IV. Resource States

This section documents the status, pressures and current protections for sanctuary resources. These resources include seafloor and water column habitats, benthic invertebrates, fishes, seabirds, sea turtles, marine mammals and maritime heritage resources. This section provides context and validation for the sanctuary action plans.

Context

The nutrient-rich waters of the Stellwagen Bank sanctuary sustain an abundant biodiversity largely representative of the GoM LME and totaling well over 575 species of marine life including over 80 species of fish, 53 species of seabirds and 22 species of marine mammals, for example. As a comparatively shallow continental shelf area, offering great variety among its geological features and topographic relief, the sanctuary is a biodiversity haven when compared to the open ocean of the North Atlantic. In addition to the array of different kinds of species, the sanctuary exhibits diverse habitats, biological communities and species assemblages and displays a complex tapestry of interwoven environmental processes, all of which are extensively impacted by multiple human uses.

Biodiversity in the sanctuary is heavily mediated through habitat type and condition. In this document, habitats are divided into two principal categories: seafloor (benthic) and water column (pelagic) habitats. These habitats are composed of multiple types, such as gravel beds and piled boulder reefs. Habitat quality and structural complexity are important factors in supporting biodiversity. For example, the condition of benthic habitat affects the life history processes of recruitment, survivorship and growth of the organisms that occupy the seafloor. The condition of habitats also influences the community processes of competition, predation and symbiosis. Within water column habitats, water quality can affect biodiversity by prohibiting or enabling survival of rare or cosmopolitan species.

Understanding the processes that control the abundance, distribution and interaction of species (i.e., the functional composition of communities) is a central challenge facing management of the sanctuary. The level of difficulty in meeting this challenge is heightened by recognition that the sanctuary's resource states are greatly compromised. Water quality is threatened by multiple sources of pollution, including point, non-point and atmospheric sources and marine debris. Population declines and biomass removals, degraded seafloor habitats and invasive species compromise the ecological integrity of the sanctuary. Coastal planning and fishery management policies have limited, but not prevented, harmful impacts—both incremental and cumulative—on sanctuary resources.

This section is organized within a Pressure-State-Response framework that mirrors the approach used in the Stellwagen Bank National Marine Sanctuary *Condition Report* (NMSP, 2006). "Pressures" are human activities (such as fishing or pollutant discharge), which alter the marine environment leading to changes in the "state or condition" of sanctuary resources (e.g., water quality, ecological integrity, habitat complexity). Sanctuary management then "responds" (e.g., Action Plans section) to changes in pressures or states with policies, programs, and/or regulations intended to prevent, eliminate or mitigate pressures and/or environmental damage in order to protect and conserve sanctuary resources.

Section 302(8) of the NMSA defines sanctuary resources as "any living or non-living resource of a national marine sanctuary that contributes to the conservation, recreational, ecological, historical, educational, cultural, archaeological, scientific, or aesthetic value of the sanctuary." The sanctuary resources described in this section on Resource States are: seafloor habitat, water column habitat, benthic invertebrates, fishes, seabirds, sea turtles, marine mammals and maritime heritage resources. Each resource subsection begins with a summary of its status based on the best available information followed by the known human pressures that impact the status. A summary of the current protection measures that are in place affecting the resource in question is presented next.

Seafloor as Habitat

Status

The species composition of seafloor communities in general is highly correlated with the grain size of benthic sediments, and seafloor substrata represent an important component of habitat for many organisms in the sanctuary. Recent studies on the continental shelf of the northeastern United States, including portions of the Stellwagen Bank 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) and 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 grain size in sand and unconsolidated mud sediments in the sanctuary (Grannis and Watling, 2004). Epifaunal species, those that live *on* the seafloor, are linked to variation in larger grain sizes at the scale of the GoM (Skinder, 2002). Within each habitat type, there are many microhabitats formed by the combination of habitats and inhabiting organisms. For example, cerianthid anemones that burrow in mud provide structure and shelter on the seafloor and serve as important habitat for redfish and hake (Figure 16).

Figure 16. Example of a microhabitat formed within a mud habitat by burrowing anemones.

In this example, Cerianthid anemones provide refuge to juvenile Acadian redfish. Image courtesy: Ivar Babb and Peter Auster, NURC-UConn.

Biological communities are formed by the interaction of populations with habitats in a particular area. The interaction of fish with their habitat is of particular concern and has been well-studied in the Stellwagen Bank sanctuary. For purposes of discussion in this document, the ecological role of seafloor habitats is largely restricted to our understanding of links to the distribution and abundance of fishes. Macroalgae (i.e. seaweeds) are virtually absent from and appear to play no substantive role in structuring seafloor habitats in the sanctuary; instead benthic invertebrates typically make up the biogenic structure of the seafloor.

Average gross benthic microalgal production on Stellwagen Bank was a relatively small fraction (approximately 6%) of average integrated water column phytoplankton production (Cahoon *et al.,* 1993). Microscopic examination of surface sediment samples showed that the benthic microflora was dominated by pennate diatoms (more than 97% of total cells). Cahoon *et al.* (1993) cite a personal communication with C. Mayo indicating that macroalgae grew on Stellwagen Bank before bottom trawling eliminated them. Macroalgae are reported growing at depths to 50 m elsewhere in New England waters (Vadas and Steneck, 1988). Benthic primary production historically on Stellwagen Bank may have been higher with the presence of macroalgae.

Habitat Mediated Interactions

There is an important biogenic component to habitat complexity. For instance, many fish species in the sanctuary associate with particular microhabitats formed by other living organisms (Auster, 1998). Attached and emergent invertebrates such as erect sponges and burrowing anemones provide important habitat structure, while certain megafaunal organisms such as skates produce pits and burrows, which also provide structure by adding to the complexity of sediment surfaces. Reductions in seafloor habitat complexity increase the mortality of early demersal phase juvenile fish, such as Atlantic cod and winter flounder that utilize the structure provided by emergent fauna and physical substrata for protection from predation (Gotceitas and Brown, 1993; Tupper and Boutilier, 1995; Lindholm *et al.,* 1999; Scharf *et al.,* 2006). Modeling studies have demonstrated that such habitat-mediated mortality of juvenile fish can have significant population-level effects (Lindholm *et al.,* 1998, 2001).

The distribution and abundance of demersal fishes at large spatial scales is correlated with temperature and depth, but medium to small-scale variation is attributed to considerable extent to habitat attributes (i.e., sediment type, structural complexity, prey type and abundance) on the seafloor (Langton *et al.,* 1995). The distribution of a variety of demersal fishes in the GoM LME is correlated with various structural habitat features such as boulder reefs, distribution of sand wave features, density of amphipod tubes, and presence and density of sponges, anemones and other epifauna (Auster *et al.,* 1997, 1998, 2003a, 2003b; Auster 2005; Auster and Lindholm 2006). The communities of fishes in the sanctuary are directly correlated with particular habitats defined by a combination of both geologic and biologic attributes (Auster *et al.,* 1998).

The patchiness and spatial arrangement of habitats mediate many of the behavioral interactions of fishes. Fish exhibit, as many mobile organisms do, a range of behavioral interactions that have negative, neutral, or positive consequences in terms of growth and survivorship. For example, predation has a positive consequence for the predator and a negative one for the prey. Other interactions include competition and mutualism. Competition for shelter sites can be intense when the abundance of individuals is high and shelter space is limited, such as rock crevices for night-time shelter required by cunner. Mutualistic relationships within and between fish species are often short term in scope and mediated in part by habitat features. For example, the foraging activities of one species can aid in prey capture of other species. Flounders are sometimes followed by piscivores such as silver hake which gain access to disturbed prey such as shrimp and small fish when flounders sift through sediments in search of infaunal prey (e.g., Auster *et al.,* 1991, 2003a). Such relationships, while lasting only tens of seconds, are repeatedly linked to particular habitats and species groups and constitute important feeding strategies.

Habitat complexity mediates access to prey and the behavioral trade-offs in minimizing risk of predation. For example, Acadian redfish are zooplanktivores and feed in the water column above boulder reefs. Height of fishes above the reef dictates the rate of water flow that delivers prey and distance to shelter is a measure of hunger level and the risk of predation individuals would take. In general, smaller fish venture less from shelter than larger individuals. Further, boulder reef structure also mediates the species composition and abundance on different parts of reefs. For example, while Acadian redfish are dominant on the central parts of reefs with deep crevices formed by piled boulders, cunner increase in abundance on the margins of reefs, possibly due to the availability of smaller shelter sites that are better suited to this species than open deep crevices. Cusk generally occur in deep crevices on the central parts of reefs while ocean pout and Atlantic wolfish occur in burrows along reef margins (Auster and Lindholm, 2006).

As the density of a species within a habitat increases there is increased competition for resources such as shelter and prey. At some stage emigration from the habitat patch and a search for new habitats is a choice made by individuals who have access only to marginal shelter sites (e.g., with increased risk of predation) or access only to areas of reduced prey abundance (e.g., with reduced growth). Acadian redfish exhibit distribution patterns that are consistent with increased migration from boulder reefs, due to competition for shelter or prey, as animals grow in size (Auster *et al.,* 2003b). While young-of-the-year redfish were found only in boulder reefs due to habitat selection or extreme predation in other habitats, some older juvenile redfish move to habitats composed of dense burrowing anemones. Such habitats provide some shelter away from boulder reefs as well as access to zooplankton prey.

Habitat Mediated Movement

Mediation of fish movement by different habitat types and features is not well understood for species in the GoM. This information is needed to understand how key predators like Atlantic cod influence the structure and composition of biological communities in the sanctuary. The degree of localized movement by individuals and their tenure of residency differentiated by habitat type and season are important aspects to be understood, as are the associated factors of size and sex. The successful conservation and management of cod and other commercially important species in the GoM is highly dependent on this information as well. Site residency and fidelity among Atlantic cod stocks is now widely documented (Green and Wroblewski, 2000; Lindholm and Auster 2003; Robichaud and Rose, 2001, 2004; Wright *et al.,* 2006; Neat *et al.,* 2006; Lindholm *et al.,* 2007; Howell *et al.,* 2007).

A study was begun in 2001 in the sanctuary that used acoustic telemetry technology to quantify cod movement over different habitat features of the sanctuary landscape. Cod were caught and tagged with coded-acoustic transmitters (each of which emits a unique identification code) then released within the overlap of the sanctuary and the Western Gulf of Maine Closed Area (WGoMCA). Movements of tagged cod were recorded by an array of four acoustic receivers deployed on the seafloor. Data were collected at the scale of minutes for several months at a time. Preliminary tracking occurred in the gravel habitat of northeastern Stellwagen Bank in 2001 (Lindholm and Auster, 2003). From May 2002 through October 2002 and from September 2004 through March 2005, cod movement was investigated at additional four piled boulder reef sites (Lindholm *et al.,* 2007). The same piled boulder reefs were used in both periods in order to quantify any influence of seasonality on cod movement behavior.

Three broad categories of movement behavior were identified at each of the four piled boulder reefs, across years and across seasons: 35% of adult cod (38-94 cm total length) showed very high site fidelity to individual boulder reefs (greater than 80% of 1-hour time bins); 51% of cod left after a couple of days and were never recorded again; the remaining 13% fell somewhere in between those two extremes. Several animals were recorded at more than one reef. A few animals exhibited behavior that may be evidence of homing. The behavior did not differ significantly with fish length, among individual reefs, and between summer and winter.

These results are strong evidence that some subset of the cod population in the sanctuary is "resident" on boulder reefs. The results of this study are consistent with the results of a review of 100 years of cod tagging studies in the North Atlantic. The review revealed that 32% of the tagged cod in the northwest Atlantic exhibited the sedentary behavior (Robichaud and Rose, 2004). The high site fidelity of many cod to individual piled boulder reefs suggests that habitat-specific management measures, such as marine reserves, may offer significant protection to cod within the sanctuary. Neat *et al*. (2006) conclude that marine protected areas could be an effective management measure in sustaining small resident populations of Atlantic cod.

Habitat and Sound Production

Sound production by fishes can serve a variety of purposes including species identity, individual identity, mate location, readiness to spawn, individual size and level of aggressiveness (Lobel, 2002). Over 150 species of fish in the northwestern Atlantic and at least 51 from the New England region are known to produce sounds (Fish and Mowbray, 1970; Rountree *et al.,* 2002). Species across a spectrum of diversity, like Atlantic cod, haddock, silver hake, longhorn sculpin, cusk, fawn cusk-eel, American eel and cunner all produce sounds, although the behavioral context for producing sounds for these and other species is not always clear. However, there are clear relationships between particular sounds and spawning events in species like Atlantic cod, haddock, cusk, and fawn cusk-eel. Assuming much of sound production is behavior-specific, correlations between habitat selection and use in terms of spawning or territorial defense among demersal fishes is inferred.

Seafloor Habitat Recovery

Context

In May 1998, NOAA Fisheries Service established the WGoMCA at the recommendation of the NEFMC for the purpose of recovering groundfish stocks, specifically Atlantic cod and haddock. Gear capable of catching groundfish was prohibited from this closed area, specifically bottom-tending trawl gear, bottom-tending gillnets, and clam and scallop dredges. Allowable gear included lobster pots, hagfish pots, pelagic longline, pelagic hook and line fishing, recreational hook and line, pelagic gillnets, tuna purse seining and midwater trawls. The closure area overlaps 22% (453 km^2) of the sanctuary along the eastern boundary; the area of overlap has been dubbed the "sliver" (Figure 17).

In May 2004, NOAA Fisheries Service, at the recommendation of the NEFMC, designated the majority of the WGoMCA as a "Level 3" habitat closed area for the purpose of protecting EFH. A Level 3 habitat closed area is closed indefinitely on a year-round basis to all bottom-tending mobile gear. In addition to prohibiting bottom-tending mobile gear, the closure prohibits bottom-tending gillnets, clam and scallop dredges, and shrimp trawls. Allowable gears in this closure are: lobster pots, hagfish pots, pelagic longline, pelagic hook and line fishing, recreational hook and line, pelagic gillnets, tuna purse seining and midwater trawls except for shrimp. For a complete listing of prohibited and allowed gear visit URL http://www.nero.noaa.gov/nero/fishermen/multispecies/gom/CAYearRound.htm#wgomca.

De Facto Reference Area

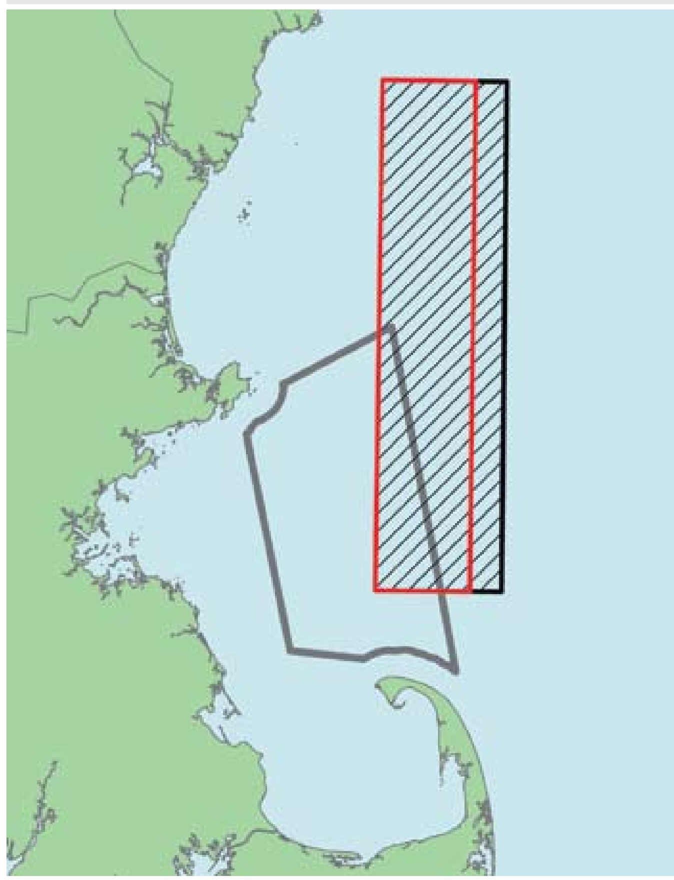
There is no formally designated undisturbed reference or control area in the Stellwagen Bank sanctuary. Because of the compelling need for a control site, the sliver has become a *de facto* reference area which the sanctuary and other researchers are using to discern the effects of human versus natural disturbance on seafloor habitats and their associated biological communities. However, the sliver is far from a true control area owing to three shortcomings: (1) several extractive activities are still allowed (i.e., fishing gears listed above) that alter the area's ecological integrity; (2) additional resources for enforcement are needed to assure deterrence of unlawful incursions; and (3) deep mud habitat is seriously underrepresented (75.5% gravel, 23.5% sand and 1.0% mud) in the sliver making it difficult to draw definitive conclusions about the effects of fishing in this habitat type.

These shortcomings need to be addressed. As a first step, the sanctuary formally proposed on July 2, 2003 to the NEFMC through its Amendment 13 process that the sliver be designated a 'habitat research area' under the MFCMA. There are several properties of the sliver that make it a suitable choice for a habitat research area, including scientific, practical and political rationales:

- The sliver includes the major seafloor habitat types found in the GoM — bedrock outcrop, boulder, gravel, mud and sand. This habitat mix enhances the exportability and extrapolation of research results to diverse areas outside the habitat research area.
- The habitats in the sliver are distributed on both sides of the closure boundaries, both within the sanctuary (to the

Figure 17. Map depicting the WGoMCA (cross-hatched) and its overlap with the Stellwagen Bank sanctuary.

Majority of the WGoMCA is a Level 3 habitat closed area (red outline) for the purpose of protecting EFH.



west) and outside of the sanctuary proper (to the east), making comparative habitat studies possible across the boundaries.

- The proximity of the sliver to the ports of Boston, Gloucester, Scituate, Plymouth and Provincetown make it accessible to researchers for day-trips using small and relatively inexpensive vessels, which makes research in the sliver more cost-effective than at alternative offshore northeast continental shelf locations.
- The sliver has already been closed to commercial bottom fishing for nine years. From a scientific perspective, this greatly enhances study of the ecological processes and expedites the timeline on which research results can be attained.
- The sanctuary has the resources to help support enforcement of the habitat research area in ways that would complement regulation under NOAA Fisheries Service purview.

In its current capacity as a *de facto* reference area, the sliver is supporting several on-going long-term studies by sanctuary staff and sanctuary-supported scientists. Projects include: (1) quantification of fish movement rates relative to seafloor habitat type (1998 to the present); (2) recovery of seafloor habitats and associated taxa following the cessation of trawling, dredging and bottom gillnet fishing (1998 to the present); and (3) species-area relationships of multiple taxa (1999 to the present).

This combined research represents a private/public investment totaling more than $3 million over the past ten years. Much of this research will continue over the next several years. The results of these ongoing projects in the sliver, and other projects currently in various stages of planning and proposal preparation, will contribute to advancing ecosystem understanding in the sanctuary and by extension the GoM. The NEFMC is in the process of revising its omnibus amendment to better protect EFH and has not yet acted on the sanctuary proposal.

Pressures

Disturbance in General

Disturbance is defined as any discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability or the physical environment (Pickett and White, 1985). Disturbance can be caused by many natural processes such as currents, predation and iceberg scour (Hall, 1994). Human caused disturbance can result from activities such as harbor dredging, cable laying and fishing with fixed and mobile gear. Disturbance can be gauged by both intensity (as a measure of the force of disturbance) and severity (as a measure of impact on the biotic community). General concepts associated with the types and ecological implications of spatially mediated disturbance are described in the accompanying Sidebar.

Types of Spatially Mediated Habitat Disturbance

The spatial extent of disturbed and undisturbed biological communities is a concern in designing and interpreting research studies (Pickett and White, 1985; Thrush *et al.*, 1994) and in managing the sanctuary. Single, widely spaced disturbances may have little overall effect on habitat integrity and benthic communities, and may show reduced recovery times as a result of immigration of mobile species (e.g., polychaetes, gastropods). In the ecological literature, this is a "Type 1" disturbance, where a small patch is disturbed but surrounded by a large unimpacted area.

In contrast, a "Type 2" disturbance is one where a small patch is unimpacted but surrounded by a large disturbed area. Recruitment into such patches requires large scale transport of larvae from outside source patches, or significant reproductive output (and high planktonic survival and larval retention) from the small undisturbed patches. Making predictions about the outcome of either type of disturbance, even where spatial extent is known, is difficult since transport of colonizers by either immigration or recruitment depends on oceanographic conditions, larval period, movement rates of juveniles and adults, time of year and distance from source.

Type 1 disturbances have habitat recovery rates that are generally faster because they are subject to immigration dominated recovery versus the dependence on larval recruitment for the recovery of Type 2 disturbances. The associated population responses of obligate and facultative habitat users to such disturbances are also variable. Obligate users are restricted by narrow requirements and have no habitat options; facultative users have options because of less restrictive requirements. Obligate habitat users have a much greater response to habitat disturbance than facultative users.

Comparatively, it would be difficult to detect responses from populations of facultative habitat users to Type 1 disturbance because of the large adjacent areas of undisturbed habitat. Type 2 disturbances would produce large responses in obligate habitat users because a large percentage of required habitats would be affected. Facultative habitat users would have a measurable response only at population levels where habitat mediated processes became important.

This discourse on the types of spatially mediated habitat disturbance and the respective responses of obligate and facultative habitat users is relevant to how the sanctuary will eventually have to approach management of fishing activities and other impacts to biogenic habitats (structure and associated populations). The majority of the sanctuary area is subjected to chronic disturbance by fishing and the sliver is the only relatively unimpacted patch (see sections on spatial distribution and density of commercial and recreational fishing under Human Uses in this management plan).

