the State of Resources section of this report, the condition of maritime heritage resources is rated "fair" and "worsening." The rating is largely due to natural degradation in the shallow marine environment and impacts from commercial fishing gear. Some degradation is also due to diver impacts, but it is not considered a major factor.

Summary

There are significant products telling the stories of historic SBNMS shipwrecks via books, magazines, and artifacts and kiosks at many museums, which would all indicate there is significant economic value associated with maritime heritage in SBNMS. At the same time, resource indicators show some decline in integrity due to natural degradation and commercial fishing gear damage, but overall, damage is not severe. These economic value and resource indicators justify a rating of “good/fair” and “improving” for this ecosystem service.

Consumptive Recreation

Status Description: Ability to provide ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

Rationale: The number of charter and party boat anglers declined from 2007–2016, while the number of private boat registrations remained stable from 2007–2015 and increased in 2016. Local communities are also highly engaged in recreational fishing. The resource indicator for the most sought after stock (Atlantic cod) is poor, but alternative stocks (haddock, pollock, etc.) are sustainably managed and responsibly harvested.

The status of consumptive recreation is “fair” (medium confidence) and the trend is “undetermined” (medium confidence). Consumptive recreation includes recreational activities that result in the removal of or damage to natural and cultural resources. For SBNMS, this activity is primarily recreational fishing. While the number of charter boat and party boat anglers (Table ES.CR.1) declined from 2007–2016, the number of private boat registrations remained stable over the same time period and increased in 2016. There is high engagement of local communities in recreational fishing activity. Mostly notably, the recreational fishing species most targeted in SBNMS (such as cod and bluefin tuna) show poor and worsening conditions.

There is very good information on recreational use and spending associated with recreational fishing on charter and party boats, but there is very little information available regarding fishing on private boats. Little information exists for other socioeconomic information. Periodic surveys are needed to gather use data for private boats; economic spending profiles; socio-demographic profiles of users; non-market economic use values; importance-satisfaction ratings of natural and cultural resource attributes, facilities, and services; and knowledge, attitudes, and perceptions of users regarding management strategies, regulations, and sanctuary natural and cultural resources. In addition to private boats, the same types of information are needed from passengers of “for hire” operations that take people into the sanctuary for non-consumptive recreation.

Economic Indicators

Since the last condition report in 2007, the number of party boat anglers (people paying individually) declined from about 18,500 per year to 11,300 in 2016 (Table ES.CR.1, Figure App.F.21). In addition to party boats, the number of charter boat anglers (people paying per group) decreased by about 2,400, from 6,700 to 4,300 (Table ES.CR.1, Figure App.F.22). The complete economic analysis summarized in this section is provided in Schwarzmann et al. (2020) and uses data provided by GARFO (2019b).

A snapshot of private boating activity within SBNMS was estimated for 2009 (Hellin et al. 2011). It was found that 92% of boats that visit the sanctuary were 26 feet or greater and there was a total of 117,120 person-days of private boat fishing in the sanctuary. This activity supported roughly $6 million in spending, $4.6 million in value-added, $2.5 million in income, and supported roughly 60 jobs in the local economy (Table ES.CR.2).

Table ES.CR.1. Number of party and charter boat vessels, anglers, and trips, 1998–2016. Source: GARFO 2019b

	Party			**Charter**		
Year	**Vessels**	**Vessel Trips**	**Anglers**	**Vessels**	**Vessel Trips**	**Anglers**
1998	19	149	3,820	44	452	3,678
1999	23	215	6,649	45	469	3,682
2000	19	222	6,716	53	751	5,243
2001	31	485	20,459	58	922	6,686
2002	23	409	16,931	76	1,044	6,622
2003	25	526	20,531	63	823	6,378
2004	34	589	23,328	65	751	5,624
2005	44	493	19,621	76	944	6,124
2006	36	474	18,467	74	950	6,400
2007	31	483	18,482	84	1,068	6,691
2008	28	398	13,270	80	1,037	6,612
2009	31	417	14,206	87	1,232	7,904
2010	30	365	12,767	91	1,420	8,536
2011	25	506	17,557	88	1,409	8,727
2012	21	351	11,744	73	1,100	6,605
2013	19	195	6,512	65	986	5,755
2014	21	329	10,800	59	943	5,863
2015	14	209	7,119	41	483	2,909
2016	17	307	11,329	45	678	4,296

Table ES.CR.2. Economic contribution/impact of private boat recreation in 2009. Source: Hellin et al. 2011

Person-days	117,120
Spending	$6,028,437
Output	$10,143,414
Value-Added	$4,589,275
Income	$2,455,113
Employment	57

Although this is a snapshot of activity, changes in the number of boat registrations over 26 feet can be analyzed. From 2007 to 2015, the number of Massachusetts boat registrations remained fairly stable, with an average of approximately 6,700 registrations for the time period; however, in 2016 there was an increase of over 2,000 boat registration from 2015, to roughly 9,000. It is unknown if this is an outlier, data error, or indication of a future trend (Figure ES.CR.1, NMMA 2016). Given the relative stability of boat registrations from 2009–2015, it can be expected that the contribution of private boat fishing to the local economy has also remained relatively stable.

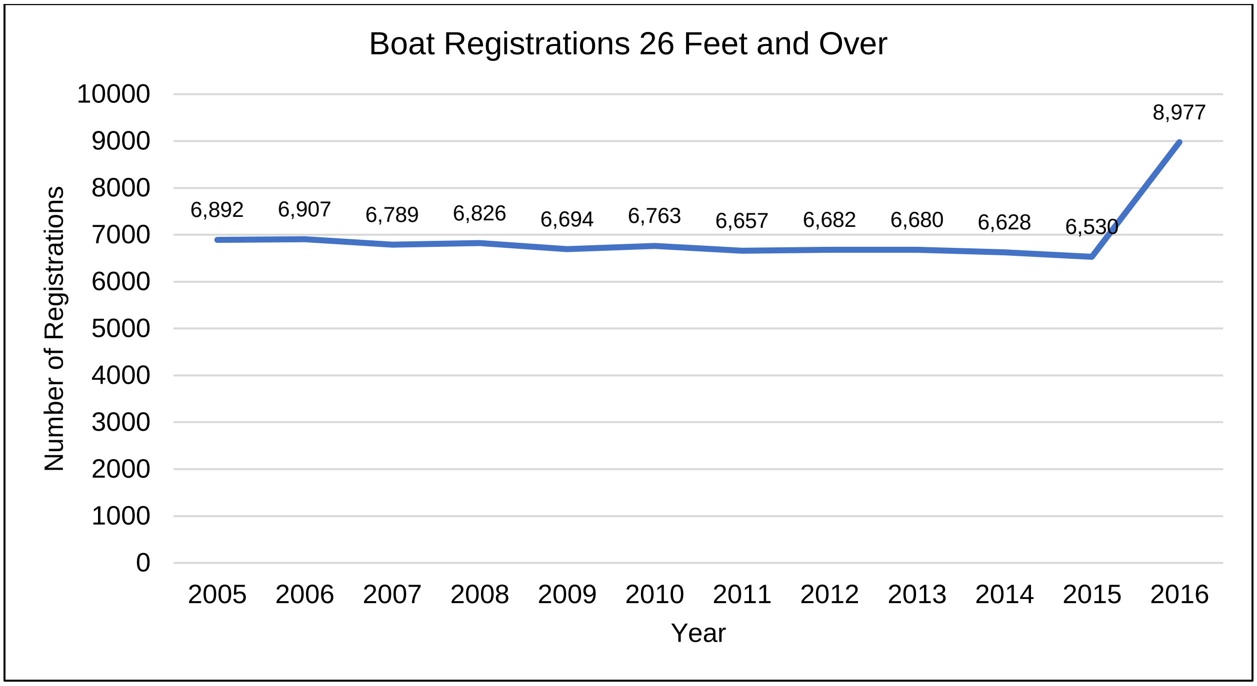


Figure ES.CR.1. Boat registrations in Massachusetts from 2005–2016. Source: NMMA 2016

Non-Economic Indicators

Non-economic indicators include the species kept by party and charter anglers, as well as fishing engagement indicators. Table ES.CR.3 and Figures App.F.23–App.F.32 show the top species kept by party and charter anglers. The top five species for both include cod, pollock, haddock, cusk, and redfish. This information is used in conjunction with the resource indicators (which discuss the state of the species) to make an integrated and informed decision about the state and trend of consumptive recreation.

Table ES.CR.3. Top species and number of fish kept by party and charter boat anglers, cumulative total 1998–2016. Source: GARFO 2019b

Species	Party Quantity Kept	Charter Quantity Kept
Cod	320,218	712,381
Haddock	274,635	279,311
Pollock	62,701	119,051
Cusk	37,847	23,410
Redfish	25,701	22,366
Mackerel	10,490	20,859
Bluefin tuna	11	19,741
Dogfish	8,748	1,374
Catfish	5,208	4,167
Bluefish	1,157	3,389

NOAA Fisheries developed an online database on fishing communities throughout the U.S. (NOAA 2018b). Indicators for recreational fishing engagement were developed for New England communities (Jepson and Colburn 2013, Figures App.F.33). The recreational fishing engagement indicator (presence of recreational fishing through fishing activity estimates) shows that the highest engagement occurs along the Massachusetts coastline, and more specifically, in Cape Cod.

Resource Indicators

Resource indicators help to determine if current use is sustainable and if there is potential for the service to improve or decline. The table below provides a summary for top species, including whether the stock is being overfished (i.e., the population size is too small) and if the stock is subject to overfishing (i.e., the annual rate of catch is too high).

Table ES.CR.4. Status of top commercial fisheries stocks. Source: NOAA Fisheries 2019b

Species	Stock is overfished? (i.e., stock size is too small)	Stock is subject to overfishing? (i.e., annual catch rate is too high)
Cod	Yes	Yes
Haddock	No	No
Pollock	No	No
Cusk[15]	Yes	Yes
Redfish	No	No
Mackerel	Yes	Yes
Bluefin tuna	Unknown	No
Ocean pout	Yes	No
Bluefish	Yes	No

While some of these species, such as cod, are overfished and subject to overfishing, others such as haddock and pollock are considered a smart seafood choice because they are sustainably managed and responsibly harvested.

Summary

While the number of charter boat and party boat anglers declined over most of the time period of interest, private boat registrations remained stable and have increased more recently. Local communities are also highly engaged in recreational fishing. Yet, the resource (recreational fishing stocks) condition is mixed. These factors suggest that there is significant and augmented economic value associated with consumptive recreational resources in SBNMS, but there are mixed results among the indicators, as well as information gaps. In addition, very little information is available for fishing on private household boats, and there is a lack of other ancillary socioeconomic data for recreational fishing. These indicators justify a rating of “fair” for the status of consumptive recreation, and the trend is “undetermined.”

[15] Candidate for listing under ESA, https://www.fisheries.noaa.gov/species/cusk

Non-Consumptive Recreation

Status Description: Unable to fully provide the ecosystem service due to prior or existing human activity, but performance is acceptable.

Rationale: Some commercial operations have noted that demand for whale watching has steadily increased and the number of reports mentioning bird sightings has been increasing. Income and population in the area have also been increasing, and stable fuel prices have led to increased non-consumptive recreational activity in the sanctuary. The resource indicators show that there is a decline in some of the focal and foundation species used for non-consumptive recreation.

The status of non-consumptive recreation is “good/fair” (low confidence) and the trend is “improving” (medium confidence). Recreational activities that do not result in the removal of or damage to natural and heritage resources are considered non-consumptive. The primary non-consumptive recreational activities include whale watching and other wildlife observation, scuba diving, sailing, and motor boating. In most studies of recreation, museum and visitor center use would be included in non-consumptive recreation. For SBNMS, this is a land-based activity, which is included in the maritime heritage ecosystem service discussion.

There is very little information for non-consumptive recreation since there are no formal institutions in place to estimate or monitor use on a regular basis. There is a need to conduct regular, periodic surveys to gather data on use by activity type; economic spending profiles; socio-demographic profiles of users; non-market economic use values; importance-satisfaction ratings of natural and cultural resource attributes, facilities, and services; and knowledge, attitudes, and perceptions of users about management strategies and regulations and sanctuary natural and cultural resources. In addition, surveys of “for hire” operations that take people out for non-consumptive recreation are needed to obtain information on intensity of use (number of days or trips) by type of activity (e.g., bird or whale watching), both inside and outside SBNMS; costs-and-earnings of the operations; and knowledge, attitudes, and perceptions of management strategies, regulations, and status of natural and cultural resources.

Economic Indicators

In 1998 and 2008, two studies of “for hire” whale-watching operations worldwide were done by the International Fund for Animal Welfare (O’Connor et al. 2009). For the New England region of the U.S., SBNMS was singled out for focus in their reports because over 80% of whale watching in the New England region was done in SBNMS. In 1998, 36 “for hire” operations took 992,000 people out for whale watching in SBNMS, with economic spending of $85.6 million (2017$). In 2008, there were 31 operations, carrying 728,000, with economic spending of $100.8 million (2017$).

Since 2008, there has been a reduction and concentration of the “for hire” industry that takes people out for whale watching and other wildlife observation in SBNMS. Currently, there are an estimated eight whale/wildlife watching operations that frequent SBNMS. Some have noted a general trend in which humpback whales are more frequently located in the southern half of the sanctuary, making it more difficult for operations located near the northern part of SBNMS to access the whales. Some operations are adapting their offerings and expanding their visitor experience to incorporate more bird and other marine mammal watching activities and outreach during their trips. Some are extending their seasons, and although there is a contraction in the industry, most existing operations are doing better financially. Some operators have noted that demand for whale watching has steadily increased.

The *Boston Globe* publishes bird sighting reports. A compilation of those reports from 2007 to 2016 recorded the percent of bird sighting reports that mentioned sightings in SBNMS (Barr, personal communication, January 17, 2018). From 2007 to 2010, none mentioned SBNMS. In 2013, 25% of reports mentioned SBNMS, in 2015 this figure doubled to 50%, and in 2016 it jumped to 94% (Figure ES.NCR.1). This correlates with the "for hire" industry shifting its focus to add more bird watching opportunities to SBNMS trips.

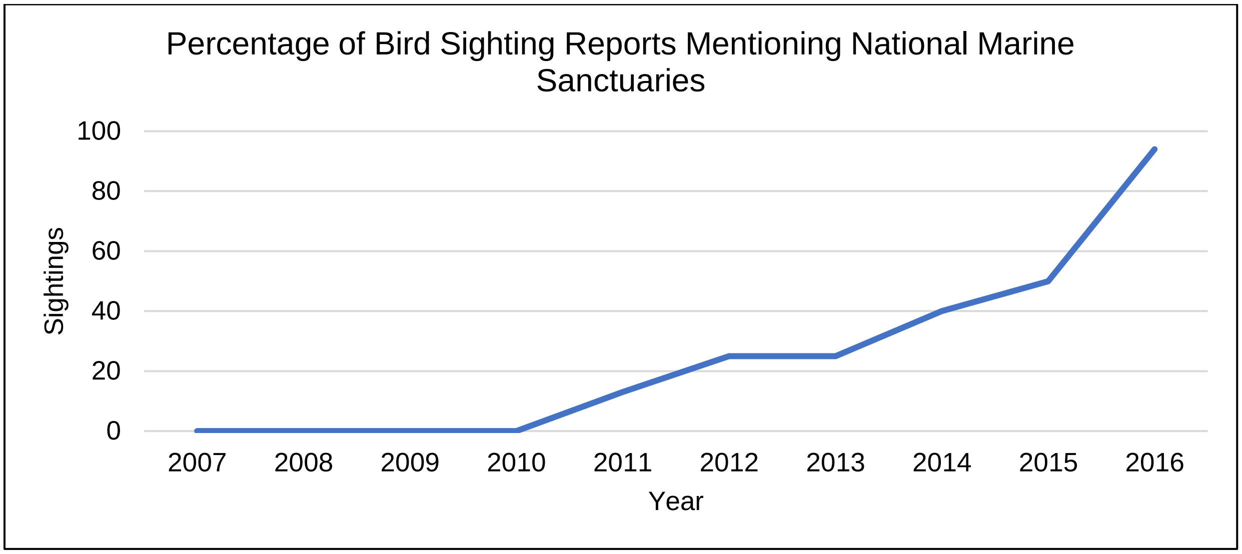


Figure ES.NCR.1. Percent of Boston Globe bird sighting reports mentioning SBNMS, 2007–2016. Source: B. Barr, personal communication, January 17, 2018

In 2010, the University of Massachusetts Boston's Urban Harbors Institute conducted a study of Massachusetts-registered marine recreational boaters (Hellin et al. 2011). Sample sizes for non-consumptive recreation were not large enough to estimate non-consumptive use in SBNMS. The study did find that of all Massachusetts recreational boaters in coastal and ocean waters, 3.2% engaged in whale watching, 12.1% engaged in bird watching, 3.3% engaged in scuba diving, 29.4% engaged in sailing, and 67.4% engaged in cruising (boating on the water for pleasure). In addition, 69% of all recreational activities were non-consumptive. Of the sampled boaters in SBNMS, 92% were in boats 26 feet in length or greater. Boat registrations for the State of Massachusetts (NMMA 2016) show a relatively flat trend from 2005 to 2015 (averaging 6,700 registrations) with a big spike upward in 2016 (to nearly 9,000 registrations) (Figure ES.CR.1, Appendix F: Table App.F.1).

Past trends and future increases in population and real per capita income (adjusted for inflation) for the U.S., Massachusetts, and the 14-county study area and stable fuel prices are indicators of positive and increasing past and future trends for non-consumptive recreation use in SBNMS (Appendix E: Tables App.E.1–E.2, Figures App.E.2–E.3).

Non-Economic Indicators

One study analyzing the public's willingness to pay for marine protected areas found that most groups would utilize for marine reserves. More specifically, depending on the size and use combinations of the protected areas, welfare estimates (willingness to pay) range from $26-$144 per year per household (Wallmo and Edwards 2008). Although a few studies have been conducted on marine protected areas in general, there have been no studies conducted on non-economic indicators for non-consumptive recreational users in SBNMS. This is a major research gap, and the only information available is at the community level. Further, for non-consumptive operators, their level of dependency on sanctuary resources for their livelihoods is unknown, which represents another data gap.

Resource Indicators

The primary resources supporting non-consumptive recreation in the SBNMS are the focal species discussed previously, as well as the foundation species on which they depend. Water quality, especially water visibility, is important for scuba diving. However, scuba diving is relatively infrequent in SBNMS and therefore, water quality, although rated "good," has a relatively low weight across all resource indicators.

Focal species include whales (right whales and humpback whales), other marine mammals (harbor porpoises, Atlantic white-sided dolphins), seabirds (great shearwater), lobster, bluefin tuna, and cod. The state of right whales in the sanctuary is poor due to the declining trend in overall abundance combined with the high entanglement risk in the sanctuary. Similarly, despite a positive growth trend for humpback whales in the Gulf of Maine (NOAA Fisheries 2019c), their co-occurrence with entangling fishing gears in the sanctuary (Wiley et al. 2003) and the relatively frequent sightings of entangled whales in the sanctuary results in a poor status rating. Harbor porpoises are increasing, while Atlantic white-sided dolphins appear stable. The status and trends among shearwaters are uncertain.

The primary foundation species on which many focal species depend include sand lance and Atlantic herring. Sand lance are rated as worsening, and there is concern about their spatial distribution, as they have not returned to the northern area of SBNMS. This is a major driver of whale distributions and the associated decline of whale watching operations located near the northern part of the sanctuary. Foundation species are rated "good/fair" with a "not changing" trend. Overall, the resource indicators demonstrate that the natural resources that support non-consumptive recreation have declined, but the decline is not widespread across species.

Summary

Economic indicators suggest there is significant value associated with non-consumptive recreation in SBNMS that is either stable or improving. As of 2008, the majority of whale watching in the New England region occurred within SBNMS, amounting to a spending value of approximately $100 million (2017$). Resource indicators suggest that, with the exception of an increase in bird sightings, there has been a decline in the natural resources that support non-consumptive recreation in the sanctuary, however, the decline is not widespread across affected resources. Therefore, non-consumptive recreation is "good/fair" because it is unable to fully provide the ecosystem service, but the trend is "improving."

Sense of Place

Status Description: Ability to provide ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

Rationale: Studies show a positive willingness to pay for marine protected areas. Opinion polls show that over the past several years, the percentage of people that prioritize environmental protection at the risk of economic growth is increasing. The resource indicators show variation in their rankings.

The status of sense of place is “fair” (medium confidence) and the trend is “improving” (high confidence). Sense of place is the aesthetic and spiritual attraction and the level of recognition and appreciation a person (visitor or resident) may have for a place’s iconic elements. National marine sanctuaries protect more than 600,000 square miles of ocean and Great Lakes waters. They are designated as marine protected areas because of their extraordinary scenic beauty, biodiversity, historical connections, and economic productivity.

Non-use, or passive economic use value, is a broad economic expression of the value people have for protecting special places. Generally, estimating non-use value for any place is relatively expensive, and thus rarely done. When it is possible, data collected from scientifically sound public surveys aimed at understanding environmental attitudes can be good predictors of people’s passive economic use value (Aldrich et al. 2007, Leeworthy et al. 2017). When these studies are replicated year after year, they can track how values are changing over time. In addition, real per capita income is a good predictor of people’s passive economic use values, so it can also be used as an indicator (Alberini et al. 2006, Leeworthy et al. 2017).

Economic Indicators

There are no studies that have estimated non-use values specifically for SBNMS, but as mentioned above a study of the willingness to pay for marine protected areas found positive values (Wallmo and Edwards 2008). However, studies conducted in other, similar marine protected areas may provide relevant economic information. For example, at Channel Islands National Marine Sanctuary (CINMS) located off the coast of southern California, commercial vessels pose a ship strike risk to whales. Similar to management actions taken at SBNMS, traffic separation lanes were established at CINMS in an effort to reduce the number of whale strikes. Vessel speed reductions are also recommended at CINMS (while mandatory at SBNMS at certain times of year in specific areas, speed reductions are voluntary at CINMS). Given these similarities, recent research at CINMS documenting the economic value associated with the avoidance of whale strikes can be relevant to SBNMS.

At CINMS, a study was conducted that focused on the non-use value of avoiding whale deaths from vessel strikes (Bone et al. 2016). In that study, a national sample was used to estimate the non-use value people would have for reducing the number of whale deaths due to ship strikes through slowing commercial vessels during seasons when whales are known to frequent the area. On average, U.S. households were willing to pay $69.92 per household (a one-time payment), which, when aggregated across almost 134 million households in 2014, yielded a total value of $9 billion. For households that actually visited the CINMS region to view whales, their willingness to pay was $24.04 per household, which, when aggregated across 31,000 households, was estimated at $755,000. SBNMS could expect similar or perhaps even higher non-use values given the similarity of issues and the highly publicized endangered status of right whales.

Bone et al. (2016) included the New Ecological Paradigm (also known as the New Environmental Paradigm) index in their estimating equation for economic values and found a strong, positive statistical relationship for people's willingness to pay to protect whales and their environmental paradigm score. The New Ecological Paradigm is a scientifically sound index of people's environmental attitudes and has been widely used (Dunlap and Van Liere 1978, Dunlap 2008, Gallup 2017) in predicting visitation and values of national parks and special places around the world.

Aldrich et al. (2007) and Leeworthy et al. (2017) also used the New Ecological Paradigm and found the same results as Bone et al. (2016). Gallup, known for its public opinion polls, has been conducting scientifically sound public polls tracking people's environmental attitudes for 45 years. One question posed to the public since 1984 has been, "How much protection of the environment should be given priority, even at the risk of curbing economic growth?" The answer has fluctuated over the years, but with an exception for the Great Recession that began in 2007, people have generally preferred environmental protection to economic growth (Figure ES.SP.1). Another Gallup Poll question asked since 2000 is, "Do you think the U.S. government is doing too much, too little, or about the right amount in terms of protecting the environment?" Again, the answer has fluctuated, but the highest proportion of Americans during this reporting period (2000–2017) responded "too little", followed by "about the right amount", and the lowest proportion responded "too much" (Figure ES.SP.2).

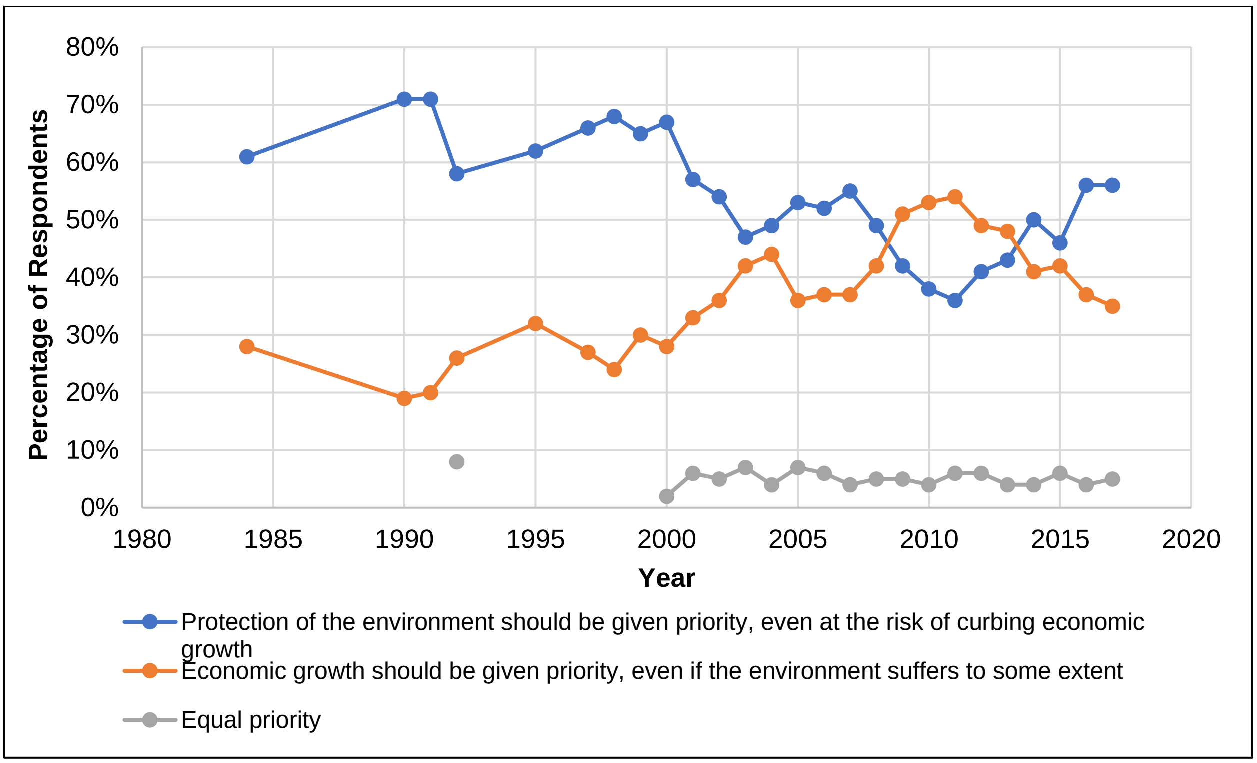


Figure ES.SP.1. Public opinions regarding protection of the environment versus economic growth from 1984 to 2017.Responses to the question: "With which one of these statements about the environment and the economy do you most agree?" Source: Gallup 2017

Figure ES.SP.2. Public opinions regarding the amount the U.S. government is doing to protect the environment. Responses to the question: "Do you think the U.S. government is doing too much, too little, or about the right amount in terms of protecting the environment?" Source: Gallup 2017

Real per capita income (adjusted for inflation) for the U.S., Massachusetts, and the 14-county area closest to SBNMS (where the primary socioeconomic effects of SBNMS use take place) has been increasing from 2000 to 2016 in all three geographies and is forecasted to continue to grow for all three areas until 2030 (Appendix E: Table App.E.2, Figure App.E.3). As income increases, it can change the demographics of a place, influencing how people feel about it.

Science, education, and outreach are key factors in people learning about the natural resources of a protected area and can therefore influence their values for protection and restoration efforts (i.e., people have to know about something in order to value it). This in turn becomes the basis for judging the return on investment in science, education, and outreach. As was demonstrated with the whale strike example from CINMS, the potential economic values associated with science, education, and outreach can be very high.

Non-Economic Indicators

The environmental attitudes cited above also serve as non-economic indicators of how people recognize and appreciate the aesthetic and spiritual attraction rendered by the resources in SBNMS. There have been no other national studies measuring other non-economic human dimensions indicators.

Resource Indicators

All of the indicators of water quality, habitat, living marine resources, and maritime heritage archaeological resources that were evaluated in the State of Resources section are relevant for assessing the status and trends of sense of place, since the health of the ecosystem affects how people relate to and appreciate their surroundings. Ratings for non-climate water quality indicators ranged from "good" to "undetermined," with trends ranging from "stable" to "undetermined." Water quality for climate indicators had a declining trend. Habitat integrity was rated “fair/poor” but with a “stable” trend. Contaminants in habitats were rated as “undetermined” for both status and trend. Living marine resources were generally rated “good/fair” and “stable.” There were mixed results for focal species, such as whales, that were showing declines. Considering all status and trends of the resource indicators relevant to sense of place, the rating of “fair” for this service is supported.

Summary

Sense of place is the aesthetic and spiritual attraction, as well as the level of recognition and appreciation a person may have for a place’s iconic elements. No studies have estimated non-use values specifically for SBNMS; however, recent research at CINMS documenting the economic value associated with the avoidance of whale strikes is relevant to SBNMS. Additional studies show that people put positive economic value on natural resources and are willing to pay to protect them. These valuation corollaries, trends in environmental attitudes, and growth in real per capita incomes suggest that economic indicators are positive and increasing. However, an evaluation of resource indicators suggests there is a decline in some natural resources, like whales, but the decline is not widespread across all relevant resources, while others, like water quality, are good. Consequently, the status of sense of place is “fair” and the trend is “improving.”

Science

Status Description: The capacity to provide the ecosystem service has been enhanced or remained unaffected.

Rationale: The number of research hours and days on the R/V *Auk*, citizen science hours, and the number of volunteers have been increasing. Further, SBNMS is at the forefront of research focused on anthropogenic noise, humpback whales, and fin whales.

Science as an ecosystem service is defined as the ability to acquire and contribute knowledge. At SBNMS, the status of science is rated “good” (high confidence) and the trend is “improving” (high confidence).

Economic Indicators

To date, no indicators have been used to evaluate the economic value of science conducted within SBNMS.

Non-Economic Indicators

The number of boat days and hours on the sanctuary’s research vessel, R/V *Auk,* can be used as a non-economic indicator. Since 2011, the number of hours and number of days has increased. Further, 40% of R/V *Auk’*s time is funded by non-NOAA research dollars. The increase in both numbers of days and hours indicates that funding for R/V *Auk* is also increasing (Table ES.S.1).

Table ES.S.1. Number of SBNMS R/V *Auk* ship days and hours. Source: NOAA

Year	Days	Hours
2011	53	577
2012	58	627
2013	36	360*
2014	53	530*
2015	51	510*
2016	68	758
2017	80	915
2018	91	947

* indicates that a constant of 10 hours per day was used to estimate ship time.

In addition to boat hours, the number of volunteer and citizen science[16] hours can serve as good non-economic indicators. Citizen science hours nearly doubled from 2013 to 2017, increasing from 1,800 to 3,400 hours and reaching a peak of 7,700 hours in 2016. The number of volunteers and volunteer hours have also increased (Figure ES.S.1, C. Fackler, personal communication, January 25, 2018). The number of volunteer hours increased from 3,400 in 2011 to 6,800 in 2017; however, the number of hours on average per volunteer has declined over the same time period from 67.7 hours to 43.4 hours per year (Figure ES.S.2). Any funding received for research is highly leveraged between volunteers and partners to maximize the level and quality of research.