Table 3. Comparison of intensity and severity of various sources of physical disturbance to the seafloor (based on Hall (1994) and Watling and Norse (1998)).

Intensity is a measure of the force of physical disturbance and severity is a measure of the impact on the benthic community (adapted from Auster and Langton (1999)).

Source	Intensity	Severity
ABIOTIC		
Waves	Low during long temporal periods but high during storm events (to 85 m depth)	Low over long temporal periods since taxa adapted to these events but high locally depending on storm behavior
Currents	Low since bed shear normally lower than critical velocities for large volume and rapid sediment movement	Low since benthic stages rarely lost due to currents
BIOTIC		
Bioturbation	Low since sediment movement rates are small	Low since infauna have time to repair tubes and burrows
Predation	Low on a regional scale but high locally due to patchy foraging	Low on a regional scale but high locally due to small spatial scales of high mortality
HUMAN		
Dredging	Low on a regional scale but high locally due to large volumes of sediment removal	Low on a regional scale but high locally due to high mortality of animals
Land Alteration (Causing silt-laden runoff)	Low since sediment-laden runoff *per se* does not exert a strong physical force	Low on a regional scale but high locally where siltation over coarser sediments causes shifts in associated communities
Fishing	High due to region wide fishing effort	High due to region wide disturbance of most types of habitat

Table 3 summarizes the effects of the range of agents which produce disturbance in marine communities. The various forms of disturbance range from small to large in spatial scale as well as acute to chronic in periodicity. From an ecological perspective, fishing is the most widespread form of direct disturbance in marine systems below depths (approximately 85 m) which are affected by storms (Watling and Norse, 1998; Auster and Langton, 1999; National Research Council, 2002).

Activities that have the greatest potential impact on the seafloor habitats of the sanctuary are the laying of underwater cables and pipelines, the use of mobile fishing gears, removal of forage species and bycatch due to fishing, and ocean dumping. The chief distinction between these activities is whether they produce chronic (repeated) or acute (intermittent) disturbance. Chronic disturbance has lasting effects because the ecosystem does not recover fully before the next disturbance. Fishing impacts have the greatest effect on seafloor habitats of any human activity in the Stellwagen Bank sanctuary for this reason.

The laying of an underwater cable has occurred only once in the sanctuary (in 2001) and is an acute impact. The results of this impact are discussed below. Ocean dumping of vessel-generated wastes occurs more frequently in the sanctuary; however, at current discharge levels and dilution rates that activity does not have the lasting effects on physical structure and ecological integrity as does fishing. Much of the following discussion of pressures applies primarily to or involves fishing activities because of the pervasiveness of those activities in the sanctuary and the abundant information available in the scientific literature on the habitat disturbance effects of fishing.

Disturbance of Seafloor Habitats in the Sanctuary

Preliminary results of the Seafloor Habitat Recovery and Monitoring Project (SHRMP) (see Sidebar and Figure 18) are listed below. This project was designed to evaluate the relative effects of disturbance due to laying the fiber-optic cable, fishing and natural disturbance over a decadal time frame. Samples have been collected from 1998-2008 and will continue through at least 2010. The preliminary results to date demonstrate patterns and trends important to consider in regards to seafloor habitat status within the Stellwagen Bank sanctuary:

1. There are significant differences in epifaunal community structure between boulder and gravel habitats despite the fact that both are composed of hard substrate (Tamsett *et al.,* in review).

2. Within boulder and gravel habitats there are differences in community structure between sites inside and outside the sliver indicative of impacts from fishing activities (Tamsett *et al.,* in review). Figure 19 presents images representative of these results.

3. Within mud habitats there are differences in infaunal community structure between sites inside and outside the sliver indicative of impacts from fishing activities (Nenadovic, 2009).

4. Contrasts in the composition of sand habitat infaunal communities inside and outside of the sliver are not clearly different, suggesting that fishing effects superimposed on

Seafloor Habitat Recovery and Monitoring Project (SHRMP)

The long-term Seafloor Habitat Recovery Monitoring Project (SHRMP) was initiated in 1998, when the WGoMCA went into effect, and is ongoing through 2010. The project uses the sliver as a relatively unimpacted reference site to quantify the recovery of seafloor habitats and associated biological communities previously subject to fishing activities and to understand the dynamics of these habitats and communities over time. The study design includes representative sites inside and outside the sliver in mud, sand, gravel and boulder habitat types. The study compares and contrasts the effects of natural and fishing-related disturbance on seafloor habitats and community structure.

In 2001, NOAA permitted installation of a fiber-optic cable across the sanctuary, including the northern portion of the sliver. At that time the objectives and hypotheses of SHRMP were modified to include the effects of the cable laying (a one-time, acute anthropogenic disturbance). The revised monitoring program began in summer 2001 and, pursuant to terms of the permit, will continue through 2010.

Sampling. Four sites are sampled along the fiber optic cable route, located directly over the cable trench and in adjacent areas, both inside and outside of the sliver (Figure 18). A total of eight other sites on four different habitat types are sampled, half inside and half outside the sliver, to monitor fishing impacts (Figure 18). Four of these sites (inside) serve as reference sites; the other four (outside) sites serve as impact sites for fishing disturbance.

Primary sampling of the fiber optic cable route, the fished sites and the respective control sites is done using underwater imaging systems (still and video) from various underwater vehicles, as well as grab samples for fine-grained sediments. Additional sampling is conducted using side-scan sonar to understand the large scale dynamics of the seafloor landscapes. Current meters are deployed on the seafloor to characterize the level of oceanographic forcing of sediment transport processes and the related variation in landscape features (e.g., natural disturbance by storm driven currents).

Project Objectives. The general objective of SHRMP is to compare the distributions of microhabitats and associated fauna in impacted and unimpacted areas with regard to the laying of the fiber optic cable and fishing. This objective can be stated as two null hypotheses (that an observed difference is due to chance alone and not due to a systematic cause):

HO(1): There are no differences in the relative abundance of each microhabitat type in impacted and unimpacted sites, and:

HO(2): There are no differences in faunal abundance, density and microhabitat associations between impacted and unimpacted sites.

The specific objectives of the project are to quantify the relative impacts of the laying of the fiber optic cable and fishing with respect to:

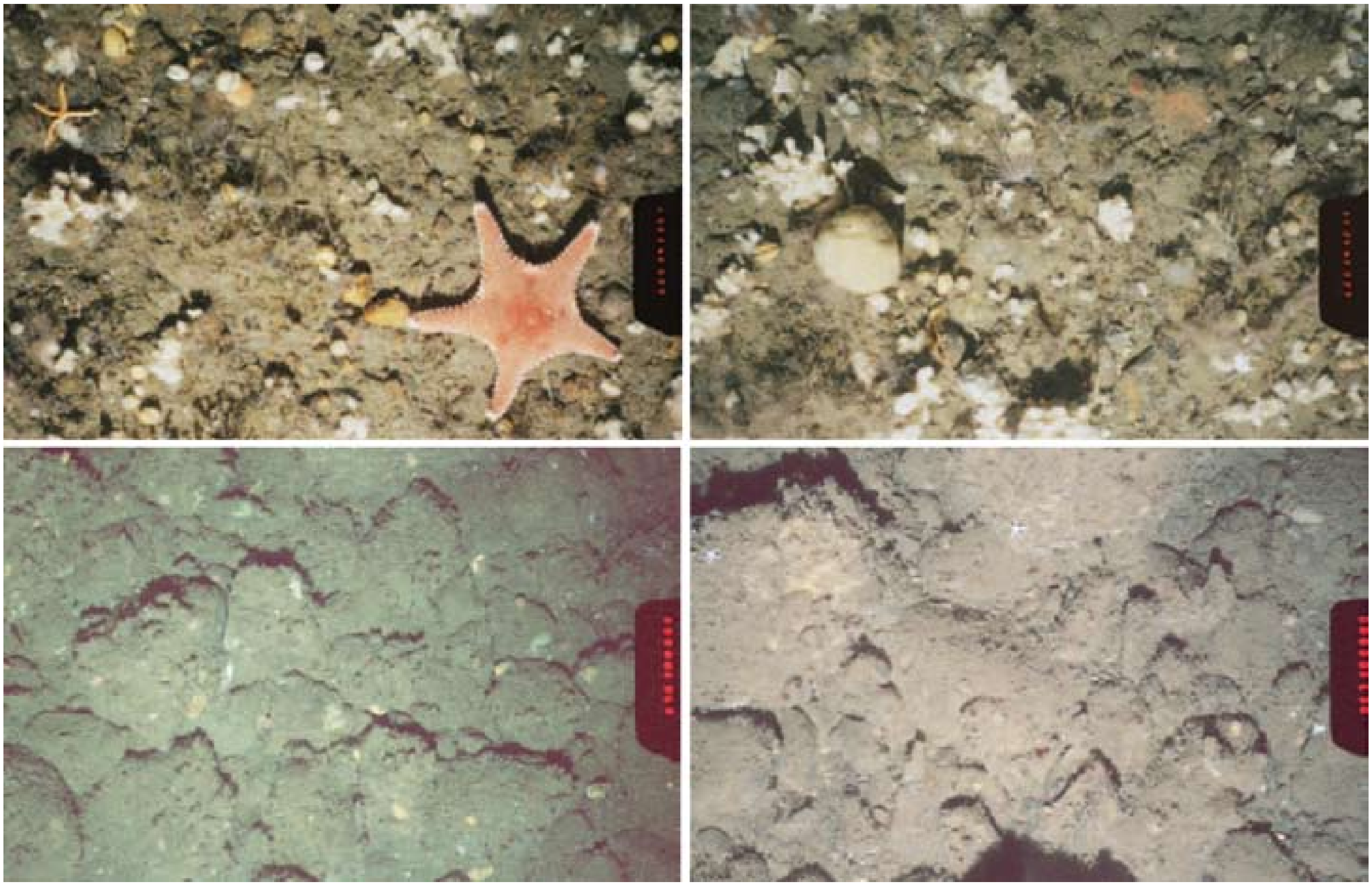
- fish communities
- microhabitat structure
- soft-sediment infaunal communities
- hard-bottom epifaunal communities

Figure 18. Location of long-term sampling sites for the Seafloor Habitat Recovery Monitoring Project.

Triangles indicate fiber optic cable monitoring sites; circles indicate SHRMP sites: 1a = mud closed, 1b = mud open; 2a = sand closed, 2b = sand open; 3a = gravel closed, 3b = gravel open; 4a = boulder closed, 4b = boulder open. Cable sites: 5a = on cable open, 5b = off cable open; 6a = on cable closed, 6b = off cable closed.

Figure 19. Images illustrating differences in community composition and abundance for hard bottom habitats in the Stellwagen Bank sanctuary where fishing is either restricted or allowed.

Top images are from sanctuary sampling sites within the WGoMCA where use of bottom tending commercial fishing gear capable of catching demersal fishes is prohibited. After seven years, these hard substrate seafloor areas are still recovering. The two bottom images show sanctuary areas where fishing with commercial gear on the seafloor is permitted. All of these photos were taken at sampling sites located at approximately 65 meters depth during a 2005 monitoring survey conducted as part of the Seafloor Habitat Recovery Monitoring Project (SHRMP). Images courtesy: Peter Auster, NURC-UConn.



background patterns of natural disturbance have similar effects on sand communities. However, there are measurable effects on emergent species in sand communities indicating the effects of fishing outside of the sliver (Nenadovic, 2009).

5. Community structure is changing across time both inside and outside the sliver in all habitats, suggesting a dynamic environment where both natural and human caused disturbances (from fishing) mediate the composition of seafloor communities (Nenadovic, 2009; Tamsett *et al.,* in review).

6. Analysis of epifaunal communities from inside and outside the sliver along the route of the fiber-optic cable does not demonstrate an effect of the acute impact of the cable being laid but does suggest a chronic effect from fishing (Grannis, 2001; Nenadovic, 2009).

7. The trench produced during the cable burial operation in 2001 is still visible in 2009 along significant parts of the path through the sanctuary based on sidescan sonar records, demonstrating that the passage of eight years has been insufficient time for sediment transport processes to fill in the feature (Auster and Lindholm, unpublished).

8. There are also trends in the composition of particular species and groups consistent with the role of different drivers of community composition (Tamsett *et al.,* in review). For example, the abundance of ascidians (primarily the tunicate *Mogula* sp.) has increased significantly inside the sliver over time while the brachiopod *Terebratulina septentrionalis* has increased outside. The exact mechanism that produced such differences is not clear but various types of direct and indirect interactions, where differential rates of survivorship or competitive interactions mediated by fishing disturbance result in such patterns, are hypothesized. Across the entire area there has been a decline in brittle stars, obviously resulting from some type of area-wide effect, such as the possible heightening of predation due to increasing demersal fish populations.

9. Finally, while community composition tended to be more similar within each station than between stations from each year, the pattern of similarity from 2005 data suggest a great-

er degree of difference in composition between replicates from inside gravel and boulder stations than those paired stations outside. This pattern suggests the dominance of local processes, such as predation and competition, may be driving community composition inside the closed areas (i.e. contributing to greater variation in species distributions within stations) in contrast to larger spatial scale disturbance processes produced either by natural events or fishing that dominate at outside stations. This pattern in community composition is consistent with the types of responses observed in single species, such as those described above.

The SHRMP findings from the hard substrata sampling sites indicate that the WGoMCA is having a significant impact on invertebrate community structure and that the community inside the closed area on both boulder and gravel habitats is recovering from chronic fishing gear impacts (Tamsett *et al*., in review). However, the lack of directionality indicated by that study suggests that community structure under protected and impacted regimes is dynamic and that "recovery" of the seafloor community has not, and perhaps will not, reach a stable climax state. These results suggest recovery without resilience (Paine *et al*., 1998; Gunderson, 2000) given that community structure or component species within the closed area have yet to reach any stable configuration. Only the results of continued monitoring over a longer time scale will determine the operative type of community model involved. For reference, the upcoming subsection on successional shifts in community state discusses generally accepted models of community change.

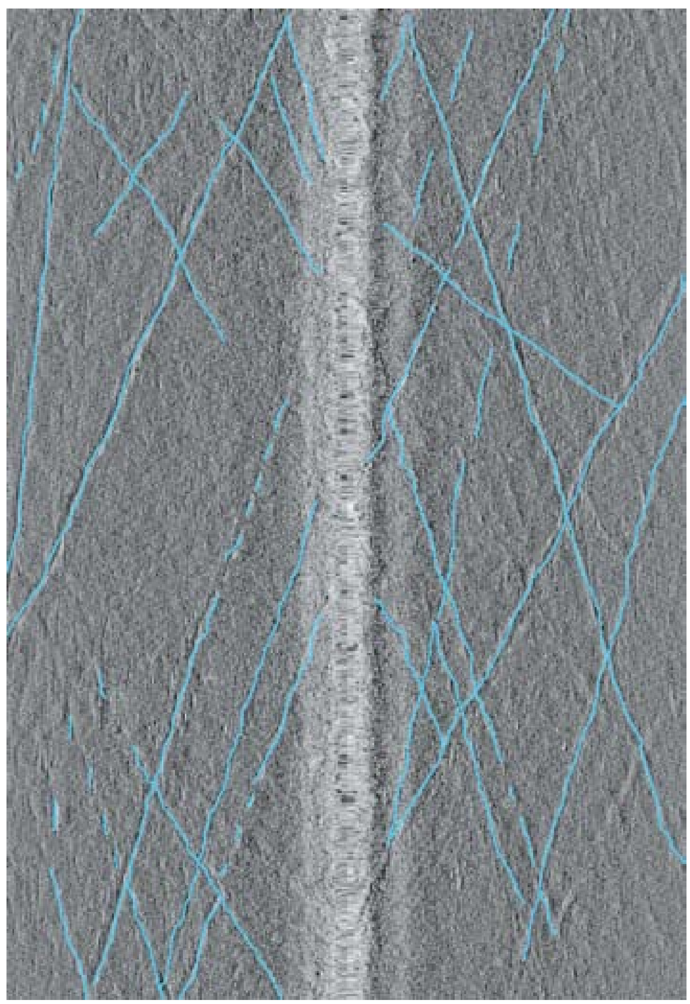
The SHRMP project is longitudinal in design, assessing annual changes in representative seafloor habitats inside and outside of the WGoMCA over a decadal time frame within the Stellwagen Bank sanctuary. Two other studies have measured the effects on benthic communities of closing fishing within the WGoMCA in areas north of the sanctuary over Jeffreys Ledge. Grizzle *et al*. (2009) and Knight (2005) conducted studies, principally during 2002-2004, that compared effects of fishing on benthic habitats inside versus outside the WGoMCA off New Hampshire and Maine, respectively. While results differed somewhat in regard to specific gear-habitat effects and recovery times, the overall conclusion of these three studies to date indicates significant impacts from multiple fishing gear types and subsequent recovery of seafloor habitats and associated benthic communities inside the WGoMCA.

Habitat Disturbance Due to Fishing

The pervasiveness of disturbance by bottom trawling and dredging and the effects of that disturbance are extensively demonstrated by the recent literature, for example: Auster *et al.,* 1996; Auster and Langton, 1999; Ball *et al.,* 1999; Caddy, 1973; Churchill, 1989; Collie *et al.,* 1997; Collie, 1998; Collie *et al.,* 2000; Chuenpagdee *et al.,* 2003; Collie *et al.,* 2005; Dayton *et al.,* 1995; DeAlteris *et al.,* 1999; Dorsey and Pederson, 1998; Duplisea *et al.,* 2002; Engel and Kvitek, 1998; Freese *et al.,* 1999; Friedlander *et al.,* 1999; Grannis, 2005; Grizzle *et al.,* 2009; Hall, 1999; Hansson *et al.,* 2000; Henry *et al.,* 2006; Jennings and Kaiser, 1998; Jennings *et al.,* 2001a,b, 2002; Johnson, 2002; Kaiser *et al.,* 1996; Kaiser, 1998; Kaiser and de Groot, 2000; Kaiser *et al.,* 2002; Kaiser *et al.,* 2006; Knight, 2005; Lindegarth *et al.,* 2000; Mayer *et al.,* 1991; McConnaughey *et al.,* 2000; Messiah *et al.,* 1991; Palanques *et al.,* 2001; Pilskahn *et al.,* 1998; Riemann and Hoffmann, 1991; Rijnsdorp *et al.,* 1998; Roberts *et al.,* 2000; Sanchez *et al.,* 2000; Simpson, 2003; Simpson and Watling, 2006; Smith *et al.,* 2000; Sparks-McConkey and Watling, 2001; Tillin *et al.,* 2006; Thrush *et al.,* 1998, 2001; Tuck *et al.,* 1998; Watling *et al.,* 2001; Watling and Norse, 1998; and Widdicombe *et al.,* 2004. The majority of these studies were conducted in the North Atlantic, and all bear on the kinds of seafloor habitat disturbance due to fishing that pertain to the Stellwagen Bank sanctuary. Many of these studies were reviewed by the NEFMC in its Amendment 13 description of fishing effects on the environment (NEFMC,

Figure 20. Side-scan sonar image of bottom otter trawl tracks over the mud habitat of Gloucester Basin in the Stellwagen Bank sanctuary.

The area depicted (100 m swath width) is extensively furrowed by trawl doors during successive tows by fishing vessels. A trawl door is attached to each side of the mouth of the net to keep it open. Recent trawl tracks are colorized to provide contrast; earlier tracks are evident in the background. The image was made by side-scan sonar towed behind a research vessel in 2005; the center stripe indicates the path of the instrument. Source: NOAA/SBNMS.



2003). An example of the intensity of bottom trawling on a seafloor habitat in the sanctuary is presented in Figure 20.

Effects of Disturbance

The structural complexity of habitats is important to supporting and maintaining biodiversity and population abundance. Based on the studies cited above, it is evident that bottom mobile fishing gear (otter trawls and dredges) can crush, bury and expose marine animals and structures on and in the substratum, sharply reducing structural complexity. This gear can decrease density of organisms, biomass and taxonomic richness in benthic communities. It can shift taxonomic composition towards taxa less tolerant of physical disturbance. It can also alter bio-geochemical cycles. This fishing gear has a number of effects that can profoundly alter the value of habitats for fishes and change the composition of epifaunal and infaunal invertebrate communities as well.

For example, a large number of research studies (e.g., Auster and Langton, 1999) has shown that bottom contact fishing gear has the following general effects on the physical structure of seafloor habitats: (1) smoothing of bedforms like sand waves and ripples; (2) removal of habitat-forming epifaunal species like sponges, bryozoans and corals; and (3) removal of "ecosystem engineers" that produce various structures based on their activities, such as crabs and fishes that produce burrows and depressions.

Studies have also shown generalized effects on community composition and ecosystem processes (e.g. Zabel *et al.,* 2003). Increased disturbance from fishing can shift stable seafloor communities from those that are dominated by slow-growing and long-lived species to those dominated by organisms that are fast-growing and short-lived (i.e., opportunistic or weedy). While communities are often a mosaic of both types, the large scale impacts of fishing can homogenize communities to those dominated by the "weedy" species that gain competitive advantage from periodic disturbance.

Bottom contact fishing gear can alter the biological structure of seafloor habitats as well and influence the diversity, biomass and productivity of the associated biota (Auster *et al.,* 1996). These effects vary according to gear used, habitats fished and the magnitude of natural disturbance, but tend to increase with depth and the stability and complexity of the substrate. The effects are most severe where natural disturbance is least prevalent, where storm-wave damage is negligible and biological processes, including growth and recruitment, tend to be slow. Long-lived epifaunal species, many of which are also structure-forming, can suffer substantial adverse effects. Benthic habitats and the effects of fishing are extensively reviewed in Barnes and Thomas, eds. (2005).

Meta-Analysis of Fishing Effects

Empirical studies of fishing effects realistically can not be done everywhere under conditions that separate the effects of gear type, habitat and community composition. However, it is possible to use a wide range of empirical studies to conduct a meta-analysis that extracts such information from existing studies. Collie *et al.* (2000) showed that inter-tidal dredging and scallop dredging had a greater impact on seafloor communities than did trawling. Further, communities in stable gravel, mud and biogenic habitats (e.g., sponges, corals) were more affected by fishing than communities in unconsolidated sediments like coarse grain sand. Rates of recovery after impacts were fastest in less stable and complex habitats like sand (e.g., six months to one year), while biogenic habitats had the longest recovery, on the order of years to decades. Similar findings regarding differential recovery rates of habitats are reported in more recent studies as well (Link *et al.,* 2005; Stokesbury and Harris, 2006; Collie *et al.,* 2005).

A recent and comprehensive summary of gear effects on benthic marine habitats was prepared by the National Research Council, which verifies and amplifies earlier research findings. This report, entitled "Effects of Trawling and Dredging on Seafloor Habitat" (NRC, 2002) reiterated four general conclusions regarding the types of habitat modifications caused by trawls and dredges:

- Trawling and dredging reduce habitat complexity.
- Repeated trawling and dredging result in discernable changes in benthic communities.
- Bottom trawling reduces the productivity of benthic habitats.
- Fauna that live in low natural disturbance regimes are generally more vulnerable to fishing gear disturbance.

The NRC report also summarized the indirect effects of mobile gear fishing on marine ecosystems. It did not consider the effects of all gear types, only the two (trawls and dredges) that are considered to most affect benthic habitats.

A related 2003 study of the collateral impacts of fishing methods ranked various types of fishing gear based on severity of impacts to habitats and degree of bycatch (Morgan and Chuenpagdee, 2003). The highest impact gears were: bottom-tending trawls, bottom-tending gillnets, dredges (e.g., scallop and clam) and pelagic gillnets. Medium impact gears were: pots and traps, pelagic longlines and bottom-tending longlines. Low impact gears were: midwater trawls, purse seines, and hook and line.

Successional Shifts in Community State

Disturbance has been widely demonstrated as a mechanism which shifts communities (Dayton, 1971; Pickett and White 1985; Witman, 1985; 1987). Auster and Langton (1999) provide an in-depth synthesis of disturbance ecology related to seafloor communities and fish habitat. General models produced from such work are useful for understanding fishing as an agent of disturbance from an ecological perspective and are discussed below.

Assumptions regarding the role of fishing on the dynamics of marine communities generally assert that the cessation or reduction of fishing will allow populations and communities to recover, that is, recover to a climax community state as is the case in long-lived terrestrial plant communities (e.g., the succession of old farm fields to mature forest). That does not always happen in marine ecosystems.

Succession of communities implies a predictable progression in species composition and abundance. Such knowledge of successional patterns would allow managers to predict future community states and directly manage patterns of biological diversity. While direct successional linkages have been found in some communities, others are less predictable. Two generalized models (from Auster and Langton, 1999) that depict patterns in shifts in community state due to disturbance are illustrated and discussed in the Sidebar.

These two models of shifts in community state due to disturbance illustrate the complexities underlying management of biological communities in the sanctuary. Changes of community structure due to disturbance may or may not be predictable based on numerous factors including type of habitat and organism. The models portend that the character and structure of present-day communities in the sanctuary very likely have changed and in ways that may not be strictly reversible.

Current Protection

Sanctuary regulations (15 C.F.R Part 922 Subpart N) prohibit drilling into, dredging or otherwise altering the seabed of the sanctuary; or constructing, placing or abandoning any structure or material or other matter on the seabed of the sanctuary, except as an incidental result of: (1) anchoring vessels; (2) traditional fishing operations; or (3) installation of navigation aids. The exemption for traditional fishing activities reduces the effectiveness of these regulations in managing habitat disturbance, and thereby protecting ecological integrity and managing for biodiversity conservation.

The most effective regulations to date for protecting seafloor habitat and communities in the sanctuary are those promulgated by NOAA Fisheries Service under the MFCMA to restore groundfish stocks in the GoM and protect EFH. Over the past two decades NOAA Fisheries Service, in collaboration with the NEFMC, has promulgated fishing regulations that have significantly reduced fishing effort, and, therefore, habitat impacts to some degree in the northeast region which includes the sanctuary. Examples of these regulations are: reducing fishing days at sea, creating groundfish and habitat closed areas (e.g., WGoMCA), increasing net mesh size to allow escapement of juvenile fish, reducing trawl net roller gear sizes to prevent trawlers from accessing high relief habitat, and creating seasonal closures to protect migrating or spawning species.

While these regulations help to reduce fishing mortality and rebuild fish stocks, with the exception of the WGoMCA and roller gear size reduction, their overall effect on protecting or recovering seafloor habitats and the biological communities of the sanctuary is less clear.

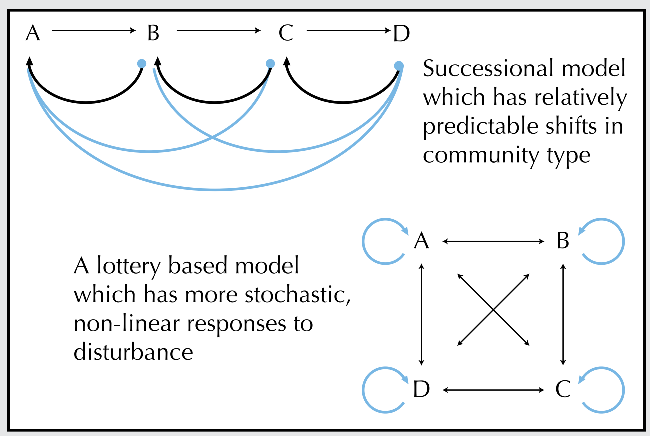
Models of Pattern Shifts in Community State Due to Disturbance

The first pattern is the successional model where communities change from type A to B to C and so forth (Figure 21). There are empirical examples of this type of succession in soft bottom benthic communities. Succession is based on one community of organisms producing a set of local environmental conditions (e.g., enriching the sediments with organic material) which make the environment unsuitable for continued survival and recruitment but are favorable for another community of organisms. Disturbance can move the succession back in single or multiple steps, depending on the type of conditions that prevail after the disturbance. The successional stages are predictable based on the conditions which result from the organisms themselves or from conditions after a perturbation.

The second pattern is the lottery model which is less predictable and disturbance mediated (Figure 21). There are multiple outcomes for community recovery after the end of the disturbance. Empirical studies of such relationships are generally found in hard substrate communities. Shifts in community type are produced by competition and disturbance (e.g., predation, grazing, storms, fishing gear) that can result in shifts toward community types which are often unpredictable because they are based on the pool of recruits available in the water column at the time that niche space becomes available.

Figure 21. Two conceptual models of pattern shifts in community state due to disturbance.

(from Auster and Langton, 1999).



Water Column as Habitat

Status

The water column in the Stellwagen Bank sanctuary represents important habitat for numerous planktonic and nektonic organisms as well as many fishes, turtles, seabirds and marine mammals. In addition to the three major water masses occurring throughout the GoM, each of which provides habitat for a variety of organisms, the interaction of moving water masses with the sanctuary's complex seafloor topography creates local zones of upwelling and mixing that serve as habitat as well. Additionally, features such as thermal fronts and the thermocline (sharp temperature gradients between water packets of differing characteristics) and shear zones (separating countervailing currents), for example, segment and highly structure the open ocean, creating ecotones that serve as unique midwater habitats. An ecotone is a transition area between two adjacent ecological communities.

In general, major surface currents flow counterclockwise in the vicinity of the sanctuary. Local productivity is seasonal with the overturning and mixing of ocean waters from deeper strata during the spring and fall producing a complex and rich system of overlapping midwater and benthic habitats. The heightened seasonal productivity supports a large variety of marine mammal and fish species in the water column. Many of these predators rely on both water column and benthic habitats for foraging.

Water column productivity due to phytoplankton was reported to be quite high at Stellwagen Bank, being consistently highest at the surface where it was more than an order of magnitude greater than at the bottom (Cahoon *et al.,* 1993). Phytoplankton production at Stellwagen Bank is also comparatively high (ca 2.9 g C m^{-2}-d^{-1}) relative to elsewhere over the northeast continental shelf. Typical phytoplankton production rates in the GoM and the mid-Atlantic Bight are ca 0.8 g C $m^{-2}d^{-1}$ (Schlitz and Cohen, 1984; Walsh, 1988) and ca 1.3 g C $m^{-2}d^{-1}$ in shallow portions of Georges Bank (Schlitz and Cohen, 1984). Based on the information in these studies and Sissenwine *et al.* (1984), primary production at Stellwagen Bank is three times greater than the GoM in general and twice as high as at Georges Bank.

While there is concern for impacts to seafloor habitats due to fishing, there is also concern for impacts to water column habitats due to pollution and contamination including biological agents like harmful algal blooms (HABs) and invasive species. Refer to the Sidebar for a description of potential sources of pollution and contamination. Refer to Bothner and Butman (2007) for a summary of processes influencing the transport and fate of contaminated sediments in Massachusetts Bay.

Regular monitoring of key water quality indicators and associated seafloor variables is conducted in and around the sanctuary to detect and evaluate trends that could favor HABs or otherwise threaten environmental functions in the sanctuary. The Stellwagen Bank sanctuary relies on collaboration with the MWRA for routine water quality monitoring and on the occasional assessments of the NOAA National Status and Trends (NS&T) Bioeffects (BE) Program and the National Benthic Surveillance (NBS) Program to understand and characterize the threats to and status of water column and related seafloor habitats in the sanctuary. The NBS Program is a collaborative effort between NS&T and NOAA Fisheries Service. The threat of introduction of water-borne invasive species may be under-appreciated and deserving fuller understanding as provided below.

Monitoring

In 2001, the Stellwagen Bank sanctuary increased the area coverage of water quality monitoring within its boundaries to better determine whether the MWRA sewage outfall, which began operating in September 2000, was causing increased eutrophication and contaminant loading. To leverage resources and obtain compatible information that could be integrated into the existing data base for ongoing monitoring work, the sanctuary added four new stations to MWRA's existing five stations within the sanctuary area (Libby *et al.,* 2006). Werme and Hunt (2008) provide an overview of MWRA outfall monitoring and background information on environmental concerns, monitoring design, and Contingency Plan thresholds for effluent, water-column, sea-floor, and fish-and-shellfish monitoring.

The MWRA's discharge permit recognizes concerns about possible effects of the outfall on the sanctuary and requires an annual assessment of those possible effects. The MWRA classifies stations as near field and far field for the purpose of assessing potential impacts from the sewage outfall; those in the sanctuary are included among the far field stations. During 2001-2005, independent contractors sampled the four additional stations in August and October, which are two of the six MWRA survey periods each year. Sampling included measurements of water column physical variables (salinity, temperature, density structure), nutrients, chlorophyll and dissolved oxygen, as well as the numbers and species of phytoplankton and zooplankton. Due to budgets, the sanctuary discontinued funding for its additional stations in 2006 and MWRA has discontinued monitoring most of its farfield sites except for two in Cape Cod Bay, one at the southern end of the SBNMS and one in the northwest corner just outside the SBNMS boundary. MWRA reduced

Potential Sources of Pollution and Contamination

Much of the pollution reaching the sanctuary comes from non-point sources or from distant point sources. Several waste water treatment facilities discharge directly into Massachusetts Bay, the largest being the Massachusetts Water Resources Authority (MWRA) Boston Harbor outfall located 9.5 miles from Boston and 12 miles west of the sanctuary border. Air pollution from power plants and industrial facilities, some as far away as the mid western part of the country, and urban smog release a variety of chemicals over Massachusetts Bay, some of which are accumulated by organisms.

In addition, the sanctuary is heavily traveled by commercial and recreational vessels and cruise ships that discharge wastes during their voyages. Shipping activities may result in a variety of chemical releases from discharges, spills and/or collisions, and the possibility of importation of invasive species. Other sources of contamination include clean material disposal at the Massachusetts Bay Disposal Site (historical dumping operations there have included hazardous military and industrial wastes and dredge spoils) and disturbances during the laying of underwater pipes and cables (only one of which crosses the sanctuary). Of particular concern are the cumulative impacts of multiple activities that could contaminate the habitats and resources of the sanctuary and increased environmental loading of nutrients and pollutants above scientifically established background levels.

Nutrient enrichment is one factor in the development of harmful algal blooms (HAB). HABs are high densities of toxic phytoplankton (e.g., *Alexandrium* sp.) that can kill marine life and impair human health. Saxitoxin from these organisms was implicated in the death of 14 humpback whales in 1987. HAB events have occurred periodically since 2005 and covered a broad area encompassing all of Massachusetts Bay (including the sanctuary) and Cape Cod Bay. While no injury or mortality of sanctuary resources has been observed, high concentrations of *Alexandrium* cysts have been recorded in the sediment of the sanctuary.

HABs can cause temporary paralytic shellfish poisoning (PSP). On June 14, 2005, at the request of the U.S. Food and Drug Administration, NOAA Fisheries Service took emergency action to temporarily close a portion of Federal waters off the coasts of New Hampshire and Massachusetts to shellfish harvest due to the presence of high levels of the toxin that causes PSP. This area is part of the Temporary PSP Closure Area. The northern component of the PSP Closure Area includes the sanctuary and, when in effect, prohibits all bivalve molluscan shellfish fishing, with the exception of sea scallop adductor muscles harvested and shucked at sea. NOAA Fisheries Service has periodically reinstituted the closure area and most recently extended it through December 31, 2010. Refer to the Web site http://www.nero.noaa.gov for the final emergency rule and background information on this series of temporary closures.

the sampling stations based on nine years of data showing no farfield effect of the outfall. MWRA will increase the sampling frequency to nine times per year for the farfield stations which will help address the sanctuary's concern about major rain events that result in increased effluent discharge.

The four sanctuary stations were strategically placed to detect nutrient inputs to the sanctuary from the GoM and Merrimack River to the north, as well as from the MWRA outfall to the west (Figure 22). The data allow inferences about fine scale circulation patterns and water column productivity in the sanctuary. The data were also entered into a three-dimensional computer model that was developed to understand how the system might respond to increased and decreased levels of nutrients, dilution of outfall and dispersion (Jiang, 2006).

While the timeframe for analyses reported in the management plan covers 1991-2005, additional results to date show no evidence of increased eutrophication or unacceptable contaminant loads in the sanctuary relative to the outfall startup (Hartwell *et al.,* 2006; Werme and Hunt, 2006, 2007; Werme *et al.,* 2008, 2009). Results from the 1991-2005 timeframe are considered to be generally representative of continued water quality conditions

Figure 22. Location of water column stations, including the additional Stellwagen Bank sanctuary stations sampled in August and October 2001-2005.

F32 and F33 sampled in February, March and April; other stations sampled in February, March, April, June, August and October. Source: MWRA, 2006.

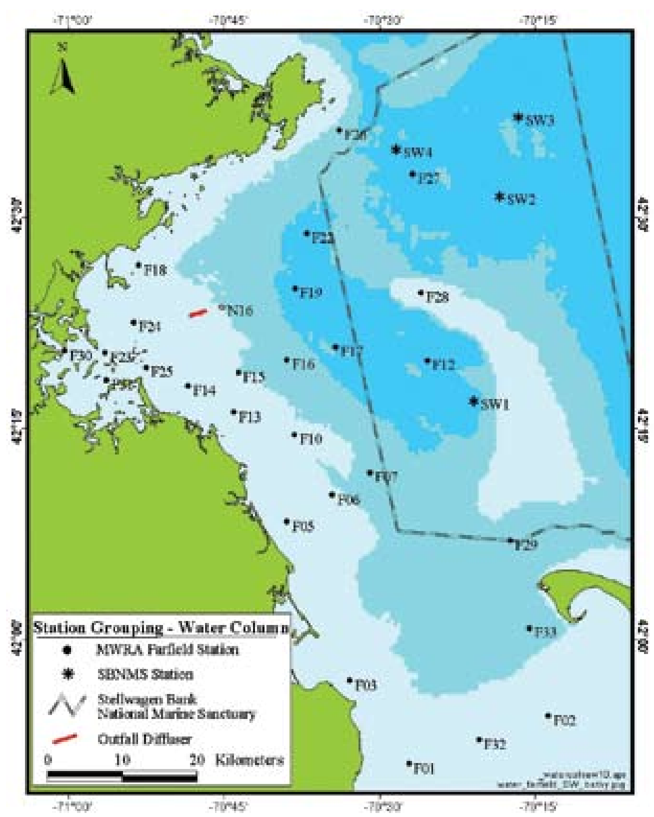
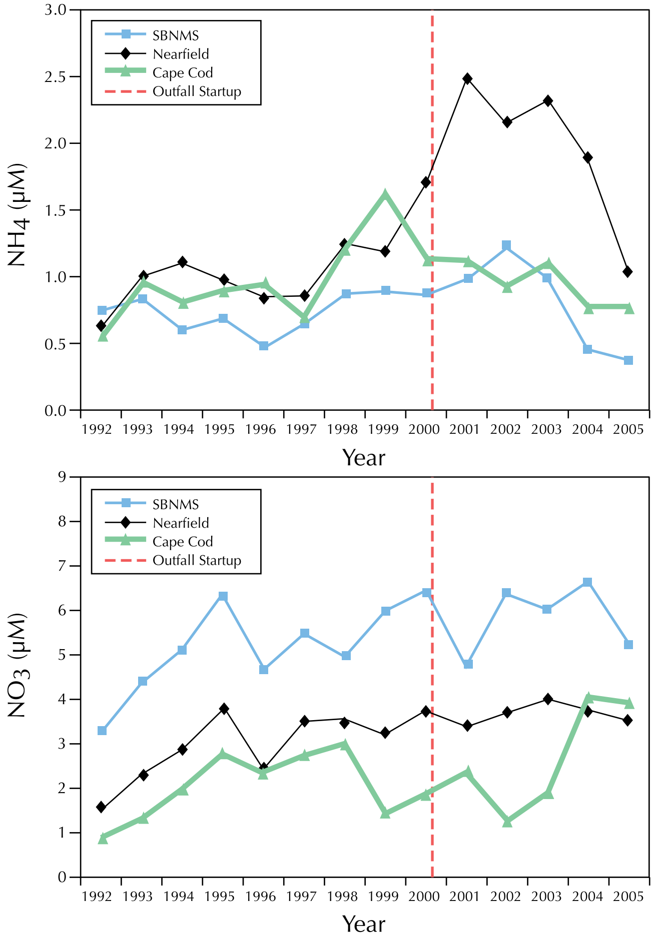


Figure 23. Annual mean ammonium (top) and nitrate (bottom) concentrations in the Stellwagen Bank sanctuary, the nearfield and Cape Cod Bay relative to the outfall startup.

Source: MWRA, 2006.



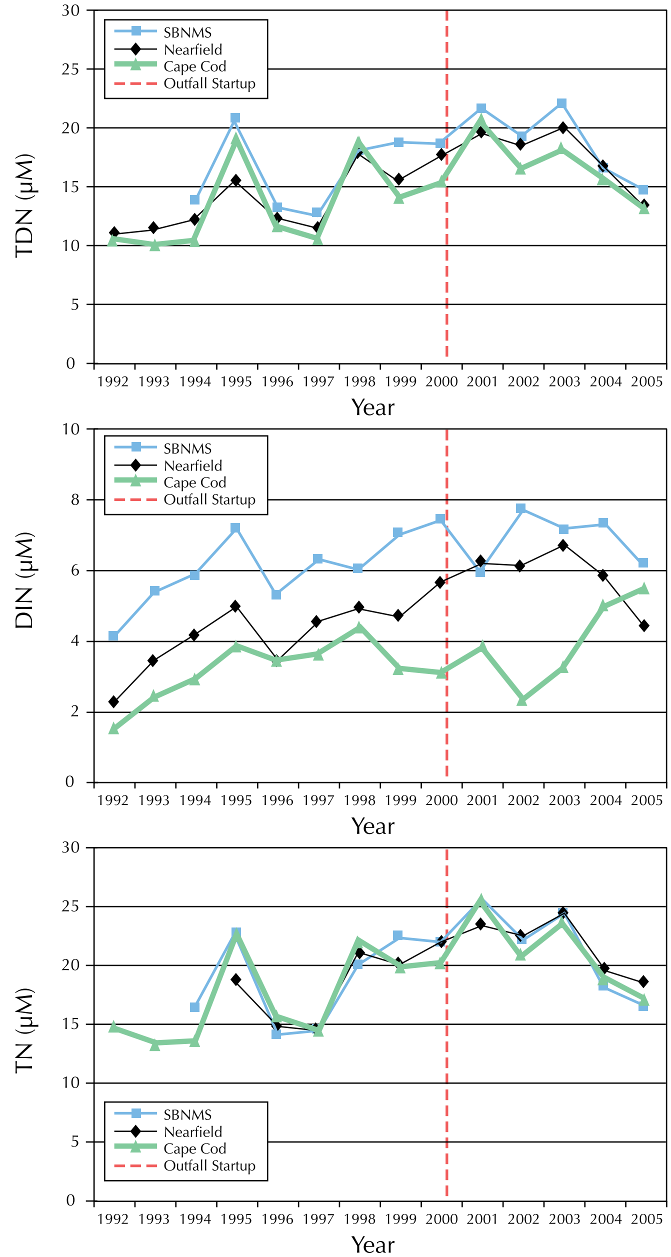
within the sanctuary. Additionally, this timeframe overlaps and allows comparison with the results of assessments of sediment contamination conducted during 1983-1994 and in 2004 as reported in the following section.