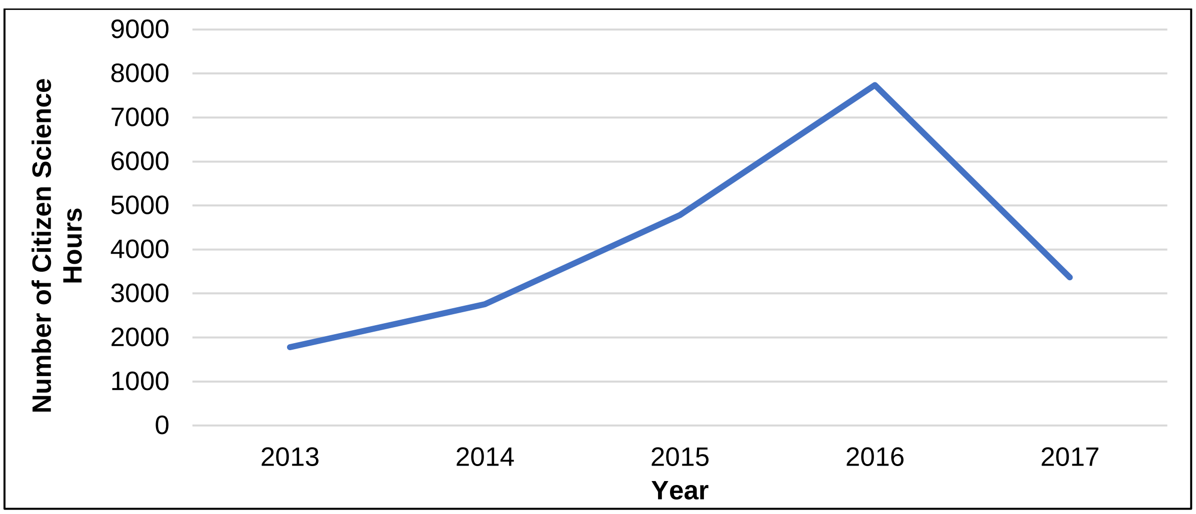


Figure ES.S.1. Number of SBNMS citizen science hours. Source: NOAA

[16] Citizen science is a term that describes projects in which volunteers partner with scientists to answer real-world questions. These volunteers can work with scientists to identify research questions, collect and analyze data, interpret results, make new discoveries, develop technologies and applications, as well as solve complex problems.

	2011	2012	2013	2014	2015	2016	2017
Volunteers	50	60	150	227	120	175	155
Hours	3,386	5,896	5,395	6,107	7,223	9,791	6,796

Figure ES.S.2. Number of SBNMS volunteers and SBNMS volunteer hours. Source: NOAA

The number of research permits issued from 2007 to 2017 remained fairly constant, with an average of four permits each year (Figure ES.S.3, NOAA Office of National Marine Sanctuaries 2018b). Although the number of permits provides some information on research, not all research requires permits, and therefore, the number of permits is not a comprehensive indicator for how much research may be occurring within the sanctuary. In fact, much of the research occurring within SBNMS has helped to change the national dialogue on certain topics. For example, impacts of anthropogenic noise and humpback and fin whale tagging research taking place at SBNMS are at the forefront of science.

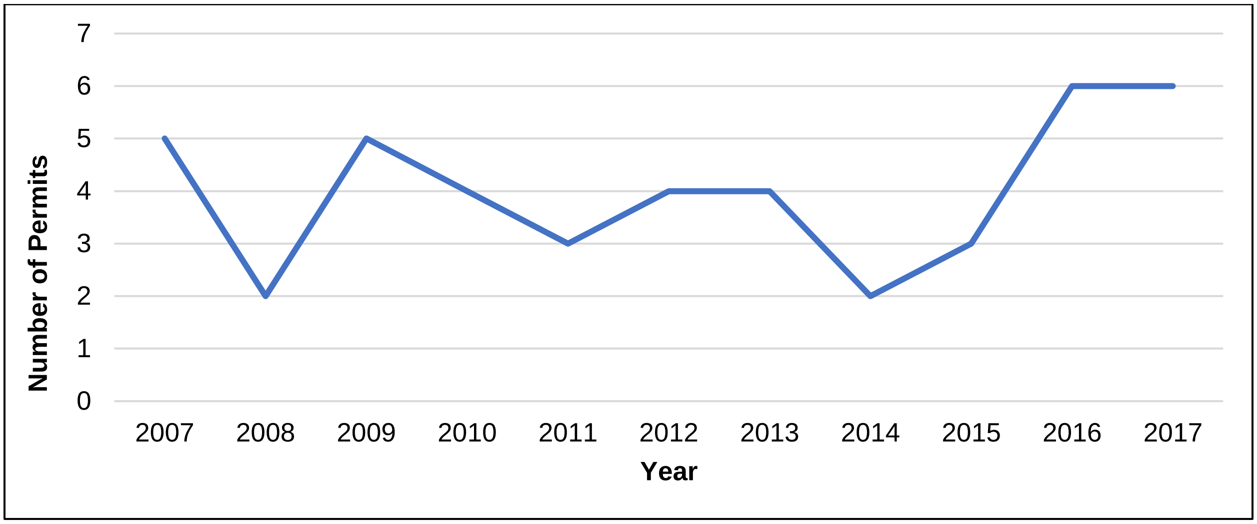
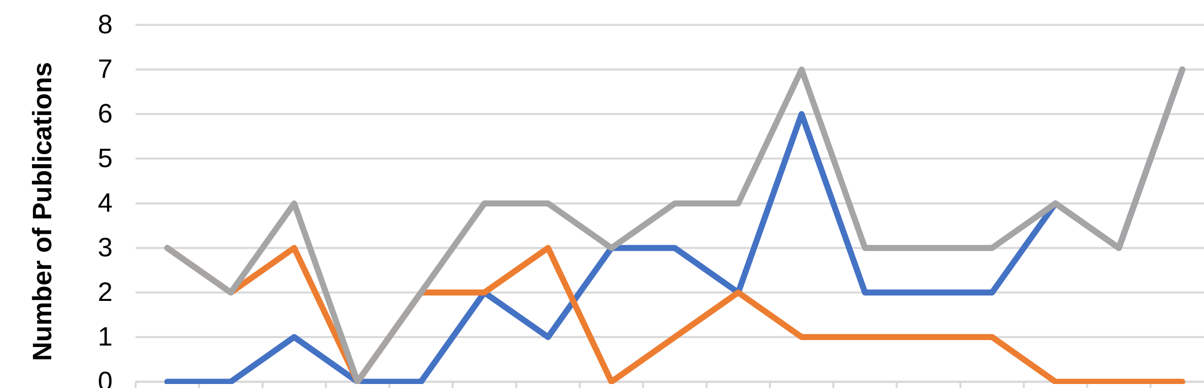


Figure ES.S.3. Number of research permits granted to allow some research activities to occur in SBNMS. Source: NOAA Office of National Marine Sanctuaries 2018b

Lastly, the number of science publications referencing research conducted in SBNMS has also increased over the past 10 years. In 2008, three articles referencing research conducted in SBNMS were published, and in 2017, seven articles were published (Figure ES.S.4, B. Barr, personal communication, January 17, 2018). This does not include non-scientific publications, such as white papers or news articles.



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Staff	0	0	1	0	0	2	1	3	3	2	6	2	2	2	4	3	7
Other	3	2	3	0	2	2	3	0	1	2	1	1	1	1	0	0	0
Total	3	2	4	0	2	4	4	3	4	4	7	3	3	3	4	3	7

Year

Figure ES.S.4. Number of scientific publications referencing research conducted in SBNMS. Source: NOAA

Resource Indicators

Science is different from most other ecosystem services in that the provision of the service does not substantially affect the state of natural and cultural resources. In fact, the state of science and knowledge learned from research aids in developing the protection and restoration strategies to improve or stabilize natural and cultural resource conditions. The body of scientific work in SBNMS has contributed significantly to the state of knowledge of resource conditions and the design and implementation of policies and management strategies to protect and/or restore resource conditions.

Summary

Given the international recognition and expansion of research occurring in SBNMS by sanctuary staff and partners, the status of the science ecosystem service (in terms of the ability to acquire and contribute knowledge in SBNMS) is "good" and "improving." There is, however, a noteworthy informational gap of indicators to estimate the economic value of science in SBNMS. Non-economic indicators—the number of research hours and days on the R/V *Auk*, citizen science hours, and the number of volunteers—have been increasing or stable through time. Further, SBNMS is at the forefront of anthropogenic noise and humpback and fin whale research. As a result of the research being conducted in SBNMS by site staff and partners, the body of scientific work in SBNMS has contributed significantly to the state of knowledge of resource conditions.

Education

Status Description: The capacity to provide the ecosystem service has been enhanced or remained unaffected.

Rationale: Studies show that parents have a willingness to pay for hands-on ocean conservation and stewardship programs. The number of Twitter and Facebook followers of SBNMS has increased over the past few years. Education activities at SBNMS have contributed to the public's understanding of SBNMS resources and programs.

Education, as an ecosystem service, is defined as the capacity to acquire and provide intellectual enrichment. At SBNMS, the status of education is rated "good" (high confidence) and the trend is "improving" (high confidence).

Economic Indicators

In 2017, ONMS completed a study estimating the economic value of the Ocean Guardian School Program (Schwarzmann et al. 2017), a grant-based program aimed at teaching students about ocean conservation and stewardship of local watersheds and special ocean areas like national marine sanctuaries (Figure ES.E.1–ES.E.2). Although Ocean Guardian schools are primarily based in California, study results are relevant to other sanctuary education programs with the same goals. Five pathways were valued: 1) refuse/reduce/reuse/recycle/compost, 2) marine debris, 3) watershed restoration, 4) schoolyard habitat/garden, and 5) energy and ocean health. The highest valued pathway or attribute of the Ocean Guardian School Program was habitat. Parents were willing to pay $59 annually per student so that their child could engage in habitat restoration and school gardening projects. The second highest willingness to pay level was watershed restoration, where parents were willing to pay $44.79 annually per student so they could participate in activities aimed at learning about and participating in projects to improve the local watershed, such as removing invasive species, planting native species, or improving fish habitat. In regard to the remaining three attributes, energy, marine debris, and recycling had the third, fourth, and fifth highest marginal willingness to pay levels per attribute in all three models, respectively. When the three models are averaged, the marginal willingness to pay for energy was $34.24, marine debris was $25.50, and recycling was $21.41.

Figure ES.E.1. Students playing a game to learn about the SBNMS foodweb. Photo: NOAA

Figure ES.E.2. The SBNMS traveling exhibit provides visitors with an introduction to SBNMS in a variety of museums and other public spaces throughout New England. Photo: NOAA

Non-Economic Indicators

Volunteers (Figure ES.E.3) and volunteer hours are non-economic indicators that can be used to monitor education. Since 2011, the number of volunteer and volunteer hours have increased. The number of volunteers more than tripled from 50 in 2011 to 155 in 2017, and the number of volunteer hours roughly doubled from 3,400 to 6,800 (Figure ES.S.2).

Social media is another non-economic indicator for education. Since September 2015, the number of Facebook and Twitter followers has grown for SBNMS. The number of Facebook followers has grown by 73.3%, and the number of Twitter followers has grown by 131%. In September 2015, the combined number of Facebook and Twitter followers was 6,315, and this number grew to 11,222 by December 2017 (Figure ES.E.4). Although not reflected in the number of followers, there are times when the number of impressions or views of sanctuary content spike. Spikes may indicate an increase in those following and learning about specific stories or events in the sanctuary.

Figure ES.E.3. A volunteer gives school-aged children a tour of an inflatable whale. Photo: NOAA

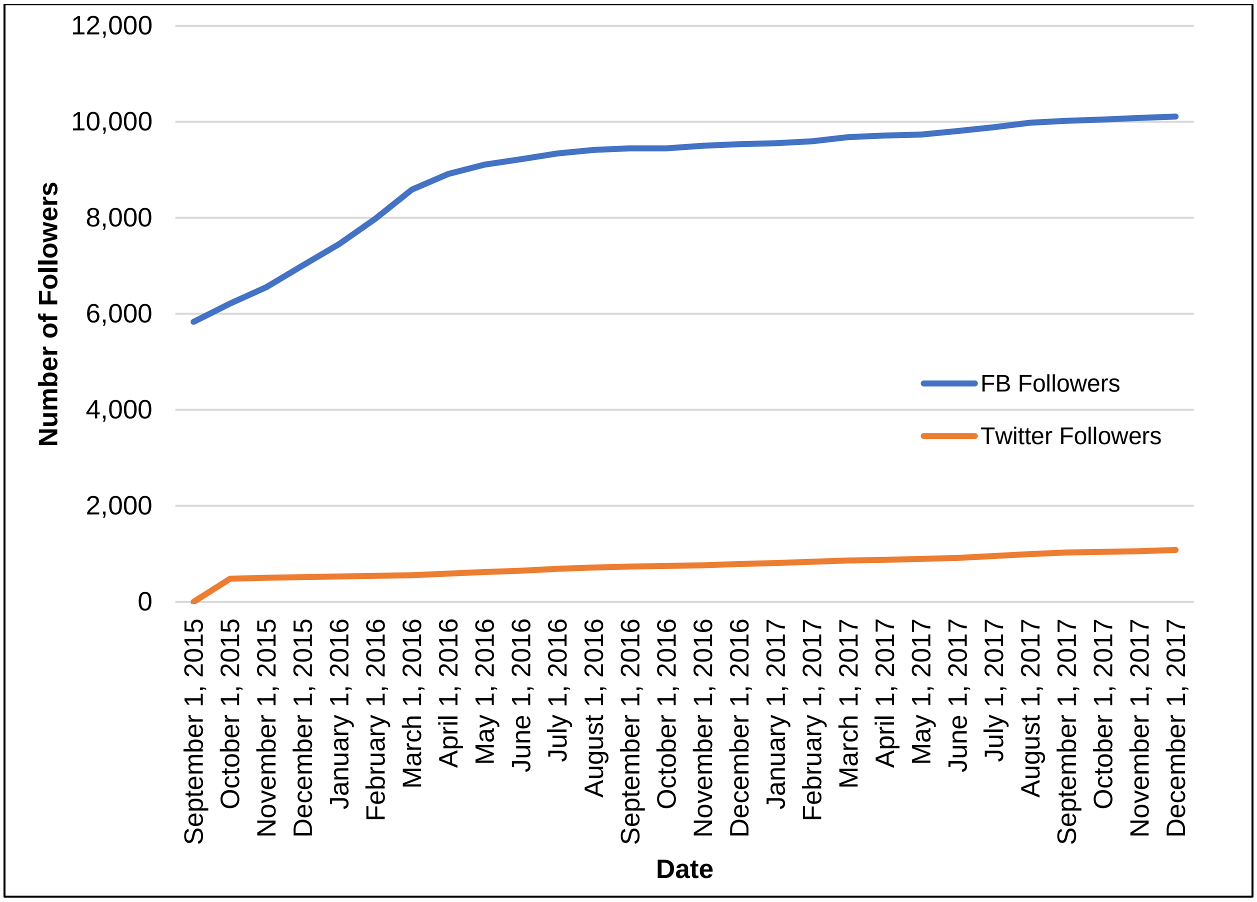


Figure ES.E.4. Number of SBNMS social media followers over time. Source: NOAA

Resource Indicators

Education is different from some other ecosystem services in that the provision of the service does not substantially affect the state of natural and cultural resources. Instead, it focuses on developing and distributing materials and services. The body of education programs and curriculum in SBNMS has contributed significantly to understanding about resources and the design and implementation of education programs and initiatives.

Summary

Although there have been no economic valuation studies done for education programs in SBNMS, studies of other environmental education programs indicate a positive value for hands-on education experiences. Further, several non-economic indicators have been increasing. In particular, the number of volunteers and volunteer hours has increased since 2011, and related social media presence, as measured by the number of SBNMS followers on Facebook and Twitter, has increased since 2015. These indicators suggest that education work in SBNMS has contributed to the understanding about SBNMS resources. Consequently, the rating of status of this service is “good” and the trend is “improving.”

Provisioning (Material Benefits)

Food Supply

Status Description: Ability to provide ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

Rationale: Pounds caught and value of landings show variability over the study period. Data indicate a shift from smaller to larger commercial vessels operating in the sanctuary. The groundfish fishery is still recovering, while lobster and sea scallop fisheries have been increasing.

The status of food supply is “fair” (very high confidence) and the trend is “not changing” (very high confidence). The food supply ecosystem service is the capacity to support market demand for nutrition-related commodities through various fisheries. For SBNMS, commercial fisheries supply this service. As described in the commercial fishing section, fisheries landings data from SBNMS was obtained from DMIS.

Regarding both economic and non-economic indicators, more information is needed on costs and earnings to assess whether there are “economic rents” (above normal return on investments) that lead to pressure on regulatory agencies to allow more fishing effort. Socio-demographic profiles of fishers are needed. This information, when combined with costs and earnings data, support assessments of dependency on fisheries. The ability of fishers to adapt to management/policy changes to improve fisheries is better understood when dependency information exists. Access to individual fishing operation records for total landings by fishing location would also allow for estimation of fishers’ dependency on SBNMS for their total fishing revenues. Knowledge, attitudes, and perceptions of management strategies, regulations, and conditions of sanctuary resources would support assessments of job satisfaction.

Economic Indicators

Value of Landings (Harvest Revenue to Fishers)

From 2007–2016, the total value of landings from species caught in the sanctuary was in excess of $194 million. During the same time period, the top 10 species harvested from SBNMS (measured in cumulative revenue across all years in 2017 dollars) accounted for 92% of the total value of landings. The top five species (cod, lobster, sea scallops, haddock, and yellowtail flounder) accounted for about 77.5% (Table ES.FS.1). In 2016 (the most recent year of data available for this assessment), the top 10 species accounted for 88%, while the top five accounted for 80%. The top ten species from 2007–2016 were cod, lobster, sea scallop, haddock, yellowtail flounder, monkfish, pollock, witch flounder, winter flounder, and Atlantic herring. The complete economic analysis summarized in this section is provided in Schwarzmann et al. (2020) and uses data provided by GARFO (2019b).

Table ES.FS.1. Top 13 commercial fishing species caught in SBNMS by value of landings (2017$). Source: GAFRO 2019 2017

Species	Total Value 2007-2016 (2017$)	% of Total Value 2007-2016	Rank 2007-2016	2016 Value	% of Total Value 2016	2016 Rank
Cod	$63,570,163	33%	1	$521,493	2%	6
Lobster	$35,450,731	18%	2	$5,582,613	24%	2
Sea scallop	$33,250,766	17%	3	$11,292,402	49%	1
Yellowtail flounder	$10,514,552	5%	5	$744,700	3%	4
Haddock	$7,579,083	4%	4	$296,678	1%	10
Monkfish	$7,106,043	4%	6	$586,745	3%	5
Pollock	$6,983,546	4%	7	$81,039	0%	16
Witch flounder	$5,541,711	3%	8	$497,626	2%	7
Winter flounder	$4,693,464	2%	9	$476,384	2%	8
Atlantic herring	$3,935,549	2%	10	$141,009	1%	13
Atlantic mackerel	$3,400,237	2%	11	$1,444,836	6%	3
Spiny dogfish	$2,941,184	2%	12	$285,360	1%	11
American plaice	$2,134,810	1%	13	$271,458	1%	12
Top 10	$178,625,609	92%		$20,220,689	88%	
Top 5	$150,365,295	77%		$18,437,885	80%	

For 2016 the top 10 species changed. Pollock and Atlantic herring fell out of the top 10, while winter flounder and bluefin tuna entered the top 10. Cod, which was rated number one in 2007–2016, was ranked sixth in 2016 having declined significantly from its 2010 high.

In 2016, sea scallops became the dominant fishery in SBNMS with $11.3 million in value of landings accounting for 49% of the total value of landings from SBNMS. This was followed by lobster, Atlantic mackerel, yellowtail flounder, monkfish, cod, witch flounder, winter flounder, bluefin tuna, and haddock.

For the top 10 species caught in SBNMS, the trends in both pounds and value of landings are presented in Appendix F (Figures App.F.1–App.F.20). For 2007 to 2016, sea scallops, lobster, and Atlantic mackerel had general upward trends.

Some species have been more variable over time, with unclear trends over the study period. Although cod had the highest value overall from 2007–2016, landings value for this species increased from 2007 to 2010 and then sharply declined through 2016. Spiny dogfish had an increasing trend in terms of landings value from 2007 to 2012, when the value of landings peaked, but value declined through 2016. Monkfish, pollock, and haddock all exhibited declining trends in value from 2007–2016. Witch flounder, winter flounder, and Atlantic herring had peaks and valleys during the study period, but when comparing 2007 to 2016, the value was flat.

Economic Contribution to the Local Area Economy

Commercial catch from SBNMS is landed at 81 ports and has economic contributions in a 14-county area. Economic contributions are measured in value of landings and then translated to economic contributions to the local area using the NEFSC IMPLAN input-output model (Steinback and Thunberg 2006). IMPLAN captures how the landings are processed and sold at different market levels and accounts for price mark-ups at each market level (e.g., fish house, processing plant, wholesale, retail, and restaurant). The model also estimates ripple or multiplier effects[17].

NEFSC ran its model for each year from 2007 to 2016 using catch data from SBNMS. All dollars were converted to 2017 dollars using the Consumer Price Index (BLS 2017). The value of landings and the economic contribution peaked in 2010 then declined from 2011 to 2015 (except for an uptick in 2012). In 2016, the contribution increased to near 2010 levels.

In 2010, the value of landings was about $23.3 million, with an economic contribution of $81.8 million in output, $27.4 million in income, which supported 893 full and part-time jobs. Comparatively, in 2016, the value of landings were about $23.1 million with an economic contribution of $73.7 million in output, $25.7 million in income, which supported 747 full and part-time jobs (Table ES.FS.2).

[17] For SBNMS, adjustments have been made by NOAA Fisheries to the IMPLAN model, including both backward and forward linkages (Steinbeck and Thunberg 2006). NOAA Fisheries used their customized IMPLAN model to estimate economic contributions to the local economy from commercial fishing in SBNMS. Backward linkages reflect the direct connection to industries from which an industry purchases its inputs in order to provide its good or service (output). For example, commercial fishers must purchase gear to fish. This direct expenditure is then used by the gear seller to purchase the inputs (supplies, heat, food, labor, etc.) necessary to run their business. The way money moves through the economy to support the gear seller is an example of backward linkages. Forward linkages reflect how industries utilize the output of another industry. In the context of national marine sanctuaries, a commercial fisher may catch their fish quota in SBNMS, then once ashore, sell their landings to a fish market, seafood processor, or restaurant. From the point of sale forward in time reflects forward linkages and traces how the outputs of commercial fishers benefit the economy.

Definition of Terms (adopted from Hackett et al., 2009)

Harvest Revenue: What fishermen receive when they land their catch at various MA ports.

Output: Total industry production, equal to shipments plus net additions to inventory.

Value Added: The value added during production to all purchased intermediate goods and services. This is equal to employee compensation plus proprietor's income plus other property income plus indirect business taxes. Often referred to as gross regional product.

Total Income: Sum of employee compensation, proprietor's income, corporate income, rental income, interest, and corporate transfer payments.

Employment: Full- and part-time jobs.

Table ES.FS.2. Economic contributions of commercial landings in SBNMS to the local area economy (2007–2016 in 2017$). Source: Schwarzmann et al. 2020

Year	Value of Landings	Output	Income	Full and Part-time Employment
2007	$18,665,067	$66,482,662	$21,643,385	754
2008	$21,558,290	$77,714,959	$25,426,350	868
2009	$19,389,542	$69,229,147	$22,591,177	775
2010	$23,287,107	$81,897,492	$27,372,385	893
2011	$19,915,754	$69,017,471	$23,203,493	758
2012	$22,880,433	$77,788,084	$27,133,479	937
2013	$16,034,664	$52,228,776	$18,319,016	571
2014	$15,206,949	$48,553,328	$17,189,160	576
2015	$13,881,393	$43,466,414	$15,141,195	454
2016	$23,066,635	$73,720,988	$25,714,818	747

Other indicators of economic health of fisheries include the number of fishing vessels operating and number of fishing trips taken (both proxies for fishing effort). However, interpreting changes in these indicators requires understanding the management context. The New England groundfish fishery was generally overfished, requiring fundamental changes in the management regime in the late 1990s. Vessel buyback and assistance programs were instituted because it was projected that even after the fisheries recovered, 50% of fishers would be unlikely to get their jobs back. Management changes in New England fisheries included a transition to a market-based approach called catch shares in 2010. The transition to catch shares enabled larger boats (>70 feet) to target cod in SBNMS. Prior to 2010, these vessels were constrained by limitations on days-at-sea and tended to stay far offshore.

The average number of vessels fishing the sanctuary during the time period of this report was 253. In 2010, the number spiked to a peak of 320 vessels, then began a steady decline from 2011 to 2015, with 181 vessels fishing the sanctuary in 2015. In 2016, the number of commercial vessels increased to 242.

The distribution of vessel size has changed over the 10-year time period, with vessels less than 50 feet and 50–70 feet declining in proportion of vessels. This indicates a shift from small to larger commercial fishing vessels operating in the sanctuary, as well as a shift in the target species in the sanctuary, primarily toward scallops. However, for all years, vessels less than 50 feet in length comprised the largest proportion of vessels in the sanctuary (Figure ES.FS.3 and Table App.F.4).

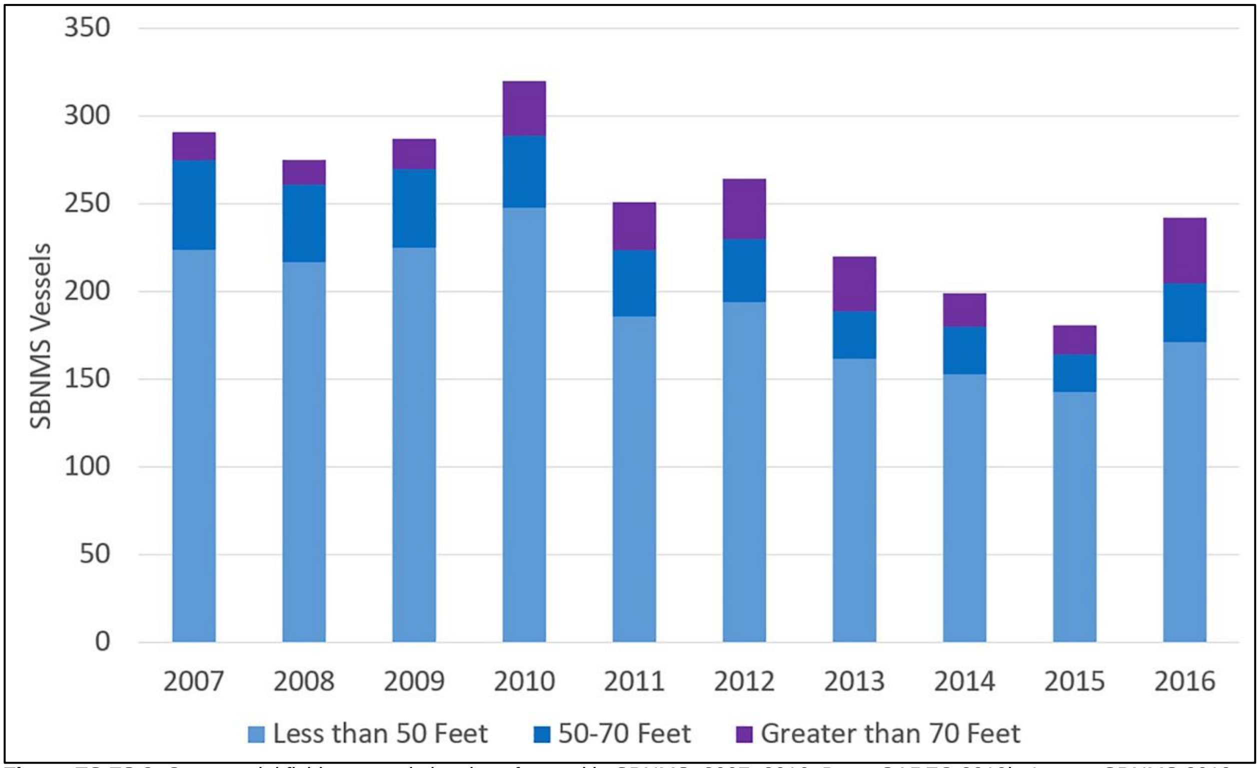


Figure ES.FS.3. Commercial fishing vessels by size of vessel in SBNMS, 2007–2016. Data: GARFO 2019b. Image: SBNMS 2019

As with vessels, the number of trips to SBNMS peaked early in 2009, then declined from 2010 to 2015 (except for the uptick in 2012) and increased in 2016 to a level slightly higher than in 2013. As with the number of vessels, the proportion of trips to SBNMS by vessel size was highest for vessels less than 50 feet in length, accounting for roughly 86% of vessel trips on average each year (Table ES.FS.3). The relevant data are presented in Question 4 in Figure S.P.4.2.

Table ES.FS.3. Number of commercial fishing vessel trips by size class of vessels in SBNMS, 2007–2016. Source GARFO 2019b

Year	Less than 50 Feet	50–70 Feet	Greater than 70 Feet	Total
2007	7,240	1,074	108	8,422
2008	8,406	1,299	191	9,896
2009	9,665	1,191	225	11,081
2010	7,855	1,093	236	9,184
2011	5,347	897	261	6,505
2012	6,496	1,037	276	7,809
2013	4,142	600	110	4,852
2014	4,032	453	78	4,563
2015	3,557	423	66	4,046
2016	4,361	435	154	4,950
2007-2016 Average	6,110	850	171	7,131
% 2007–2016	85.69	11.92	2.39	100.00
% 2007–2009	86.09	12.12	1.78	100.00
% 2010	85.53	11.90	2.57	100.00
% 2016	88.10	8.79	3.11	100.00

Economic indicators show that value of landings and their economic contribution peaked in 2010 then declined from 2011 to 2015 (except for an uptick in 2012). In 2016, economic contributions increased to near 2010 levels. The number of vessels fishing the sanctuary followed a similar pattern. In 2010, the number of vessels spiked to a peak of 320 then began a steady decline from 2011 to 2015, reaching 181 vessels in 2015. In 2016, the number of commercial vessels increased to 242. From 2015–2016, economic indicators were positive, but over the study period, economic indicators were not stable.

Non-Economic Indicators

There have not been any studies conducted on commercial fisheries in SBNMS to develop non-economic indicators for fishers, such as importance/satisfaction ratings of various commercial fishing attributes or regulations.

Resource Indicators

Several resource indicators reported in the State of Resources are related to the health of fish stocks and invertebrates and are important to commercial fisheries; those ratings are repeated below.

Water Quality

6. What is the eutrophic condition of sanctuary waters and how is it changing?

7. Do sanctuary waters pose risks to human health and how are they changing?

Habitat Resources

10. What is the integrity of major habitat types and how is it changing?

11. What are contaminant concentrations in sanctuary habitats and how are they changing?

Living Resources

12. What is the status of keystone and foundation species and how is it changing?

13. What is the status of other focal species and how is it changing?

Climate change and rapidly warming ocean water is resulting in Gulf of Maine species migrating to deeper and/or more northerly waters, while Mid-Atlantic species are moving into the Gulf of Maine and SBNMS. Key among these species shifting into the region is black sea bass, which could become an important commercial species.

Sea scallops, lobsters, haddock, herring, and Atlantic mackerel were stable or increasing, while pollock and haddock were in decline, and seven groundfish stocks were in an overfished status. This was especially true for cod; therefore, it is concluded that there is a decline in some of the fish stocks, but it is not widespread across all stocks.

Although the groundfish fishery is still in recovery in the New England region, the lobster and sea scallop fisheries are still in good condition, leading to increasing economic contributions/impacts to the local-area economy. The decline in the natural capital stock is attributed to the herring and groundfish fisheries, therefore the ratings for status was fair and the trend was stable or not changing.

Summary

The status of the capacity or ability to support market demand for nutrition-related commodities, namely fish, is “fair” and the trend is “not changing,” largely due to mixed results for the economic indicators. From 2007 to 2016, the total value of landings (cumulative revenue across all years, 2017$) from species caught in the sanctuary was in excess of $194 million, with cod, lobster, sea scallops, haddock, and yellowtail flounder accounting for approximately 78%. Trends in both landings values and pounds from 2007 to 2016 for sea scallops, lobster, and Atlantic mackerel were generally improving. Additionally, some resource indicators suggest a decline in the natural stock, but it is important to note that this trend is not widespread or unilateral across all stocks (e.g., there may be emerging stocks as a result of changing species distributions within the region). More information is needed for both economic and non-economic indicators on costs-and-earnings to assess whether there are above normal returns on investments (i.e., what economists refer to as ‘rents’) that result in more fishing effort, and, non-economic indicators are needed that gauge the socio-demographic profiles of fishers.

RESPONSE TO PRESSURES

The Driving Forces and Pressures section of this report describes a variety of issues and human activities occurring within and beyond the sanctuary that warrant attention, tracking, study, and, in some cases, specific management actions. Addressing any of these issues requires participation by and coordination with a variety of agencies and organizations. ONMS is fortunate to be able to work with many entities that contribute to managing human activities and addressing marine conservation issues. Central to that collaborative approach is the Stellwagen Bank National Marine Sanctuary Advisory Council, a community-based advisory body established to provide advice and recommendation to ONMS on issues including management, science, service, and stewardship (see text box).

Stellwagen Bank National Marine Sanctuary Advisory Council

Stellwagen Bank National Marine Sanctuary established its advisory council on October 3, 2001. The council is a community-based body that advises the sanctuary superintendent on issues relevant to the effective implementation of the sanctuary management plan. The council is the formal organizational link to the sanctuary's user community and others interested in the management of this nationally significant area of the marine environment.

Duties of the council include:

- Providing advice and recommendations to the superintendent regarding management of the sanctuary, drawing upon the expertise of its members and other sources;
- Serving as liaisons between their communities and the sanctuary by keeping the sanctuary staff informed of issues and concerns, as well as performing outreach to their respective communities on the sanctuary's behalf;
- Serving as a forum for consultation and deliberation among its members and as a source of consensus advice to the superintendent.

The council membership consists of 17 non-governmental voting members, one non-voting youth member, and six governmental ex-officio members (non-voting).

For each of the main issues and human activities presented in the Driving Forces and Pressures section of this report, this Response Section provides a summary of related activities and management actions led or coordinated by sanctuary staff. The activities described below are not exhaustive of all the ways the sanctuary serves the community and the marine ecosystems encompassed within the sanctuary, but highlights significant contributions that are responsive to known or emerging pressures.

Recommended future response actions are not presented in this section; however, in 2020 sanctuary staff will begin updating the sanctuary’s management plan[18]and this condition report’s findings will serve as an important foundation on which to build new action plans designed to address priority needs.

[18] The sanctuary management plan serves as a non-regulatory policy framework for addressing the issues facing the sanctuary over the next five years. It lays the foundation for restoring and protecting the sanctuary‘s ecosystem, details the human pressures that threaten the qualities and resources of the sanctuary, and recommends actions that should be taken both now and in the future to better manage the area and resources.

Described below is a summary of actions that ONMS has taken, primarily since 2007, to address the issues and human activities that were described in the Driving Forces and Pressures section of this report.

Noise

Meeting marine resource protection and management objectives in SBNMS necessitates understanding the relative inputs of sound sources within the sanctuary and the possible effects of these sounds on marine animal behavior. Standardized data collection methods, such as passive acoustic monitoring and acoustic tags that are attached to whales, are being used to help characterize the acoustic environment and understand animal behavior in the sanctuary. These data can be used to compare acoustic habitat across sanctuary sites and other marine environments.

Vessel Noise Policy

SBNMS's acoustic research program has provided opportunities for partnership and leadership in the development of regional, national, and international policies for managing noise impacts on marine life. In 2010, the SBNMS management plan recognized the importance of this larger-scale work to site-based goals, and identified development of a marine acoustics policy framework as a continuing action to address noise impacts to marine mammals in the sanctuary.

Close collaboration with NEFSC has provided NOAA Fisheries with a case study environment for their broader regional scientific work on whale and fish calling behavior, distribution, abundance, and population health (Van Parijs et al. 2009, 2015). SBNMS, in partnership with the U.S. National Park Service, has explored lessons learned from management of soundscape attributes within national parks and particularly the challenges of addressing noise impacts to wildlife from air and marine transportation networks within protected areas on both land and in the ocean (Hatch and Fristrup 2009).

From 2008 to 2014, SBNMS worked with staff from multiple NOAA offices to chair a correspondence group within the Marine Environmental Protection Committee of the IMO. In 2014, this effort led to the IMO's ratification of voluntary guidelines for quieting commercial vessels (IMO 2013). These guidelines continue to support dialogue among IMO member states and organizations regarding the relationship between reducing noise and new regulatory and market pressures for both existing and newly built ships to improve fuel economy and reduce carbon emissions.

From 2010 to 2016, SBNMS staff co-led an agency-wide initiative to improve NOAA's science and management addressing ocean noise impacts to marine life. This culminated in the release of NOAA's Ocean Noise Strategy Roadmap (Gedamke et al. 2016). The roadmap summarizes relevant NOAA management and science capacities and recommends cross-agency actions that could be taken to achieve more comprehensive management of noise impacts. Two out of the four chapters draw from SBNMS for examples and have now been published in peer-reviewed literature (Hatch et al. 2016, Redfern et al. 2017).

In 2017, SBNMS began working with regional partners to create a Boston-based consortium focused on technical solutions to quieting commercial ships. The group's intent was to develop both port-based and more globally-focused projects.

Long-Term Passive Acoustic Monitoring in SBNMS

SBNMS has an extensive large whale passive acoustics program and leads an ongoing program to tag humpback and other large whales with synchronous motion, acoustic recording, and video recording tags to understand underwater behavior as it relates to mitigating ship strikes and entanglement.

In 2014, SBNMS became a co-lead on a national initiative to deploy the first ever NOAA-maintained long-term passive acoustic monitoring network, including the installation of a hydrophone in SBNMS, located within the Stellwagen Dedicated Habitat Research Area (DHRA)[19]. Data from 2014–2018 sampling continue to be analyzed to compare trends in low-frequency noise throughout U.S. waters and specifically among shallower water sampling sites in protected areas (Haver et al. 2018, 2019).

In addition, beginning in 2016, SBNMS and NEFSC acoustic researchers developed and implemented a new program to conduct coordinated shallow-water acoustic monitoring in relatively shallow water sanctuaries on the east coast and in the Gulf of Mexico, including Stellwagen Bank, Gray's Reef, Florida Keys, and Flower Garden Banks national marine sanctuaries. These deployments were coordinated in order to provide comparable data among sanctuaries. Data analysis is expected to demonstrate variability among these sanctuaries in both the natural and human-induced noise contributions to their soundscapes, including, as examples, temporal peaks in spawning activity by fish, feeding activity by baleen whales, small and large vessel activity, and offshore energy exploration/research using airguns. This research is ongoing, and future analysis will focus on deriving new metrics that can be extracted from long-term monitoring of soundscapes to reflect important ecological thresholds for consideration in management. This work was also supported by a NOAA Dr. Nancy Foster Scholar, who used opportunistic sightings from whale watching trips and acoustic detections from gliders to develop the first model of sanctuary acoustic habitat use by odontocete species.

Marine Debris and Pollution

As described in the Pressures section, although the EPA has designated all of Massachusetts state waters "No Discharge Zones," making it illegal to discharge both treated or untreated sewage in state waters, these regulations do not apply to the sanctuary because it is located entirely in federal waters. Understanding how wastewater discharge from all vessel types may or may not be impacting sanctuary waters is an important issue.

Whale Watching

SBNMS staff are involved in a variety of education and outreach efforts to inform the public and ocean users about avoiding adverse interactions with whales. The Whale SENSE program, which began in 2009 and involves sanctuary partners, allows SBNMS staff and volunteers to conduct on-water education programs with vessel captains and other boaters. These programs teach proper boating procedures around whales, with the aim of reducing harassment of whales by boaters. Participation in this training program is voluntary, but participants receive a form of certification when completed. The See a Spout, Watch Out! program is an online whale watch boaters' education course that offers tips to both commercial and recreational boaters to encourage safe and responsible boating when in the vicinity of whales. Also, the

[19] The Stellwagen DHRA was designated in 2018. It is within the WGOM Closure Area and is closed to all commercial mobile bottom-tending gear, commercial sink gillnet gear, and commercial demersal longline gear.

Boater Outreach for Whale Watching program described below provides on-the-water education about safe boating around whales. These efforts, while important outreach programs, still only reach a small segment of the recreational boating public.

Recreational Diving

Recreational diving in SBNMS has increased significantly in the past decade. Most divers access the sanctuary on charter boats for the purpose of visiting shipwreck sites. To facilitate diver access, SBNMS has installed mooring buoys at three dive sites; these buoys also serve to protect the wrecks from anchor damage. In addition, SBNMS staff conduct outreach to dive organizations and clubs by providing presentations and lectures. The sanctuary advisory council includes a recreational diving seat, which is intended to serve as a conduit to the recreational diving community.

Recreational Fishing and Boating

In 2017, the sanctuary made a public statement to confirm that recreational fishing is allowed and recreational fishers are encouraged to visit SBNMS. SBNMS continues to communicate these messages to the recreational fishing community, including by providing small grants in 2018 and 2019 that promote sustainable fishing and support research questions important to these stakeholders.

In 2016, the sanctuary initiated the Boater Outreach for Whale Watching program, which is intended to improve recreational boating etiquette around whales. Staff make 3–4 trips into the sanctuary on busy summer days and intercept recreational boaters to inform them about the sanctuary and proper boat handling around whales. The program is very successful and should be expanded to reach more boaters.

Commercial Fishing

ONMS does not regulate fishing in the sanctuary. GARFO is responsible for regulating fishing in the sanctuary. Sanctuary staff work closely with staff from GARFO, NEFSC, and NEFMC on issues of concern and raise them with GARFO early in the regulatory process so they can be addressed. SBNMS currently lacks a resource protection specialist, whose job is to track relevant fishery actions; however, existing staff attempt to stay informed by attending NEFMC meetings, talking with fisheries managers, and seeking advice from sanctuary advisory council members. Sanctuary staff have had some involvement in the following fishery actions that have or will result in some increased protection of sanctuary resources.

- **Forage fish**: In 2018, NEFMC approved Amendment 8 of the Atlantic herring plan. SBNMS expressed concerns that the amendment could result in the localized depletion of forage fish during critical fall feeding by humpback whales, endangered minke and fin whales, as well as other migratory species. At the time of this writing, one of the proposed regulations to implement Amendment 8 to the Atlantic Herring Fishery Management Plan is to create a 12 nautical mile buffer seaward from the shore from Maine to Cape Cod, which would be closed to midwater trawling year round (Figure R.1). This buffer will overlap the southwest and northwest corners of the sanctuary, which would help protect these critical foraging areas; however, it may also concentrate midwater and pair trawling activity in the remainder of the sanctuary. Sanctuary staff will monitor this activity during upcoming fishing seasons.

- **Scallops**: NEFMC and NOAA Fisheries agreed to remove a regulatory provision for the Northern Gulf of Maine scallop fishery that allowed large scallop dredge boats to participate in the fishery alongside smaller dredge boats. This alleviated the derby-style fishery that occurred in 2017, leading to a reduction in risk to maritime heritage resources in the area where this fishery takes place.
- **Habitat**: In 2014, NEFMC approved the Omnibus Habitat Amendment (a final rule implementing approved changes to year-round and seasonal closure areas) and, in 2018, NOAA Fisheries issued regulations. The regulations established the Stellwagen DHRA that overlaps with the eastern side of the sanctuary by 22%. Regulations for the DHRA are the same as the ones for the habitat closed area it overlaps with and essentially prohibit bottom-tending mobile and fixed gear; however, lobster trapping and recreational fishing are allowed. The DHRA serves as the sanctuary's de facto reference area for studies on habitat use and recovery and is being used as a site for long-term acoustic monitoring of low-frequency sound (10–2,500 Hz).

SBNMS, Massachusetts Lobstermen's Association, and NOAA's Office of Law Enforcement collaborated on a program in 2015 to reduce the wet storage of trap-pots in and around the sanctuary to reduce entanglement. SBNMS is also a member of NOAA's Large Whale Take Reduction Team, which is tasked with reducing the serious injury and mortality of large whales caused by commercial fisheries to below the calculated PBR. Serious injury and mortality for right and humpback whales continue to be above PBR in almost all years.

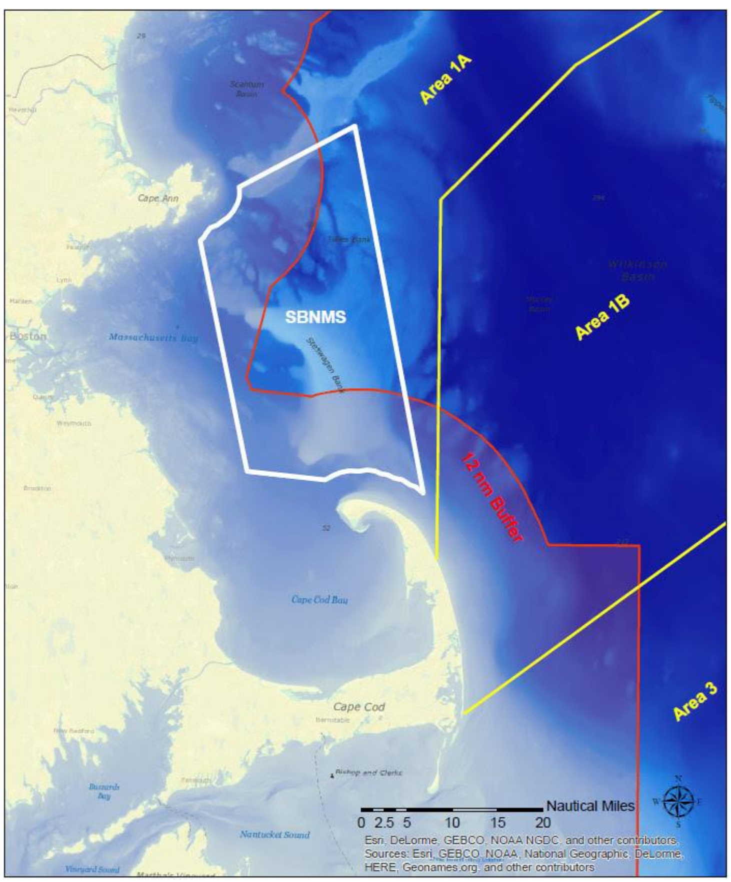


Figure R.1. Proposed 12 nautical mile buffer where midwater trawling for herring would be prohibited year-round. This proposed action, under consideration by NOAA Fisheries, is part of Amendment 8 for the Atlantic Herring Fishery Management Plan. Image: NOAA

Commercial Shipping

In April 2012, SBNMS, along with numerous partners, launched Whale Alert, a free app designed to assist commercial ships in complying with whale protection regulations. The app, aimed at a shipping industry audience, displays speed zone regulations and whale management areas along the U.S. Atlantic Coast. Whale Alert aims to ease compliance with existing regulations by providing regulation measures and near real-time data on easy-to-read nautical charts with pop-up alerts to serve as reminders when vessels enter regulated areas. SBNMS was the first sanctuary to be a part of Whale Alert project and it uniquely leverages acoustic technology to help detect the presence of right whales in Boston shipping lanes. Since its inception, the Whale Alert project has expanded to all five west coast sanctuaries (Channel Islands, Cordell Bank, Greater Farallones, Monterey Bay, and Olympic Coast national marine sanctuaries).

Since 2009, SBNMS has partnered with the International Fund for Animal Welfare and the National Marine Sanctuary Foundation to use AIS and GIS technologies to evaluate mariner compliance with seasonal management areas in the sanctuary and provide report cards to ships and companies transiting the areas. In 2015, SBNMS initiated a corporate responsibility program, which, in addition to report cards, provides certificates of corporate responsibility to ships and companies whose commitment levels were evaluated to be A+ or A. In 2016, 82% of the companies and 83% of the ships received grades of A+ or A.

Liquefied Natural Gas Deepwater Ports

Shortly after the last condition report was published, two LNG terminals were constructed adjacent to the sanctuary's western boundary. Northeast Gateway finalized construction of one port in December 2007, and began operating it in January 2008. Neptune finalized construction of the other in October 2009, and began operating it in spring 2010. Following recommendations from SBNMS to mitigate impacts of LNG ports on marine mammals, an array of 10 real-time passive acoustic detection buoys were deployed to reduce the risk of right whale ship collisions in the TSS, and will be maintained for the life of the port (25-40 years). Additional real-time buoys were recommended to listen for right whales during construction activities in order to trigger mitigation action, reducing ensonification and collision risk. The real-time TSS array was deployed in January 2008 and remains in operation in 2019, co-funded by the two companies under the terms of their licenses.

In 2018, Neptune indefinitely suspended operations at its port, leaving Northeast Gateway as the only active deepwater port in the Northeast. While that port is still active, the right whale listening buoy array will remain in operation; however, Northeast Gateway has considered suspending operations due to unfavorable market conditions for the import of LNG. SBNMS is concerned that decommissioning of one or both ports would result in loss of funding for the listening array. The array provides one of several tools for monitoring the presence of right whales in the area and alerting ships to be cautious. If the listening array is defunded, serious consideration should be given to whether it is worth keeping the array operational through other means.

Outfall Discharges and Dump Sites

In 2018, USACE began the Boston Harbor Deepening Project, which will take place over three years and include dredging the Boston navigation channel and other port improvements. The project will require the removal of 11.7 million cubic yards of material. In order to accommodate this material, the EPA has modified MBDS by temporarily expanding its boundaries into the historic IWS. The expansion would open the area only for the disposal of suitable dredged material generated during the dredging project. This will allow for the IWS barrel field to be covered and restored, protecting both the ecosystem and fishers utilizing the area.

The Harbor Dredging project and the associated dredge disposal at MBDS will increase turbidity in surrounding areas and has the potential to adversely impact nearby benthic communities due to potential contamination and smothering. Impacts are expected to be short-term, with habitat recovery occurring within 18-24 months (Sturdivant and Carey 2017). As plans for this project are finalized and implemented, sanctuary staff will carefully review plans and pay close attention to dredged material disposal activities as they are conducted and monitored. For example, dredge barges will carry AIS transponders that will allow the sanctuary to independently monitor barge tracks and dumping locations.

In 2019, SBNMS is supporting a research program designed by a NOAA Dr. Nancy Foster Scholar to monitor the MWRA outfall for contaminants of emerging concern, such as flame retardants and pharmaceuticals. This project, conducted in collaboration with the EPA and MWRA, will enhance the long-standing MWRA monitoring program and will provide better understanding of the status of water quality in SBNMS.

Submerged Cables and Pipelines

There have been no identifiable adverse impacts from cables or pipelines since the last condition report. However, in 2017–2018 SBNMS received several inquiries from the industry and regulators about installing new submarine cables across the sanctuary. SBNMS staff have been actively involved with federal and state agencies in the review of at least two proposed projects, and have worked to fully inform stakeholders of SBNMS regulations. If a future submarine cable was approved and installed in any part of the sanctuary, cable proponents would be required to receive different federal permits and undergo environmental review for different federal statutes. At a minimum, SBNMS would require the issuance of a Special Use Permit, which includes assessment of a fair market value fee for use of sanctuary resources; funds from this fee could be used for monitoring and research on project impacts.

Climate Change

SBNMS protects waters vital for whales, seabirds, and economically important species such as lobster, sea scallops, and cod. A coastal blue economy thrives on the resources of the sanctuary. These resources are at risk from a rapidly changing ocean environment due to climate change.

Water temperatures in the Gulf of Maine region are increasing three times faster than the global average, causing major shifts in species distributions and even the extirpation of economically important species, such as pink shrimp. Regional government agencies are reacting by developing regulations and licensing to create new commercial fisheries. For example, Maine regulators are working on creating a licensing process for black sea bass, a species historically associated with the Mid-Atlantic region. Other predicted impacts from climate change include increasing acidity due to absorption of atmospheric CO_2, increasing sea level, and increasing runoff due to rain events.

The sanctuary incorporates climate change into its research and monitoring programs. The sand lance is a pencil-sized forage fish and essential prey for whales, bluefin tuna, cod, and many other species. The sanctuary and University of Connecticut researchers are studying the little-known ecology of this fish, including its susceptibility to ocean acidification. Seabirds are the ocean equivalent of the “canary in the coal mine” because of their sensitivity to changing ocean conditions. The sanctuary’s seabird research and monitoring program allows managers to understand how climate change is impacting the ecology of these important species. These programs and others have made SBNMS an important sentinel site in the Gulf of Maine.

Communicating about climate change and its impacts is an important part of the sanctuary’s public outreach efforts. For example, the sanctuary works with whale watch naturalists to communicate climate change. Whale watch companies interact with over one million people each year and help them understand how climate change is impacting the animals they have come to see. The sanctuary is also incorporating climate change into its volunteer training to enable them to communicate essential messages to sanctuary visitors. Further, climate change and its potential biological, economic, and social impacts is an important part of the sanctuary’s 2019 condition report and the next sanctuary management plan.

Impacts to Maritime Heritage Resources

Since late 2017, there has not been an archaeologist on staff at the sanctuary and there are currently no plans to fill that position. SBNMS maritime heritage needs are being addressed by existing SBNMS staff with support from ONMS headquarters and other sites. Given these staffing limitations, it is unlikely that SBNMS will be able to conduct regular monitoring and documentation of impacts to the sanctuary’s known archaeological resources. Additionally, there will be no locally coordinated activity to identify and search for new archaeological resources in the sanctuary, or to conduct outreach and education regarding maritime heritage.

After a modern shipwreck was impacted during the 2017 scallop season, in an attempt to mitigate further impacts to heritage resources in 2018, sanctuary staff worked with colleagues at GARFO to implement and test an experimental approach to mitigation by disclosing the location of historic wrecks and requesting that the scallop fleet voluntarily avoid the six known historic and non-historic wrecks, including the *North Star*, by keeping their gear 360 feet away from the wreck. Side scan sonar surveys were conducted before and after the fishing season to determine effectiveness of the mitigation strategy; results were mixed (see Table R.MHR.1). Further engagement with fishers focused on the context, goals, and value of such mitigation measures may help with voluntary compliance and site preservation.

Table R.MHR.1. Results of the pre- and post-season side scan surveys of six shipwreck sites vulnerable to scallop dredge impacts in 2018. Source: B. Haskell/NOAA

SiteID	Vessel Name	Status	Depth (fathoms)	Pre-season survey results Date: 4/11-12/2018 (distance to nearest dredge mark in ft.)	Post-season survey results Date: 5/11/2018 (distance to nearest dredge mark in ft.)	Pre-season survey results Date: 3/29/2019 (distance to nearest dredge mark in ft.)	Post-season survey results Date: 5/23/2019 (distance to nearest dredge mark in ft.)	Avoidance buffer (ft.)
STB022	*Heroic*	Historic	16	156	no survey	no dredge marks	no dredge marks	360
STB023	*Ruth and Margaret*	Historic	18	no dredge marks	135	no dredge marks	no dredge marks	360
STB025	*Madonna Catena*	Historic	47.5	300	210	no dredge marks	no dredge marks	360
STB032	*STB032*	Historic	46	no dredge marks	no survey	no dredge marks	no survey	360
STB045	*North Star*	Modern	16	75	0 (hit by dredge)	no dredge marks	>360	360
STB049	*Patriot*	Modern	16	90	600	no dredge marks	no dredge marks	360

SBNMS and GARFO initiated a research project to interview fishers to determine the effectiveness of the outreach effort and learn whether the notice changed fishers' behavior (and if so, how and why).

Conclusion

Given the sanctuary's offshore setting and diverse mix of human activities, effectively responding to the wide range of issues and threats presented in the Driving Forces and Pressures section of this report requires a long-term commitment to marine conservation using a multidisciplinary, partnership-based approach. This involves the need for scientific research and monitoring, enforcement of existing regulations, close attention to emerging threats, community-based initiatives, and the use of education and outreach to inspire others to care and help. Groups such as the Stellwagen Bank National Marine Sanctuary Advisory Council are critical for crafting sound management advice and helping to identify, assess, and prioritize emerging issues. The collection of actions summarized in this Response section are representative of this type of multi-faceted and partnership-based approach, but not necessarily adequate for addressing every threat. The dynamic and emerging nature of many issues requires that recurring assessment and adaptation are part of the sanctuary's management cycle. Going forward, this condition report will inform the next sanctuary management plan update process, which will begin in 2020. That process will identify priority actions, whether new or continuing, to help address issues raised in this report.

CONCLUDING REMARKS

A statement from Stellwagen Bank National Marine Sanctuary Superintendent, Captain Peter DeCola, U.S. Coast Guard (Retired)

This report updates the 2007 Condition Report for Stellwagen Bank National Marine Sanctuary. As we prepare to update and revise the sanctuary's management plan, we can use the updated data and other information in this report as the basis for action plans and metrics to evaluate their effectiveness.

This report shows that despite several potential stressors, sanctuary water quality is good/fair and that habitat, living resources and the condition of maritime heritage resources continue to be impacted in various ways by human activities such as shipping traffic and commercial/recreational fishing. Furthermore, it highlights the need to fill gaps in research and monitoring.

Against the backdrop of these challenges, sanctuary staff have built a strong research program that is providing us with insights to better understand the behaviors of the marine mammals, birds, and fish that live in our sanctuary. In addition, innovative successes such as our corporate responsibility program and the creation of the Whale Alert app are making a difference in mitigating the impacts from human activities both inside and outside the sanctuary.

The next management plan review process will begin immediately after the publication of this report. The process will involve significant public input, agency consultations, and environmental compliance work. Based on this condition report, we know that the next management plan will need to address, among other things, climate change, water quality monitoring, the effects of underwater noise, and a better understanding of the maritime cultural landscape, in addition to renewed education, outreach, and citizen science efforts. I'm looking forward to engaging with the public to identify other important issues to include in our next management plan and developing the action plans needed to address these challenges.

Finally, I'm fond of saying that ocean management is a team sport. There is no greater example of that sentiment than in the creation of this report. Its completion would not have been possible without the dedicated involvement of the 23 participants in the expert panel workshop, the 18 participants in the invited partner review, the 4 peer reviewers and numerous advisory council members and staff, both at SBNMS and at ONMS headquarters, who have seen this massive project through from first draft to final copy. It's this team, along with our federal, state, and local agencies and numerous research partners that give us hope for making a positive difference moving forward. On behalf of the Office of National Marine Sanctuaries (ONMS) and myself, I want to express our sincerest gratitude for these efforts in addition to the past and ongoing contributions to sanctuary monitoring and management. It is only through these continued collaborations and partnerships that we will successfully protect and conserve this special place for generations to come.

Captain Peter DeCola
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ACKNOWLEDGEMENTS

This report would not have been possible without significant contributions from many state and federal agencies, academic and non-governmental organizations, consortia, partners, funders, and researchers. Specific individuals are mentioned below.

Expert Workshop Participants and Reviewers

Jennifer Anderson (NOAA), Michelle Bachman (NEFMC), Kevin Blinkoff (*On The Water*), Diane Borggaard (NOAA), Arne Carr (retired), Peter Christopher (NOAA), Danielle Cholewiak (NOAA), Amy Costa (Center for Coastal Studies), Tracey Dalton (University of Rhode Island), John Galluzzo (South Shore YMCA), Vito Giacalone (Gloucester Fishing Community), Porter Hoagland (Woods Hole Oceanographic Institution), Peter Hong (SBNMS), Carlton Hunt (retired), Ken Keay (Massachusetts Water Resources Authority), Marty Klein (Martin Klein Consultants), Heather Knowles (Northern Atlantic Dive Expeditions), Joe Levine (Researcher), Charles Mayo (Center for Coastal Studies), Calvin Mires (Bridgewater State University), Wayne Peterson (Massachusetts Audubon Society), Kevin Powers (retired), Allison Rosner (NOAA), Dave Slocum (SBNMS), Kimberly Starbuck (University of Massachusetts-Boston), Kevin Stokesbury (University of Massachusetts-Dartmouth), Bruce Terrell (NOAA ONMS), Eric Thunberg (NOAA), Page Valentine (US Geological Survey).

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Peer Reviewers

ONMS would like to give special thanks to the peer reviewers of his document: Stefan Claesson (NearView LLC), Lew Incze (retired), Candace Oviatt (University of Rhode Island), and Geret DePiper (NOAA).

Finally, we are also grateful to Kathryn Lohr (NOS ONMS) for providing copy edits and Dayna McLaughlin and Shannon Shikles (NOS ONMS) for designing the final report.

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APPENDIX A:
Rating Scheme for System-Wide Monitoring Questions

The purpose of this appendix is to clarify the questions and possible responses used to report the condition of sanctuary resources in "condition reports" for all national marine sanctuaries. The Office of National Marine Sanctuaries (ONMS) and subject matter experts used this guidance, as well as their own understanding of the condition of resources, to make judgments about the status and trends of sanctuary resources.

The questions derive from the National Marine Sanctuary System's mission, and a system-wide monitoring framework (NMSP 2004) developed to ensure the timely flow of data and information to those responsible for managing and protecting resources in the ocean and coastal zone, and to those that use, depend on, and study sanctuary resources. The questions are being used to guide ONMS and its partners at each of the sanctuary system's 14 units in the development of periodic sanctuary condition reports. Evaluations of status and trends were based on interpretation of quantitative and, when necessary, non-quantitative assessments and observations of scientists, managers, and users.

In 2012, ONMS led an effort to review and edit the set of questions and their possible responses that were developed for the first round of condition reports (drafted between 2007 and 2014) (NMSP 2004). The questions that follow are revised and improved versions of those original questions. Although all questions have been edited to some degree, both in their description and status ratings, the nature and intent of most questions have not changed. Five questions (i.e., Questions 1, 8, 10, 12, and 13), however, are either new or are significantly altered and therefore, are not directly comparable to the original questions. For these, a new baseline will need to be established.

- A new question that addresses the status and trend of driving forces that ultimately influence the pressures on sanctuary resources was added.
- Among the Water Quality questions, one was added on climate change. This was necessary to address the constantly increasing awareness and attention to the issue following the original design of the condition report process, which began in 2002. It also removed the need to combine climate change discussions with other questions.
- Two Habitat Quality questions were combined due to feedback received during the development of the first round of reports. A single question regarding the "integrity of major habitat types" has been created and combines prior questions that separately inquired about non-biogenic and biogenic habitats. Our experience showed that species constituting biogenic habitat (e.g., kelp, corals, seagrass, etc.) were considered adequately within questions about living resources, and need not be covered twice in the reports.
- Among the Living Resource Quality questions, one used in the first round of condition reports was removed entirely. It asked about "the status of environmentally sustainable fishing." It was removed for a variety of reasons — it was the only question focused on a single, specific human activity and because fishing activity discussions were already included in the question regarding "human activities that may influence living resource quality." In addition, living resource quality that would provide a basis for judgement for this question was typically considered as part of other living resource questions, and need not be covered twice. Another change to the Living Resource Quality questions pertains to the question about the "health of key species" which was

previously addressed in a single question, but is now split into two. The first asks specifically about the status of "keystone and foundation" species, the second about "other focal species." In either case, the health of any species of interest can be considered in judgement of status and trends.
- One of the initial maritime archaeology questions addressed potential environmental hazards presented by heritage resources like shipwrecks. While the assessment of such threats is important, it was decided that the question should actually address environmental hazards in general rather than apply specifically to historic maritime properties. Therefore, the question was removed from the maritime heritage resources section of the report and the subject is discussed in the context of other questions.

Ratings for a number of questions depend on judgments of the "ecological integrity" within a national marine sanctuary. This is because one of the foundational principles behind the establishment of sanctuaries is to protect ocean ecosystems. The term ecological integrity is used to imply "the presence of naturally occurring species, populations and communities, and ecological processes functioning at appropriate rates, scales, and levels of natural variation, as well as the environmental conditions that support these attributes" (modified from NPS 2018). Sanctuaries have ecological integrity when they have their native components intact, including abiotic components (i.e., the physical forces and chemical elements, such as water), biotic elements (such as habitats), biodiversity (i.e., the composition and abundance of species and communities), and ecological processes (e.g., competition, predation, symbioses) (modified from Parks Canada 2019). For purposes of this report, the level of integrity that is judged to exist is based on the extent to which humans have altered specific components of the system, and the effect of that change on the ability of an ecosystem to resist continued change and recover from it. The statements for many questions are intended to reflect this judgment. Reference is made in the rating system to "near-pristine" conditions, for which this report would imply a status as near to an unaltered ecosystem as can reasonably be presumed to exist, recognizing that there are virtually no ecosystems on Earth completely free from human influence.

Not all questions, however, use ecological integrity as a basis for judgment. One focuses on the impacts of water quality factors on human health. Two questions rate the status of keystone and key species compared with that expected in an unaltered ecosystem. One rates maritime archaeological resources based on their historical, archaeological, scientific, and educational value. Another considers the level and persistence of localized threats posed by degrading archaeological resources. Finally, four ask specifically about the levels of ongoing human activities (i.e., Pressures) that could affect resource condition.