Overall, water quality within the sanctuary was excellent during 2005 and there was no indication of any effect of the MWRA outfall (Libby *et al.,* 2006). While ammonium concentrations rose in the near field sampling stations following start of the outfall diversion, there has been no parallel annual increase in the area of Stellwagen Bank or Cape Cod Bay (Figure 23 top). Nitrate concentrations (Figure 23 bottom) continue to show an upward trend in offshore Massachusetts Bay and in the near field, a regional phenomenon that predates the outfall diversion and is not well understood.

Other measurements of nitrogen and dissolved phosphate also show these long-term trends. Concentrations of total dissolved nitrogen (Figure 24 top) and dissolved inorganic nitrogen (Figure 24 middle) have consistently been higher in samples from the sanctuary than those measured at other

Figure 24. Top: annual mean total dissolved nitrogen (TDN); Middle: dissolved inorganic nitrogen (DIN); Bottom: total nitrogen (TN) in the Stellwagen Bank sanctuary, the nearfield and Cape Cod Bay relative to the outfall startup.

Source: MWRA, 2006.

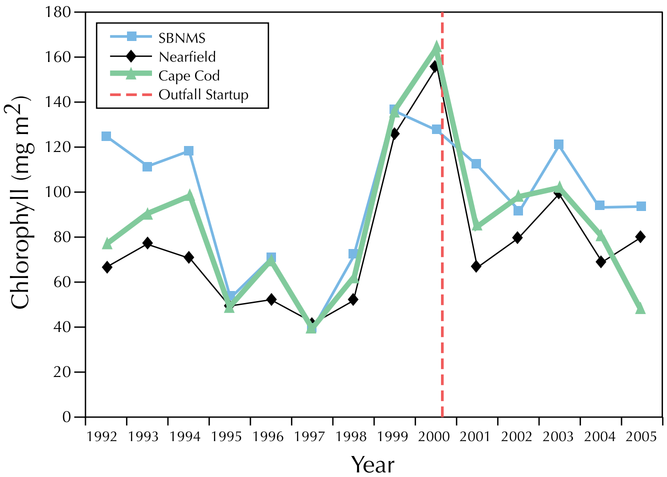


stations. In contrast, concentrations of total nitrogen have been similar in all regions (Figure 24 bottom).

The mean annual chlorophyll levels have not changed in response to the outfall discharge (Figure 25). Annual chlorophyll levels were similar in the nearfield, Cape Cod Bay and Stellwagen Bank. Concentrations of dissolved oxygen and percent saturation have not declined in the Stellwagen Basin or in the near field (not shown). Rather than showing a decline, levels in 2005 were slightly high compared to the baseline years (1992–2000).

Figure 25. Annual mean chlorophyll in the Stellwagen Bank sanctuary and other regions relative to the outfall startup.

Source: MWRA, 2006.



No changes in concentrations of sewage tracers or sewage-related contaminants were observed in the sediment samples from stations within the sanctuary and there were no changes in community parameters in 2005 (Maciolek *et al.,* 2006). The deep-water stations continued to support a distinct infaunal community with recognizable differences from communities in the nearfield and Cape Cod Bay. Benthic community parameters at individual stations showed no pattern of change following start-up of the outfall in 2000 (Figure 26). Overall the numbers of individual organisms and species per sample have increased, as has the index of species diversity (log series alpha), paralleling results from throughout Massachusetts Bay. No consistent pattern has been found that relates to outfall operation.

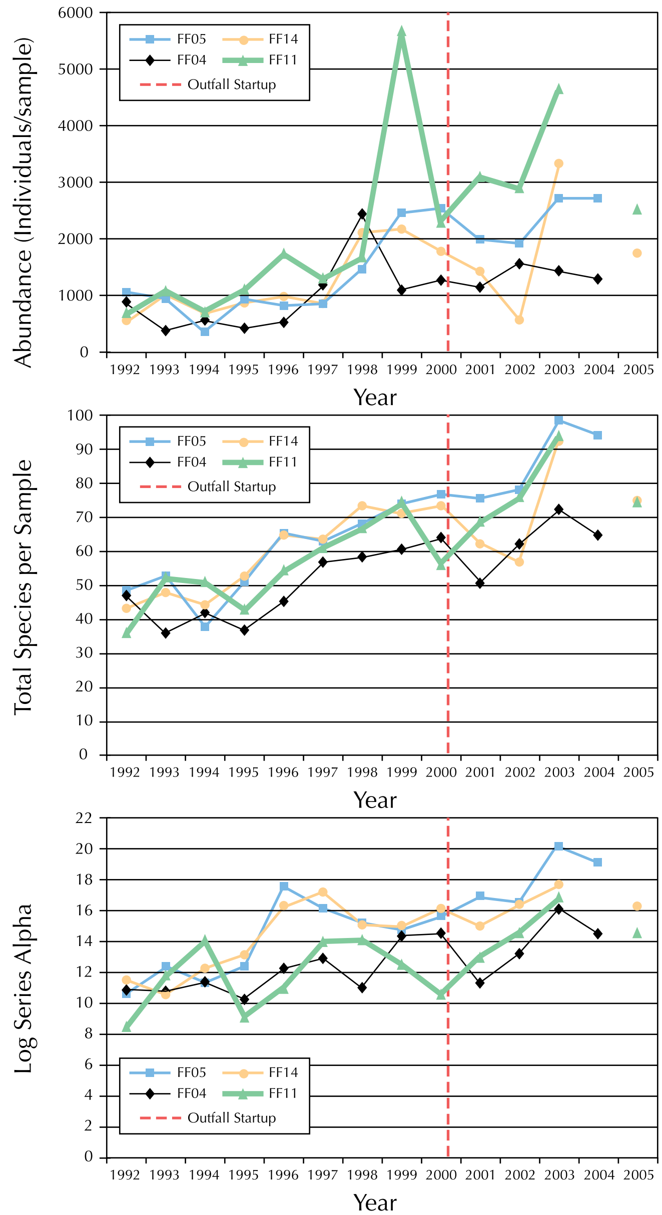
Assessment

In 2004, field samples were taken to assess the status and trends of chemical contamination in sediments and resident biota and to assess the biological condition of the various habitat types found in the Stellwagen Bank sanctuary area (Figure 27). Sampling efforts employed a combination of the NOAA NS&T BE Program and the NBS Program protocols. The BE Program assesses sediment contamination, toxicity and benthic community condition. The NBS Program also addresses sediment contamination, in addition to contaminant body burdens and histological indicators in resident fish. Data from 2004 were contrasted with historical (1983–1994) NOAA data, and the data from the MWRA to assess the spatial and temporal trends in chemical contamination in and around the sanctuary. The work reported here was done by NCCOS in cooperation with the sanctuary and unless indicated otherwise, the following account is excerpted from Hartwell *et al.* (2006).

In an analysis of the spatial distribution of select contaminants in sediments, the lowest concentrations were consistently found in the Stellwagen Bank sites (Figure 28). Contaminant data from the 2004 sampling effort are consistent with

Figure 26. Benthic community parameters at stations (FF05, FF04) in or (FF14, FF11) near Stellwagen Bank sanctuary (1992-2005) relative to the outfall startup.

Source: MWRA, 2006.



historical data. The NS&T NBS long-term sediment monitoring data (1984–1991) showed similar spatial distribution patterns. The larger pattern indicates a gradient of contaminant concentration from inshore to offshore. This suggests an export of contaminants from Boston Harbor eastward toward Stellwagen Bank and southward toward Cape Cod Bay via suspended sediments and/or the water column.

The NBS data show similar patterns of spatial distributions based on contaminant concentrations in winter flounder liver. Overall, tissue contaminant concentrations were higher in organisms collected in and around Boston Harbor than those from remote sites, with intermediate concentrations in the mid-Bay area between the Harbor and Stellwagen Bank. These observations also suggest that export from Boston

Harbor is a source of contamination for Massachusetts Bay and possibly for the sanctuary.

The Hartwell *et al.* (2006) study evaluates and summarizes contaminant conditions in the sanctuary area over a period of about twenty years. The current (2004) status of chemical contaminants in the shallow portions of Stellwagen Bank is significantly lower than those of the other regions of Massachusetts Bay including Cape Cod Bay. Boston Harbor is the most polluted zone of the Massachusetts Bay/Cape Cod Bay system. Sediments in the deep areas in Stellwagen basin are accumulating contaminants from a variety of sources.

The temporal assessment revealed no statistically significant trends for trace metals and Polycyclic Aromatic Hydrocarbons (PAHs), while banned but persistent organic contaminants (DDTs and chlordanes [both pesticides]) show very slow decreasing trends over the monitoring years. The persistence of some organic compounds at relative high concentrations in Boston Harbor implies that the Harbor may be a continuing source of contaminants to other areas of Massachusetts Bay including the sanctuary. However, data in the current study indicates that pollution impacts in the sanctuary appear minimal and are largely consistent with the finding from MWRA monitoring.

In a separate study, a comparison of PCBs, organochlorine pesticides and trace metals in cod liver from Georges Bank

Figure 27. Location of the NOAA NS&T BE sampling sites (2004) within Massachusetts Bay including the Stellwagen Bank sanctuary.

Sampling was done within six zones indicated by the red lines: Boston Harbor, Massachusetts Bay, Area Between Bays, Cape Cod Bay, Stellwagen Basin and Stellwagen Bank. Source: Hartwell *et al.,* 2006.

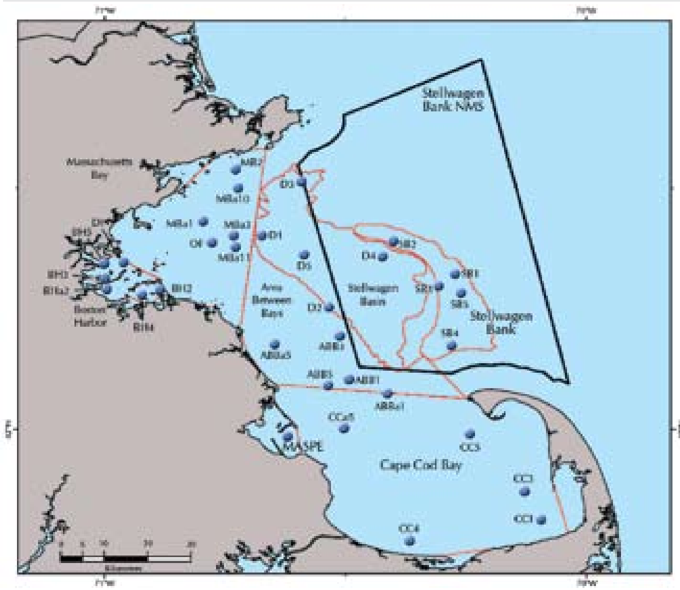
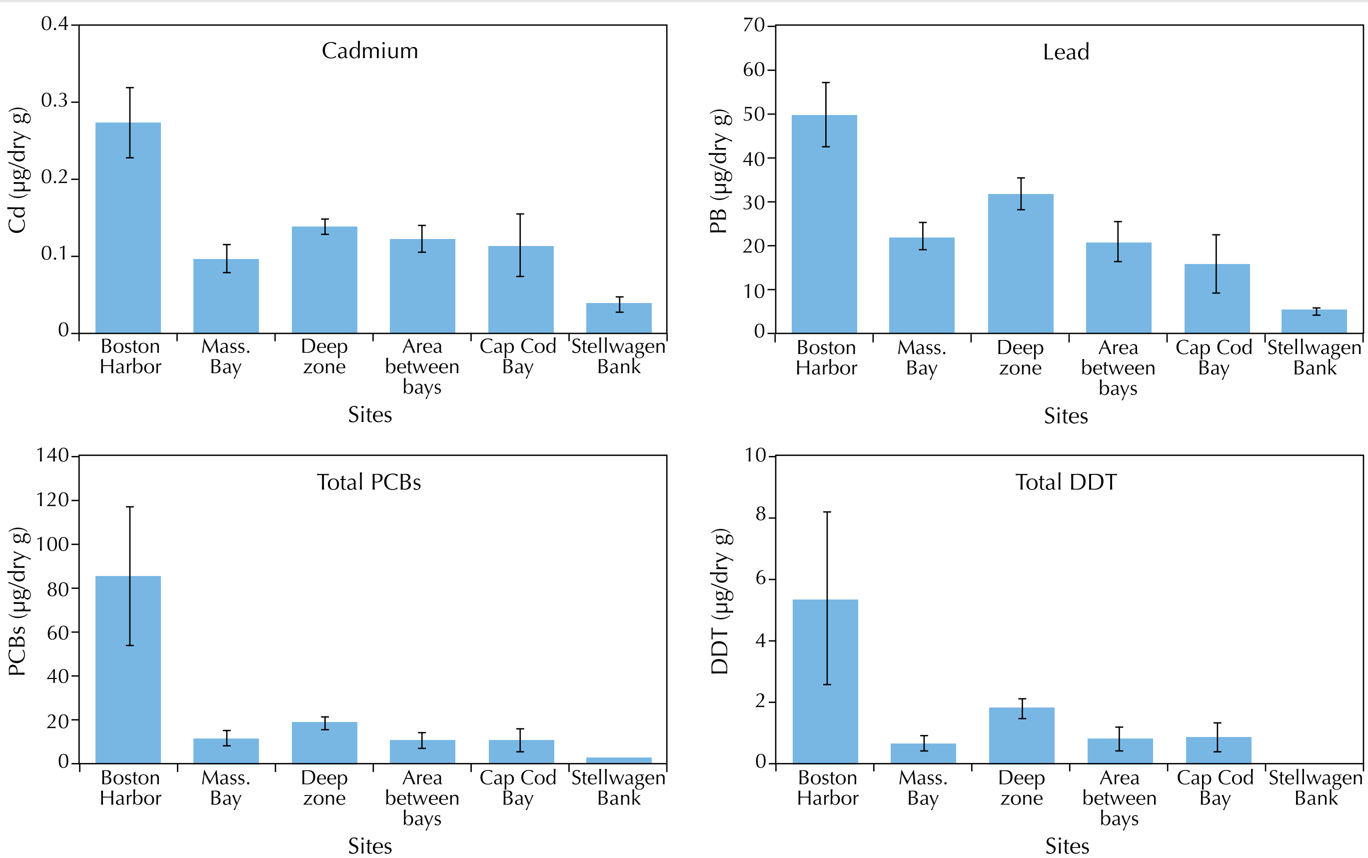


Figure 28. Concentration of contaminants, select metals (Cd [cadmium] and Pb [lead]) and organic compounds (total PCBs [Polychlorinated Biphenyls] and DDT [pesticide]), in sediments within Massachusetts Bay including the Stellwagen Bank sanctuary.

Source: Hartwell *et al.,* 2006.



(GB), Wilkinson Basin (WB) and Stellwagen Bank (SB) was conducted in 2003-2004 (Monosson and Lincoln, 2006). Heavy metals As, Cu, Se, and Zn were detected in cod livers at all sites, while Hg, Cd, and Ag were detected primarily in cod livers from GB. Several metals including Al, Cr, Mn, Tl, and V were detected in only a few fish across all sites or not at all. Concentrations of detectable metals in female cod livers from GB tended to be consistently higher than in cod from WB of SB. PCBs were detectable in the majority of cod livers from all sites with the highest mean concentrations measured in female cod livers from SB. Of the several organochlorine pesticides and their metabolites analyzed in this study, only DDT and its metabolites, α-chlordane, endrin and heptachlor were detected in more than 50% of the samples across the sites. While detectable, these different contaminants tended to be present in relatively low concentrations, and the authors conclude that the levels of contamination in cod at these sites pose little risk to reproduction and development in this species.

Invasive Species

Invasive species, also commonly referred to as non-indigenous, alien, exotic, introduced, nuisance or bio-invader species, are organisms that have moved into an area outside of their natural geographic range, often assisted by anthropogenic agents (e.g., ships, aquaculture). Once introduced, marine invasive species can spread rapidly by water borne dispersal of planktonic eggs and larvae. Their environmental effect can be similar to that of the relatively rare species in a biological community that, when triggered by environmental signals, suddenly expands in population and geographic distribution with negative consequences (e.g., HABs). Once established, their numbers can be difficult to control.

Efforts are in progress to eradicate outbreaks of invasive species at widely scattered locales around the world (Bax *et al.,* 2001). As rates of bio-invasions continue to increase, the need will increase to reduce the impact of such invaders and to provide control options (Thresher and Kuris, 2004). However, the public trust nature of marine resources and the openness of marine systems, particularly over large spatial scales such as the GoM or even the sanctuary, potentially compromise many of the solutions heretofore used to manage terrestrial and aquatic invasive species, e.g., physical removal, biocidal eradication, environmental remediation (Lafferty and Kuris, 1996; Thresher 2000; Kuris, 2003). Morris and Whitfield (2009) address the challenges to controlling and managing invasive Indo-Pacific lionfish along the southeast U.S.A. within areas of high ecological importance including national marine sanctuaries.

Invasive species are recognized as a serious emerging threat to biological diversity (Drake and Mooney, 1989). Impacts of invasive species threaten 36% of marine species, yet only 8% of the conservation studies published on marine systems have dealt with this topic (Lawler *et al.,* 2006). Importantly, community ecology theory can be used to understand and to possibly anticipate biological invasions by applying new concepts to alien species and the communities that they invade (Shea and Chesson, 2002) (see Sidebar). To be forewarned is to be forearmed.

Long evident in the management of agricultural pests, early detection and rapid response afford the greatest opportunity to control pest invasions. Thresher (2000) evaluated the results of efforts to control marine invasive species and makes four key points. (1) Exotic species have been and continue to be introduced by a range of vectors; priorities for management action need to be based on a critical evaluation of the real risks posed by each vector, and encompass an understanding that even major effort directed at a few vectors will not prevent new incursions of invasive species. (2) Eradication of new incursions is achievable, but is uncommon and limited to those situations where the exotic was either detected quickly or otherwise still had a limited distribution. (3) Long-term options for management of invasive species have to take into account social and cultural issues that make some options unfeasible. And (4), groups likely to pose major threats in the future include pathogens, marine macroalgae and genetically enhanced production lines developed for use in mariculture.

Specific Occurrences

Didemnum sp. 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). It is part of a growing global problem of tunicate invasions (Lambert, 2007) that includes southern New England and the GoM (Dijkstra *et al.,* 2007a, b; Osman and Whitlatch, 2007; Mercer *et al.,* 2009). *Didemnum* sp. is a particular concern on Georges Bank (Valentine *et al.,* 2007; Lengyel *et al.,* 2009; Morris *et.al.,* 2009; York *et al.,* 2008) where detailed analysis of bottom photographs suggest it is able to out-compete other epifaunal and macrofaunal taxa and where it has had a significant impact on the species composition of the benthic community (Lengyel *et al.,* 2009). At present, there is no evidence that the spread of the tunicate there will be held in check by natural processes other than smothering by moving sediment (Valentine *et al.,* 2007). *Didemnum* sp. has the potential to become a significant problem in the sanctuary as well.

First observed in 2003, *Didemnum* sp. has invaded gravel habitats on Georges Bank fishing grounds and the infestation is persistent and increasing in density (USGS, 2006). Within the 88 sq mi study area, the colonies doubled at 75 percent of the sites observed in 2005 and 2006. Preliminary evaluation of the sample data indicates that 50-75 % of the gravel is covered at some study sites. Sea-squirt mats smother the gravel habitat and render it unusable by the native community; no other species are known to prey on or over-grow the mats. The tunicate potentially can be spread by mobile bottom fishing gears that break-up and fragment the colonies and aid in their dispersion and colonization of new areas. For more information visit URL http://woodshole.er.usgs.gov/project-pages/stellwagen/didemnum/.

Didemnum sp. was also noted as occurring in the Stellwagen Bank sanctuary as early as 2003. During 2009 the sanctuary worked with researchers at WHOI using HabCam to continuously photographically survey, at high resolution along transects, the most likely seafloor habitats within the sanctuary for infestation by *Didemnum* sp. and to sample possible infestations to confirm presence at the time of detection. HabCam is a towed camera sled originally designed as a tool to survey sea scallops which has evolved into an optical habitat mapping system for characterizing benthic community structure, sediment characteristics and water column properties. This effort is the first comprehensive assessment of a major harmful invasive species to be undertaken in the sanctuary and pending findings, may serve as the foundation to help formulate and direct potential control actions.

Biological agents such as phytoplankton spores or cysts which develop HABs can behave similarly to invasive species. Nutrient enrichment is one factor in the development of HABs, but so too are the niche opportunities created by the disturbance of their associated biological communities. These communities occupy water column and seafloor habitats and support the HAB organism in its various life stages. Planktonic and benthic predators as well as competitors for seafloor habitat settlement space serve as natural controls that limit population. HAB events due to the toxic phytoplankton *Alexandrium* sp. have been recorded in the sanctuary since 2005. As noted above, some of the highest concentrations of *Alexandrium* cysts in Massachusetts Bay and Cape Cod Bay have been recorded in the sediment of the sanctuary.

Means of Introduction

While niche opportunities for invasive species may be created by human activities that disturb biological communities and their habitats, the primary means by which many of these invasive species are introduced in the marine environment is via ballast water from ships. Scientists estimate that as many as 3,000 alien species per day are transported by ships around the world; however, not all transported species survive the trip or exposure to their new environment (MITSG, 2004). Other methods of introduction include:

Community Ecology Theory Relating to Biological Invasions

Two concepts that are relevant to understanding the introduction of invasive species in the GoM and the Stellwagen Bank sanctuary are: community maturity and niche opportunity (Shea and Chesson, 2002).

Community Maturity. Community maturity is defined as the opportunity an ecosystem has had to accumulate species and for species adaptation within the ecosystem to have taken place. It depends on the time that the ecosystem has had the current climate, including its short-term fluctuations and recurring disturbance events. Maturity depends also on the size of the species pool that has historically served as a source of species to the ecosystem.

Biological communities that have had less evolutionary time to assemble, and less time for their constituent species to adapt to the local conditions, are likely to have fewer species with broader niches. Species in these communities might also have lower competitive abilities than those in communities such as coral reefs) that have had a longer time to evolve under their present environmental regime. The former communities, which characterize those in the GoM, tend to be less invasion resistant.

The North Atlantic is relatively young, the assembly of its biota from the North Pacific is recent, i.e., 3.5 Mya (Vermeij, 1991), its nearshore environments have been frequently glaciated causing localized extinctions at approximately 20,000 year cycles (Adey and Steneck, 2001), and its species pool is comparatively low throughout the region. On the basis of community maturity, both the GoM and the sanctuary as a subset would seem inherently susceptible to biological invasion.

Niche Opportunity. Niche opportunity is a concept which defines conditions that promote invasions in terms of resources, natural enemies, the physical environment, interactions between these factors, and the manner in which they vary in time and space. Niche opportunities vary naturally between biological communities but can be greatly increased by disruption of communities, i.e., disturbance. Recent niche theory predicts that low niche opportunities (high invasion resistance) result from high species diversity (Stachowicz *et al.*, 1999; Shea and Chesson, 2006). This theory has been confirmed in experimental communities of sessile marine invertebrates where increased species richness significantly decreased invasion success, apparently because species-rich communities more completely and efficiently used available space (Stachowicz *et al.*, 2002).

The sanctuary would also seem prone to biological invasion because of the niche opportunities afforded (together with the sanctuary's location amid extensive commercial shipping traffic that can serve as primary vectors for the introduction of exotics from hull bottoms and ballast water). The majority of the sanctuary area is chronically disturbed by fishing, especially seafloor habitats regularly swept by bottom otter trawling. The results of the SHRMP research (described in the subsection on Seafloor Habitats) indicate the greater relative ecological importance of physical disturbance by fishing versus natural events such as storms. See also Figure 19 in this document for portrayal of seafloor habitats in the presence and absence of bottom contact fishing and the respective difference in their associated biological complexity.

Analysis of historical baselines indicates that the diversity of bottom-dwelling species in the western GoM including the sanctuary area appears to have declined significantly from ca. 1900 to 2000 due to the extensive exploitation of fish populations (Claesson and Rosenberg. 2009). The widespread chronic disturbance of seafloor habitats due to fishing and the history of lowered species diversity are factors that may create niche opportunities for biological invasion in the sanctuary.

- Organisms attaching to the hulls of vessels
- Algae used as packing material for fisheries products
- Fouling or accumulation of organisms in fishing nets that are then re-deployed in other areas
- Mariculture of introduced marine species (e.g., fish, shellfish and seaweed)
- Natural processes such as ocean currents

The introduction of invasive species is considered to be one of the most harmful types of disturbances that can occur within any ecological system (Dietz, 2005). Once established, these species have the potential to change the structure, pattern and function of a biological community. Some of the ecological impacts associated with the introduction of invasive species in the marine environment include:

- Occupying habitat space and competing for food of native species
- Altering the gene pools of native organisms through cross breeding
- Shifting predator/ prey relationships
- Spreading disease and/or parasites

These impacts can take time to present themselves. Oftentimes invasive species, although present, remain in low abundance until some aspect of their environment changes allowing their competitive release against native species. These changes could be the result of a change in temperature that allows for an increase in growth rate or reproduction, or a change in the abundance of a native competitor or predator that enables the invasive to become better established (Dietz, 2005).

General Status

A growing number of non-native marine organisms are appearing in the waters of the GoM (Table 4). Of these only the tunicate *Didemnum lahillei* is documented from the Stellwagen Bank sanctuary. Researchers attribute this increase in number of invasive species to two regional trends: (1) warming coastal waters becoming more hospitable to non-native species; and (2) lower biodiversity resulting from the urbanization of shore lands and the increase in human activity and pollution stressing critical marine habitats (Dietz, 2005). According to the Massachusetts Institute of Technology Sea Grant (MITSG) Rapid Assessment Survey (RAS) conducted in August of 2000 and 2003, a total of 34 introduced organisms, several of which were identified for the first time in this region, and 37 organisms whose native geographic distribution is unknown were discovered throughout New England coastal waters (Pederson *et al.,* 2005). For more information visit URL http://www.usm.maine.edu/gulfofmaine-census/Docs/About/Organisms/Invasive.htm.

Table 4. Inventory of known invasive species to the Gulf of Maine region.

Of these only the ascidian (tunicate) *Didemnum lahillei* is documented from the Stellwagen Bank sanctuary. Common name is included in parentheses if known. Source: Dietz (2005).

Scientific Name and Type of Organism
Chlorophyta (green algae)
Codium fragile (deadman's fingers, green fleece)
Rhodophyta (red algae)
Bonnemaisonia hamifera
Grateloupia turuturu
Lomentaria clavellosa
Lomentaria orcadensis
Neosiphonia harveyi
Porifera (sponges)
Halichondria bowerbankia (bread-crumb sponge)
Cnidaria (hydroids, anemones, jellyfishes)
Cordylophora caspia (colonial hydroid)
Diadumene lineate (striped anemone)
Sagartia elegans (purple anemone)
Polychaeta (segmented worms)
Janua pagenstecheri (formerly *Spirorbis pagenstecheri*) (bristleworm)
Gastropoda (snails)
Littorina littorea (common periwinkle)
Bivalvia (clams, oysters, mussels)
Ostrea edulis (European oyster)
Arthropoda (crabs, shrimps)
Praunus flexuosus (mysid shrimp)
Ianiropsis sp. (isopod)
Caprella mutica (skeleton shrimp)
Microdeutopus gryllotalpa (amphipod)
Carcinus maenas (European green crab)
Hemigrapsus sanguineus (Asian shore crab)
Anisolabis maritime (maritime earwig)
Bryozoa (moss animals)
Barentsia benedeni
Bugula neritina
Membranipora membranacea (lacy crust bryozoan)
Ascidiacea (tunicates, sea squirts)
Ascidiella aspersa
Botrylloides violaceus
Botryllus schlosseri (golden star tunicate)
Didemnum lahillei
Diplosoma listerianum
Molgula manhattensis (sea grapes)
Styela canopus (formerly *Styela partita)*
Styela clava (club tunicate)
Protozoa (single-celled organisms)
Haplosporidium nelsoni (Eastern oyster parasite)
Perkinsus marinus (Eastern oyster parasite)
Bonamia ostreae (European oyster parasite)

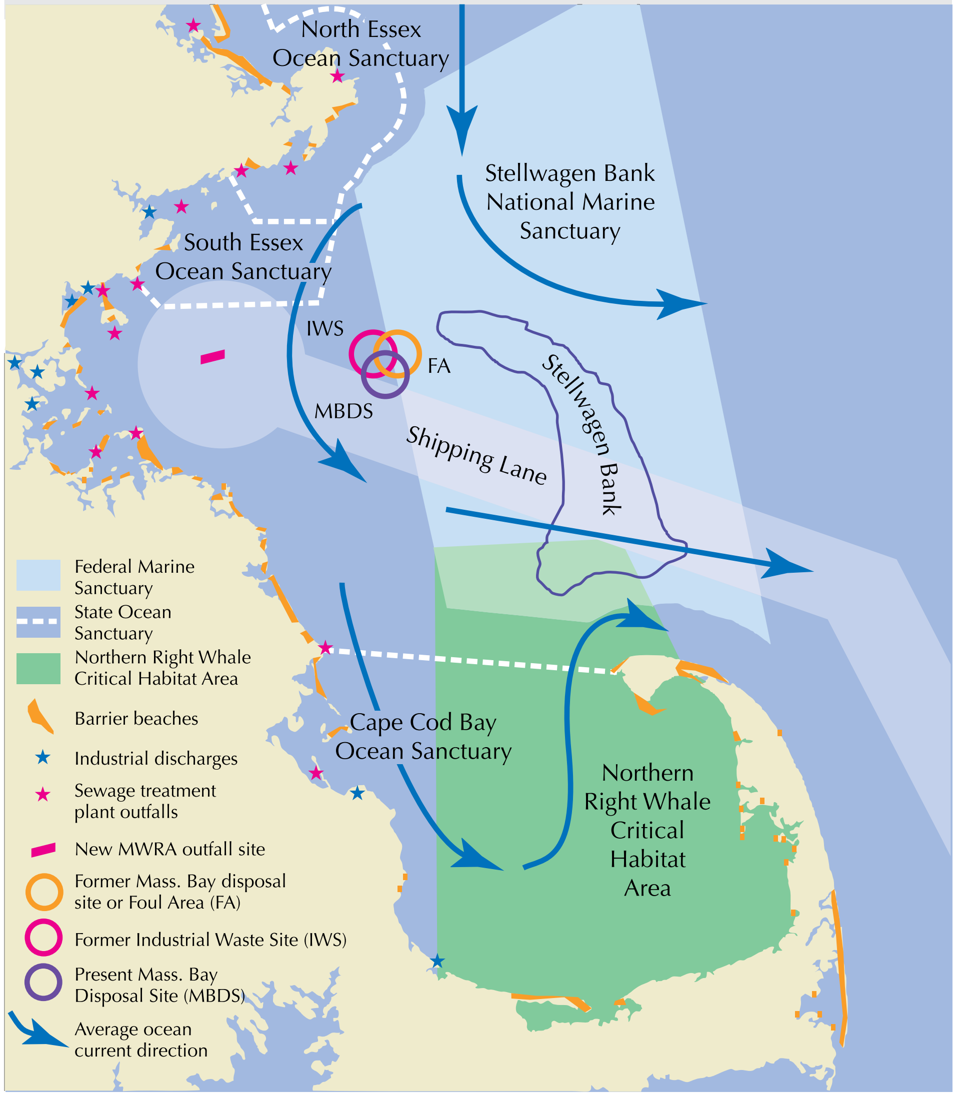
Pressures

Although studies show that water quality in and around the Stellwagen Bank sanctuary is currently at acceptable levels by most standards, the continuing pressures of point- and non-point sources of pollution are cause for continued concern and constant vigilance. Given the sanctuary's proximity to the populous coastal zone in Massachusetts, New Hampshire and southern Maine, as well as being "downwind" from the industrial activity of the mid-west and northeastern part of the U.S., the sanctuary is exposed to pollutants from a variety of anthropogenic sources. These sources include direct discharge of waste to coastal waters (generally referred to as point sources) and indirect contamination (generally referred to as non-point sources).

Point source discharges potentially impacting the sanctuary include discharges from publicly owned treatment works (POTWs), industrial discharges permitted under the National Pollutant Discharge Elimination System, effluents from combined sewer overflows (CSOs) and disposal of dredge materials at the MBDS. Nonpoint sources of contamination entering the sanctuary, such as pesticides, manufacturing chemicals, fertilizer and automobile runoff are primarily derived from the rivers of the GoM, especially the Merrimack River, discharges from vessel traffic and atmospheric inputs.

Figure 29. Location of sewer outfalls, the MWRA outfall, industrial discharge sites and dumping/disposal sites within Massachusetts Bay.

Also indicated are the locations of state ocean sanctuaries, the Cape Cod Bay Right Whale Critical Habitat Area and the Stellwagen Bank sanctuary as well as the pattern of general ocean circulation for the area. Source: MWRA (2004).



While it appears that inputs from point source discharges have been decreasing over the past decade, it has been difficult to adequately estimate the magnitude of the non-point source inputs. A major component missing in the present MWRA and the Stellwagen Bank sanctuary water monitoring projects is "event-driven" sampling geared to wastewater system failures and storm-water overflows. While 98% of the effluent in 2002 underwent secondary treatment, for example, there was still part of the waste-stream that was released untreated or only partially treated due to storm events and temporary inability of the facility to handle the overflow.

The most significant types of point and non-point source discharge and disposal activities occurring in the sanctuary vicinity are discussed in greater detail below.

Sources

Municipal Waste Discharges

Massachusetts Bay and Cape Cod Bay historically have received inputs of waste in the form of effluent or sludge from a number of pipes extending from municipal wastewater treatment plants along the coast of Massachusetts (Figure 29). In the past, the total combined flow of this material was reported to be 566 million gallons per day (MGD), with approximately 500 MGD of that total being discharged by the MWRA treatment works at Deer and Nut Islands, the plants that served the greater Boston Area.

These discharges into Boston Harbor combined with CSOs were considered to be the greatest point sources of contaminants (metals, PAHs, PCBs, nutrients) to the Massachusetts Bay area (Menzie-Cura, 1991). However, over the years improved treatment and pre-treatment methods and technologies have helped to dramatically lessen the quantity of pollutants discharged into the Massachusetts Bay/Cape Cod Bay system (MWRA, 2002).

In a major effort to improve the quality of waste water entering into Massachusetts Bay, the MWRA constructed a new wastewater treatment facility on Deer Island. The facility, completed in 2000, provides a more effective, secondary treatment of the wastewater and eliminates the discharge of sludge into coastal waters. This new plant also moved the discharge point, known as the ocean outfall, from the entrance of Boston Harbor to the waters between 12.7 km and 15.1 km (7.9 mi. and 9.4 mi.) east-northeast of Deer Island inside Massachusetts Bay.

The MWRA is the discharge site of most significance to the sanctuary, with the new location being sited approximately 23.12 km (12.5 nm) from the sanctuary western boundary. The facility discharges 350 million gallons of secondary treated sewage per day. While the new MWRA outfall tunnel remains a leading source of contaminants in Massachusetts Bay, the repeated environmental monitoring and assessments conducted by the MWRA and NOAA discussed above conclude that scientifically determined baselines for key indicator variables are not being exceeded in the sanctuary and adjacent areas.

Currently, under the Massachusetts Ocean Sanctuaries Act (MOSA) any new discharge of wastewater into areas designated as ocean sanctuaries by POTWs and CSOs is prohibited along the coast of Massachusetts except for the area between Marshfield and Lynn. However, according to the MOSA, existing wastewater treatment plants may increase their discharge volumes if a case of "public necessity and convenience" can be made (Massachusetts Department of Conservation and Recreation, M.G.L. c. 132A, 12A-16F, 18, and 302 CMR 5.00).

Massachusetts Bay Disposal Site

Between the 1940s and the 1970s, numerous offshore areas throughout Massachusetts Bay were used for the disposal of a variety of industrial waste products including canisters, construction debris, derelict vessels and radioactive waste. These activities were largely unregulated and unrecorded. Today, this type of disposal activity is not allowed within Massachusetts Bay. Currently there are only two dredge disposal sites active within Massachusetts Bay and Cape Cod Bay: the MBDS designated in 1993, and the Cape Cod Bay Disposal site designated in 1990. Each of these active sites is monitored by the U.S. Army Corps if Engineers under their Disposal Area Monitoring System (DAMOS).

The MBDS is the disposal site of most significance to the Stellwagen Bank sanctuary. The MBDS is located directly adjacent to the western boundary of the sanctuary and encompasses an area two nautical miles in diameter, centered at 42° 25.1′N X 70° 35.0′W (Figure 29). This site incorporates the areas of two historic disposal sites, the Industrial Waste Site (IWS), an area that was once authorized for the disposal of toxic, hazardous and radioactive materials and the Interim MBDS (also known as the Foul Area Disposal Site [FADS]) designated only for the disposal of dredged materials. Given the proximity of the dumpsite to the sanctuary, there is lingering concern that these dumped materials have impacted sanctuary habitats and that previously-dumped toxic materials might be leaking. Currently, the MBDS is the most active disposal site in DAMOS, receiving dredge materials from many ports, including Scituate, Hingham, Boston, Salem and Gloucester.

Since 1982, approximately 8.4 million cubic yards of dredged material have been disposed at the current MBDS or the original MBDS location, established in 1977 and located one nautical mile eastward and one-half nautical mile northward of the current MBDS location (USACE,

Figure 30. Annual disposal volumes at the Massachusetts Bay Disposal Site for the period 1982–2003.
Source: USACE (2004).

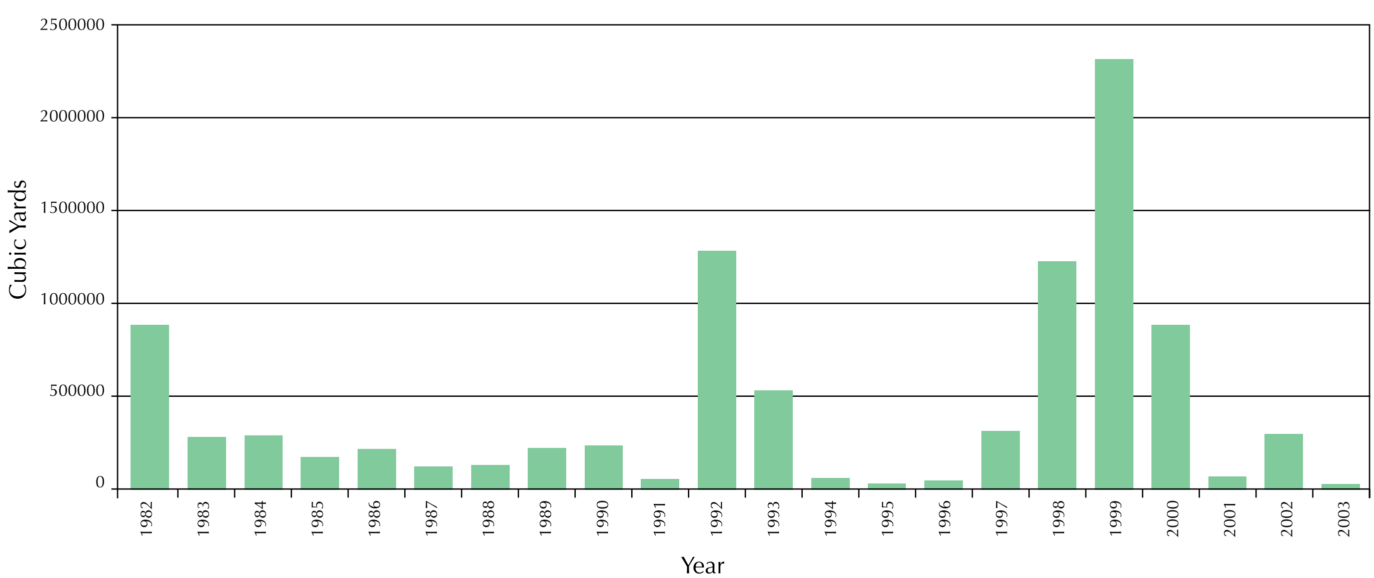


Table 5. Time taken for objects to dissolve at sea.

(Source:
IMO http://www.imo.org/Environment/mainframe.asp?topic_id=297)

Paper bus ticket	2–4 weeks
Cotton cloth	1–5 months
Rope	3–14 months
Woolen cloth	1 year
Painted wood	13 years
Tin can	100 years
Aluminum can	200–500 years
Plastic bottle	450 years

2004). Annual disposal volumes for the period 1982-2003 are indicated in Figure 30. While sediments derived from dumping, as well as contaminants from the IWS (e.g., toxic chemicals, low level radioactive waste), have the potential to contaminate the sanctuary (Wiley *et al.* 1992), both the EPA and NOAA concluded in 1993 that MBDS would not threaten resources within the sanctuary. Recent assessments (Hartwell *et al.,* 2006) support that early assessment.

In areas approved for ocean disposal of dredged material, such as the MBDS, those that utilize the site must conform to the EPA's ocean dumping criteria regulations. The site can only be used for disposal following an individual disposal determination that concludes that ocean disposal is an "environmentally appropriate alternative" as compared with other disposal alternatives. If there are no economically feasible alternatives to a particular dumping proposal, EPA is directed to grant a project-specific waiver unless "certain unacceptable environmental harms would result." Currently disposal of contaminated materials, as defined by state regulations, is not permitted at the MBDS (USACE, 2003).

Vessel Discharges

The location of many ports and harbors in Massachusetts Bay and Cape Cod Bay, particularly the Port of Boston, means that large numbers of vessels regularly travel through the sanctuary. On average, over the period 2000-2005, there were 2,257 transits per year to/from the Port of Boston by large deep drafts ships, the majority of which crossed the sanctuary. There are approximately 100 cruise ship departures or ports of call from Boston annually and this number is expected to increase; Boston is now considered one of the fastest growing high-end cruise markets in the country. See the Maritime Transportation section of this document for details.

Approximately 800 commercial fishing vessels use Massachusetts Bay as a fishing area or as a transit zone to open ocean fishing areas. On average, 327 commercial fishing vessels and 105 party and charter boats fished the sanctuary on an annual basis during 1996–2005. The popularity of recreational fishing and whale watching in the sanctuary accounts for many of the boats frequenting the area, especially during the months of April through October. On average, party and charter fishing boats made 1,967 trips per year to the sanctuary during 1996–2005. (See the Commercial and Recreational Fishing sections of this document for details.)

Discharges from vessels have the potential to be a significant source of pollution to the sanctuary. Appendix K provides information on the types of vessel discharges, their production and current status of regulation. Cruise ships serve as the example for type and production, but the regulations apply generally or as specified. Time taken for representative types of discarded objects to dissolve in seawater is provided in Table 5.