During workshops in which status and trends are rated, subject matter experts discuss each question and available data, literature (e.g., published scientific studies, reports), and experience associated with the topic. They then discuss the statements provided as options for judgments about status; these statements have been customized for each question. Once a particular statement is agreed upon, a color code and status rating (e.g., good, fair, poor) is assigned. Experts can also decide that the most appropriate rating is "N/A" (i.e., the question does not apply) or "Undet." (i.e., resource status is undetermined due to a paucity of relevant information).

A subsequent discussion is then held about the trend. Conditions are determined to be improving, remaining the same, or worsening in comparison to the results found in the first round of condition reports. Symbols used to indicate trends are the same for all questions: "▲" — conditions appear to be improving; "▬" — conditions do not appear to be changing; "▼" — conditions appear to be worsening; and "?" — trend is undetermined.

Drivers/Pressures

Question 1 (Drivers/Human Activities): What are the states of influential human drivers and how are they changing?

Driving forces are those characteristics of human societies that influence the nature and extent of pressures on resources. They are the underlying cause of change in coastal marine ecosystems, as they determine human use. Drivers are influenced by demographics (e.g., age structure, population, etc.), demand, economic circumstances, industrial development patterns, business trends, and societal values. They operate at global, regional, and local scales. Examples include increasing global demand for agricultural commodities, which increases the use of chemicals that degrade coastal water quality; difficult economic times that reduce fishing efforts for a period of time within certain regions; or local construction booms that alter recreational visitation trends. Other drivers could be the demands that govern trends, such as global greenhouse gas generation, regional shipping or offshore industrial development, local recreation and tourism, fishing, port improvement, manufacturing, and age-specific services (e.g., retirement). Each of these, in turn, influences certain pressures on natural and cultural resources.

Integrated into this question should be consideration of societal values, which include such matters as levels of conservation awareness, political leanings, opinion about environmental issues relative to other concerns, or changing opinions about the acceptability of specific behaviors (e.g., littering, fishing). Understanding these values gives one a better understanding of the likely future trends in drivers and pressures, as well as the nature of the societal tradeoffs in different uses of the ecosystem resources (e.g., the effects of multiple changing drivers on each other and the resources they affect). This can better inform policy and management responses, and education and outreach efforts that are designed to change societal values with the intention to change drivers and reduce pressures.

In rating the status and trends for drivers, the following should be considered:

- the main driving forces behind each pressure affecting natural resources and the environment
- the best available indicators of each driving force
- the status and trend of each driving force
- societal values behind each driving force
- the best indicators of societal value
- the status and trend of societal values

Good	Few or no drivers occur that have the potential to influence pressures in ways that will negatively affect resource qualities.
Good/Fair	Some drivers exist that may influence pressures in ways expected to degrade some attributes of resource quality.
Fair	Selected drivers are influencing pressures in ways that cause measurable resource impacts.
Fair/Poor	Selected drivers are influencing pressures in ways that result in severe impacts that are either widespread or persistent.
Poor	Selected drivers are influencing pressures in ways that result in severe, persistent, and widespread impacts.

Question 2 (Water/Human Activities): What are the levels of human activities that may adversely influence water quality and how are they changing?

Among the human activities in or near sanctuaries that affect water quality are those involving direct discharges and spills (vessels, onshore and offshore industrial facilities, public wastewater facilities), those that contribute contaminants to groundwater, stream, river, and water control discharges (agriculture, runoff from impermeable surfaces through storm drains, conversion of land use), and those releasing airborne chemicals that subsequently deposit via particulates at sea (vessels, land-based traffic, power plants, manufacturing facilities, refineries). In addition, dredging and trawling can cause resuspension of contaminants in sediments. Many of these activities can be controlled through management actions in order to limit their impact on protected resources.

Good	Few or no activities occur that are likely to negatively affect water quality.
Good/Fair	Some potentially harmful activities exist, but they have not been shown to degrade water quality.
Fair	Selected activities have caused measurable resource impacts, but effects are localized and not widespread or persistent.
Fair/Poor	Selected activities have caused severe impacts that are either widespread or persistent.
Poor	Selected activities have caused severe, persistent, and widespread impacts.

Question 3 (Habitat/Human Activities): What are the levels of human activities that may adversely influence habitats and how are they changing?

Human activities that degrade habitat quality do so by affecting structural (physical), biological, oceanographic, acoustic, or chemical characteristics of the habitat. Structural impacts, such as removal or mechanical alteration of habitat, can result from various fishing methods (e.g., trawls, traps, dredges, longlines, and even hook-and-line in some habitats), dredging of channels and harbors, dumping dredge spoil, grounding of vessels, anchoring, laying pipelines and cables, installing offshore structures, discharging drill cuttings, dragging tow cables, and placing artificial reefs. Removal or alteration of critical biological components of habitats can occur due to several of the above activities, most notably trawling, groundings, and cable drags. Marine debris, particularly in large quantities (e.g., lost gill nets and other types of fishing gear), can degrade both biological and structural habitat components. Changes in water circulation often occur when channels are dredged, fill is added, coastlines are armored or other construction takes place. Management actions such as beach wrack removal or sand replenishment on high public-use beaches, may impact the integrity of the natural ecosystem. Alterations in circulations can lead to changes in food delivery, waste removal, water quality (e.g., salinity, clarity and sedimentation), recruitment patterns, and a host of other ecological processes. Chemical alterations most commonly occur following spills and can have both acute and chronic impacts. Many of these activities can be controlled through management actions in order to limit their impact on protected resources.

Good	Few or no activities occur that are likely to negatively affect habitat quality.
Good/Fair	Some potentially harmful activities exist, but they have not been shown to degrade habitat quality.
Fair	Selected activities have caused measurable resource impacts, but effects are localized and not widespread or persistent.
Fair/Poor	Selected activities have caused severe impacts that are either widespread or persistent.
Poor	Selected activities have caused severe, persistent, and widespread impacts.

Question 4 (Living Resources/Human Activities): What are the levels of human activities that may adversely influence living resources and how are they changing?

Human activities that degrade the condition of living resources do so by causing a loss or reduction of one or more species, by disrupting critical life stages, by impairing various physiological processes, or by promoting the introduction of non-indigenous species or pathogens. (Note: Activities that impact habitat and water quality may also affect living resources. These activities are dealt with in Questions 2 and 3, and some may be repeated here as they also directly affect living resources).

For most sanctuaries, recreational or commercial fishing and collecting have direct effects on animal or plant populations, either through removal or injury of organisms. Related to this, lost fishing gear can cause extended periods of loss for some species through entanglement and "ghost fishing." In addition, some fishing techniques are size-selective, resulting in impacts to particular life stages. High levels of visitor use in some places also cause localized depletion, particularly in intertidal areas or on shallow coral reefs, where collecting and trampling can be chronic problems.

Mortality and injury to living resources has also been documented from cable drags (e.g., towed barge operations), dumping spoil or drill cuttings, vessel groundings, or repeated anchoring. Contamination caused by acute or chronic spills or increased sedimentation to nearshore ecosystems from road developments in watersheds (including runoff from coastal construction or highly built coastal areas), discharges by vessels, or municipal and industrial facilities can make habitats unsuitable for recruitment or other ecosystem services (e.g., as nurseries or spawning grounds). And while coastal armoring and construction can increase the availability of surfaces suitable for hard bottom species, the activity may disrupt recruitment patterns for other species (e.g., intertidal soft bottom animals), and natural habitat may be lost.

Oil spills (and spill response actions), discharges, and contaminants released from sediments (e.g., by dredging and dumping) can all cause physiological impairment and tissue contamination. Such activities can affect all life stages by direct mortality, reducing fecundity, reducing disease resistance, loss as prey and disruption of predator-prey relationships, and increasing susceptibility to predation. Furthermore, bioaccumulation results in some contaminants moving upward through the food chain, disproportionately affecting certain species.

Activities that promote the introduction of non-indigenous species include bilge discharges and ballast water exchange, commercial shipping and vessel transportation. Intentional or accidental releases of aquarium fish and plants can also lead to introductions of non-indigenous species.

Many of these activities are controlled through management actions in order to limit their impact on protected resources.

Good	Few or no activities occur that are likely to negatively affect living resource quality.
Good/Fair	Some potentially harmful activities exist, but they have not been shown to degrade living resource quality.
Fair	Selected activities have caused measurable living resource impacts, but effects are localized and not widespread or persistent.
Fair/Poor	Selected activities have caused severe impacts that are either widespread or persistent.
Poor	Selected activities have caused severe, persistent, and widespread impacts.

Question 5 (Maritime Heritage Resources/Human Activities): What are the levels of human activities that may adversely affect maritime heritage resources and how are they changing?

Maritime heritage resources are the wide variety of tangible and intangible elements (archaeological, cultural, historical properties) that reflect our human connections to Great Lakes and ocean areas.

Some human activities threaten the archaeological or historical condition of maritime heritage resources. Archaeological or historical condition is compromised when elements are moved, removed, or otherwise damaged. Threats come from looting, inadvertent damage by recreational divers, improper research methods, vessel anchorings and groundings, and commercial and recreational fishing activities, among others. Other human activities may alter or damage heritage resources by impacting the landscape or viewshed of culturally significant places or locations. Many of these activities can be controlled through management actions in order to limit their impact to maritime heritage resources.

Good	Few or no activities occur at maritime heritage resource sites that are likely to adversely affect their condition.
Good/Fair	Some potentially damaging activities exist, but they have not been shown to degrade maritime heritage resource condition.
Fair	Selected activities have caused measurable impacts to maritime heritage resources, but effects are localized and not widespread or persistent.
Fair/Poor	Selected activities have caused severe impacts that are either widespread or persistent.
Poor	Selected activities have caused severe, persistent, and widespread impacts.

Water Quality

Question 6 (Water/Eutrophic Condition): What is the eutrophic condition of sanctuary waters and how is it changing?

Eutrophication is the accelerated production of organic matter, particularly algae, in a water body. It is usually caused by an increase in the amount of nutrients (largely nitrogen and phosphorus) being discharged to the water body. As a result of accelerated algal production, a variety of interrelated impacts may occur, including nuisance and toxic algal blooms, depleted dissolved oxygen, and loss of submerged aquatic vegetation (Bricker et al. 1999). Indicators commonly used to detect eutrophication and associated problems include nutrient concentrations, chlorophyll content, rates of water column or benthic primary production, benthic algae cover, algae bloom frequency and intensity, oxygen levels, and light penetration.

Eutrophication of sanctuary waters can impact the condition of other sanctuary resources. Nutrient enrichment often leads to plankton and/or algae blooms. Blooms of benthic algae can affect benthic communities directly through space competition. Indirect effects of overgrowth and other competitive interactions (e.g., accumulation of algal-sediment mats) often lead to shifts in dominance in the benthic assemblage, oxygen depletion, etc. Disease incidence and frequency can also be affected by algae competition and changes in the chemical environment along competitive boundaries. Blooms can also affect water column conditions, including light penetration and plankton availability, which can alter pelagic food webs. Harmful algal blooms (HABs), some of which are exacerbated by eutrophic conditions, often affect other living resources, as biotoxins are consumed or released into the water and air, or decomposition depletes oxygen concentrations.

Good	Eutrophication has not been documented, or does not appear to have the potential to negatively affect ecological integrity.
Good/Fair	Eutrophication is suspected and may degrade some attributes of ecological integrity, but has not yet caused measurable degradation.
Fair	Eutrophication has caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Eutrophication has caused severe degradation in some but not all attributes of ecological integrity.
Poor	Eutrophication has caused severe degradation in most if not all attributes of ecological integrity.

Question 7 (Water/Human Health): Do sanctuary waters pose risks to human health and how are they changing?

Human health concerns are generally aroused by evidence of contamination (usually bacterial or chemical) in bathing waters or seafood intended for consumption. They also arise when harmful algal blooms are reported or when cases of respiratory distress or other disorders attributable to harmful algal blooms increase dramatically. Any of these conditions should be considered in the course of judging the risk to humans posed by waters in a marine sanctuary.

Some sanctuaries may have access to specific information about beach closures and seafood contamination. In particular, beaches may be closed when criteria for water safety are exceeded. Shellfish harvesting and fishing may be prohibited when contaminant or biotoxin loads or infection rates exceed certain levels. Alternatively, seafood advisories may also be issued, recommending that people avoid or limit intake of particular types of seafood from certain areas (e.g., when ciguatera poisoning is reported). Any of these conditions, along with changing frequencies or intensities, can be important indicators of human health problems and can be characterized using the descriptions below.

Good	Water quality does not appear to have the potential to negatively affect human health.
Good/Fair	One or more water quality indicators suggest the potential for human health impacts but human health impacts have not been reported.
Fair	Water quality problems have caused measurable human impacts, but effects are localized and not widespread or persistent.
Fair/Poor	Water quality problems have caused severe impacts that are either widespread or persistent.
Poor	Water quality problems have caused severe, persistent, and widespread human impacts.

Question 8 (Water/Climate Change): Have recent, accelerated changes in climate altered water conditions and how are they changing?

The purpose of this question is to capture shifts in water quality, and associated impacts on sanctuary resources, due to climate change. Though temporal changes in climate have always occurred on Earth, evidence is strong that changes over the last century have been accelerated by human activities. Indicators of climate change in sanctuary waters include water temperature, acidity, sea level, upwelling intensity and timing, storm intensity and frequency, changes in erosion and sedimentation patterns, and freshwater delivery (e.g., rainfall patterns). Climate-related changes in one or more of these indicators can impact the condition of habitats, living resources, and maritime archaeological resources in sanctuaries.

Increasing water temperature has been linked to changing growth rates, reduced disease resistance, and disruptions in symbiotic relationships (e.g., bleaching on coral reefs), and changes in water temperature exposure may affect a species' resistance or the capacity to adapt to disturbances. Acidification can affect the survival and growth of organisms throughout the food web, as well as the persistence of skeletal material after death (through changes in rates of dissolution and bioerosion). Recent findings also suggest acidification impacts at sensory and behavioral levels, which can alter vitality and species interactions. Sea level change alters habitats, as well as their use and persistence. Variations in the timing and intensity of upwelling is known to change water quality through factors such as oxygen content and nutrient flow, further disrupting food webs and the natural functioning of ecosystems. Changing patterns and intensities of storms alter community resistance and resilience within ecosystems that have, over long periods of time, adapted to such disturbances. Altered rates and volumes of freshwater delivery to coastal ecosystems affects salinity and turbidity regimes and can disrupt reproduction, recruitment, growth, disease incidence, phenology, and other important processes.

Good	Climate-related changes in water conditions have not been documented or do not appear to have the potential to negatively affect ecological integrity.
Good/Fair	Climate-related changes are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.
Fair	Climate-related changes have caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Climate-related changes have caused severe degradation in some but not all attributes of ecological integrity.
Poor	Climate-related changes have caused severe degradation in most if not all attributes of ecological integrity.

Question 9 (Water/Other Stressors): Are other stressors, individually or in combination, affecting water quality, and how are they changing?

The purpose of this question is to capture shifts in water quality due to anthropogenic stressors not addressed in other questions. For example, localized changes in circulation or sedimentation resulting from coastal construction or dredge spoil disposal can affect light penetration, salinity regimes, oxygen levels, productivity, waste transport, and other aspects of water quality that in turn influence the condition of habitats and living resources. Human inputs, generally in the form of contaminants from point or non-point sources, including fertilizers, pesticides, hydrocarbons, heavy metals, and sewage, are common causes of environmental degradation. When present in the water column, any of these contaminants can affect marine life by direct contact or ingestion, or through bioaccumulation via the food chain.

[Note: Over time, accumulation in sediments can sequester and concentrate contaminants. Their effects may manifest only when the sediments are resuspended during storm or other energetic events. In such cases, reports of status should be made under Question 11 — Habitat contaminants.]

Good	Other stressors on water quality have not been documented, or do not appear to have the potential to negatively affect ecological integrity.
Good/Fair	Selected stressors are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.
Fair	Selected stressors have caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Selected stressors have caused severe degradation in some but not all attributes of ecological integrity.
Poor	Selected stressors have caused severe degradation in most if not all attributes of ecological integrity.

Habitat

Question 10 (Habitat/Integrity): What is the integrity of major habitat types and how are they changing?

Ocean habitats can be categorized in many different ways, including water column characteristics, benthic assemblages, substrate types, and structural character. There are intertidal and subtidal habitats. The water column itself is one habitat type (FGDC 2012). There are habitats composed of substrates formed by rocks or sand that originate from purely physical processes. And, there are certain animals and plants that create, in life or after their death, substrates that attract or support other organisms (e.g., corals, kelp, beach wrack, drift algae). These are commonly called biogenic habitats.

Regardless of the habitat type, change and loss of habitat is of paramount concern when it comes to protecting marine and terrestrial ecosystems. Of greatest concern to sanctuaries are changes to habitats caused, either directly or indirectly, by human activities. Human activities like coastal development alter the distribution of habitat types along the shoreline. Changes in water conditions in estuaries, bays, and nearshore waters can negatively affect biogenic habitat formed by submerged aquatic vegetation. Intertidal habitats can be affected for long periods by oil spills or by chronic pollutant exposure. Marine debris, such trash and lost fishing gear, can degrade the quality of many different marine habitats including, beaches, subtidal benthic habitats, and the water column. Sandy seafloor and hard bottom habitats, even rocky areas several hundred meters deep, can be disturbed or destroyed by certain types of fishing gear, including bottom trawls, shellfish dredges, bottom longlines, and fish traps. Groundings, anchors, and irresponsible diving practices damage submerged reefs. Cables and pipelines disturb corridors across numerous habitat types and can be destructive if they become mobile.

Integrity of biogenic habitats depends on the condition of particular living organisms. Coral, sponges, and kelp are well known examples of biogenic habitat-forming organisms. The diverse assemblages residing within these habitats depend on and interact with each other in tightly linked food webs. They may also depend on each other for the recycling of wastes, hygiene, and the maintenance of water quality. Other communities that are dependent on biogenic habitat include intertidal communities structured by mussels, barnacles, and algae and subtidal hard-bottom communities structured by bivalves, corals, or coralline algae. In numerous open ocean areas drift algal mats provide food and cover for juvenile fish, turtles, and other organisms. The integrity of these communities depends largely on the condition of species that provide structure for them.

This question is intended to address acute or chronic changes in both the extent of habitat available to organisms and the quality of that habitat, whether non-living or biogenic. It asks about the quality of habitats compared to those that would be expected in near-pristine conditions (see definition above).

Good	Habitats are in near-pristine condition.
Good/Fair	Selected habitat loss or alteration is suspected and may degrade some attributes of ecological integrity, but has not yet caused measurable degradation.
Fair	Selected habitat loss or alteration has caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Selected habitat loss or alteration has caused severe degradation in some but not all attributes of ecological integrity.
Poor	Selected habitat loss or alteration has caused severe degradation in most if not all attributes of ecological integrity.

Question 11 (Habitat/Contaminants): What are contaminant concentrations in sanctuary habitats and how are they changing?

Habitat contaminants result from the introduction of unnatural levels of chemicals or other harmful material into the environment. Contaminants may be introduced through discrete entry locations, called point sources (e.g., rivers, pipes, or ships) and those with diffuse origins, called non-point sources (e.g., groundwater and urban runoff). Chemical contaminants themselves can be very specific, as in a spill from a containment facility or vessel grounding, or a complex mix, as with urban runoff. Familiar chemical contaminants include pesticides, hydrocarbons, heavy metals, and nutrients. Contaminants may also arrive in the form of materials that alter turbidity or smother plants or animals, therefore affecting metabolism and production.

This question is focused on risks posed primarily by contaminants within benthic formations, such as soft sediments, hard bottoms, or structure-forming organisms (see notes below). Not only are contaminants within benthic formations consumed or absorbed by benthic fauna, but resuspension due to benthic disturbance makes the contaminants available to water column organisms. In both cases contaminants can be passed upwards through the food chain. While the contaminants of most common concern to sanctuaries are generally pesticides, hydrocarbons, and nutrients, the specific concerns of individual sanctuaries may differ substantially.

Notes: 1) contaminants in the water column addressed in the water quality section of this report should be cited, but details need not be repeated here; 2) many consider noise a pollutant, but in the interest of focusing here on more traditional forms of habitat degradation caused by contaminants, ONMS recommends addressing the impacts of acoustic pollution within the living resource section, most likely as it impacts key species.

Good	Contaminants have not been documented, or do not appear to have the potential to negatively affect ecological integrity.
Good/Fair	Selected contaminants are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.
Fair	Selected contaminants have caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Selected contaminants have caused severe degradation in some but not all attributes of ecological integrity.
Poor	Selected contaminants have caused severe degradation in most if not all attributes of ecological integrity.

Living Resources

Question 12 (Living Resources/Keystone and Foundation Species): What is the status of keystone and foundation species and how is it changing?

Certain species are defined as "keystone" within ecosystems, meaning they are species on which the persistence of a large number of other species in the ecosystem depends (Paine 1966). They are the pillars of community stability (among other things, they strongly affect both resistance and resilience) and their contribution to ecosystem function is disproportionate to their numerical abundance or biomass. Their impact is therefore important at the community or ecosystem level. Keystone species are often called "ecosystem engineers" and can include habitat creators (e.g., corals, kelp), predators that control food web structure (e.g., Humboldt squid, sea otters), herbivores that regulate benthic recruitment (e.g., certain sea urchins), and those involved in critical symbiotic relationships (e.g., cleaning or co-habitating species).

"Foundation" species are single species that define much of the structure of a community by creating locally stable conditions for other species, and by modulating and stabilizing fundamental ecosystem processes (Dayton 1972). These are typically dominant biomass producers in an ecosystem and strongly influence the abundance and biomass of many other species. Examples include krill and other zooplankton, kelp, forage fish, such as rockfish anchovy, sardine, and coral. Foundation species exhibit similar control over ecosystems as keystone species, but their high abundance distinguishes them.

Changes in either keystone or foundation species may transform ecosystem structure through disappearances of or dramatic increases in the abundance of dependent species. Not only do the abundances of keystone and foundation species affect ecosystem integrity, but measures of condition can also be important to determining the likelihood that these species will persist and continue to provide vital ecosystem functions. Measures of condition may include growth rates, fecundity, recruitment, age-specific survival, contaminant loads, pathologies (e.g., disease incidence, tumors, deformities), the presence and abundance of critical symbionts, or parasite loads.

Good	The status of keystone and foundation species appears to reflect near-pristine conditions and may promote ecological integrity (full community development and function).
Good/Fair	The status of keystone or foundation species may preclude full community development and function, but has not yet led to measurable degradation.
Fair	The status of keystone or foundation species suggests measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	The status of keystone and foundation species suggests severe degradation in some but not all attributes of ecological integrity.
Poor	The status of keystone and foundation species suggests severe degradation in most if not all attributes of ecological integrity.

Question 13 (Living Resources/Other Focal Key Species): What is the status of other key species and how is it changing?

This question targets other species of particular interest from the perspective of sanctuary management. These "key species" may not be abundant or provide high value to ecosystem function, but their presence and health is important for the provision of other services, whether conservation, economic, or strategic. Examples include species targeted for special protection (e.g., threatened or endangered species), species for which specific regulations exist to minimize perturbations from human disturbance (e.g., touching corals, riding manta rays or whale sharks, disturbing white sharks, disturbing nesting birds), or indicator species (e.g., common murres as indicators of oil pollution). This category could also include so-called "flagship" species, which include charismatic or iconic species associated with specific locations, ecosystems or are in need of specific management actions, are highly popular and attract visitors or business, have marketing appeal, or represent rallying points for conservation action (e.g., humpback and blue whales, Dungeness crab).

Status of these other key species can be assessed through measures of abundance, relative abundance, or condition, as described for keystone species in Question 12. In contrast to keystone and foundation species, however, the impact of changes in the abundance or condition of key species is more likely to be observed at the population or individual level, and less likely to result in ecosystem or community effects.

Good	Selected key species appear to reflect near-pristine conditions.
Good/Fair	Reduced abundances in selected key species are suspected but have not yet been measured.
Fair	Selected key species are at reduced levels, but recovery is possible.
Fair/Poor	Selected key species are at substantially reduced levels, and prospects for recovery are uncertain.
Poor	Selected key species are at severely reduced levels, and recovery is unlikely.

Question 14 (Living Resources/Non-Indigenous Species): What is the status of non-indigenous species and how is it changing?

This question allows sanctuaries to report on the threat posed and impacts caused by non-indigenous species. Also called alien, exotic, non-native, or introduced species, these are animals or plants living outside their native distributional range, having arrived there by human activity, either deliberate or accidental. Activities that commonly facilitate invasions include vessel ballast water exchange, restaurant waste disposal, and trade in exotic species for aquaria. In some cases, climate change has resulted in water temperature fluctuations that have allowed range extensions for certain species.

Non-indigenous species that have damaging effects on ecosystems are called “invasive” species. Some can be extremely destructive, and because of this potential, non-indigenous species are usually considered problematic and warrant rapid response after invasion. For those that become established, however, their impacts can sometimes be assessed by quantifying changes in affected native species. In some cases, the presence of a species alone constitutes a significant threat (e.g., certain invasive algae and invertebrates). In other cases, impacts have been measured, and may or may not significantly affect ecosystem integrity.

Evaluating the potential impacts of non-indigenous species may require consideration of how climate change may enhance the recruitment, establishment, and/or severity of impacts of non-indigenous species. Altered temperature or salinity conditions, for example, may facilitate the range expansion, establishment and survival of non-indigenous species while stressing native species, thus reducing ecosystem resistance. This will also make management response decisions difficult, as changing conditions will make new areas even more hospitable for non-indigenous species targeted for removal.

Good	Non-indigenous species are not suspected to be present or do not appear to affect ecological integrity (full community development and function).
Good/Fair	Non-indigenous species are present and may preclude full community development and function, but have not yet caused measurable degradation.
Fair	Non-indigenous species have caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Non-indigenous species have caused severe degradation in some but not all attributes of ecological integrity.
Poor	Non-indigenous species have caused severe degradation in most if not all attributes of ecological integrity.

Question 15 (Living Resources/Biodiversity): What is the status of biodiversity and how is it changing?

Broadly defined, biodiversity refers to the variety of life on Earth, and includes the diversity of ecosystems, species and genes, and the ecological processes that support them (United Nations Convention on Biological Diversity). This question is intended as an overall assessment of biodiversity compared to that expected in a near-pristine system (one as near to an unaltered ecosystem as people can reasonably expect, given that there are virtually no ecosystems completely free from human influence). It may include consideration of measures of biodiversity (usually aspects of species richness and evenness) and the status of functional interactions between species (e.g., trophic relationships and symbioses). Intact ecosystems require that all parts not only exist, but that they function together, resulting in natural symbioses, competition, predator-prey relationships, and redundancies (e.g., multiple species capable of performing the same ecological role). Intact structural elements, processes, and natural spatial and temporal variability are essential characteristics of community integrity and provide a natural adaptive capacity through resistance and resilience.

The response to this question will depend largely on changes in biodiversity that have occurred as a result of human activities that cause depletion, extirpation or extinction, illness, contamination, disturbance, and changes in environmental quality. Examples include collection of organisms, excessive visitation (e.g., trampling), industrial activities, coastal development, pollution, activities creating noise in the marine environment, and those that promote the spread of non-indigenous species.

Loss of species or changing relative abundances can be mediated through selective mortality or changing fecundity, either of which can influence ecosystem shifts. Human activities of particular interest in this regard are commercial and recreational harvesting. Both can be highly selective and disruptive activities, with a limited number of targeted species, and often result in the removal of high proportions of the populations, as well as large amounts of untargeted species (bycatch). Extraction removes biomass from the ecosystem, reducing its availability to other consumers. When too much extraction occurs, ecosystem stability can be compromised through long-term disruptions to food web structure, as well as changes in species relationships and related functions and services (e.g. cleaning symbioses). This has been defined as “ecologically unsustainable” extraction (Zabel et al. 2003).

Good	Biodiversity appears to reflect near-pristine conditions and promotes ecological integrity (full community development and function).
Good/Fair	Selected biodiversity loss or change is suspected and may preclude full community development and function, but has not yet caused measurable degradation.
Fair	Selected biodiversity loss or change has caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Selected biodiversity loss or change has caused severe degradation in some but not all attributes of ecological integrity.
Poor	Selected biodiversity loss or change has caused severe degradation in most if not all attributes of ecological integrity.

Maritime Heritage Resources

Question 16 (Maritime Heritage Resources/Condition): What is the condition of known maritime heritage resources and how is it changing?

Maritime heritage resources are the wide variety of tangible and intangible elements (archaeological, cultural, historical properties) that reflect our human connections to Great Lakes and ocean areas.

Maritime heritage resources include archaeological and historical properties, and material evidence of past human activities, including vessels, aircraft, structures, habitation sites, and objects created or modified by humans. The condition of these resources in a marine sanctuary significantly affects their value for science and education, as well as the resource's eligibility for listing in the National Register of Historic Places. The "integrity" of archaeological/historical resources, as defined within the National Register criteria, refers to their ability to help scientists answer questions about the past through archaeological research. Historical significance of an archaeological resource depends on its integrity and/or its representativeness of past events that made a significant contribution to the broad patterns of history, its association with important persons, or its embodiment of a distinctive type or architecture.

Maritime heritage resources also include certain culturally significant resources, locations and viewsheds, the condition of which may change over time. Such resources, often more intangible in nature, may still be central to traditional practices and maintenance of cultural identity. The integrity of both cultural resources and cultural locations are included within the National Register criteria.

Section 110 of the National Historic Preservation Act requires federal agencies to inventory, assess, and nominate appropriate maritime heritage resources ("historic properties") to the National Register. The Maritime Cultural Landscape approach, adopted by the sanctuary system, provides a comprehensive tool for the assessment of archaeological, historical and cultural (maritime heritage) resources.

Assessments of heritage resources include evaluation of the apparent condition, which results from deterioration caused by human and natural forces (unlike questions about water, habitat, and living resources, the non-renewable nature of many heritage resources makes any reduction in integrity and condition, even if caused by natural forces, permanent). While maritime heritage resources have intrinsic value, these values may be diminished by changes to their condition.

Good	Known maritime heritage resources appear to reflect little or no unexpected natural or human disturbance.
Good/Fair	Selected maritime heritage resources exhibit indications of natural or human disturbance, but there appears to have been little or no reduction in aesthetic, cultural, historical, archaeological, scientific, or educational value.
Fair	The diminished condition of selected maritime heritage resources has reduced, to some extent, their aesthetic, cultural, historical, archaeological, scientific, or educational value, and may affect the eligibility of some sites for listing in the National Register of Historic Places.
Fair/Poor	The diminished condition of selected maritime heritage resources has substantially reduced their aesthetic, cultural, historical, archaeological, scientific, or educational value, and is likely to affect their eligibility for listing in the National Register of Historic Places.
Poor	The degraded condition of known maritime heritage resources in general makes them ineffective in terms of aesthetic, cultural, historical, archaeological, scientific, or educational value, and precludes their listing in the National Register of Historic Places.

APPENDIX B:
Description of Ecosystem Services and Methods to Determine Ratings

The following provides descriptions of the various ecosystem services considered in sanctuary condition reports and the process for rating them. Office of National Marine Sanctuaries (ONMS) defines ecosystem services (ES) in a slightly more restrictive way than some other experts. Specifically, "ecosystem services" are defined herein as the benefits *people* obtain from nature through use, consumption, enjoyment, and/or simply knowing these resources exist. The descriptions below reflect this definition, and therefore, only those ecosystem services are evaluated in sanctuary conditions reports. In contrast, there are some supporting services, such as biodiversity, decomposition, and carbon storage, that are included in the State section of these reports instead. Specifically, these services are critical to ecosystem function and considered "intermediate" ecosystem services that are not directly used, consumed, or enjoyed by humans to meet the ONMS condition report definition of ecosystem services. In other words, these secondary or intermediate services support ecosystems and are not final ecosystem services in and of themselves.

As an example, biodiversity is often considered an ecosystem service, but ONMS recognizes biodiversity as an *attribute* of the ecosystem on which many "final" ecosystem services depend (e.g., recreation and food supply/commercial fishing). For this reason, it is considered a secondary ecosystem service and it is evaluated in the State section of the report.

In addition, ONMS does not consider climate regulation or stabilization in condition reports. The impacts of climate change on water quality and biodiversity, however, are considered separately in the State section of the report. While sanctuaries are not large enough to influence climate stability, they may locally buffer climate-related factors, such as temperature change and ocean acidity; thus, the extent to which they may locally buffer climate-related factors is reflected in resource conditions in the State section.