Hazardous Material Spills

Accidental discharges and vessel casualties do occur within the sanctuary. For example, according to the USCG, a total of four fishing vessels sank within the boundaries of the sanctuary during 2003–2005. These vessel casualties resulted in only minor discharges of oil into the marine environment and had no significant impact on the sanctuary. Other than such incidents, there have been no spills or accidental discharges in or around the sanctuary area over the last decade that would have placed sanctuary resources at risk (S. Lehmann, NOAA/NOS, personal communication, 2005).

Transport Pathways

Contaminant levels are a concern due to: (1) the discharge from the MWRA outfall; (2) the historic and current discharge of municipal sewage from the Boston metropolitan area and other cities and towns along Massachusetts Bay; (3) the historic dumping of toxic material at the Massachusetts Bay Disposal Site; and (4) the air deposition of toxic materials transported from the western part of the country. Knowledge of transport pathways and residence times of contaminants in the Massachusetts Bay/Cape Cod system helps in the evaluation of the threats they pose to sanctuary resources.

Boston Harbor, Stellwagen Basin and Cape Cod Bay are long-term sinks for fine-grained sediments and associated contaminants from all sources in the region. Bottom deposits on the inner shelf of the western shore of Massachusetts Bay are gravel, coarse sands and bedrock. Fine sediments do not accumulate here because storm currents resuspend and displace them. During much of the year, a weak counterclockwise circulation persists in Massachusetts and Cape Cod Bays, driven by the southeastward coastal current from the GoM. Currents flow southwesterly into the Massachusetts Bay south of Cape Ann, southward along the western shore, and easterly out of the Bay north of Race Point at the tip of Cape Cod. This flow pattern may reverse in the fall, especially near the western shore. The flow-through flushing time for the surface waters in most of Massachusetts Bay ranges from 20 to 45 days (USGS, 1998).

Northeasters (storms) generate large waves that enter Massachusetts Bay from the east. The currents associated with these waves resuspend the bottom sediments in exposed areas along the western shore of Massachusetts Bay. The wind-driven currents flow southeastward parallel to the coast (with an offshore component near the bottom) and carry the suspended sediments toward Cape Cod Bay and offshore into Stellwagen Basin. Sediments settle to the sea floor along these transport pathways. Currents caused by surface waves are the principal cause of sediment resuspension. Cape Cod Bay is sheltered from large waves by the arm of Cape Cod, and waves are rarely large enough to resuspend sediments at the seabed in the deep areas of Stellwagen Basin. Thus once sediments reach Stellwagen Basin or Cape Cod Bay, carried either by the mean current flow or transported by storm waves, it is unlikely that they will be re-suspended and transported away again.

As indicated previously, sampling for this assessment was coordinated by NS&T in collaboration with the NOAA Northeast Fisheries Science Center. Data from 2004 were contrasted with historical data, and data from the MWRA to assess the spatial and temporal trends in chemical contamination in the region as a whole. Both the NOAA and MWRA sampling regimes included sampling sites within the following four zones: Boston Harbor, Massachusetts Bay, Area Between Bays and Stellwagen Bank (Figure 27). The lowest contaminant concentrations were consistently found in the Stellwagen Bank sites (Bothner *et al.,* 1993, 1994; Bothner and Butman 2005; Hartwell *et al.,* 2006).

Current Protection

Sanctuary regulations (15 C.F.R Part 922 Subpart N) specifically prohibit:

1. Discharging or depositing, from within the boundary of the sanctuary, any material or other matter except:

- fish, fish wastes, chumming materials or bait used in or resulting from traditional fishing operations in the sanctuary;
- biodegradable effluent incidental to vessel use and generated by marine sanitation devices approved in accordance with the Federal Water Pollution Control Act [Clean Water Act (CWA)];
- water generated by routine vessel operations (e.g., cooling water, deck wash down and gray water as defined by the Federal Water Pollution Control Act), excluding oily wastes from bilge pumping; or
- engine exhaust.

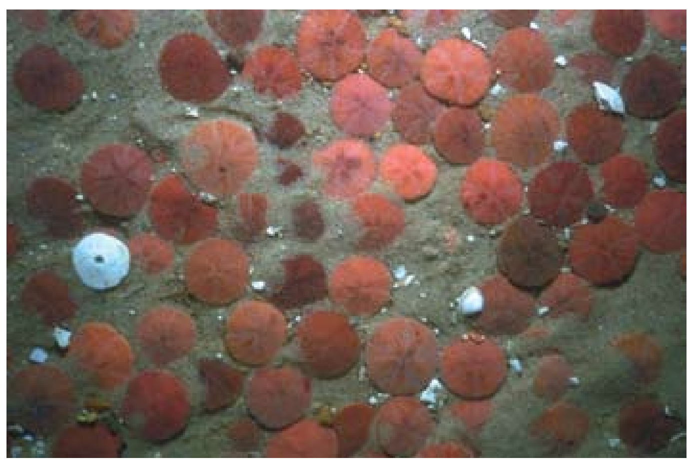
2. Discharging or depositing, from beyond the boundary of the sanctuary, any material or other matter except those listed above, that subsequently enters the sanctuary and injures a sanctuary resource or quality;

3. Lightering in the sanctuary (transferring cargo, usually oil, between vessels).

Oil spills or spills of hazardous substances in U.S. waters come under policies and procedures that are known as Natural Resource Damage Assessments (NRDA). It is possible to apply NRDA to any vessel discharge that contains oil and petroleum, and/or toxic substances if the discharge causes injury and damage to marine resources and living organisms. The environmental laws addressing NRDA include the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA/Superfund) and the Oil Pollution Act of 1990 (OPA). It is also possible to apply the CWA to discharges of petroleum and hazardous substances as well as excessive nutrients, and sewage containing pathogens and bacteria that could impair water quality. Lastly, the disposal of plastic trash, and other overboard trash by vessels is regulated by the Marine Plastic Pollution Research and Control Act of 1987 in the U.S. as well as MARPOL 73/78 Annex V.

Vessel discharges and potential contaminants that could be problematic are: black water (vessel sewage), gray water (soils, cleaning solvents, metals, pesticides, medical waste), bilge water (fuel, oils, cleaning agents, paint, rags), ballast water (foreign marine organisms), hazardous materials (chemicals from cleaning and photo processing, paints, solvents, inks) and solid waste disposal.

There are no direct federal regulations for control of nutrients such as nitrogen and phosphorous (NRC, 2000), for biologically active agents (hormones, endocrine disrupters), or for pathogens, including viruses, parasites and bacteria (NRC, 1994). Concern over biologically active agents is increasing because of their potential to alter the health of organisms, the growing industrial proliferation and public use, and the high density of biotechnology companies in the Boston metropolitan area that may inadvertently discharge these agents.



Benthic Invertebrates

Status

The sanctuary's benthic invertebrates include species from nearly all GoM invertebrate phyla. These animals live in (infauna) or on (epifauna) the seafloor during most of their lives, although most species have pelagic larvae. Characterized as "sessile" (sedentary or attached) or "motile" (free moving), benthic invertebrates range in size from little known microscopic forms (hydroid medusae) to the more common larger macroscopic organisms (e.g., scallops). Invertebrate communities vary with substrate; while cerianthid anemones may be the most visible in deep-mud basins, sand dollars might dominate shallow sand areas.

The Stellwagen Bank sanctuary supports a wide variety of seafloor substrates including mud, sand, gravel, piled boulder reefs and bedrock habitats. The seafloor provides a base for attachment by a variety of sessile invertebrates including bryozoans (moss animals), ascidians or tunicates (sea squirts), sponges, anemones, barnacles and hard-tube worms that form dense encrustations. Larger sessile invertebrates, such as sea whips (gorgonians) and sponges, provide refuges for many smaller cryptic (camouflaged) invertebrates. Other dominant benthic invertebrates include brittle stars, starfish, bivalves, shrimps, crabs and lobsters.

Structure-forming epifaunal invertebrates (such as sponges and anemones) provide critical habitat for juvenile fish of many species (such as Atlantic cod and Acadian redfish), while the greater invertebrate community provides an important source of food for these and many other fish species in the sanctuary. In the GoM, invertebrates, including sponges, jellyfish, worms, mollusks, echinoderms such as starfish, sea urchins and sand dollars, and crustaceans, outnumber vertebrates such as fishes, birds, and mammals, almost two-to-one (1,669 known invertebrate species versus 914 vertebrates).

GoM and Northeast Region

The diversity of invertebrate animals in the GoM is only generally described in the scientific literature; their many types are sorely under-represented in species counts. Many of the following citations are the principal works representative of the major taxonomic groups in the Northeast region. Although this section is intended to be primarily about the macrobenthic invertebrates of the sanctuary (and principally those that are structure-forming), the following annotated overview strives to recognize the greater cross-section of invertebrate diversity. Scientific nomenclature not explained in the text is described in the glossary of this document.

The aggregate macrobenthic invertebrate fauna of the continental shelf ecosystems of the Northeastern United States consists of 44 major taxonomic groups (phyla, classes, orders) (Theroux and Wigley, 1998). A striking fact is that only five of those groups (belonging to four phyla) account for over 80% of both total biomass and number of individuals of the macrobenthos. The five dominant groups are Bivalvia, Annelida, Amphipoda, Echinoidea and Holothuridea. The macrobenthos of the New England region (a subset of the northeastern continental shelf area) is dominated by members of only four phyla: Annelida (e.g., segmented worms), Mollusca (e.g., shellfish and squid), Arthropoda (e.g., crabs and shrimp) and Echinodermata (e.g., starfish and sea cucumbers).

Hartman (1964) describes the region's Porifera (sponges); Larson (1976) discusses Cnidarian taxonomy of the northeastern United States. Caims (1991) provides a checklist of the cnidaria and ctenophores from North America. The region's species of Hydrozoa (hydroids, jelly fishes) are described in Fraser (1944). Bush (1981) discusses the Turbellaria (flat worms) in the Northwestern Atlantic. Smith (1964) covers the taxonomy of nemerteans (flat worms) and nematodes (round worms) in the region. Bryozoans (moss animals) are critical sources of benthic structure and their taxonomy in the northeastern United States has been recently revised (Ryland and Hayward, 1991). Although the literature may suggest that the Bryozoa are well studied overall, remarkably little is known about the distribution of species within the GoM.

Molluscs are ever-present. Cephalopods such as squid are nektonic predators with a complex life history (Mauerer and Bowman, 1985). Gastropods (snails) and Bivalves (clams, mussels) are part of the epifaunal and infaunal benthic community (Maney and Ebersole, 1990). Nudibranchs (sea slugs) have been well described and many have a unique life history (Bleakney, 1996). Hunter and Brown (1964) describe the taxonomy of local molluscs. Work by Cook and Brinkurst (1973) covers the taxonomy of the Annelida (segmented worms) of the northeastern United States.

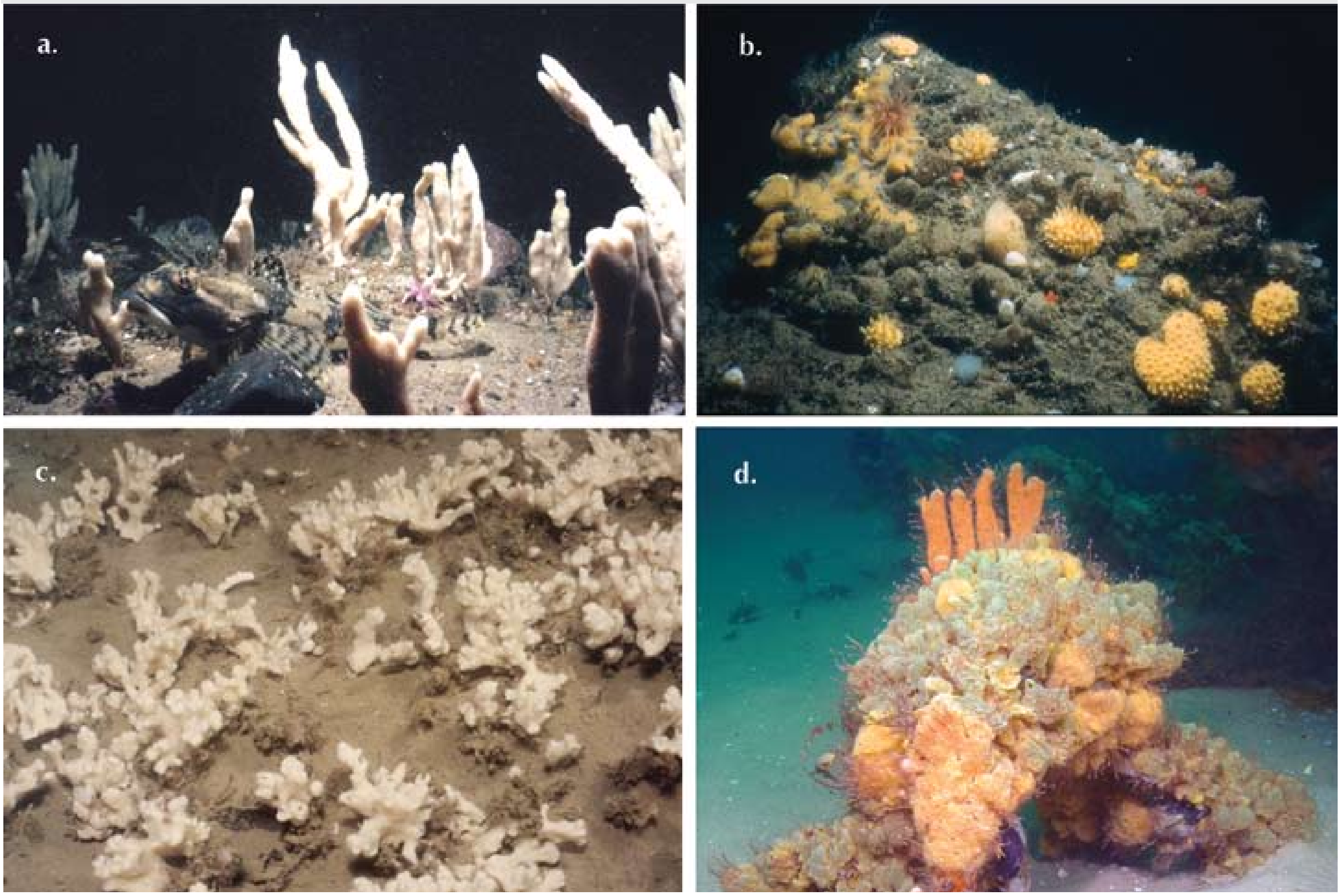
Coffin (1979) and Ho (1977, 1978) wrote the classic descriptions of the Copepoda in the region; a more recent analysis was done by Dudley and Illg (1991a, b). Tremblay and Anderson (1984) provide an annotated list of local species. Durbin *et al*. (1995a, b) discuss the relationship between environmental variables and the copepod community (notably *Calanus finmarchicus*). Kahn and Wishner (1995) describe the spatial and temporal patterns of this and other copepod species on baleen whale feeding grounds. Lynch *et al*. (1998) present a model of the population growth of *Calanus finmarchicus*; Meise-Munns *et al*. (1990) discuss longer-term population trends and the inter-annual variability in availability. Copepods may play an important link in the ecology of toxic dinoflagellates (Teegarden and Cembella, 1996); the species diversity of the two groups may be closely related.

Bowman and Abele (1982) review the Crustacea and their species diversity as a whole. Productivity and growth of the Decapoda (crustaceans e.g., lobster, crabs) is extensively researched because of that taxonomic group's commercial importance. Steneck *et al.* (1991), Wahle (1995) and Rangeley and Lawton (1999) discuss the geographical distribution of the American lobster. Fell (1982) covers the general taxonomy of the Echinodermata; Pawson (1997) covers the holothurians. Ecinoderms are greatly affected by physical disturbance to the benthos of the GoM, according to Collie *et al*. (1997) and Thrush *et al*. (1998). Smith (1964) covers the ascidian (tunicate) taxonomy.

A first-order assessment (presence/absence) of the kinds and species of invertebrates in the sanctuary was conducted based on the analysis of a 19-year database (1953-1972) collected during NOAA Fisheries Service research cruises beginning over 50 years ago as described in Theroux and Wigley (1998). The analysis was done in 2003 by John Crawford of the University of Pennsylvania who served as visiting scientist with the Stellwagen Bank sanctuary during that year. The analysis included over 4,000 data records for the sanctuary obtained using standardized sampling methods involving four gear types: (1) Campbell grab, (2) 1.0

Figure 31. Representative species of sponges in the Stellwagen Bank sanctuary.

(a) common palmate sponge (*Isodictya palmata*) sheltering a sculpin; (b) boring sponge *(Cliona celata)* on left side of image, *Halichondria panicea* with knobs on right side of image; (c) *Iophon nigricans*; and (d) miscellaneous sponge species interspersed with hydroids (feathery organisms pictured here). Credits: (a-c) NURC-UConn; and (d) Tane Casserley, NOAA Maritime Heritage Program.



meter dredge, (3) scallop dredge, and (4) otter trawl. The analysis produced a taxonomic list documenting invertebrate species in the sanctuary, which has been incorporated into the sanctuary's species list (Appendix J).

Importance of Structure-Forming Invertebrates

A great diversity of structure-forming invertebrate species lives on or in the seafloor of the Stellwagen Bank sanctuary. Many of these invertebrates create and are the source of important biogenic habitats (e.g., anenome forests, sponge gardens, hydroid meadows, worm tube beds, burrows and other substrate modifications) which promote and sustain biodiversity and make a pivotal contribution to ecosystem function. Structure-forming macrobenthic invertebrates, such as sponges, bryozoans, tunicates and anemones, play a particularly important role in the ecology of small, juvenile fishes, offering shelter from currents and serving as nurseries and refugia from predation, for example.

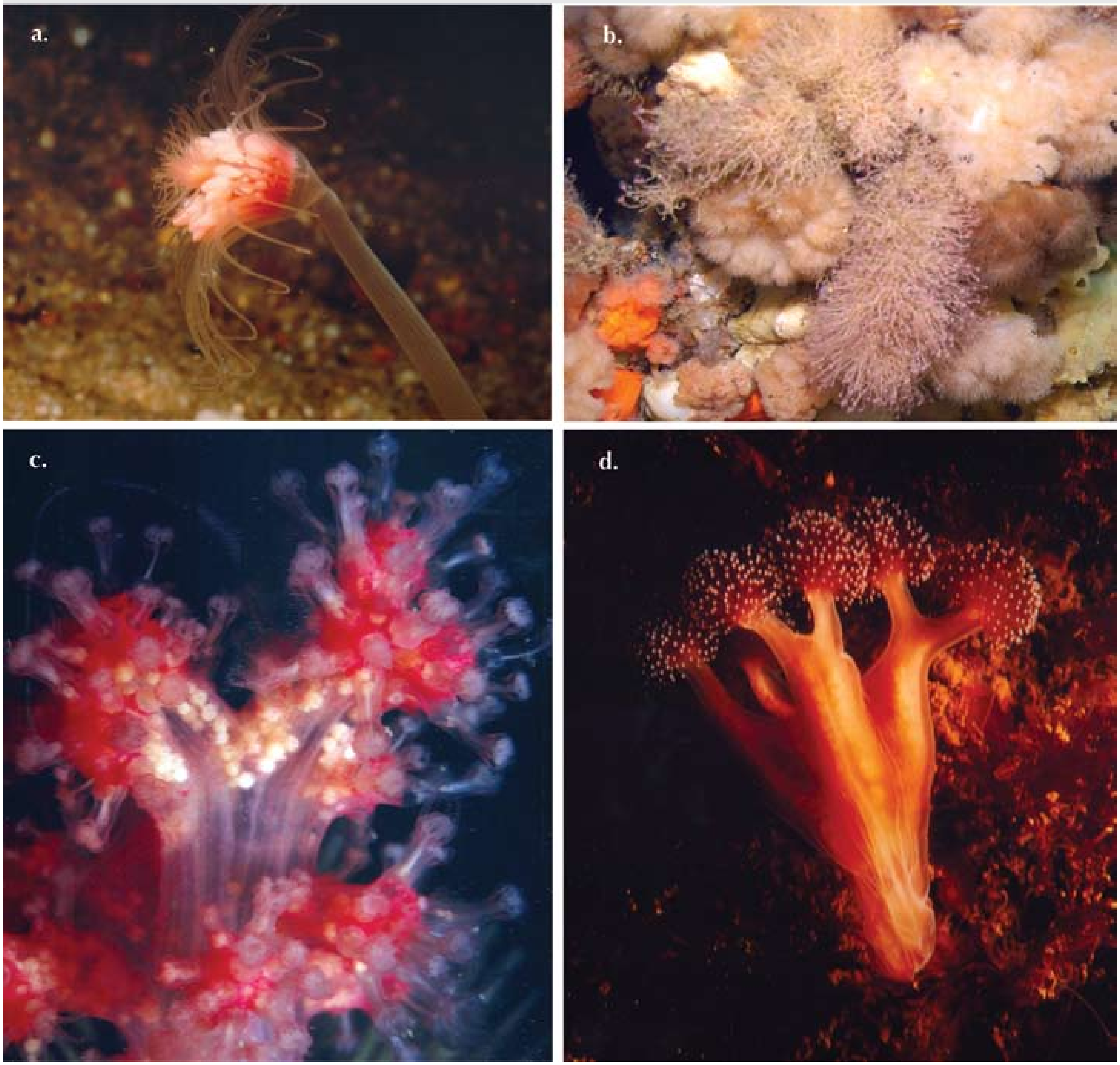
As explained in the section on seafloor habitats, biogenic structures underpin and shape the biological communities associated with them; they form the "living landscapes" that carpet the sanctuary seafloor. Their three-dimensional structure and sessile behavior make these particular invertebrates highly susceptible to damage from mobile fishing gear, e.g., trawls and dredges. Below are some examples of the invertebrate species that form the living landscapes of the sanctuary. The accompanying discussion does not include the hundred or so other species of benthic invertebrates, such as echinoderms (e.g., starfish, brittle stars, sand dollars, sea cucumbers) and crustaceans (e.g., lobsters, crabs, shrimp, isopods) that serve different ecological roles (e.g., predators, scavengers) within the benthic communities of the sanctuary. Many of these structure-forming and other benthic invertebrate species are colorfully pictured in Martinez (2003).