Below are brief descriptions of the ecosystem services considered within each sanctuary condition report (more complete descriptions are provided below the list).

Cultural (Non-Material Benefits)

1. Heritage — Recognition of historical or heritage legacy
2. Consumptive recreation — Recreational activities that result in the removal of or damage to natural or cultural resources
3. Non-consumptive recreation — Recreational activities that do not result in the removal of or damage to natural or cultural resources
4. Sense of place — Aesthetic and spiritual attraction, and the level of recognition and appreciation given to efforts to protect a place's iconic elements
5. Science — The capacity to acquire and contribute information and knowledge
6. Education — The capacity to acquire and provide intellectual enrichment

Provisioning (Material Benefits)

7. Food — The capacity to support market demands for nutrition-related commodities through various fisheries
8. Water — Providing water for human use by minimizing pollution, including nutrients, sediments, pathogens, chemicals, and trash
9. Ornamentals — Resources collected for decorative or aesthetic purposes
10. Biotechnology — Medicine and other chemicals found in sanctuary animals or plants, or manufactured from them
11. Energy — Use of ecosystem-derived materials or processes for the production of energy

Regulating (Buffers to Change)

12. Coastal protection — Flow regulation that protects habitats, property, coastlines, and other features

Sanctuaries vary with regard to the ecosystem services they support, so each sanctuary is likely to have a different mix of services and information to support its assessment. To rate the status and trends for each relevant ecosystem service, the following was considered:

- the ecosystem services relevant to the sanctuary
- the best available indicators for each ecosystem service (economic, non-economic human dimensions, and ecological)
- the status and direction of change of each ecosystem service
- whether economic and non-economic human dimensions indicators yield the same conclusions about the status and trend for each ecosystem service
- whether economic indicators send a false signal about the status and trend of an ecosystem service (namely, conflicting ecological and economic indicators, suggesting that people are sacrificing natural capital for short-term economic gain)

The steps used to rate ecosystem services were adapted from the multi-year study "Marine and Estuarine Goal Setting for South Florida" (MARES) of three south Florida marine ecosystems, including Florida Keys National Marine Sanctuary. It used Integrated Conceptual Ecosystem Models (ICEMs) for each ecosystem under the Driving forces (Drivers)-Pressure-State-Ecosystem Services-Response (DPSER) Model (Nuttle and Fletcher 2013), and evaluation of three types of indicators: 1) economic; 2) human dimension non-economic (Lovelace et al. 2013); and 3) ecological for each ecosystem service.

Determining status and trend ratings is a two-step process, where first economic indicator data is used to develop preliminary ratings, which is then followed by an advisory-panel workshop. Discussions during each workshop consider and integrate non-economic and resource indicators, allowing participants to characterize an ecosystem service within the five-tier rating system below. The final rating ("Good," "Fair," etc.) corresponds to the criteria in the table above. The Status Description from that table is used to convey the rating in the condition report.

Rating Scheme for Ecosystem Services

Rating	Status Description	Rationale
Good	The capacity to provide the ecosystem service has been either enhanced or remained unaffected.	Economic indicators are positive and increasing, human dimension non-economic indicators are increasing or stable, and resource indicators do not indicate there is a decline in the natural capital stock.
Good/Fair	Unable to fully provide the ecosystem service due to prior or existing human activity, but performance is acceptable.	Economic indicators are positive and stable, human dimension non-economic indicators are increasing or stable, and resource indicators do not indicate there is a decline in the natural capital stock.
Fair	Ability to provide ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.	Mixed results for the economic and non-economic indicators and some resource indicators indicate a decline in the natural capital stock but not widespread.
Fair/Poor	Ability to provide ecosystem service is compromised, and it is uncertain whether new or enhanced management would restore it.	Economic indicators are negative and declining, while non-economic indicators are negative or stable. Resource indicators are showing more widespread declines in natural capital stock.
Poor	Unable to deliver ecosystem service due to the extreme, pervasive, or widespread nature of human activities, and it is doubtful that new or enhanced management would restore it.	Economic and non-economic indicators are negative and declining. Resource indicators are negative showing widespread declines in the natural capital stock.

The discussion of ecosystem services ratings within the written report should focus on the influence of drivers and societal values considered responsible for the ratings. This discussion may also consideration of whether economic and non-economic indicators yield the same conclusions; this will enable consideration of the sometimes conflicting relationship between economic gain and the preservation of natural capital. For example, economic indicators (e.g., dive operator income) may suggest improving recreational services while resource indicators (e.g., anchor damage) suggest that natural resource qualities are being sacrificed for short-term gain, making the activity unsustainable.

Descriptions of Ecosystem Services

CULTURAL (non-material benefits)

Sense of place — Aesthetic and spiritual attraction, and the level of recognition and appreciation given to efforts to protect a place's iconic elements

Marine environments serve as places of aesthetic and spiritual attraction for many people, and inspire works of art, music, architecture, and tradition. Many people also value particular places as sources of therapeutic rejuvenation and to offer a change of perspective. Iconic places serve as motifs in books, film, artworks, and folklore and as part of national symbols, architecture, and advertising efforts. Many people even consider places as defining parts of their personality, especially if they have lived there during or since childhood; they associate them with fond memories and past experiences. Many people even incorporate water or water-related activities as habitual or significant parts of their lives and cultures. Different factors are considered to measure/assess sense of place, including level of uniqueness, recognition, reputation, reliance, and appreciation for a place. By accounting for sense of place, managers can evaluate or find reasons to support conservation, preservation, and restoration efforts.

Despite its value as a cultural ecosystem service indicator, it is difficult to quantify a sense of place with direct measures. Polls are often used to evaluate public opinions regarding economic and non-economic values of a place. One type considers "passive economic use values" (also called "non-use value"). Using estimates generated from survey analyses, this is the value people would be willing to pay for resources to stay in a certain condition even though they may never actually use them.

Non-consumptive recreation — Recreational activities that do not result in removal of or damage to natural or cultural resources

Recreational activities , including ecotourism and outdoor sports, are often considered a non-consumptive ecosystem service that provides experiential opportunities. Non-consumptive recreational activities include those on shore or from private boats and for-hire operations, such as relaxing, exploring, diving and snorkeling, kayaking, birdwatching, surfing, sailing, and wildlife viewing.

It should be noted that private boating often includes both non-consumptive and consumptive recreational activities (e.g., snorkeling and fishing during a single trip). Thus, field and survey data can be ambiguous, reflecting the heterogeneous preferences of boaters. This also has implications for interpretations of data regarding attitudes and perceptions of management strategies and regulations to protect and restore natural and cultural resources.

Indicators used to assess status and trends in market values for recreation can include direct measures of use (e.g., person-days of use by type of activity) that result in spending, income, jobs, gross regional product, and tax revenues. They can also be non-market economic values (the difference between what people pay to use a good/service and what they would be willing to pay). The data can be used to estimate the value a consumer receives when using a good or service over and above what they pay to obtain the good or service. Indirect measures are also used. For example, populations and per capita incomes at numerous scales influence demand for recreational products and services. Fuel prices can even serve as indirect measures of recreational demand because the levels of use by some recreational users tracks fuel prices.

Consumptive recreation — Recreational activities that result in the removal of or damage to natural or cultural resources

Sometimes culturally valued pursuits, rituals, or traditions involve activities that result in the death or disturbance of wildlife, or the destruction of natural habitats, whether intentional or not. Perhaps the most popular activity that involves consumptive recreation is sport fishing from private boats and for-hire operations. Targeted species and bycatch are removed from the environment, and those that are released (e.g. "catch-and-release" fishing) sometimes die due to stress or predation. Nonetheless, fishing is a highly valued cultural tradition for many people, as well as a popular recreational activity; therefore, for these reasons, sport fishing is considered here as a cultural ecosystem service. Other activities than can affect habitats or wildlife including beachcombing (shell collecting) and tidepooling (trampling), are also considered to be a cultural ecosystem service.

Indicators of status and trends for consumptive recreation often include levels of use (direct counts or estimates made from commercial vessel records and landings, and fishing license registrations) and production of economic value through job creation, income, spending, and tax revenue. Public polls can also be used to assess non-market indicators, such as importance and satisfaction, social values, willingness to pay, and facility and service availability.

Science — The capacity to acquire and contribute information and knowledge

Sanctuaries serve as natural laboratories that can advance science and education. NOAA provides vessel support, facilities, and information that is valuable to the research community, including academic, corporate, non-governmental and government agency scientists, citizen scientists, and educators that instruct others using research. Sanctuaries serve as long-term monitoring sites, provide minimally disturbed focal areas for many studies, and provide opportunities to restore or maintain natural systems.

Status and trends for science can be assessed by counting and characterizing the number of research permits and tracking the accomplishments and growth of partnerships, activity levels of citizen monitoring, and participation of the research community in sanctuary management. The number and types of research cruises and other expeditions conducted can also provide useful indicators. Indirect indicators, such as per capita income and gross regional or national product, may be helpful as higher incomes and better economic conditions often result in higher investments in research and monitoring.

Education — The capacity to acquire and provide intellectual enrichment

As with science, national marine sanctuaries' protected natural systems and cultural resources attract educators at many levels for both formal and informal education. Students and teachers often either visit sanctuaries or use curricula and information provided by sanctuary educators.

The status and trends for education can be tracked by evaluating the number of educators and students visiting the sanctuary and visitor centers, the number of teacher trainings, use of sanctuary-related curricula in the classroom, and levels of activity in volunteer docent programs. The number of outreach offerings provided during sanctuary research and education expeditions can also be a good indicator. Education can also follow trends in populations and per capita income locally, regionally, and nationally. Populations create demand for services, and higher incomes lead to investment, making these useful indirect indicators.

Heritage — Recognition of historical or heritage legacy

The iconic nature of many national marine sanctuaries or particular places within them generally means that they have long been recognized, used, and valued. Communities developed around them, traveled through them, and depended on their resources. This shared past created the unique cultural character of many present-day coastal communities, and can be an important part of the current economy. The remnants of the past, including artifacts, records, and stories, provide not only a tangible link to the maritime heritage of these areas, but a way to better understand their history.

Economic indicators that reflect status and trends for heritage value as an ecosystem service may include spending, income, jobs, and other revenues generated from visitation, whether it is to dive on wreck sites or patronize museums and visitor centers where artifacts are displayed and interpreted. Non-market indicators, such as willingness to pay, activity levels for training and docent interpretation, and changes in threat levels (looting and damage caused by fishing), may also be considered.

PROVISIONING (material benefits)

Among the valued products provided to people by marine and freshwater ecosystems are: wild and cultured seafood, a source of freshwater, keepsakes, energy and biochemical, medical, and genetic resources.

Food — The capacity to support market demands for nutrition-related commodities through various fisheries

Humans consume a large variety and abundance of products originating from the oceans and Great Lakes, whether for nutrition or for use in other sectors. This includes fish, shellfish, other invertebrates, roe, and algae. More than a billion people worldwide depend on fishing for their main source of animal protein and it accounts for 16 percent of world animal protein consumption. Ten to twelve percent of people around the world depend on fishing for their livelihoods.

Fisheries located in national marine sanctuaries are usually encompassed by larger regional fisheries that are regulated by fisheries management plans. Fisheries management plans may include sanctuary-specific restrictions to protect sanctuary habitats, living resources, and archaeological resources. Different data can be used to assess status and trends for this ecosystem service including: catch levels by species and species groups; and economic contributions in the form of sector-related jobs, income, sales, and tax revenue. Indirect measures include data on licensing, fleet size, fishing vessel types and sizes, days at sea, and commodity prices.

Water — Providing water for human use by minimizing pollution, including nutrients, sediments, pathogens, chemicals, and trash

Clean water is considered a final ecosystem service when the natural environment is improving water quality for human consumption or other direct use (e.g., irrigation). Although sanctuary ecosystems often function to improve water quality, most do not result in the final ecosystem service of clean water for human use. For most natural resources, improving water quality in a sanctuary is a supporting or intermediate ecosystem service that may, for example, result in better water quality for fish species that are then enjoyed by commercial or recreational anglers, safer water in which to swim, or improved water clarity for diving. These are aspects of other final ecosystem services and the water quality itself is an indicator that is inherently important to them; however, ONMS does not include this aspect of clean water in condition reports because it would result in a double counting of its ecosystem service value. Instead, ONMS evaluates clean water as a final ecosystem service, where the natural environment is improving water for human consumption, such as drinking water, or for irrigation (e.g., through filtration or suitability for desalination). In this way, the benefits of management policies and actions that improve water quality are captured separately, but in relation to the relevant final ecosystem services they support.

Ornamentals — Resources collected for decorative or aesthetic purposes

In sanctuaries where the collection of ornamental products is not prohibited or is allowed under permit, they are taken for their aesthetic or material value for souvenirs, fashion, handicrafts, jewelry, display, and worship. This includes live animals for aquaria and trade, pearls, shells, corals, sea stars, furs, feathers, ivory, and more. Some, particularly animals for the aquarium trade, are sold commercially and can be valued like other commodities; others cannot. Status and trends can also be evaluated using indicators, such as the number of permitted collectors, and frequency of operations and collection levels.

Biotechnology — Medicine and other chemicals found in sanctuary animals or plants, or manufactured from them

Biochemical and genetic resources, medicines, chemical models, and test organisms are all potential products that can be derived or sourced from national marine sanctuaries. Biochemical resources are compounds extracted from marine animals and plants and used to develop or manufacture medicines, pharmaceuticals, cosmetics, and other products (e.g., omega-3 fatty acids from fish oil). Genetic resources are the genetic content of marine organisms used for animal and plant breeding and for biotechnology. Natural resources can also be used as a model for new products (e.g., the development of fiber-optic technology, based on the properties of sponge spicules).

In sanctuaries, activities involving the collection of biochemical products may be allowed under permit. The value of many products associated with biotechnology may be available. Sanctuary permit databases can be used to gauge demand and collection activity within a given national marine sanctuary.

Energy — Use of ecosystem-derived materials or processes for the production of energy

In the offshore environment, energy production sources are considered to be either non-renewable (oil and gas) or renewable (wind, solar, tidal, wave, or thermal). While oil and gas technically are ecosystem-sourced and may be renewable over a time frame measured in millions of years, as an ecosystem service, they are not subject to management decisions in human time frames; therefore, they are not considered an ecosystem service in this section. The activities and management actions related to hydrocarbon production are, however, considered elsewhere in condition reports, primarily with regard to resource threats, impacts, and protection measures.

In contrast, "renewable" forms of energy that depend on ecosystem materials and processes operating over shorter time periods are evaluated. Indicators of status and trends for these energy sources include the types and number of permitted or licensed experimental or permanent operations, energy production, revenues generated, and jobs created. Indirect indicators that inform trends and provide some predictive value include social and market trends, energy costs, and expected demand based on service market populations trends.

REGULATING (buffers to change)

Coastal protection — Natural features that control water movement and/or wind energy, thus protecting habitat, property, and coastlines.

Coastal and estuarine ecosystems can buffer the potentially destructive energy of environmental disturbances, such as floods, tidal surges and storm waves, and wind. Wetlands, kelp forests, mangroves, seagrass beds, and reefs of various types all absorb some of the energy of local disturbances, protecting themselves, submerged habitats closer to shore, intertidal ecosystems, and emergent land masses. They also can trap sediments and promote future protection through shoaling. They can also become sources of sediments for coastal dunes and beaches that control flooding and protect coastal properties from wave energy and the impacts of sea-level rise.

The value of coastal protection can be estimated by evaluating the basis of the value of vulnerable coastal properties and infrastructure and modeled estimates of losses expected under different qualities of coastal ecosystems (replacement cost). Levels of historical change under different energy scenarios can be used to support these estimates. Public polls can also reveal information on willingness to pay that is used to value this service.

APPENDIX C:
Stellwagen Bank National Marine Sanctuary 2007 Condition Report Ratings

The following table summarizes the condition and trend ratings as presented in the 2007 Stellwagen Bank National Marine Sanctuary Condition Report.

Stellwagen Bank National Marine Sanctuary Condition Summary Table

Condition Summary: The results in the following table are a compilation of findings from the “State of Sanctuary Resources” section of this report. (For further clarification of the questions posed in the table, see Appendix A.)

#	Issue	Rating	Basis for Judgment	Description of Findings
WATER				
1	Are specific or multiple stressors, including changing oceanographic and atmospheric conditions, affecting water quality?	—	Numerous contaminants at low levels	Selected conditions may preclude full development of living resource assemblages and habitats, but are not likely to cause substantial or persistent declines.
2	What is the eutrophic condition of sanctuary waters and how is it changing?	—	Specific aspects of ongoing monitoring	Conditions do not appear to have the potential to negatively affect living resources or habitat quality.
3	Do sanctuary waters pose risks to human health?	—	Specific aspects of ongoing monitoring	Conditions do not appear to have the potential to negatively affect human health.
4	What are the levels of human activities that may influence water quality and how are they changing?	—	Vessel discharges and outfall discharge	Some potentially harmful activities exist, but they do not appear to have had a negative effect on water quality.
HABITAT				
5	What is the abundance and distribution of major habitat types and how is it changing?	▲	Alteration of microhabitat due to bottom dragging & dredging	Selected habitat loss or alteration may inhibit the development of assemblages, and may cause measurable but not severe declines in

				living resources or water quality.
6	What is the condition of biologically-structured habitats and how is it changing?	▲	Fishing gear impacts	Selected habitat loss or alteration has caused or is likely to cause severe declines in some but not all living resources or water quality.
7	What are the contaminant concentrations in sanctuary habitats and how are they changing?	—	Limited monitoring results	Selected contaminants may preclude full development of living resource assemblages, but are not likely to cause substantial or persistent degradation.
8	What are the levels of human activities that may influence habitat quality and how are they changing?	▲	Fishing gear impacts	Selected activities have caused or are likely to cause severe impacts, and cases to date suggest a pervasive problem.
LIVING RESOURCES				
9	What is the status of biodiversity and how is it changing?	▲	Long-term changes in fish diversity	Selected biodiversity loss has caused or is likely to cause severe declines in some but not all ecosystem components and reduce ecosystem integrity.
10	What is the status of environmentally sustainable fishing and how is it changing?	▲	Published and unpublished literature on regional and local groundfish populations	Extraction has caused or is likely to cause severe declines in some but not all ecosystem components and reduce ecosystem integrity.
11	What is the status of non-indigenous species and how is it changing?	▼	Recent invasives discovered	Non-indigenous species exist, precluding full community development and function, but are unlikely to cause substantial or persistent degradation of ecosystem integrity.
12	What is the status of key species and how is it changing?	—	Cod (keystone species) Sand lance (key species)	The reduced abundance of selected keystone species has caused or is likely to cause severe declines in some but not all ecosystem components and reduce ecosystem integrity; or, selected key species are at substantially reduced levels, and prospects for recovery are uncertain.
13	What is the condition or health of key species and how is it changing?	—	Whale strikes & entanglements	The diminished condition of selected key resources may cause a measurable but not severe reduction in ecological function, but recovery is possible.
14	What are the levels of human activities that may influence living resource quality and how are they changing?	—	Stable levels of activity	Selected activities have caused or are likely to cause severe impacts, and cases to date suggest a pervasive problem.
MARITIME ARCHAEOLOGICAL RESOURCES				
15	What is the integrity of known maritime archaeological resources	▼	Fishing gear impacts	The diminished condition of selected archaeological resources has reduced, to some extent, their

	and how is it changing?			historical, scientific, or educational value and may affect the eligibility of some sites for listing in the National Register of Historic Places.
16	Do known maritime archaeological resources pose an environmental hazard and is this threat changing?	–	Lack of hazardous cargo	Known maritime archaeological resources pose few or no environmental threats.
17	What are the levels of human activities that may influence maritime archaeological resource quality and how are they changing?	▼	Fishing gear impacts	Selected activities warrant widespread concern and action, as large-scale, persistent, and/or repeated severe impacts have occurred or are likely to occur.

APPENDIX D: Consultation with Experts, Documenting Confidence, and Document Review

The process for preparing condition reports involves a combination of accepted techniques for collecting and interpreting information gathered from subject matter experts. The approach varies somewhat from sanctuary to sanctuary in order to accommodate different styles for working with partners. Stellwagen Bank National Marine Sanctuary approach was closely related to the Delphi Method, a technique designed to organize group communication among a panel of geographically dispersed experts by using questionnaires, ultimately facilitating the formation of a group judgment. This method can be applied when it is necessary for decision makers to combine the testimony of a group of experts, whether in the form of facts or informed opinion, or both, into a single useful statement.

The Delphi Method requires experts to respond to questions with a limited number of choices to arrive at the best supported answers. Feedback to the experts allows them to refine their views, gradually moving the group toward the most agreeable judgment. For condition reports, the Office of National Marine Sanctuaries (ONMS) uses standardized questions related to the status and trends of sanctuary resources, with accompanying definitions and five possible choices that define resource condition (Appendix A).

In order to address the standardized state of the ecosystem questions and ecosystem services, ONMS selected and consulted outside experts familiar with water quality, habitat, living resources, maritime heritage resources, and socioeconomics in the sanctuary. A three-day workshop was held February 13–15, 2018 to discuss and evaluate a series of questions about each resource area. At the workshop, experts participated in facilitated discussions about the questions related to pressures (Questions 2–4), water quality (Questions 6–9), habitat (Questions 10 and 11), living resources (Questions 12–15), maritime archaeological resources (Questions 16 and 17), and ecosystem services. Experts represented various affiliations; a list of experts who provided input is available in the Acknowledgements section of this report. The drivers question (Question 1) was determined and reviewed by ONMS socioeconomists, who used indicators to make a preliminary status and trend rating and draft an accompanying summary statement. This material was then reviewed by SBNMS staff.

At the workshop, experts were introduced to the questions and provided with relevant time series datasets ONMS had collected from experts prior to the meeting. Attendees were then asked to review the datasets, identify data gaps or misrepresentations, and suggest any additional datasets that may be relevant. Once all datasets were reviewed, experts were asked to provide status and trend recommendations and supporting arguments. In order to ensure consistency with the Delphic Method, a critical role of the facilitator was to minimize dominance of the discussion by a single individual or opinion (which often leads to "follow the leader" tendencies in group meetings) and to encourage the expression of honest differences of opinion. As discussions progressed, the group converged in an opinion of each rating that most accurately described the current resource condition. After an appropriate amount of time, the facilitator asked whether the group could agree on a rating for the question, as defined by specific language linked to each rating (see Appendix A). If an agreement was reached, the result was recorded and the group moved on to consider the trend in the same manner. If agreement was not reached, the facilitator recorded the vote of individuals for each rating category and that information helped to inform the confidence scoring process.

Experts were then asked to assign a level of confidence for each status and trend rating by: (1) characterizing the sources of information they used to make judgments, and (2) their agreement with the selected status and trend ratings. The evidence and agreement ratings were then combined to determine the overall confidence ratings, as described in the table below.

Step 1: Rate Evidence
Consider three categories of evidence typically used to make status or trend ratings: (1.) data,(2.) published information and(3.) personal experience.

Evidence Scores		
Limited	**Medium**	**Robust**
Limited data or published information, and little or no substantive personal experience.	Data available, some peer reviewed published information, or direct personal experience.	Considerable data, extensive record of publication, or extensive personal experience.

Step 2: Rate Agreement
Rate agreement among those participating in determining the status and trend rating, or if possible, within the broader scientific community. Levels of agreement can be characterized as *"low," "medium"* or *"high."*

Step 3: Rate Confidence
Using the matrix below, combine ratings for both evidence and agreement to identify a level of confidence. Levels of confidence can be characterized as *"very low," "low," "medium," "high" or "very high."*

Agreement →			
	"Medium" High agreement Limited evidence	*"High"* High agreement Medium evidence	*"Very High"* High agreement Robust evidence
	"Low" Medium Agreement Limited evidence	*"Medium"* Medium agreement Medium evidence	*"High"* Medium agreement Robust evidence
	"Very Low" Low agreement Limited evidence	*"Low"* Low agreement Medium evidence	*"Medium"* Low agreement Robust evidence

Evidence (type, amount, quality, consistency) ⟶

An initial draft of the report, written by ONMS, summarized the new information, expert opinions, and level of confidence expressed by the experts. Comments, data, and citations received from the experts were included, as appropriate, in text supporting the ratings and compiled in three appendices. This initial draft was made available to contributing experts and data providers, which allowed them to review the content and determine if the report accurately reflected their input, identify information gaps, provide comments, or suggest revisions to the ratings and text.

Following the expert review, the document was then sent to representatives of partner agencies, including members of the SBNMS Advisory Council, GARFO, USFWS, and NEFSC. These representatives were asked to review the technical merits of resource ratings and accompanying text, as well as to point out any omissions or factual errors. Upon receiving reviewer comments, ONMS revised the text and ratings as appropriate.

In May 2019, a draft final report was sent to four regional science experts for a required external peer review. External peer review became a requirement when the White House Office of Management and Budget (OMB) issued a Final Information Quality Bulletin for Peer Review (OMB Bulletin) that established peer review standards to enhance the quality and credibility of the federal government's scientific information (OMB 2004). Along with other information, these standards apply to "Influential Scientific Information," which is information that can reasonably be determined to have a "clear and substantial impact on important public policies or private sector decisions." Condition reports are considered Influential Scientific Information. For this reason, these reports are subject to the review requirements of both the Information Quality Act and the OMB Bulletin guidelines; therefore, every condition report is reviewed by a minimum of three individuals who are considered to be experts in their field, were not involved in the development of the report, and are not ONMS employees. Comments and recommendations of the peer reviewers were considered and incorporated, as appropriate, into the final text of this report. Furthermore, OMB Bulletin guidelines require that reviewer comments, names, and affiliations be posted on the agency website, http://www.cio.noaa.gov/. Reviewer comments, however, are not attributed to specific individuals. Comments by the external peer reviewers are posted at the same time as the formatted final document.

In all steps of the review process, experts were asked to review the technical merits of resource ratings and accompanying text, as well as to point out any omissions or factual errors; however, the interpretation, ratings, and text in the condition report were the responsibility of and received final approval by ONMS. To emphasize this important point, authorship of the report is attributed to ONMS; subject matter experts are not authors, though their efforts and affiliations are acknowledged in the report.

Stellwagen Bank National Marine Sanctuary

Confidence Ratings from February 13–15, 2018 Expert Workshop

A summary table for the findings regarding confidence ratings for the questions pertaining to SBNMS is included below:

Question		Evidence (Limited, Medium, Robust)	Agreement (Low, Medium, High)	Confidence (Very Low, Low, Medium, High, Very High)
1	Status	Robust	High	Very High
	Trend	Robust	High	Very High
2	Status	Limited	High	Medium
	Trend	Limited	High	Medium
3	Status	Limited	High	High
	Trend	Medium	Medium	Medium
4	Status	Medium	High	High
	Trend	Medium	High	High
5	Status	Medium	Medium	Medium
	Trend	Medium	High	High
6	Status	Robust	High	Very High
	Trend	Robust	High	Very High
7	Status	Medium	High	High
	Trend	Medium	High	High
8	Status	Medium	High	High
	Trend	Medium	High	High
9	Status	Medium	High	High
	Trend	Limited	High	Medium
10	Status	Medium	Medium	Medium
	Trend	Medium	High	High
11	Status	Limited	High	Medium
	Trend	Limited	High	Medium

12	Status	Robust	High	Very High
	Trend	Medium	High	High
13	Status	Medium	Medium	Medium
	Trend	Medium	High	High
14	Status	Medium	High	High
	Trend	Medium	High	High
15	Status	Medium	High	High
	Trend	Medium	High	High
16	Status	Medium	High	High
	Trend	Medium	High	High
17	Status	Robust	High	Very High
	Trend	Robust	High	Very High

Ecosystem Service		**Evidence (Limited, Medium, Robust)**	**Agreement (Low, Medium, High)**	**Confidence (Very Low, Low, Medium, High, Very High)**
Heritage	Status	Limited	High	Medium
	Trend	Medium	High	High
Consumptive Recreation	Status	Medium	Medium	Medium
	Trend	Limited	High	Medium
Non-Consumptive Recreation	Status	Limited	Medium	Low
	Trend	Limited	High	Medium
Sense of Place	Status	Limited	High	Medium
	Trend	Medium	High	High
Science	Status	Medium	High	High
	Trend	Medium	High	High
Education	Status	Medium	High	High
	Trend	Medium	High	High
Food Supply	Status	Robust	High	Very High
	Trend	Robust	High	Very High

APPENDIX E:
Driving Forces and Pressures — Supplemental Graphs and Figures

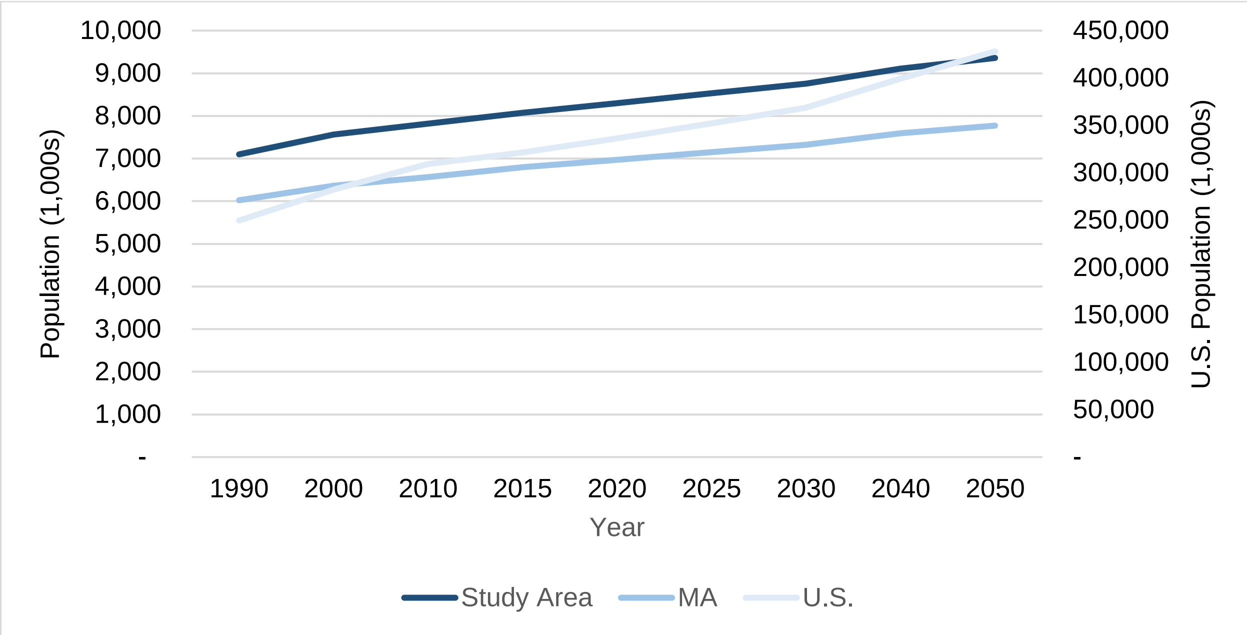

Figure App.E.1. Population of the 14-county study area representing the SBNMS local economy, Massachusetts, and the United States in 1,000s, 1990–2050. Source: Woods and Poole Economics, Inc. 2016

Table App.E.1. Population of the 14-county study area representing the SBNMS local economy, Massachusetts, and the United States in 1,000s, 1990–2050. Source: Woods and Poole Economics, Inc. 2016

Year	Study Area	MA	U.S.
1990	7,099	6,023	249,623
2000	7,562	6,361	282,162
2010	7,820	6,565	309,347
2015	8,076	6,794	321,421
2020	8,300	6,970	336,383
2025	8,531	7,151	352,315
2030	8,756	7,325	368,644
2040	9,112	7,595	399,419
2050	9,359	7,773	428,119

Table App.E.2. Average annual population growth rates (%). Source: Woods and Poole Economics, Inc. 2016

Year[1]	Study Area	MA	U.S.
2000-2015	0.45	0.45	0.93
2015-2030	0.56	0.52	0.98
2030-2050	0.34	0.31	0.81

1. 2000–2015 and 2015–2030 report average annual growth rates for those time periods.

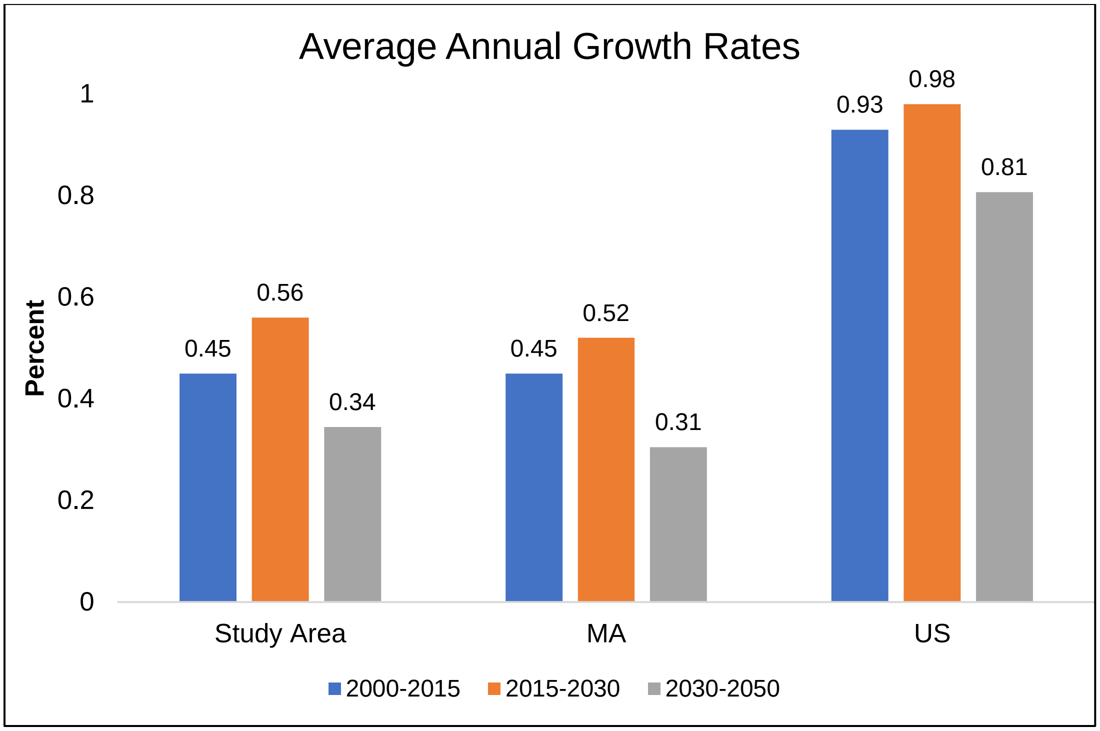

Figure App.E.2. Average annual population growth rates. Source: Woods and Poole Economics, Inc. 2016

Table App.E.3. Real per capita income from 1990 to 2050 and real per capita growth rates (%) for 2000-2015 and 2015-2030. Source: Woods and Poole Economics, Inc. 2016

Year[1]	Study Area	MA	U.S.
1990	$38,712	$39,355	$33,282
2000	$52,004	$53,129	$42,152
2010	$58,507	$59,733	$45,344
2015	$64,140	$65,409	$50,267
2020	$69,546	$70,876	$54,220
2025	$74,840	$76,385	$58,311
2030	$79,958	$81,720	$62,186
2040	$89,572	$91,780	$69,049
2050	$100,409	$103,128	$76,550
2000-2015	1.56	1.54	1.28
2015-2030	1.64	1.66	1.58
2030-2050	1.28	1.31	1.15

1. For 2000-2015 and 2015-2030, annual average growth rates

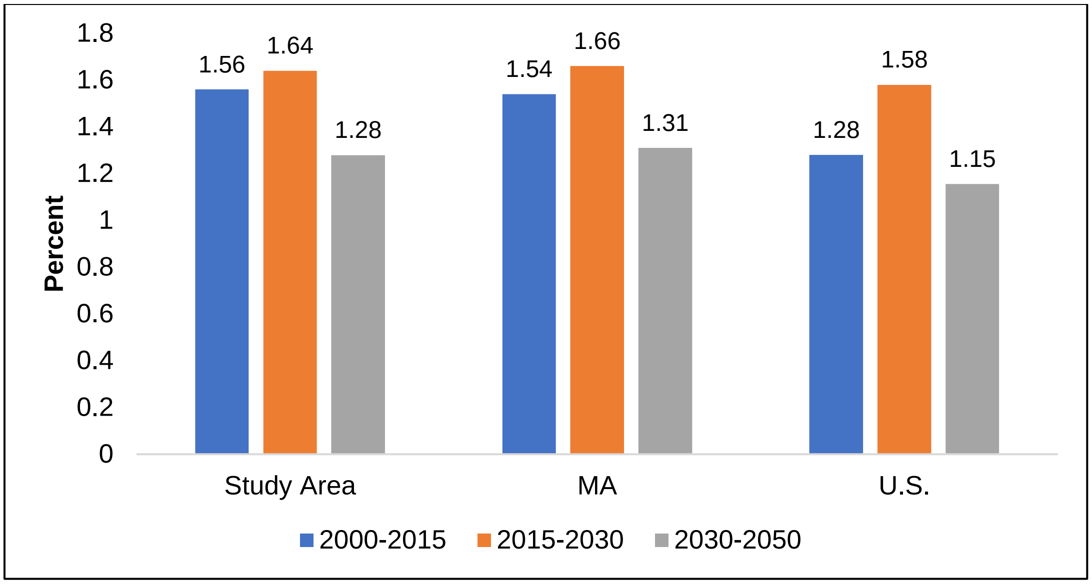

Figure App.E.3. Real per capita growth rates. Source: Woods and Poole Economics, Inc. 2016

Table App.E.4. Annual growth rates of real gross domestic product of Canada, the European Union, China, Japan, and South Korea, 2000–2022. Source: Trading Economics 2017

Year	Canada	European Union	China	Japan	S. Korea
2000	5.2	3.9	8.4	2.8	8.9
2001	1.8	2.3	8.3	0.4	4.5
2002	3.0	1.5	9.1	0.1	7.4
2003	1.8	1.5	10.0	1.5	2.9
2004	3.1	2.7	10.1	2.2	4.9
2005	3.2	2.3	11.3	1.7	3.9
2006	2.6	3.6	12.7	1.4	5.2
2007	2.1	3.3	14.2	1.7	5.5
2008	1.0	0.6	9.6	-1.1	2.8
2009	-2.9	-4.3	9.2	-5.4	0.7
2010	3.1	2.1	10.6	4.2	6.5
2011	3.1	1.7	9.5	-0.1	3.7
2012	1.7	-0.4	7.9	1.5	2.3
2013	2.5	0.3	7.8	2.0	2.9
2014	2.6	1.7	7.3	0.3	3.3
2015	0.9	2.4	6.9	1.2	2.8

2016	1.4	2.0	6.7	1.0	2.8
2017	1.9	2.0	6.6	1.2	2.7
2018	2.0	1.8	6.2	0.6	2.8
2019	1.8	1.8	6.0	0.8	3.0
2020	1.8	1.8	5.9	0.2	3.0
2021	1.8	1.7	5.8	0.7	3.1
2022	1.8	1.7	5.7	0.6	3.1
2000–2017 avg.	2.2	1.7	9.8	1.0	4.3
2018–2022 avg.	1.8	1.8	5.9	0.6	3.0

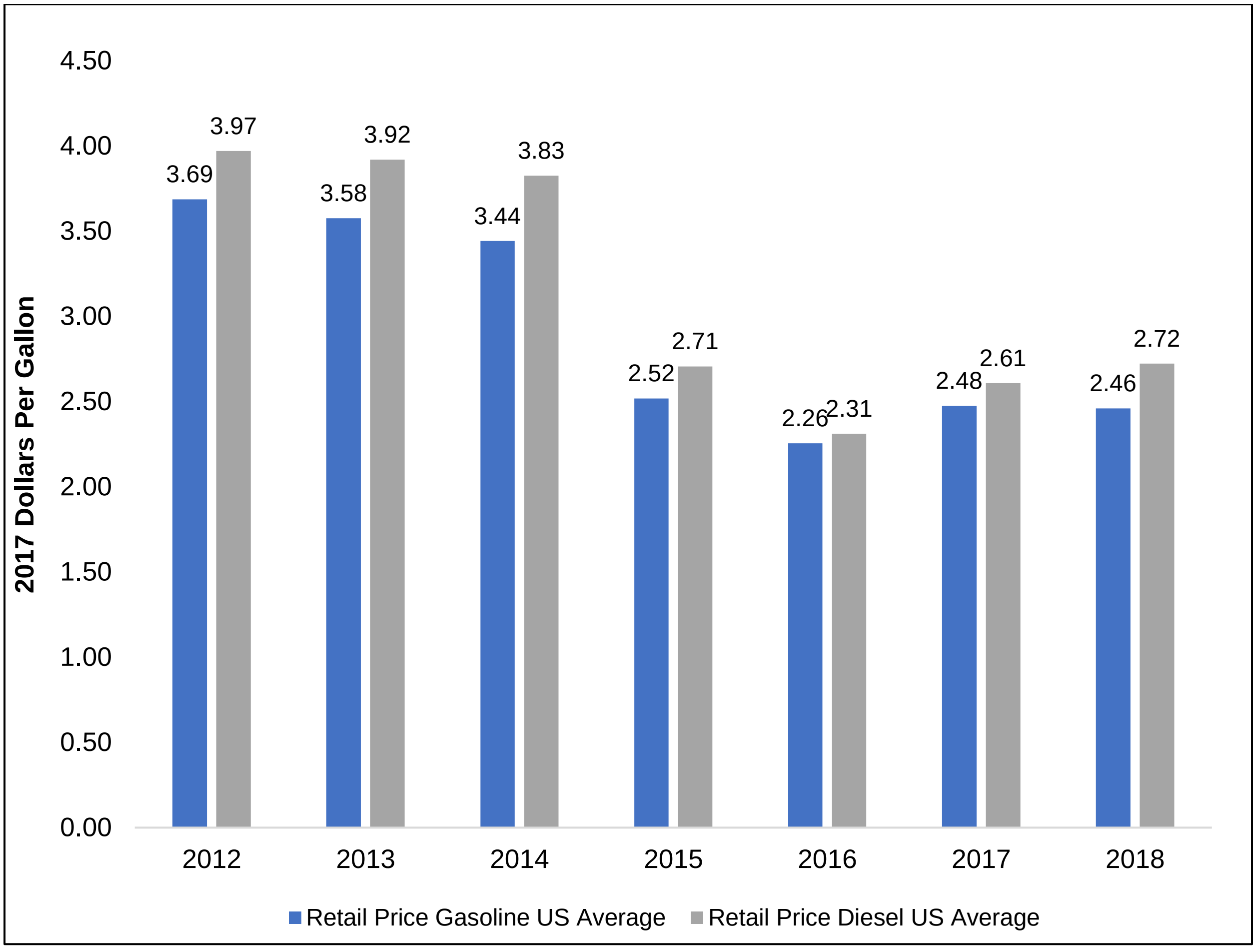

Figure App.E.4. Fuel prices in 2017$, 2012–2017. Source: U.S. Energy Information Administration 2017

APPENDIX F:
Ecosystem Services — Supplemental Graphs and Figures

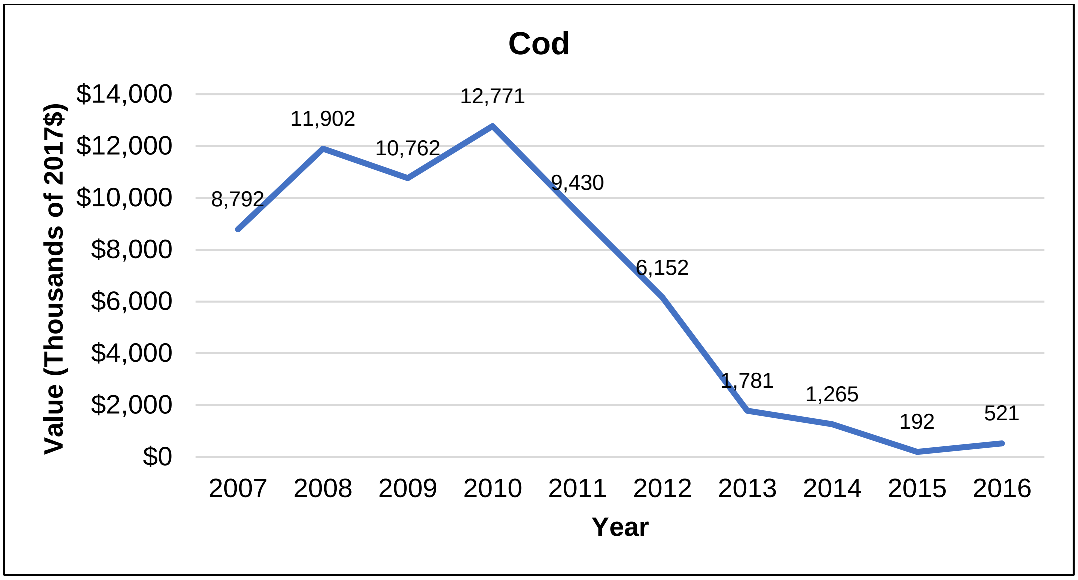

Figure App.F.1. Value of cod landings 2007–2016 (2017$). Source: GARFO 2019b

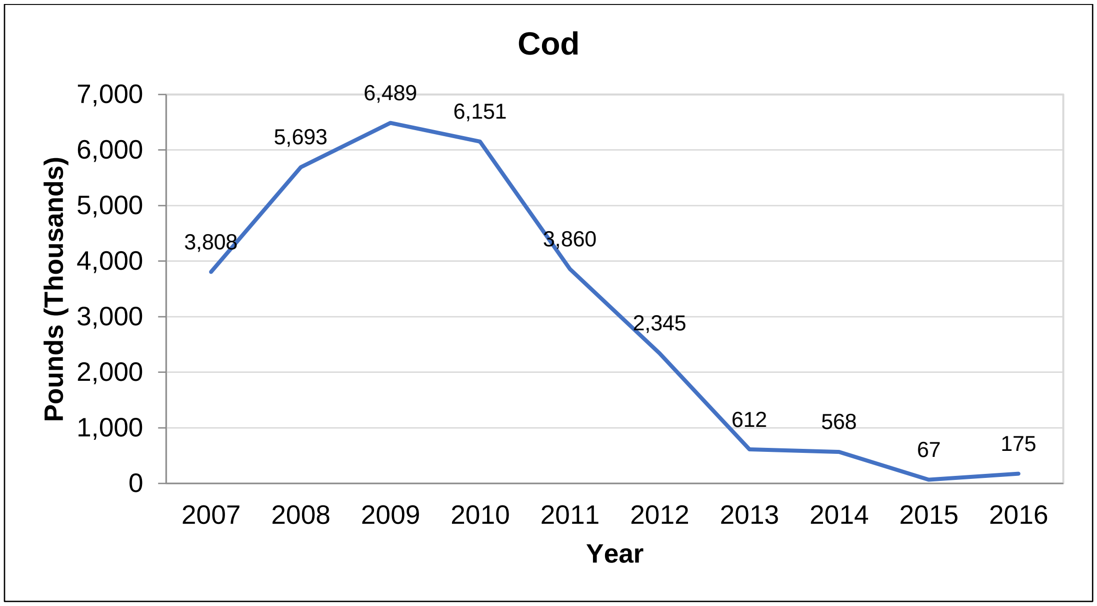

Figure App.F.2. Pounds of cod landed 2007–2016 (2017$). Source: GARFO 2019b

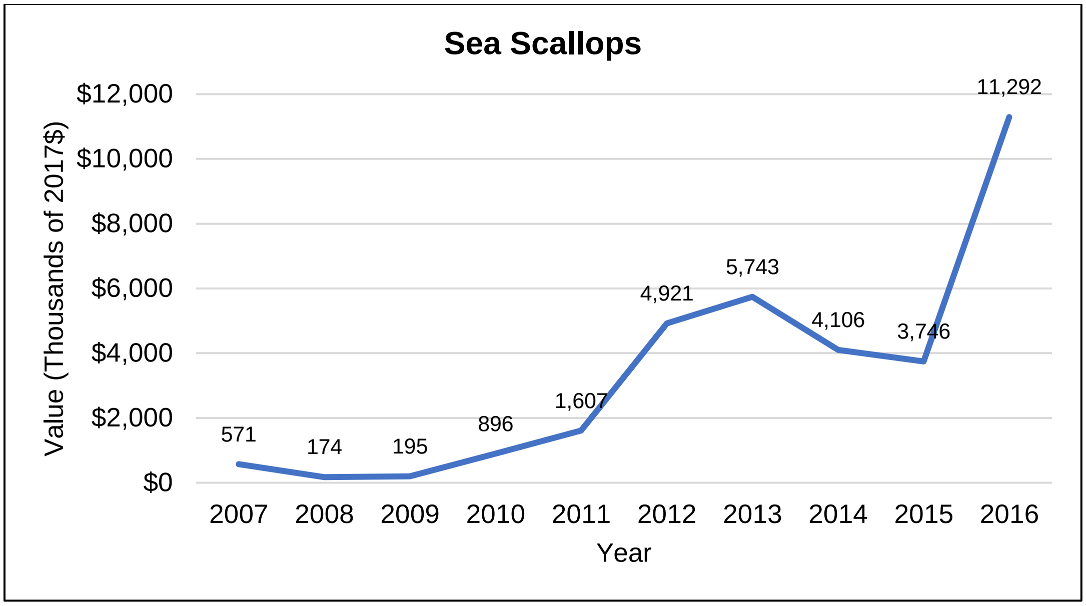

Figure App.F.3. Value of sea scallops landed 2007-2016 (2017$). Source: GARFO 2019b

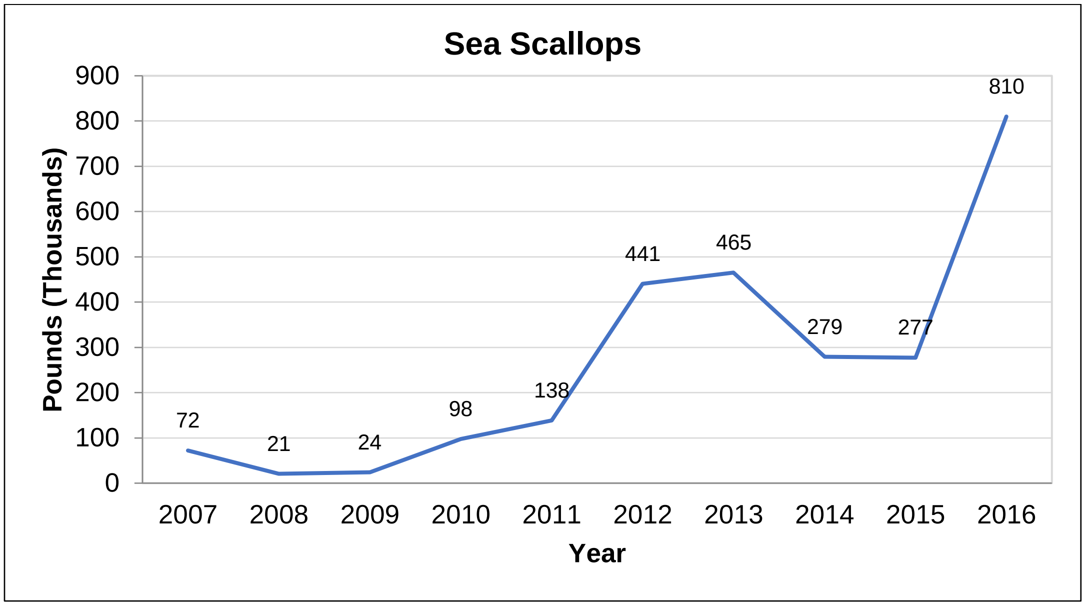

Figure App.F.4. Pounds of sea scallops landed 2007–2016 (2017$). Source: GARFO 2019b

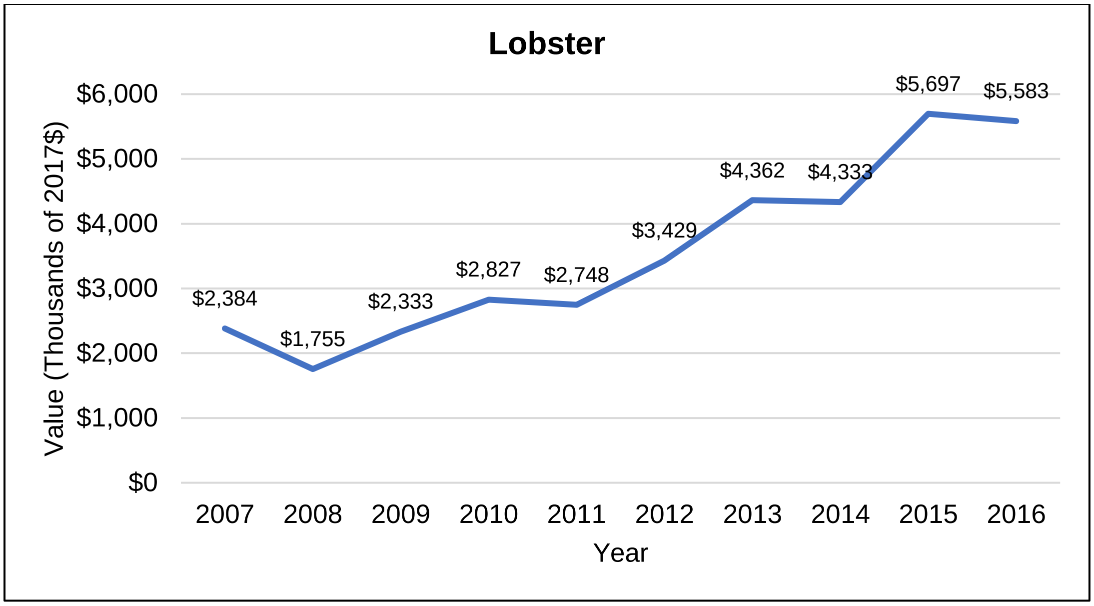

Figure App.F.7. Value of lobster landed 2007–2016 (2017$). Source: GARFO 2019b

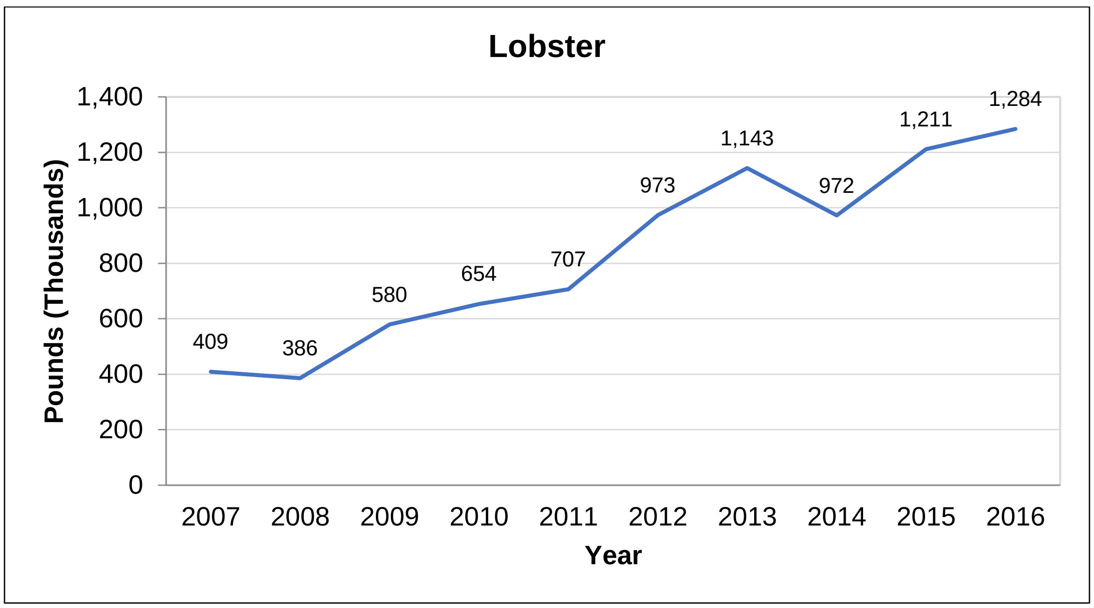

Figure App.F.8. Pounds of lobster landed 2007–2016 (2017$). Source: GARFO 2019b

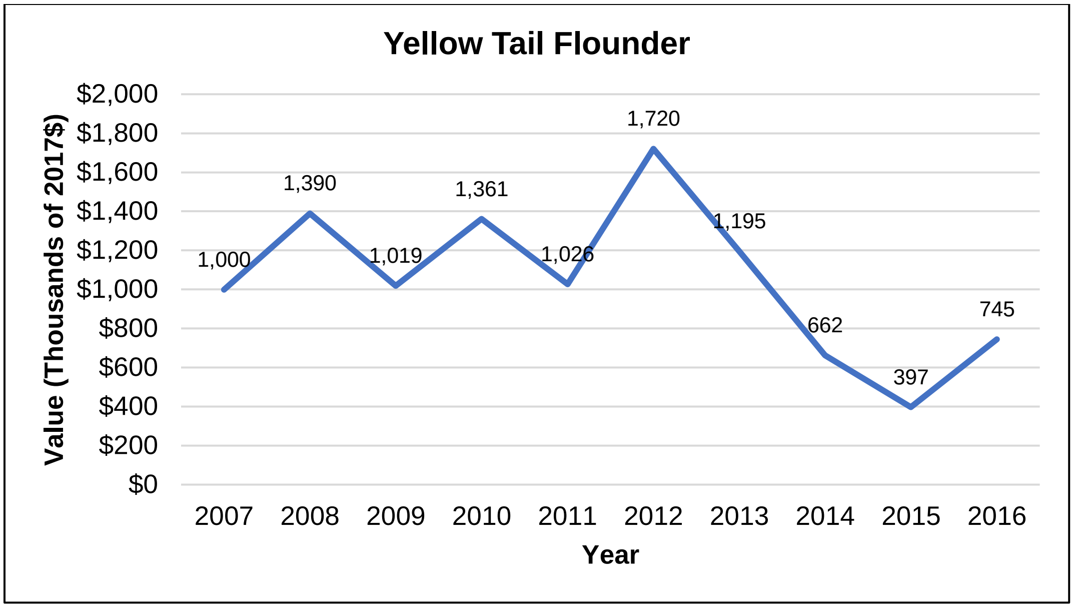

Figure App.F.5. Value of yellowtail flounder landed 2007–2016 (2017$). Source: GARFO 2019b

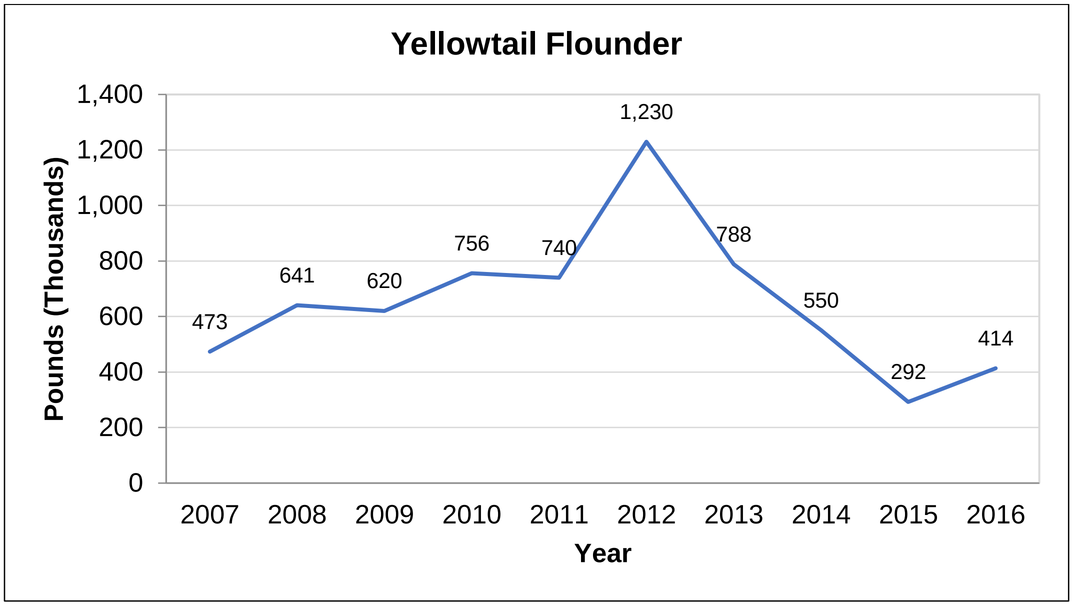

Figure App.F.6. Pounds of yellowtail flounder landed 2007–2016 (2017$). Source: GARFO 2019b