Sponges

Sponges are common throughout the Stellwagen Bank sanctuary and serve as important habitat and refugia for a variety of organisms (Figure 31). The boring sponge *Cliona celata* is known within the sanctuary (Ward, 1995) and grows on mollusk shells at depth to 40 m (Gosner, 1971). They attach to both living and abandoned shells, contributing to the breakdown of shells on the sea floor. *Cliona* may grow to a diameter of 20 cm and can be free-standing (Ruppert and Fox, 1988). Gosner reports that the gamma form may be

Figure 32. Representative species of cnidarians in the Stellwagen Bank sanctuary.

(a) stalked hydroid (*Corymorpha pendula*); (b) pink-hearted hydroid *(Tubularia corcea)*; (c) soft coral *(Gersemia rubriformis)*; and (d) stalked jelly *(Haliclystus auricula)*. Credits: (a) NURC-UConn; (b) Tane Casserley, NOAA Maritime Heritage Program; (c) Bob Michelson; and (d) Jeff Hannigan.



a massive free-standing structure (Gosner, 1971). *Iophon nigricans* is an erect sponge that has been collected in the sanctuary (McNaught, in preparation) and lives at depths of 29–740 m (Gosner, 1971).

Cnidarians

Cnidarians are a large and varied phylum including jellies, hydroids, corals and anemones. These soft-bodied invertebrates serve as refugia for other organisms and are highly vulnerable to damage from fishing gear. Many cnidarians such as the hydroids have a polyp (attached) and medusa (free floating) stage (Figure 32). Each “flower” of the pink-hearted hydroids (*Tubularia corcea*) is an animal or polyp approximately 3 cm long with the blossom about 1 cm across. These hydroids are found in the sanctuary (Ward, 1995) and serve as habitat for other organisms. Another species, the stalked hydroid (*Corymorpha pendula*) is known to extensively carpet the seafloor in some areas of the sanctuary. The branching soft coral (*Gersemia rubiformis*) is known to occur within the sanctuary and grows to 15 cm or more in height (Ward, 1995), occurring at depths of 37–91 m (Gosner, 1971). Gorgonians may take 30 years to reach full size (Ruppert and Barnes, 1994).

Sea pens and pansies (*Pennatulacea*) are found anchored to soft bottoms (sand or mud) and are fleshy structures which generally have a stalk or pedestal anchored to the substrate and secondary polyps at the upper end of the stalk (Barnes, 1974). Sea pens are common in Georges Basin, the Stellwagen Bank area and Jeffreys Ledge with densities as high as 8/m-2 having been measured (Langton *et al.,* 1990). They are found on mud and silt bottoms, at depths of 174–351 m. They have been collected as by-catch by fishermen (Langton *et al.,* 1990) and are sometimes damaged by traps (Eno *et al.,* 2001). The Pennatulacea encountered by Theroux and Wigley (1998) were feather-shaped and stood 10–25 cm high.

Anemones are a common, abundant class of cnidarian that serve many important functions in the sanctuary such as: refugia, a food source, and, in turn, a predator on zooplankton and even fish (Figure 33). They are found throughout the sanctuary on all bottom types, but are most common on sandy substrata and are most abundant at depths of 100 m or more (Theroux and Wigley, 1998). The colorful and abundant northern red anemone *Urticina felina* is found to 73 m depth and is 5 cm high by 12 cm wide. The burrowing anemones, *Ceriantheopsis americanus* and *Cerianthus borealis*, may have tubes extending over 45 cm into the water column and 4 cm in diameter. *Cerianthus borealis* is most common in deep muddy basins (130 m to > 400 m) with burrowed tube lengths of 45 cm. Behavioral-ecological studies have revealed a close association between *Cerianthus* sp. and Acadian redfish within the Stellwagen Bank sanctuary (Auster *et al.* 2003).

Annelid Worms

Worms are an important food source for many bottom-dwelling fishes. They can be important detritivores (decomposers), predators or filter feeders. Some worm species build

Figure 33. Representative species of anemones in the Stellwagen Bank sanctuary.

(a) mud anemone *(Cerianthus borealis)*; (b) northern red anemones *(Urticina felina)* shown on boulder [These animals catch, kill and digest prey as large as fish. They sting prey with nematocysts on their tentacles and draw the stunned prey into the mouth in the center of the tentacles.]; (c) shipwrecks can serve as substrate for frilled anemones *(Metridium senile)*; and (d) unidentified frilled anemone species. Credits: (a-c) NURC-UConn; and (d) Norman Depres.

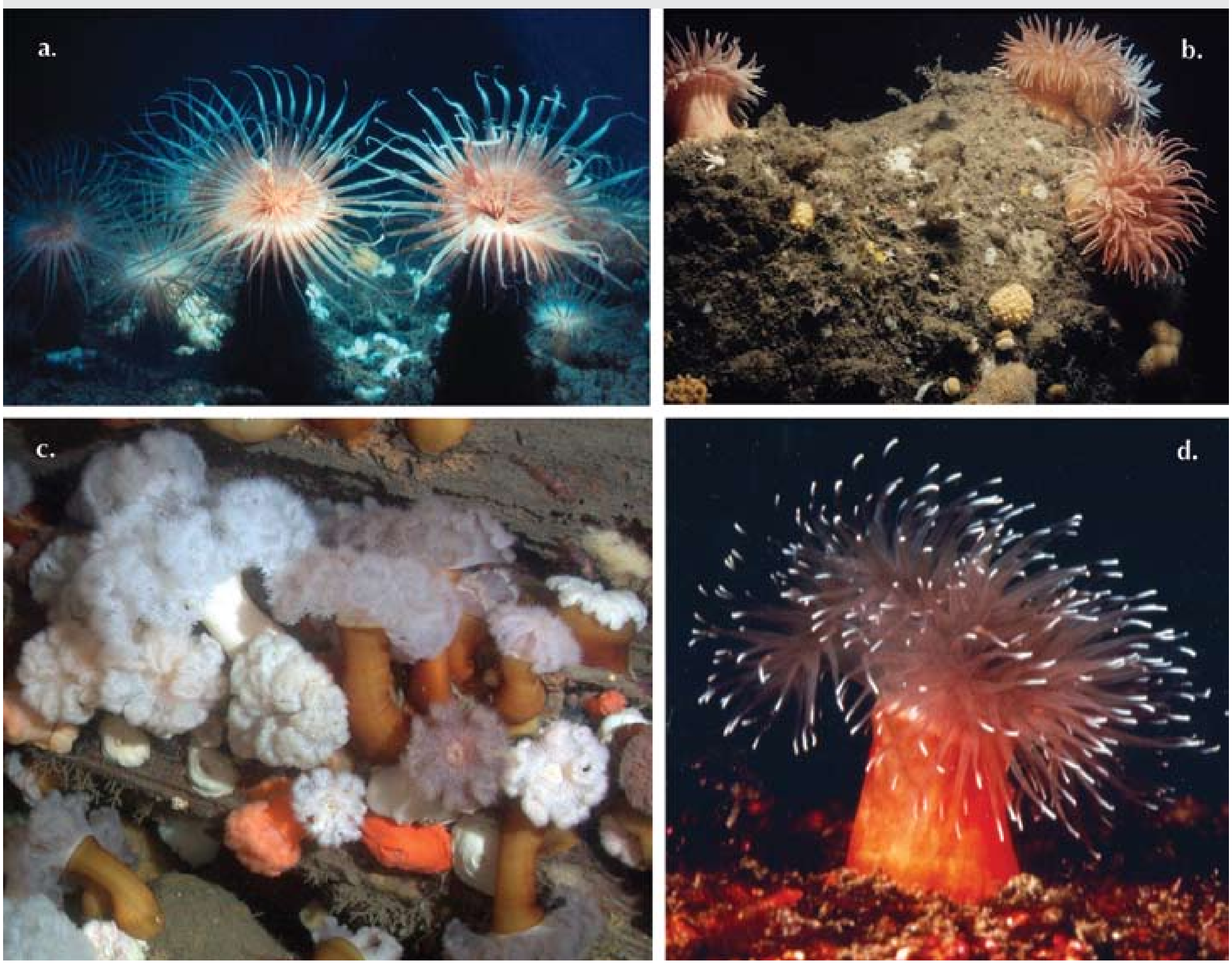


Figure 34. Empty ocean quohog shells (*Arctica islandica*) serve as habitat for a variety of fish such as the ocean pout shown here.

(Credit: NURC-UCconn).

complex three-dimensional structures. The serpulid worm (*Filograna implexa*) is an important member of the seafloor community on pebble/cobble substrate in Georges Bank, where its abundance is known to be reduced by dredging (Collie *et al.,* 1997). This species occurs in the sanctuary (McNaught, in preparation) and is found at depths from 33–55 m (Gosner, 1971). It can grow to a tube length of 5 cm with groups of tubes joining to form large above-surface structures (Ruppert and Fox, 1988). *Myxicola infundibulum* is a soft-bodied burrowing worm approximately 3x20 cm in size (Gosner, 1971). McNaught *et al.* (in prep) found them in the northern parts of the sanctuary around the submerged fiber-optic cable in the sliver (closed area). Depths range from the shallow littoral zone to 55 m (Gosner, 1971). Trumpet worms (*Pectinari goudi*) are known in the sanctuary (Ward, 1995). Their delicate tubes are made from sand grains and most of the tube is buried.

Bryozoans

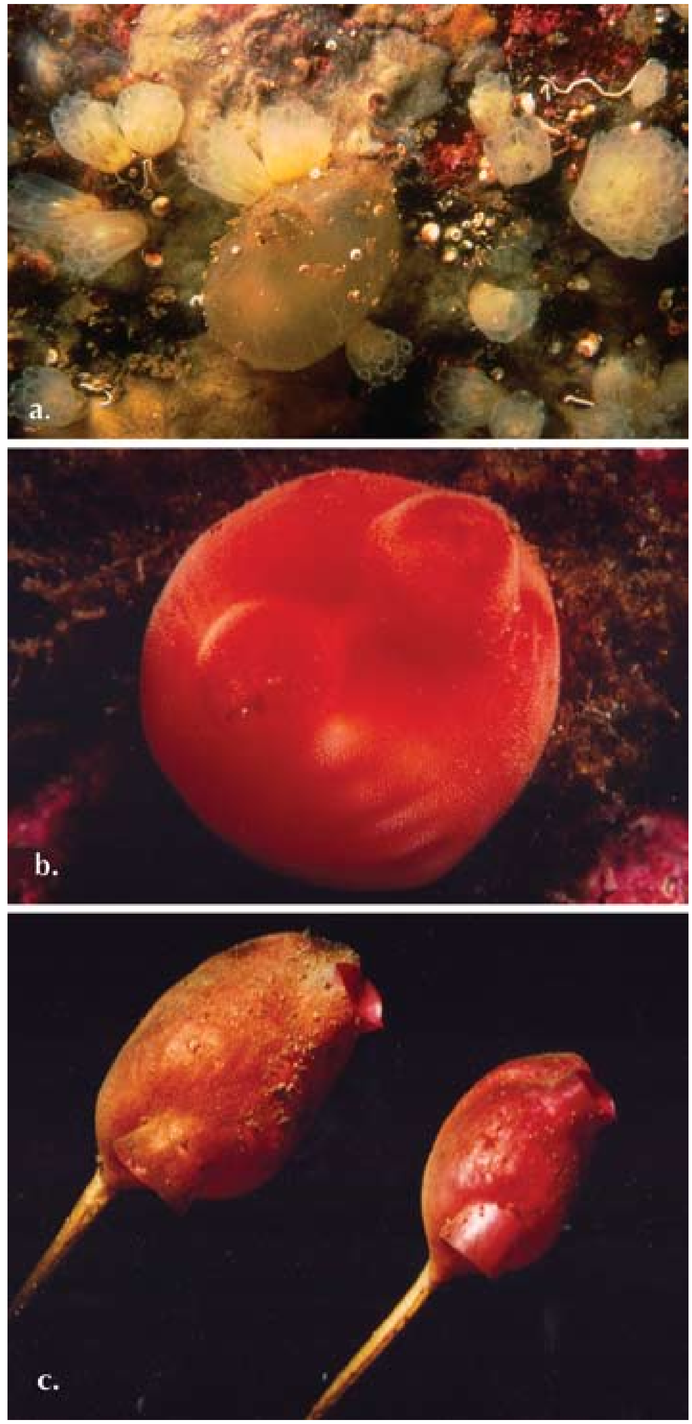
Bryozoans are sessile colonial animals, commonly referred to as "moss animals." They are most common on shell and gravel substrata and are most abundant in shallow water (less than 100 m) in Massachusetts Bay (Theroux and Wigley, 1998). Colonies of spiral tufted bryozoans (*Bugulia turrita*) are found within the sanctuary (Ward, 1995) and are known from very shallow depths to more than 27 m. Colonies of *Bugula* spp. tend to be small, less than 2.5 cm in height (Gosner, 1971), and are soft, bushy and plant-like in form (Ruppert and Fox, 1988; Ruppert and Barnes, 1994). Two species of erect bryozoans were reported from the sanctuary in the SHRMP study, *Caberea ellisii* and *Idmidronea atlantica.* These species were more abundant within the cable closed area (sliver), which is protected from the effects of fishing that occur outside the closed area.

Molluscs

Molluscs such as clams, mussels and scallops are an important component of the sanctuary ecosystem serving as habitat and a food source for many species, while filtering plankton and organic particles from the water column. The shells of dead ocean quohog (*Arctica islandica*) are known to provide habitat for juvenile hake (Auster *et al.* 1991) and other fish as well as invertebrate species (Figure 34). Found at depths from 11–165 m, shells may be 10 cm in length (Gosner, 1971). Ocean quohogs can live to be more than

Figure 35. Representative species of tunicates in the Stellwagen Bank sanctuary.

(a) sea grape (*Molgula* spp.); (b) sea peach (*Halocynthia pyriformis*); and (c) stalked tunicate (*Boltenia ovifera*). Credits: (a) Jeff Hannigan; (b) Bob Michelson; and (c) Kevin McCarthy.



100 years old and have been aged in excess of 200 years (NMFS, 2000).

Tunicates

The tunicates (sea squirts) fall within the phylum Chordata, meaning they are primitive relatives of vertebrates (Figure 35). *Ciana intestinalis* and *Mogula* spp. are reported from the littoral zone to depths of about 500 m (Gosner, 1971) and are found throughout the sanctuary. *Ciana intestinalis* forms colonies to a height of 12 cm; *Mogula* spp are smaller, with the largest species forming colonies to only 7 cm, and most less than 3 cm (Gosner, 1971) (Ruppert and Fox, 1988). *Didemnum* sp. is discussed in the previous section under invasive species.

Pressures

Pressures are the same as those for seafloor habitats, principally fishing practices that disturb seafloor communities and the laying of cables or pipelines.

Current Protection

Sanctuary regulations (15 C.F.R Part 922 Subpart N) prohibit drilling into, dredging or otherwise altering the seabed of the sanctuary; or constructing, placing or abandoning any structure or material or other matter on the seabed of the sanctuary, except as an incidental result of: (1) anchoring vessels; (2) traditional fishing operations; or (3) installation of navigation aids. The exemption for traditional fishing activities reduces the effectiveness of these regulations in protecting ecological integrity including habitat and biodiversity.

Several indices of biodiversity are based on numbers of individuals of a species as well as the number of species. These measures of diversity are sensitive to the effects of traditional fishing. A reduction in biodiversity in the sanctuary does not require that species are entirely removed (i.e., local extinction). "Local extinction" is a common scientific term in community ecology and conservation biology. It is defined as the eradication of any geographically discrete population of individuals while others of the same species or subspecies survive elsewhere.

The most effective regulations for protecting benthic invertebrates are those promulgated by NOAA Fisheries Service under the MSA in order to restore groundfish stocks in the GoM and protect EFH. Specifically, over the past two decades NOAA Fisheries Service in collaboration with the NEFMC has promulgated fishing regulations that have significantly reduced fishing effort, and therefore disturbance to invertebrates, in the entire northeast, including the sanctuary. Some examples of these regulations are: reducing fishing days at sea, creating groundfish and habitat closed areas (e.g., WGoMCA), reducing trawl net roller gear sizes to prevent bottom trawlers from accessing high relief habitat, and creating seasonal closures to protect migrating or spawning species. The protections provided by the WGoMCA and the results to date are previously described.

Fishes

Status

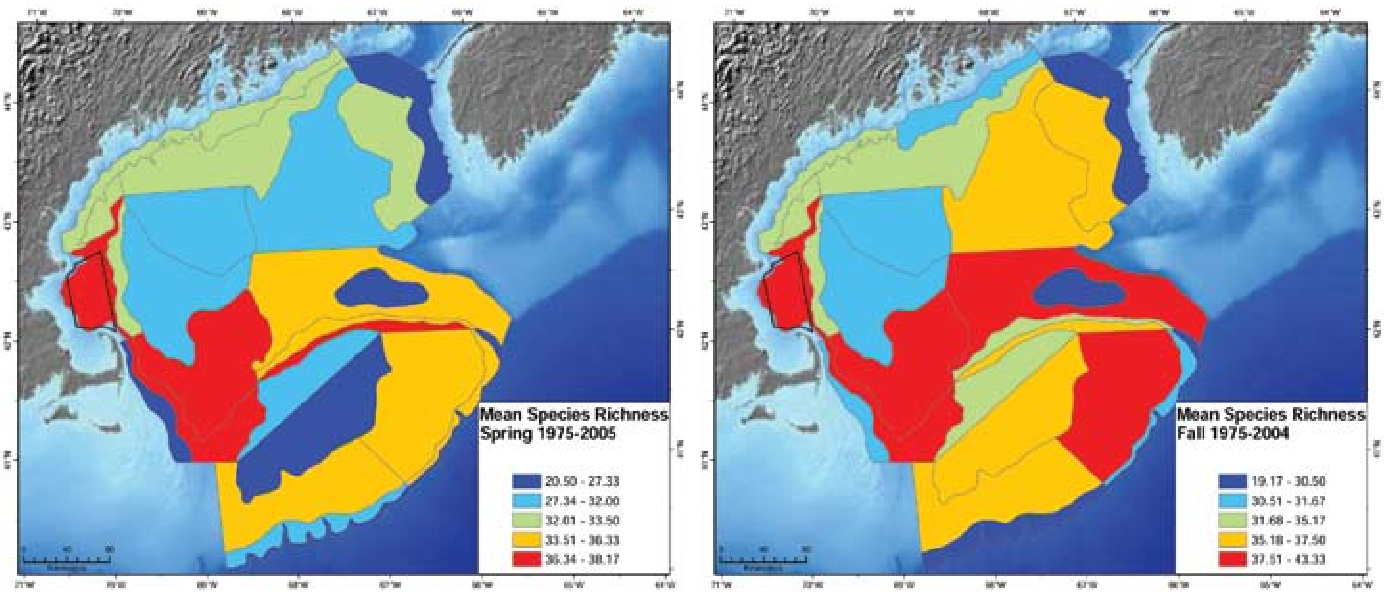
Fish are a vital component of the sanctuary's biological diversity and also one of its strongest links to the human population. The groundfish community in the sanctuary, made up of fishes such as Atlantic cod, haddock, whiting (silver hake) and various flatfish, has been sought for food from the earliest European settlements to the present. The fish species found in the sanctuary are generally representative of fish assemblages in the GoM region. Of the known 652 GoM species, over 80 species of fish exist in the sanctuary. These known species are listed by common and scientific name in Appendix J.

The diverse seafloor topography and nutrient-rich waters in the sanctuary result in increased primary productivity and large zooplankton populations, which support abundant populations of small schooling species such as sand lance, herring and mackerel. Many groundfish and larger pelagic fish prey upon these schooling species, which also form part of the varied diet of marine mammals and seabirds. Fish found in the sanctuary range in size from small snake blennies to basking sharks. Some fish, such as giant bluefin tuna, are annual migrants to the area, while others, such as the Acadian redfish, are likely year-round residents.

Fishes are among the species most identified with use of and co-dependence on both seafloor and water column habitats because of their obvious mobility. Their distribution and abundance in the sanctuary was used to illustrate the ecological role of seafloor habitats and was described extensively in that section. As juveniles and adults, many species become closely associated with benthic habitats and communities (e.g., Atlantic cod, haddock), but virtually all species spend part of their life in the water column as eggs or larvae (as also do many benthic invertebrate species). Many species of fish live on the seafloor and feed in the water column (e.g., Acadian redfish, sand lance) and many other species live entirely in the water column (Atlantic herring, bluefin tuna). Out of the wide array of ecological niches filled by fishes, and the related sets of selective forces that shape their speciation, diverse species have evolved.

Figure 36. Seasonal mean fish species diversity (species richness) across the GoM for the period 1975–2005.

(Figure excerpted from Auster *et al*, 2006.)



Species Diversity

One of the most geographically comprehensive data sets of species composition and abundance across the GoM LME is for demersal fishes (e.g., Atlantic cod, haddock). NOAA Fisheries Service has collected a unique time series of data that stretches across more than four decades (1963-present). This time series has been the basis for two comprehensive analyses of fish species diversity in the GoM inclusive of the sanctuary that address both temporal trends and spatial patterns.