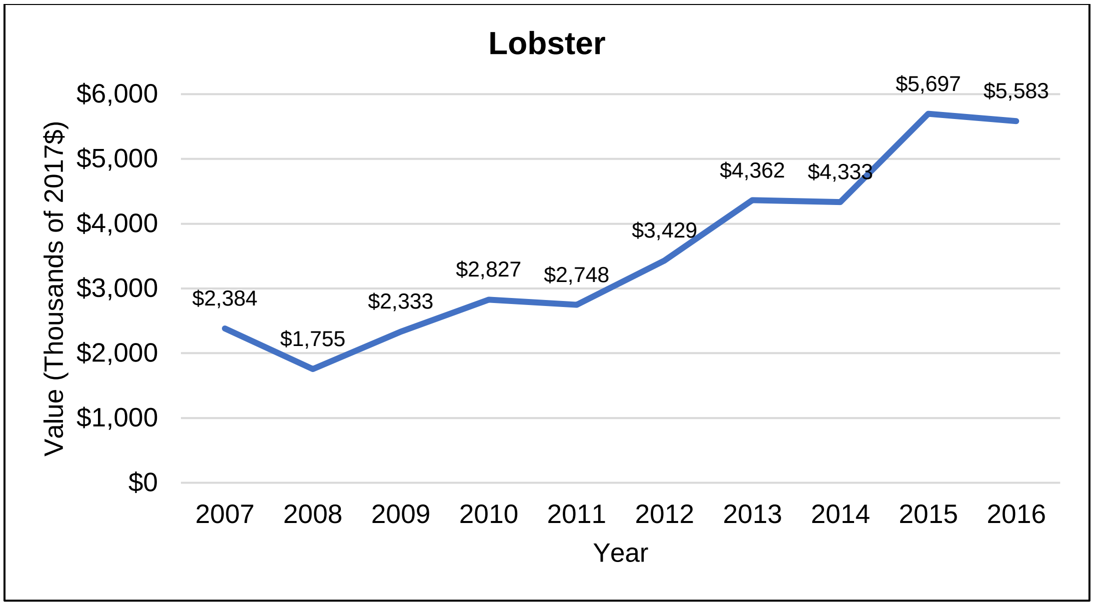

Figure App.F.7. Value of lobster landed 2007–2016 (2017$). Source: GARFO 2019b

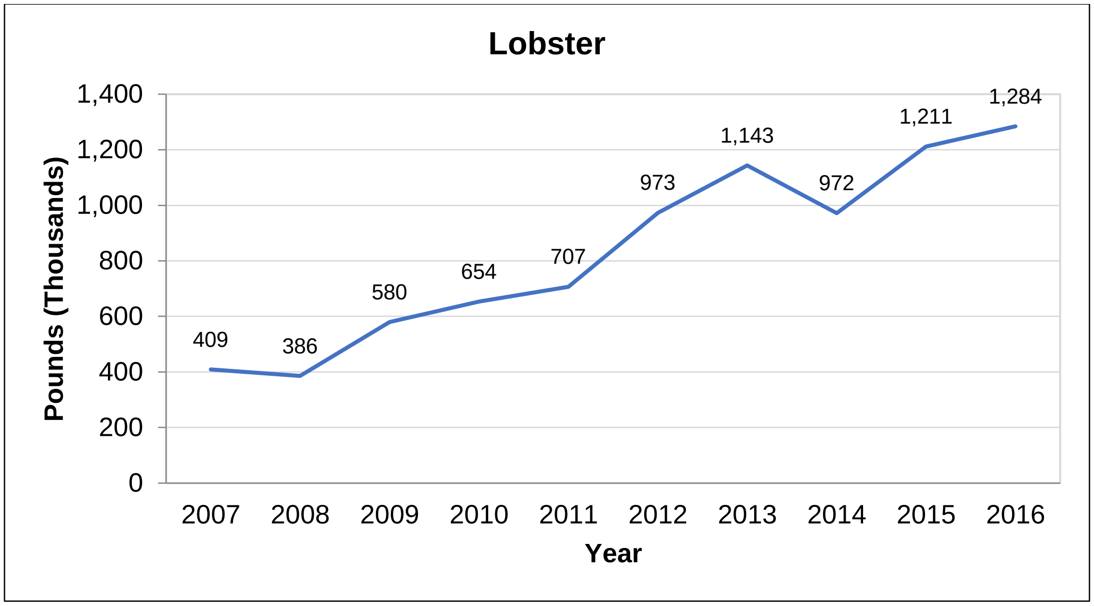

Figure App.F.8. Pounds of lobster landed 2007–2016 (2017$). Source: GARFO 2019b

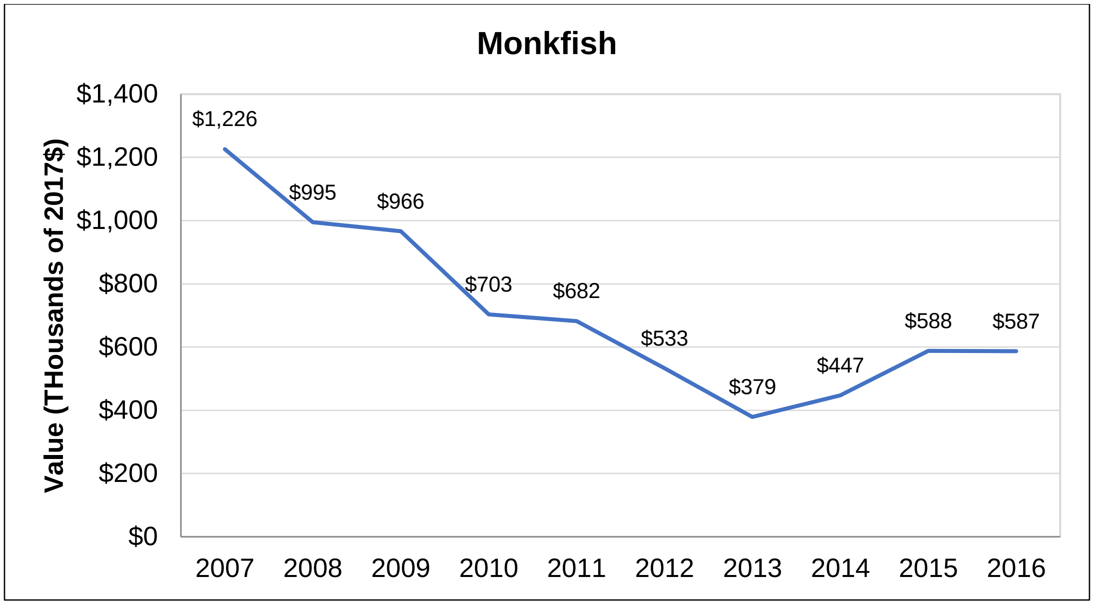

Figure App.F.9. Value of monkfish landed 2007–2016 (2017$). Source: GARFO 2019b

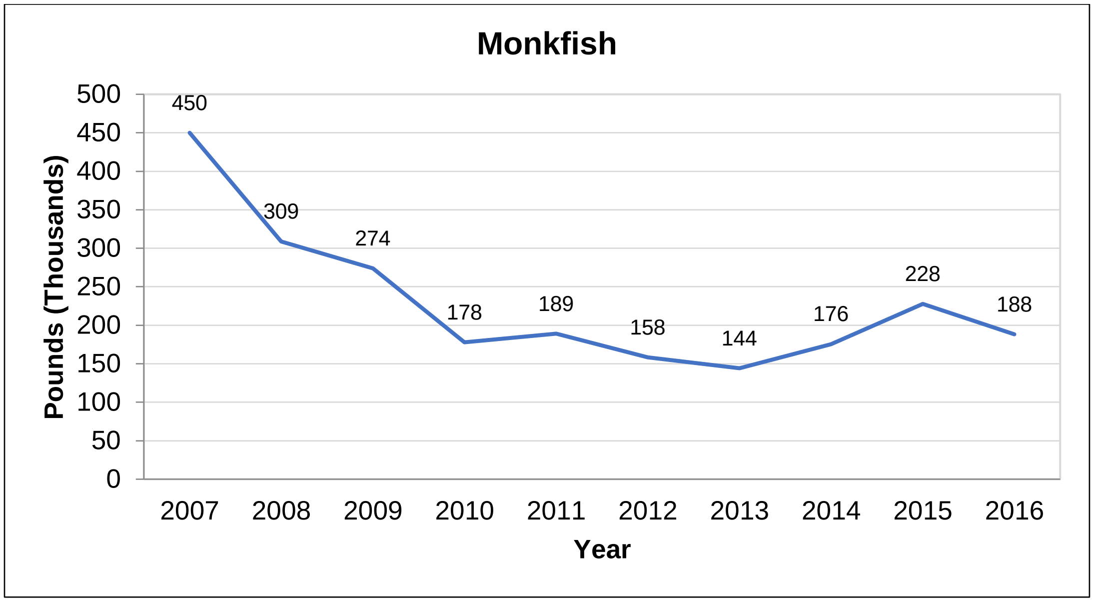

Figure App.F.10. Pounds of monkfish landed 2007–2016 (2017$). Source: GARFO 2019b

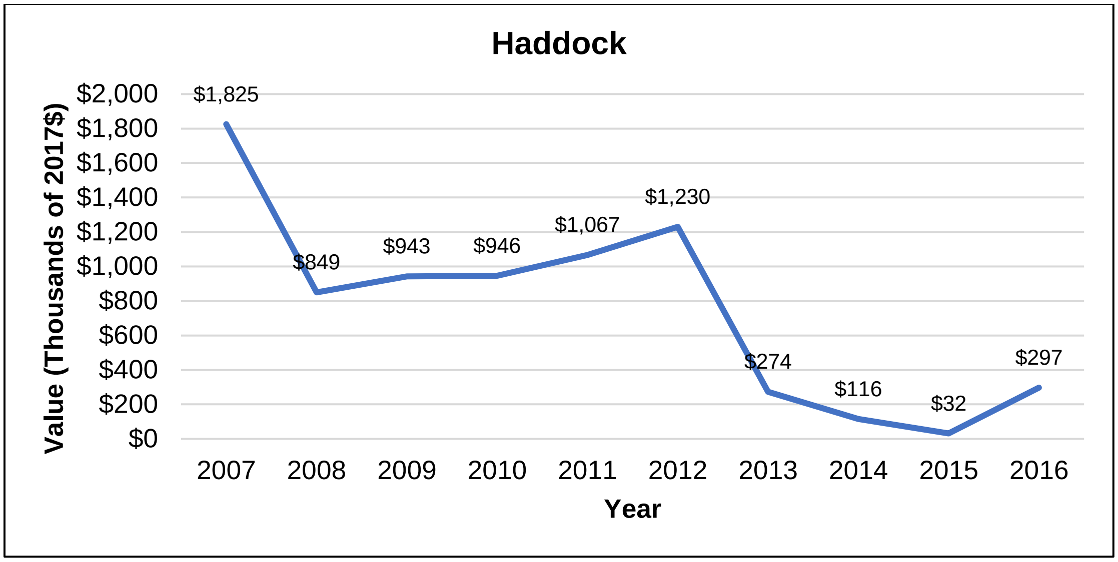

Figure App.F.11. Value of haddock landed 2007–2016 (2017$). Source: GARFO 2019b

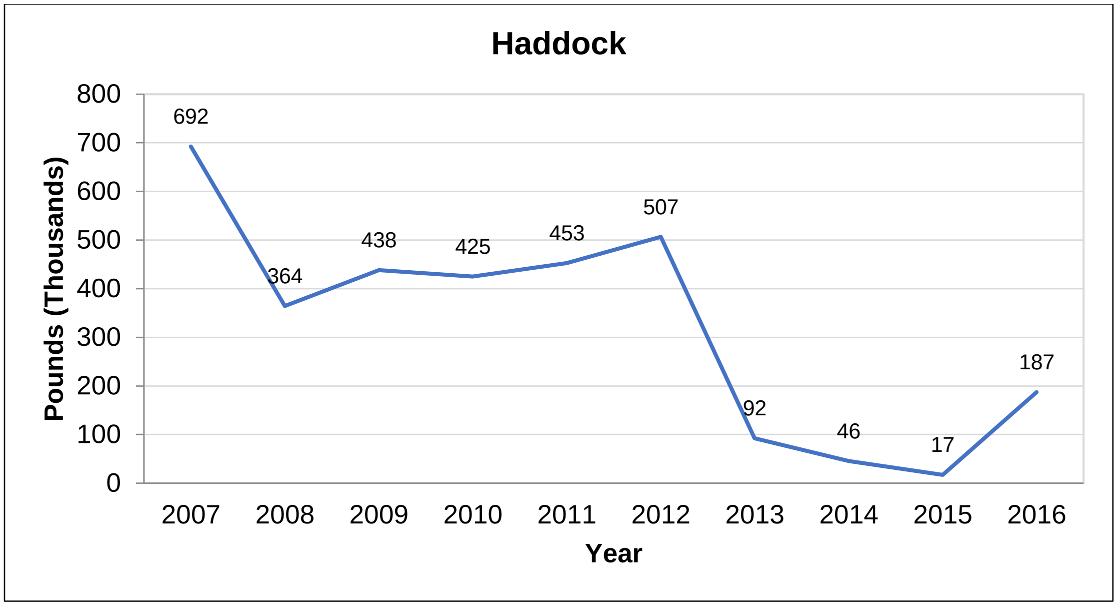

Figure App.F.12. Pounds of haddock landed 2007–2016 (2017$). Source: GARFO 2019b

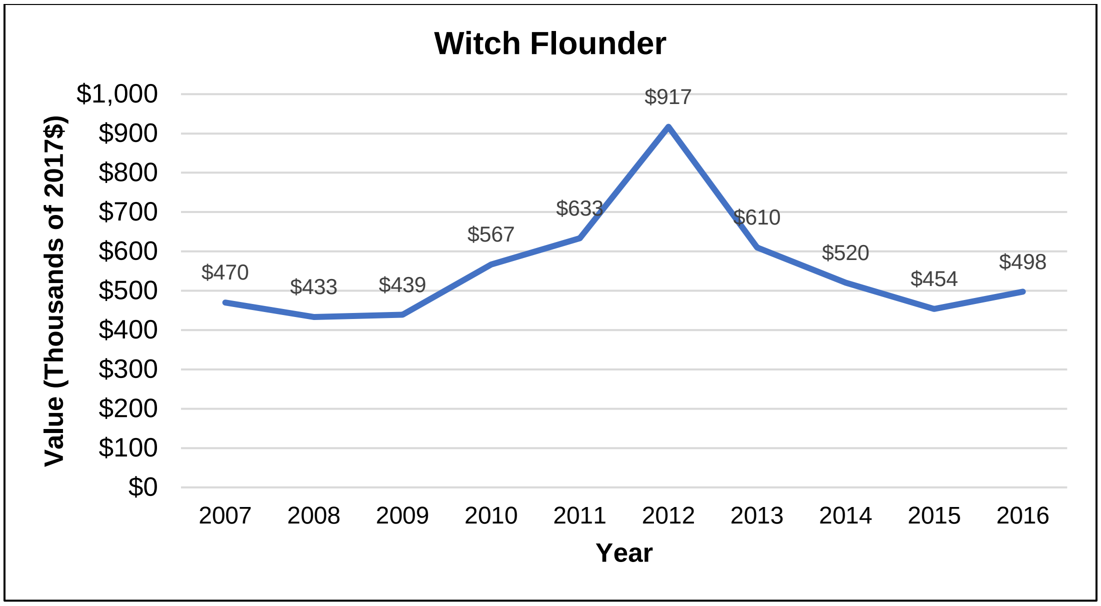

Figure App.F.13. Value of witch flounder landed 2007–2016 (2017$). Source: GARFO 2019b

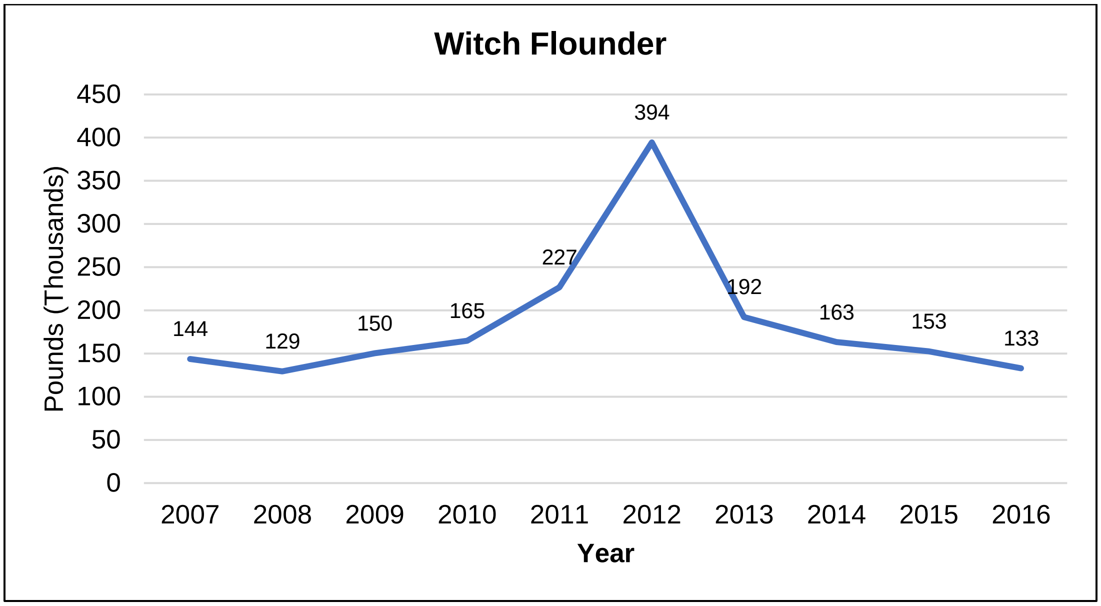

Figure App.F.14. Pounds of witch flounder landed 2007–2016 (2017$). Source: GARFO 2019b

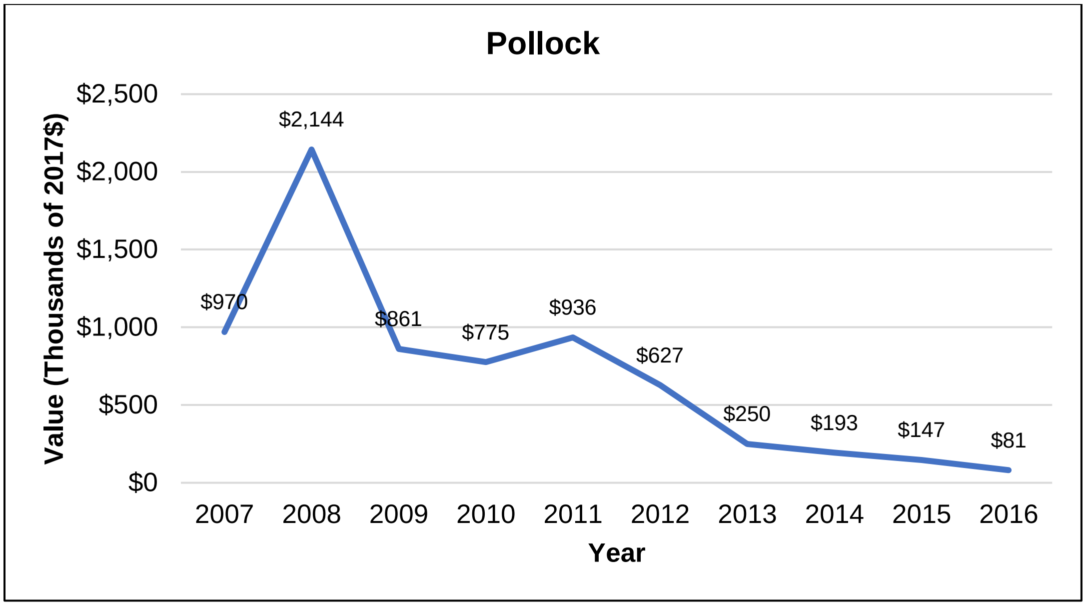

Figure App.F.15. Value of pollock landed 2007–2016 (2017$). Source: GARFO 2019b

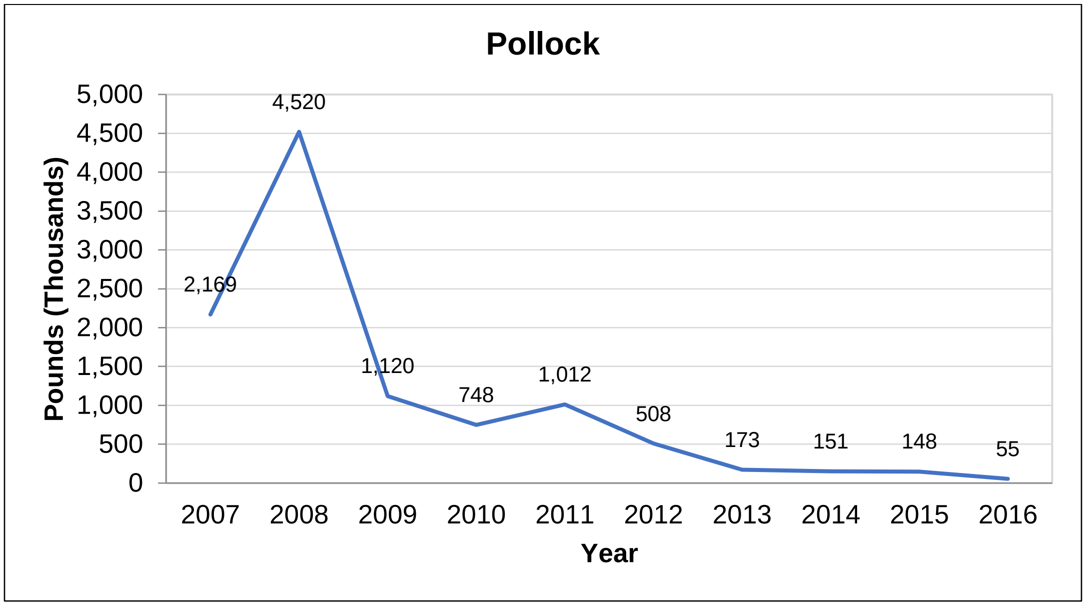

Figure App.F.16. Pounds of pollock landed 2007–2016 (2017$). Source: GARFO 2019b

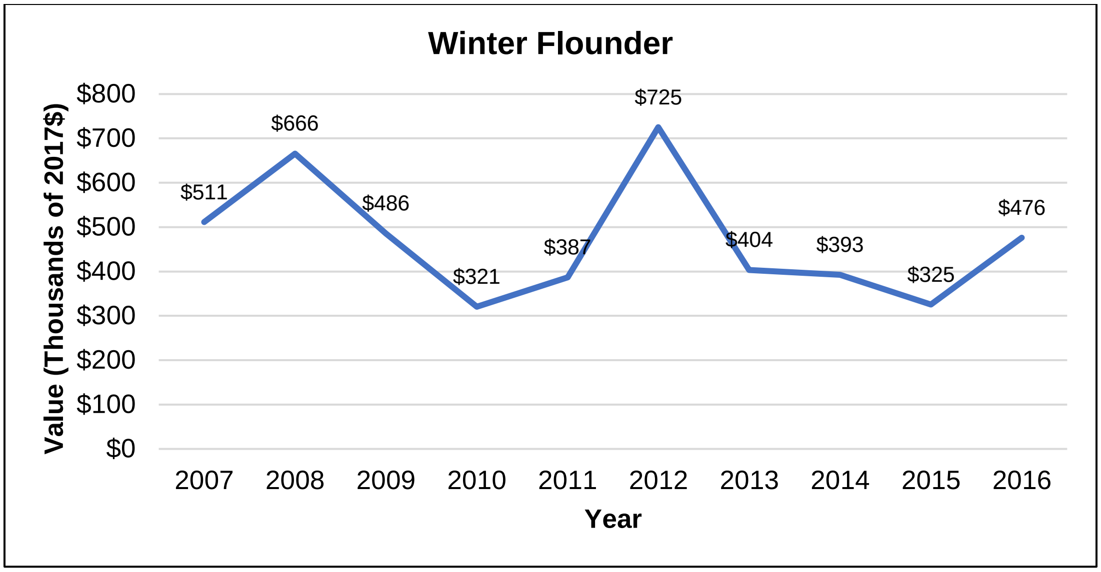

Figure App.F.17. Value of winter flounder landed 2007–2016 (2017$). Source: GARFO 2019b

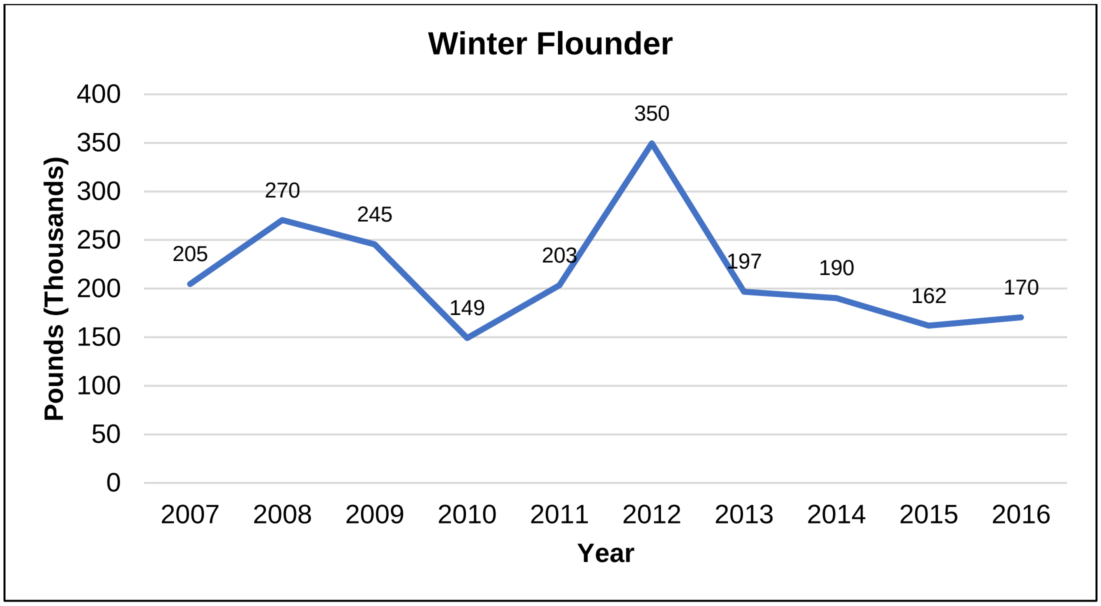

Figure App.F.18. Pounds of winter flounder landed 2007–2016 (2017$). Source: GARFO 2019b

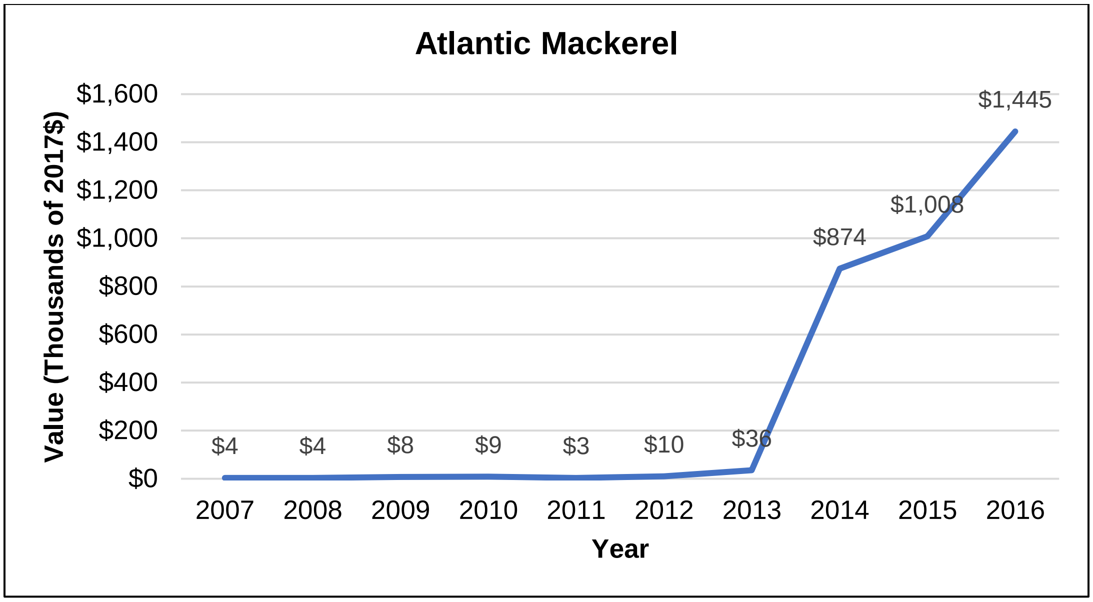

Figure App.F.19. Value of Atlantic mackerel landed 2007–2016 (2017$). Source: GARFO 2019b

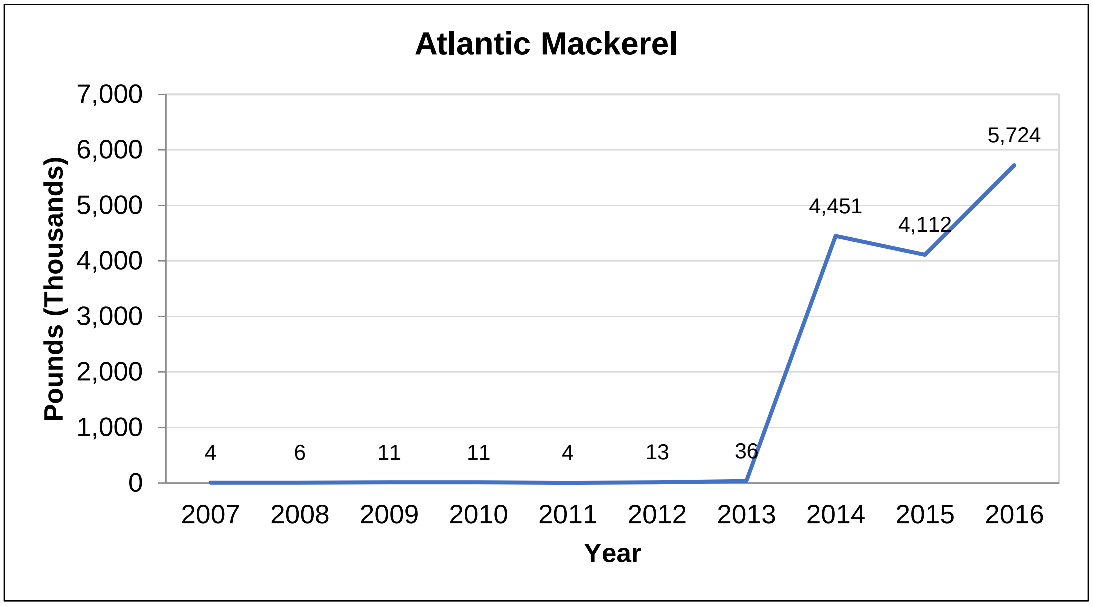

Figure App.F.20. Pounds of Atlantic mackerel landed 2007–2016 (2017$). Source: GARFO 2019b

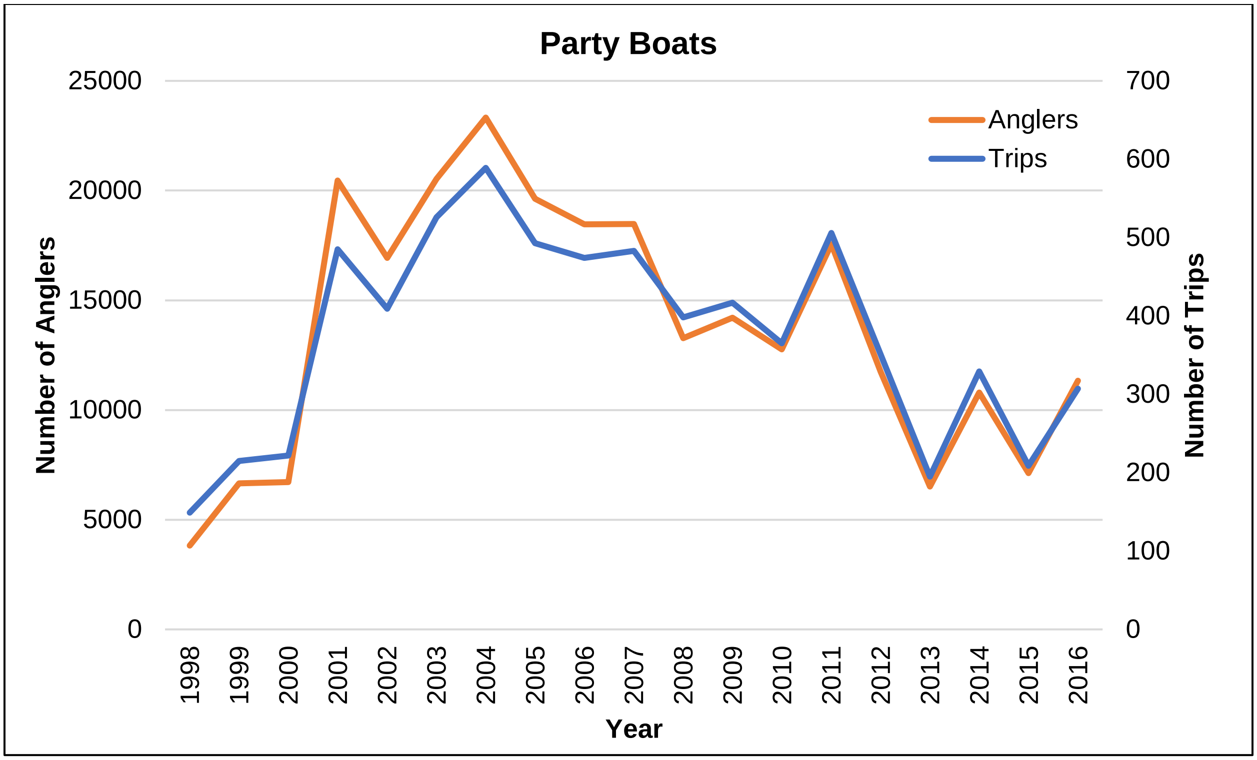

Figure App.F.21. Number of party boat anglers and trips, 1998–2016. Source: GARFO 2019b

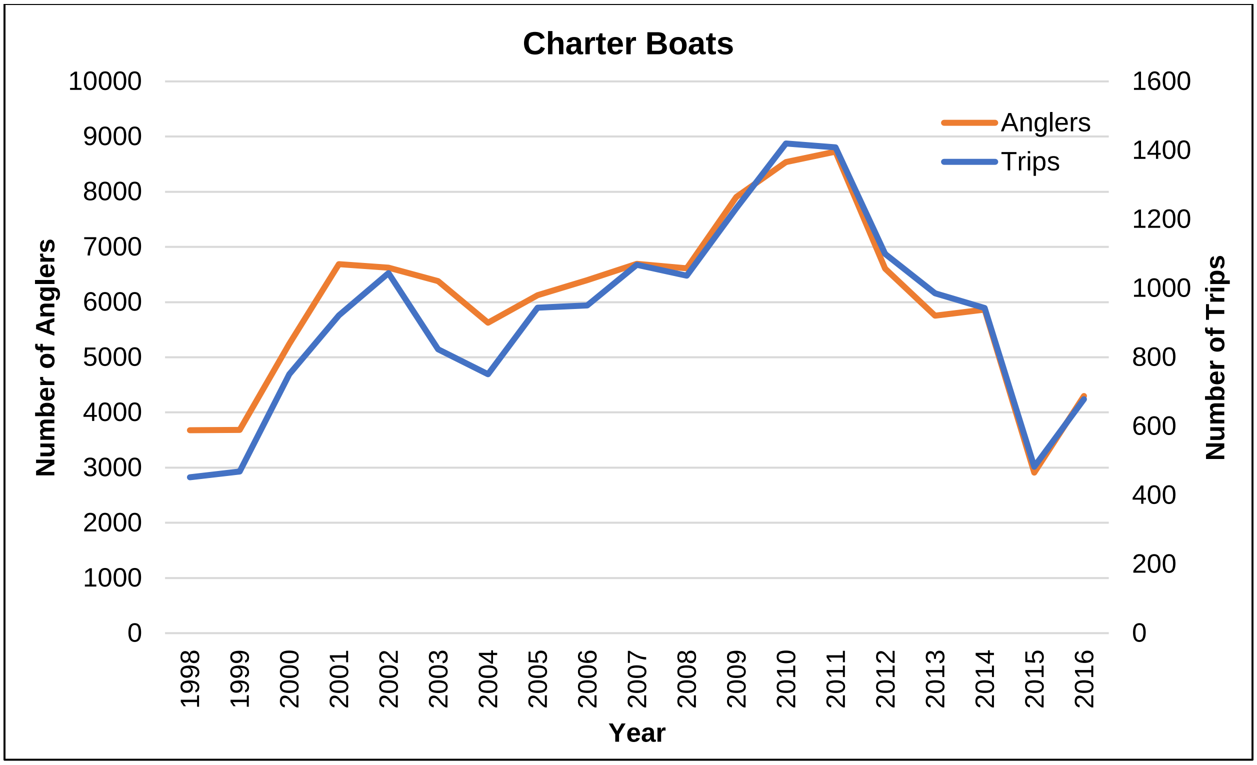

Figure App.F.22. Number of charter boat anglers and trips, 1998–2016. Source: GARFO 2019b

Table App.F.1. Boat registrations in Massachusetts, 2005–2016. Sources: NMMA 2016

Year	Boat Registrations 26 Feet and Over	Total Boat Registrations	Percent 26 feet and over
2005	6,892	150,026	4.59
2006	6,907	148,640	4.65
2007	6,789	145,496	4.67
2008	6,826	145,113	4.70
2009	6,694	142,625	4.69
2010	6,763	141,959	4.76
2011	6,657	139,991	4.76
2012	6,682	139,123	4.80
2013	6,680	137,668	4.85
2014	6,628	135,750	4.88
2015	6,530	134,678	4.85
2016	8,977	140,008	6.41

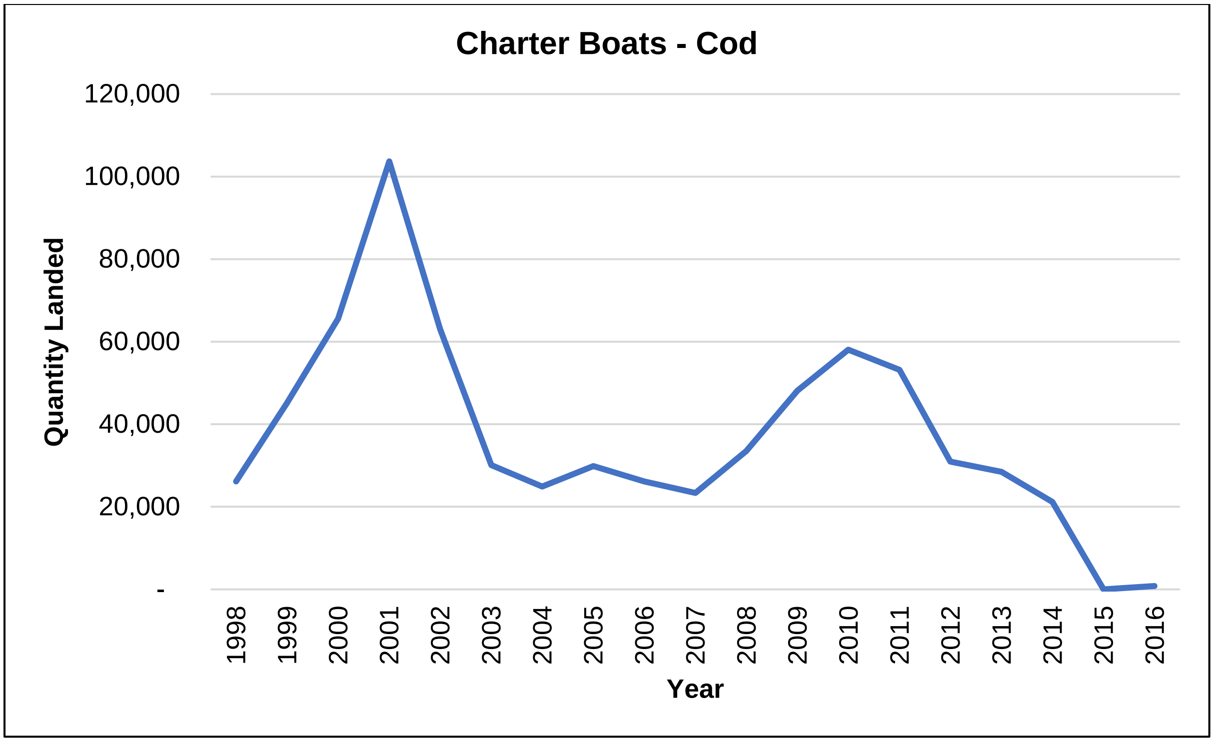

Figure App.F.23. Number of cod landed— charter boats, 1998–2016. Source: GARFO 2019b

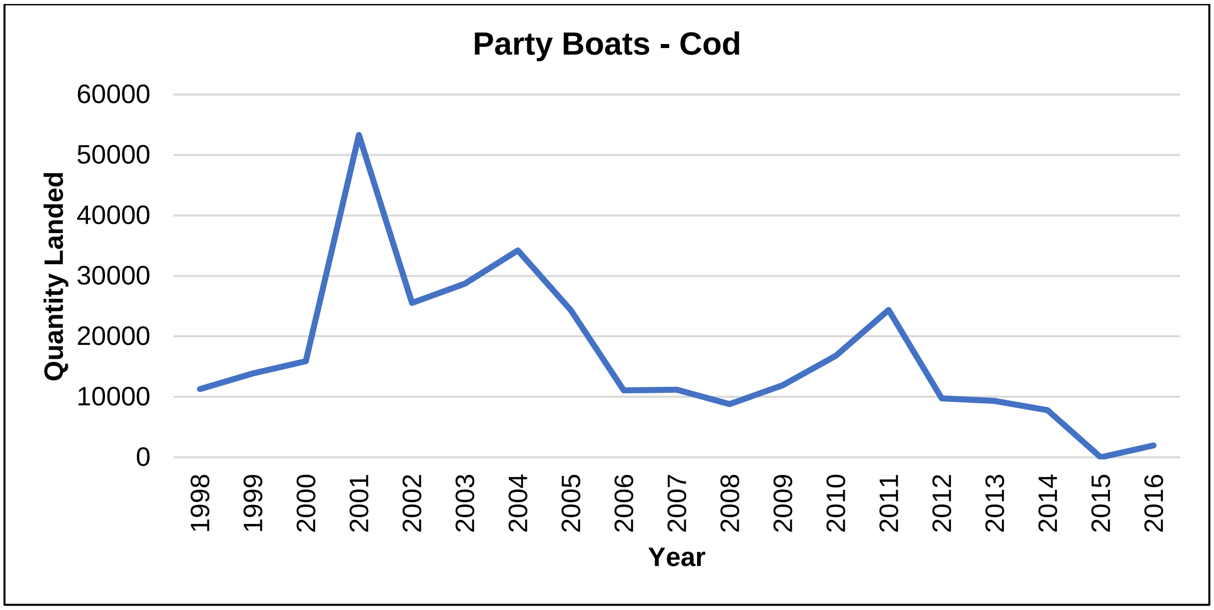

Figure App.F.24. Number of cod landed — party boats, 1998–2016. Source: GARFO 2019b

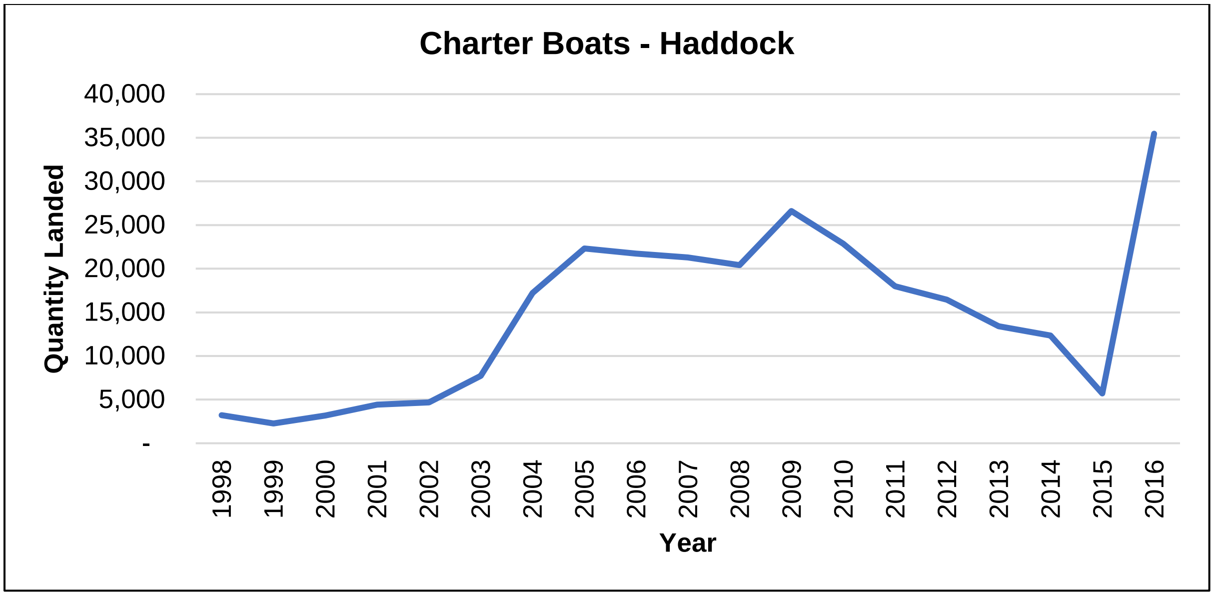

Figure App.F.25. Number of haddock landed — charter boats, 1998–2016. Source: GARFO 2019b

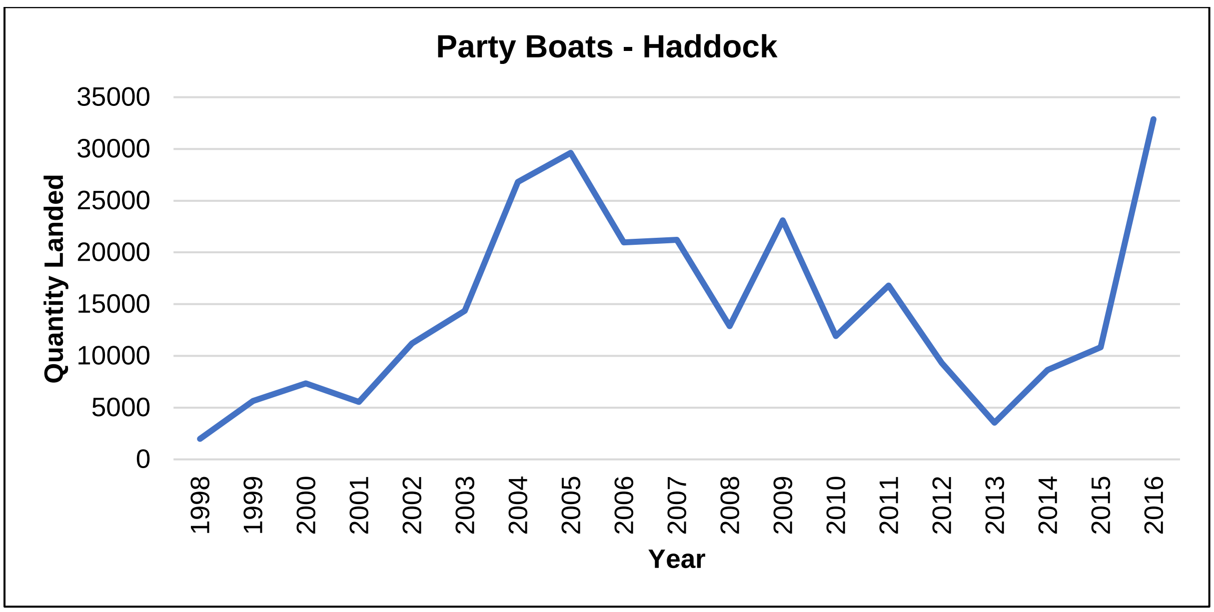

Figure App.F.26. Number of haddock landed — party boats, 1998–2016. Source: GARFO 2019b

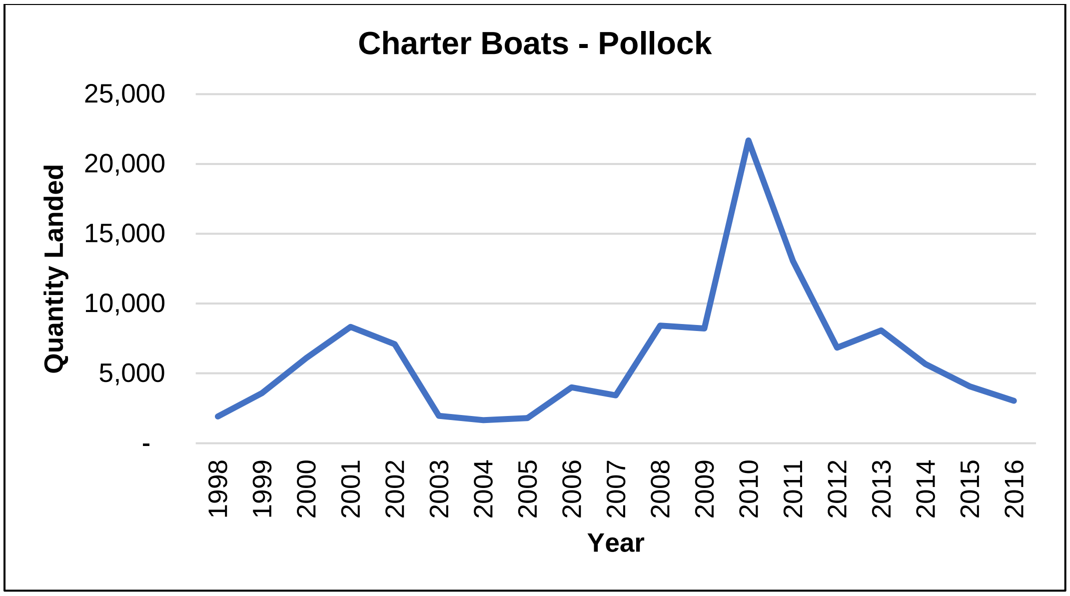

Figure App.F.27. Number of pollock landed — charter boats, 1998–2016. Source: GARFO 2019b

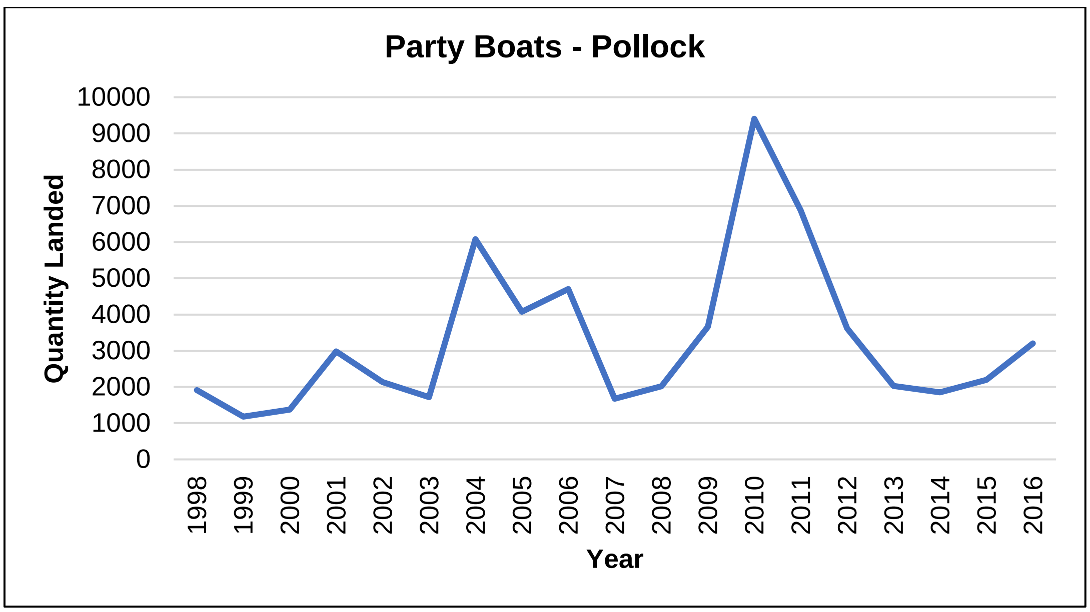

Figure App.F.28. Number of pollock landed — party boats, 1998–2016. Source: GARFO 2019b

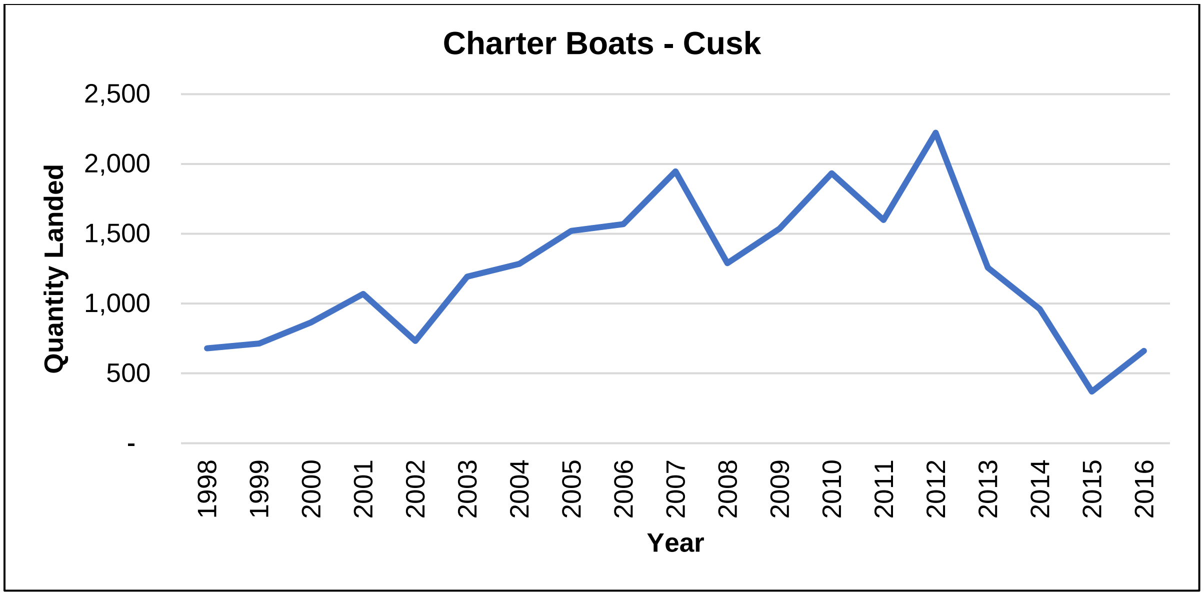

Figure App.F.29. Number of cusk landed — charter boats, 1998–2016. Source: GARFO 2019b

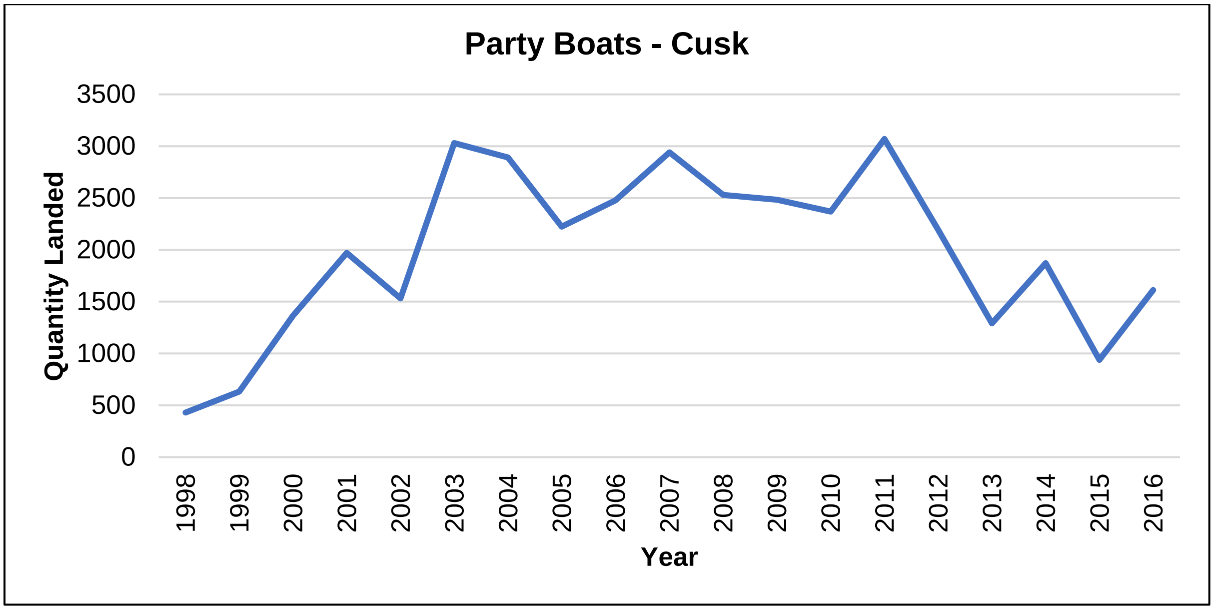

Figure App.F.30. Number of cusk landed — party boats, 1998–2006. Source: GARFO 2019b

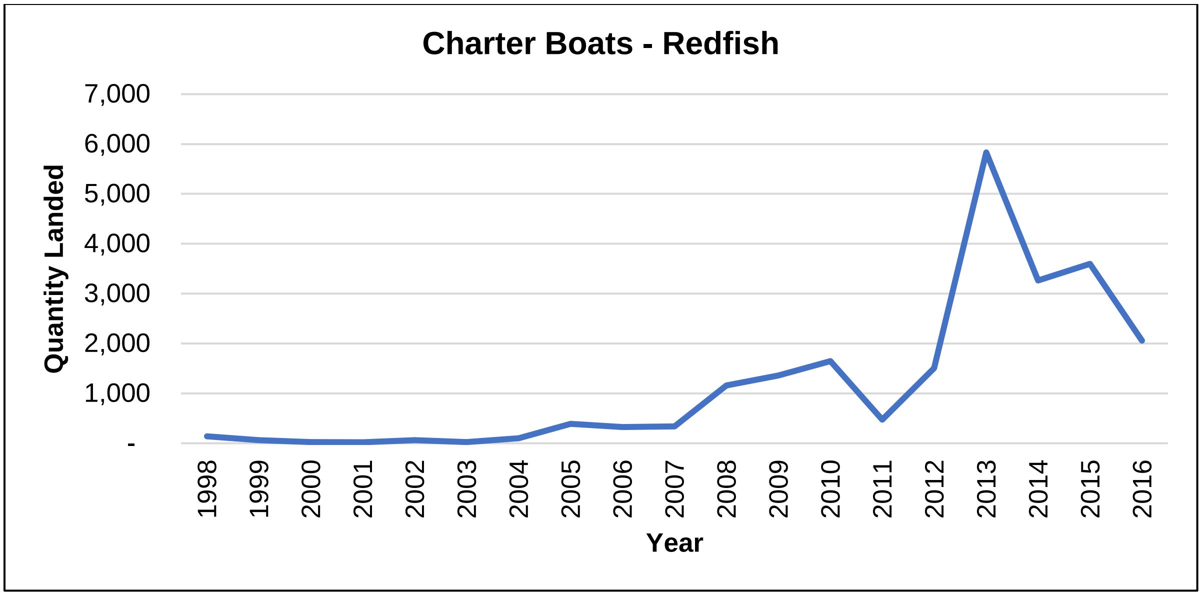

Figure App.F.31. Number of redfish landed —charter boats, 1998–2016. Source: GARFO 2019b

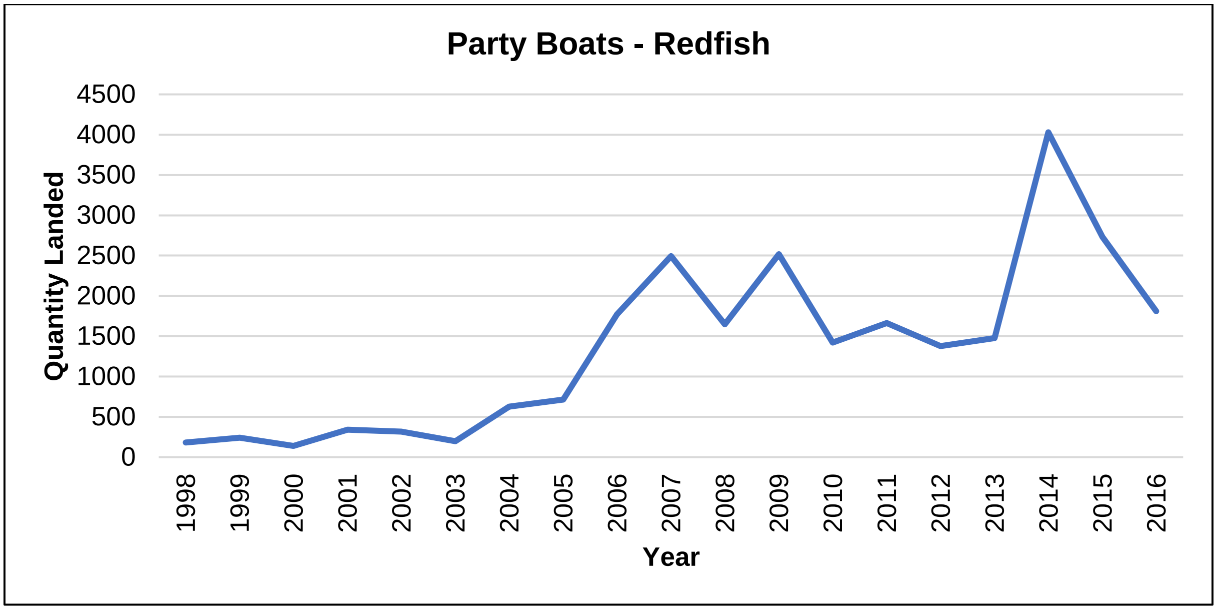

Figure App.F.32. Number of redfish landed party boats, 1998–2016. Source: GARFO 2019b

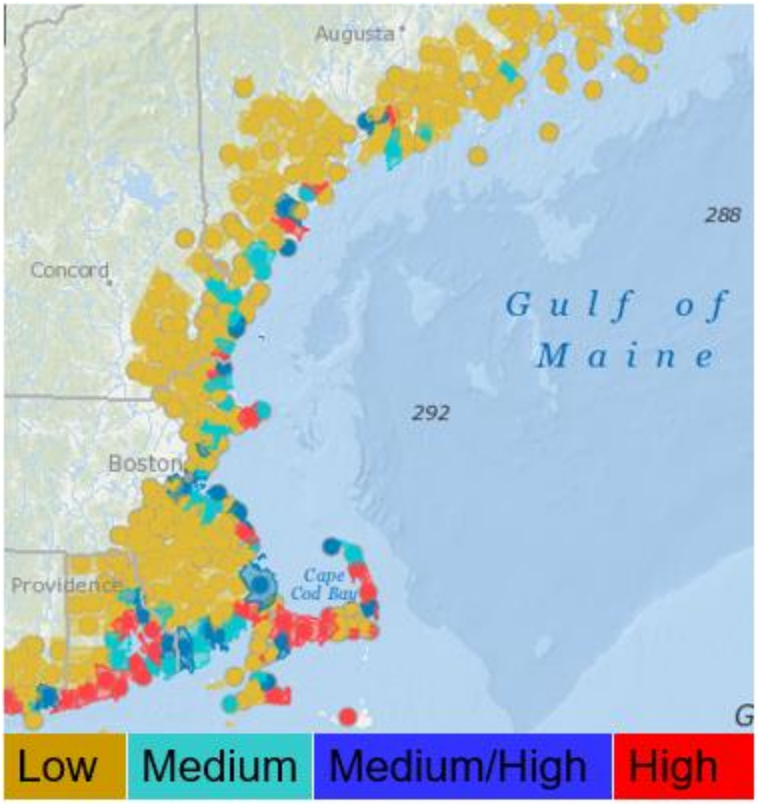

Figure App.F.33. Social vulnerability indicators; recreational engagement. Source: NOAA 2018b

Table App.F.2. Responses to the question "With which one of these statements about the environment and the economy do you most agree: (1) protection of the environment should be given priority, even at the risk of curbing economic growth, or (2) economic growth should be given priority, even if the environment suffers to some extent?" Source: Gallup 2017

Year	Protection of the environment should be given priority, even at the risk of curbing economic growth	Economic growth should be given priority, even if the environment suffers to some extent	Equal priority	No opinion
1984	61%	28%		11%
1990	71%	19%		10%
1991	71%	20%		9%
1992	58%	26%	8%	8%
1995	62%	32%		6%
1997	66%	27%		7%
1998	68%	24%		8%
1999	65%	30%		5%
2000	67%	28%	2%	3%

2001	57%	33%	6%	4%
2002	54%	36%	5%	5%
2003	47%	42%	7%	4%
2004	49%	44%	4%	3%
2005	53%	36%	7%	4%
2006	52%	37%	6%	4%
2007	55%	37%	4%	4%
2008	49%	42%	5%	3%
2009	42%	51%	5%	3%
2010	38%	53%	4%	5%
2011	36%	54%	6%	4%
2012	41%	49%	6%	4%
2013	43%	48%	4%	5%
2014	50%	41%	4%	5%
2015	46%	42%	6%	5%
2016	56%	37%	4%	3%
2017	56%	35%	5%	4%

Table App.F.3. Responses to the question “Do you think the U.S. government is doing too much, too little, or about the right amount in terms of protecting the environment?” Source: Gallup 2017

Year	Too much	Too little	Right amount
1992	4%	68%	26%
2000	10%	58%	30%
2003	7%	51%	37%
2004	5%	55%	37%
2005	5%	58%	34%
2006	4%	62%	33%
2010	15%	46%	35%

2011	16%	49%	33%
2012	17%	51%	30%
2013	16%	47%	35%
2014	17%	48%	34%
2015	16%	48%	34%
2016	12%	57%	29%
2017	11%	59%	26%

Table App.F.4. Commercial fishing vessels by size of vessel in SBNMS, 2007–2016. Source: GARFO 2019b

Year	Less than 50 Feet	50–70 Feet	Greater than 70 Feet	Total
2007	224	51	16	291
2008	217	44	14	275
2009	225	45	17	287
2010	248	41	31	320
2011	186	38	27	251
2012	194	36	34	264
2013	162	27	31	220
2014	153	27	19	199
2015	143	21	17	181
2016	171	34	37	242
2007–2016 Average	192	36	24	253
% 2007–2016	76.01	14.39	9.60	100.00
% 2007–2009	78.08	16.41	5.51	100.00
% 2010	77.50	12.81	9.69	100.00
% 2016	70.66	14.05	15.29	100.00

APPENDIX G: Glossary

AIS	Automatic Identification System
CINMS	Channel Islands National Marine Sanctuary
DHRA	Dedicated Habitat Research Area
DMIS	Data Matching and Imputation System
DPSER	Driving forces-Pressures-State-Ecosystem services-Response
EPA	Environmental Protection Agency
ESA	Endangered Species Act
GARFO	Greater Atlantic Regional Fisheries Office
GDP	gross domestic product
GOM/GBK	Gulf of Maine / Georges Bank
HAB	harmful algal bloom
IMO	International Maritime Organization
IWS	Industrial Waste Site
LNG	liquified natural gas
MA DMF	Massachusetts Division of Marine Fisheries
MBDS	Massachusetts Bay disposal site
MWRA	Massachusetts Water Resources Authority
NEFMC	New England Fisheries Management Council
NOAA	National Oceanic and Atmospheric Administration
ONMS	Office of National Marine Sanctuaries
PAH	polycyclic aromatic hydrocarbons
PBR	potential biological removal
PCB	polychlorinated biphenyls
POP	persistent organic pollutants
SBNMS	Stellwagen Bank National Marine Sanctuary
SNE	Southern New England
TEU	twenty-foot equivalent unit
TSS	transportation separation strategy
USACE	US Army Corps of Engineers
VMS	vessel monitoring system
VTR	vessel trip report
WGOM	Western Gulf of Maine

NATIONAL MARINE
SANCTUARIES

AMERICA'S UNDERWATER TREASURES

http://sanctuaries.noaa.gov