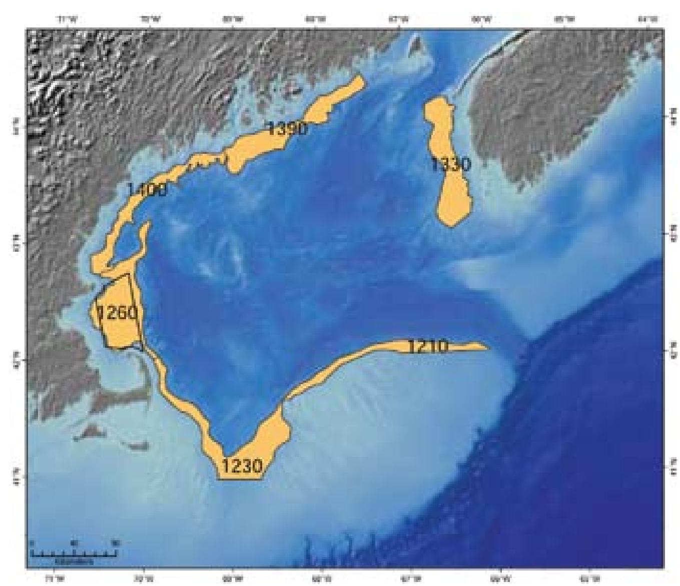
Trends

The first analysis of these trawl data using a 25-year time series (1970–1994) found that the sanctuary had 41 of 48 resident fish species, 7 of 17 annual migrants, and 6 of 12 shallow coastal species suggesting that the sanctuary supported a significant number of the species represented in the GoM LME (Auster, 2002). The author concludes that patterns in species richness and evenness are conservative properties of fish assemblages at the scale of the GoM but not at the scale of the sanctuary and that managing fishing at the regional scale does not necessarily maintain trends in diversity in the sanctuary.

The second analysis of the NOAA Fisheries Service trawl data using a 30-year time series (1975–2005) showed that the Stellwagen Bank sanctuary is in an area of high fish species diversity in the GoM (Auster *et al.,* 2006) (Figure 36). Values for mean species richness at the regional scale were variable across the GoM and between spring and fall in most of the sample strata, but were consistently high in the sanctuary. Overall, slightly lower richness values were evident in spring than in fall. This difference is attributed to colder temperatures in spring and a reduced number of southern migrants that draw from a more diverse species pool than do migrants from the north during this season.

Figure 37. Geographic strata of similar bathymetric profile used to compare diversity indices with the Stellwagen Bank sanctuary.

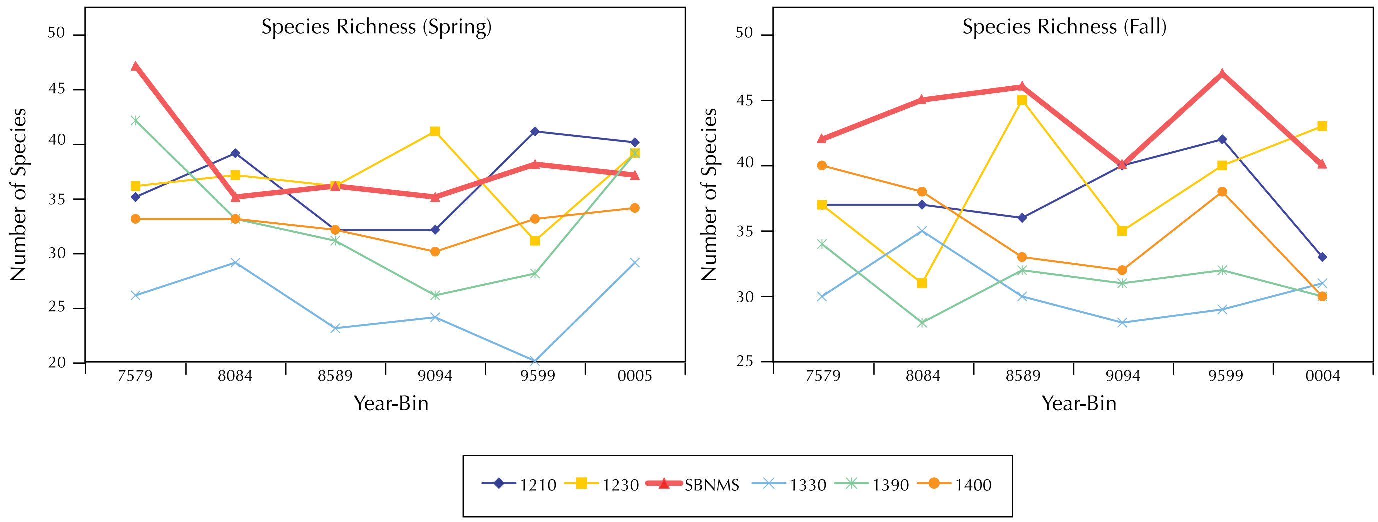
(Figure excerpted from Auster *et al.,* 2006.)



In order to contrast the uniqueness of the Stellwagen Bank sanctuary with other similar regions in the GoM, fish species richness within the sanctuary was compared across other geographic strata that have similar bathymetric ranges (Figure 37). Species richness within the sanctuary was overall higher than or equal to species richness within most of the other strata (Figure 38) (Auster *et al.,* 2006). This difference was most pronounced in the fall. Figures 36, 37 and 38 are based on NOAA Fisheries Service sampling strata for the GoM.

Figure 38. Comparison of fish species diversity (species richness) between the Stellwagen Bank sanctuary and other similar strata within the GoM for the period 1975–2005.

(Figure adapted from Auster *et al.,* 2006.)



Relative to other indices, species richness is a conservative and robust metric for general comparison of fish species diversity across these strata. The high abundance of sand lance captured within the sanctuary during spring 1980-1984 severely depressed the diversity index value of several other indices examined by Auster *et al.* (2006). The lower diversity index values reported for the Margalef's, Shannon, Simpson, and taxonomic diversity indices in the spring during the 1975–1989 time period all occurred because sand lance dominated trawl sample abundance within the sanctuary and this species alone comprised more than 50% of the total abundance. High fish larval abundance within the sanctuary during the winter and spring months during 1977–1988 was also driven by sand lance (Auster *et al.,* 2006), where their long hatching period (Nov-May) and persistent larval stage maintains a dominant presence in the sanctuary area (Reay, 1970).

The diversity indices presented in the foregoing discussion are described as follows. Species richness is the simplest index and represents the total number of species from each sample. Margalef's index incorporates both species richness and the number of individuals in a sample; it is a measure of the number of species per individual. The Shannon index is a measure of both species richness and the number of individuals of each species in a sample; it is most sensitive to changes in the number of rare species in a sample. The Simpson index is an estimate of the probability that any two individuals drawn from a sample are members of the same species; it is most sensitive to changes in number and abundance of dominant species in a sample. Taxonomic diversity depends on the relatedness of species connected through links of a classification tree (i.e., number of links between species in a sample based on connections at generic, family, class levels, etc.) and is based on the average number of links between two individuals chosen at random from the sample. Magurran (2004) and Clarke and Warwick (2001) provide overviews of the range of diversity indices available, their calculation and issues regarding interpretation.

Patterns

In general, the greater an area that is sampled the greater number of species that are found. An analysis of the rate at which fish species increase with increasing area sampled in the sanctuary showed that more complex habitats do not necessarily harbor greater species diversity overall. Different habitats (i.e., gravel, boulder reef, mud) were found to contain some similar and some unique species and that particular habitats, like boulder reefs, were not significantly more species diverse than others; however the highest slope for both species-area and species-individual curves was for mud habitat (Auster *et al.,* 2006). These data were collected using an ROV and counts of fish and classification of habitats were accomplished using video observations of fish communities on the seafloor, much like divers counting fish on coral reefs, and allowed sampling within particular habitats.

The patterns of species diversity identified for both the large and small scale studies cited above suggest that habitats within regions and the regions within the larger GoM LME contain part of the overall pool of species. That is, the number of species coexisting in local communities, such as in the sanctuary, must be a result of processes that function at both local and regional spatial scales. Any sites within the GoM should be expected to have some, but not all of the species represented within the LME and that a network of sites across the GoM would be needed to contain representative examples of diversity for the entire biogeographic province. A study of marine invertebrate communities that occur on shallow rock walls from around the world has found similar patterns for epifaunal species (Witman *et al.,* 2004).

The findings reported here and in other sections of this document describing resource states support the conclusion that the sanctuary is an important biodiversity area and a priority area for networked marine ecosystem management in the GoM (Crawford and Smith, 2006).

Truncation of Size and Age Structure

Large fish produce many more potential offspring than small fish because egg number and volume increase with the maternal weight (Figure 39). Weight increases roughly with the cube of length and as fish mature they devote a greater proportion of energy stores to egg production. It is now also evident that old fish produce healthier (higher fertility) eggs and larvae than do young fish (Berkeley *et al.,* 2004a; Marteinsdottir and Steinarsson, 1998; Wright and Gibb, 2005). The eggs of older fish are invariably of higher quality than the eggs of younger fish due to the greater amount of oil stored in the yolk sac at parturition (i.e., hatching). This produces larvae that grow faster and which are more resistant to starvation than larvae from younger females. A doubling of the growth rate of larval Atlantic cod for example, due to sufficient energy stores in the yolk sac, can produce a 5- to 10-fold increase in survival rate (Meekan and Fortier, 1996).

Figure 39. Annual per capita egg production (in millions of eggs) for cod (*Gadus morhua*) as a function of age (and by implication size).

Fecundity estimated from Bireta and Warwood (1982); mean lengths at age estimated from O'Brien (1999). (Figure excerpted from Carr and Kaufman, 2009.)

Many species of marine fish are long-lived, with the maximum age of species in a diverse range of families often exceeding 100 years (Cailliet *et al.,* 2001). The association of longevity with variability in recruitment is also widespread among many fish species (Longhurst, 2002). The adaptive value of a long life span is that reproductive output is allocated across many years, a bet-hedging strategy that ensures some reproductive success despite potentially long periods of environmental conditions unfavorable for larval survival (e.g., Secor, 2000a). A growing body of evidence indicates that a broad age distribution can also reduce recruitment variability (Lambert 1990; Marteinsdottir and Thorarinsson 1998; Secor, 2000b).

Berkeley *et al.* (2004) offer two mechanisms by which reproductive optimization due to broad age distribution can occur: (1) there may be age-related differences in the time and location of spawning, effectively spreading larval production over temporally and spatially variable environmental conditions (Hutchings and Myers, 1993; Lambert, 1987); and (2) older fish may produce eggs and larvae, which can survive under conditions inadequate for survival of progeny from younger fish (Hislop, 1988; Marteinsdottir and Steinarsson, 1998). Whereas older fish are likely to produce larvae of better condition, in larger numbers and in more frequent batches than younger fish, thereby ensuring population viability, fishing offsets this benefit by selectively removing larger, older individuals.

These findings are important considerations for sanctuary management because high numbers of larger, older fish are important for the longterm persistence of fish populations (Lambert, 1990; Leaman and Beamish, 1984; Marteinsdottir and Thorarinsson, 1998; Trippel *et al.,* 1997). Larger fish, especially among keystone species such as Atlantic cod, are important agents in the structuring of biological communities through size mediated differences in food habits and rates of predation, as well as in competitive outcomes between species of the same or similar feeding guilds (e.g., Garrison, 2000). Large fish are also the target of commercial and recreational fishing activities, which in light of current knowledge may be contrary to optimizing conservation benefit (Berkeley *et al.,* 2004b; Birkeland and Dayton, 2005), depending on the management objective, e.g., maintenance of biological communities.

Big Old Fat Females

Research on a variety of fish species indicates the importance of experienced spawners (BOFFs or "big old fat females") to the sustainability of fish populations. Empirical studies indicate that Atlantic cod exhibit a BOFF effect. Researchers examined the strength and significance of this effect to stock rebuilding using a dynamic model and the Stellwagen Bank sanctuary as the target area (Carr and Kaufman, 2009). Results of this modeling study indicated that first, second and third-time spawners were cod ages 1 to 9 years old and experienced (BOFF) spawners were ages 10 and 11. BOFF spawners contributed about ten times more offspring that survived their first year than did younger, less experienced spawners. Third-time spawners contributed the greatest proportion of recruits but still had much lower per capita reproductive output than BOFF year classes. The reproductive value of first and second-time spawners was negligible due to both low output and low larval survival.

Chronic overfishing of many New England groundfish stocks has resulted in much younger average age populations than would occur under a more conservative fishing mortality objective. The relative contribution to spawning stock biomass by age class of GoM cod for 1983 to 2007 (Figure 40) reveals the dominant proportions coming from ages 5 and under (NOAA, 2008). Cumulative contributions of cod age 8 and older have only been about 10% since 1983. In contrast, the biological reference points for managing

Figure 40. Population composition by percent biomass of GoM cod 1983-2007.

(Adapted from Figure 38.1 in NOAA, 2008.)

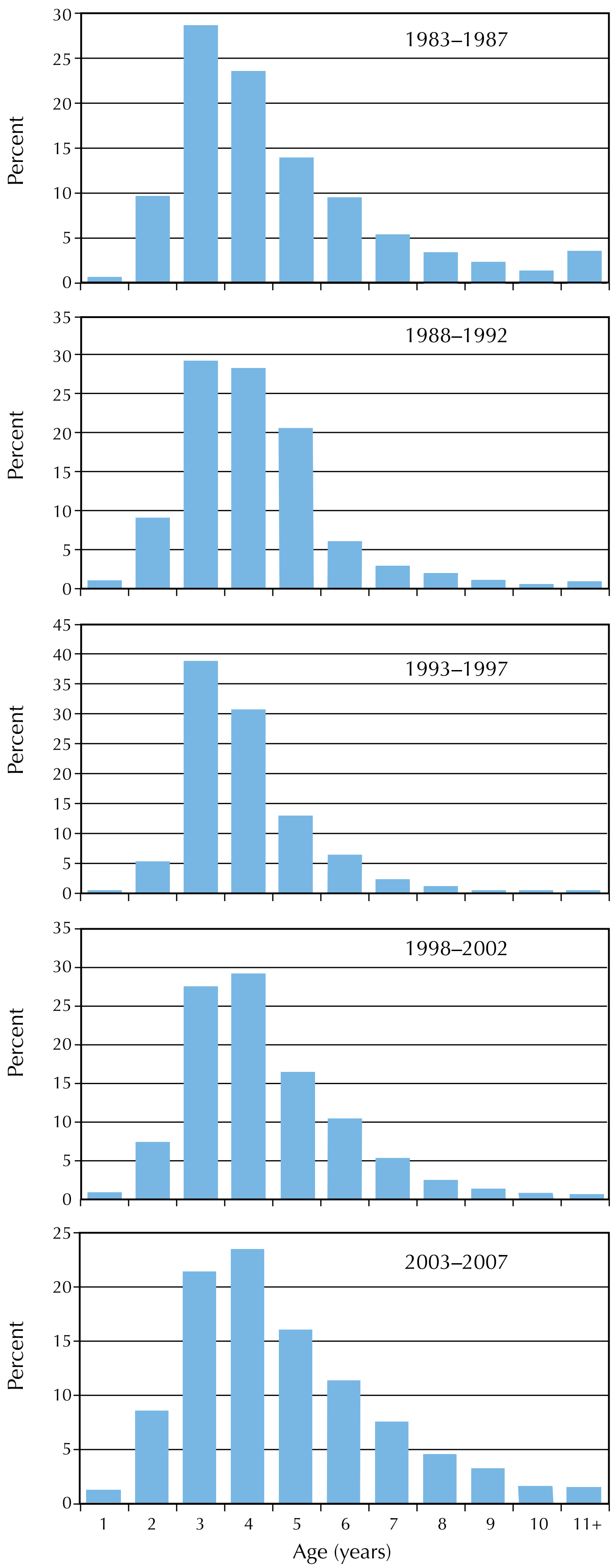
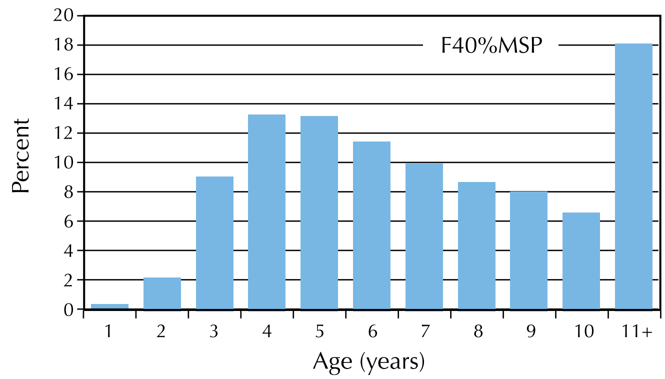


Figure 41. Equilibrium age composition by percent biomass of GoM cod exploited at the fishing mortality rate (F_{MSY}) projected to achieve 40% maximum spawning potential.

(Adapted from Figure 38.2 in NOAA, 2008.)



the fishery are based on preserving 40% of the maximum spawning potential (MSP) of the unfished cod population. The expected consequences of fishing at a rate much lower than contemporary exploitation patterns are shown in Figure 41. In this example, about 41% of the annual recruits would be expected to come from cod ages 8 and older. While this outcome is yet to be realized, current management advocates a nearly four-fold increase in the proportion of older fish in the population.

Carr and Kaufman (2009) conclude that failure to protect large, experienced female cod produces a yield that may be optimal in a conventional sense but may not be sustainable under historic high levels of exploitation. Current fishery management explicitly recognizes this principle by establishing proxy values for fishing mortality rates at maximum sustainable yield (F_{msy}) that are based on preservation of an acceptably large fraction of maximum spawning potential rather than seeking maximum yield per recruit. Under a fishing policy that controls fishing mortality to protect 40% of the maximum spawning potential (F40%MSP), the expected proportion of age 11 and older cod would be about 14 times the average fraction observed between 1983 and 2007 (NOAA, 2008). Contrary to popular belief, contemporary fishery objectives advocate a much larger range of ages in the spawning population and much larger reproductive contributions from larger fish than currently occurs.

Historic truncation of the age structure is the consequence of chronic overfishing and the failure to meet target mortalities rather than a consequence of management policy. Truncation of the cod size distribution from chronic overfishing eliminates large "old growth" cod as a functional component of the ecosystem, altering the food web and possibly also other aspects of community structure. Carr and Kaufman (2009) conclude that if fishery management objectives are for cod populations to rebuild and for cod to once again become a major functional part of the ecosystem, then the BOFF effect should be incorporated explicitly into management models for fishing in the Stellwagen Bank area; most likely they should apply to the GoM as a whole for the sanctuary to appreciate major benefits.

Changes in Fish Maximum Length

Retrospective time series of mean body length of Atlantic cod from kelp forests in the coastal GoM declined from 1.0 m 3550 yrs B.P. (before present) to 0.3 m at present time, indicating a 3-fold decrease in trend due to fishing (Jackson *et al.,* 2001). This analysis was conducted on data derived from archaeological and historic sources. This trend has extended offshore to Georges Bank (Sherman, 1991) and, as explained below, to the Stellwagen Bank sanctuary for cod and other species as well. In the 1960s and 70s, the maximum length of cod in the sanctuary approximated what the mean length had been historically in the GoM.

In 2003 the 38 years of NOAA Fisheries Service research trawl data available at the time (1963-2000) was analyzed to assess changes in fish maximum length within the sanctuary. The length of the largest individuals sampled each year (for example Figure 42), and by separate analysis the length of the 90 percentile point, were regressed over time for each of the 15 species studied with comparable findings. Based on the regressions of the length of the largest individuals sampled, all of the species examined showed decreasing trends in maximum length over the 38-year period (Figure 43). The analysis was done by John Crawford of the University of Pennsylvania who served as visiting scientist with the Stellwagen Bank sanctuary during 2003.

Figure 42. Decrease in maximum length of white hake sampled in the Stellwagen Bank sanctuary by NOAA Fisheries Service standardized trawl surveys over the period 1963–2000.

(Figure excerpted from Crawford and Cooke, in preparation.)

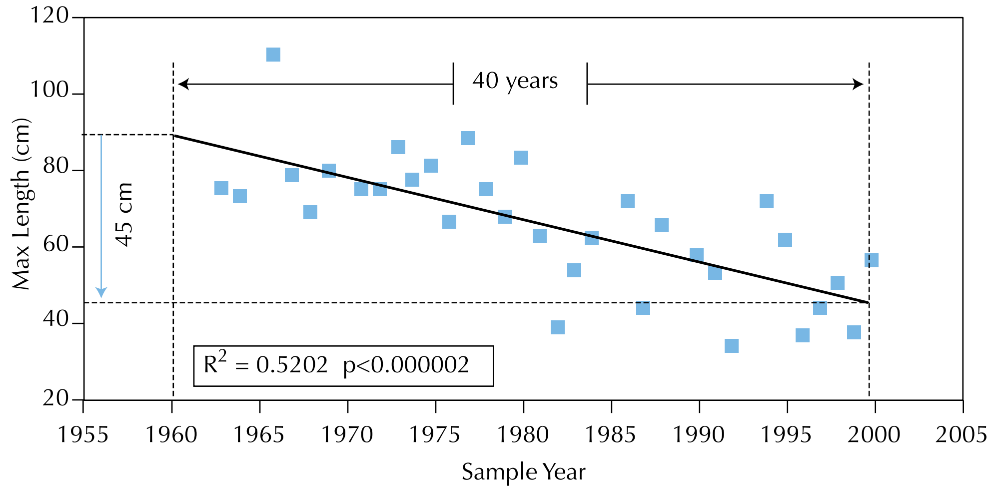
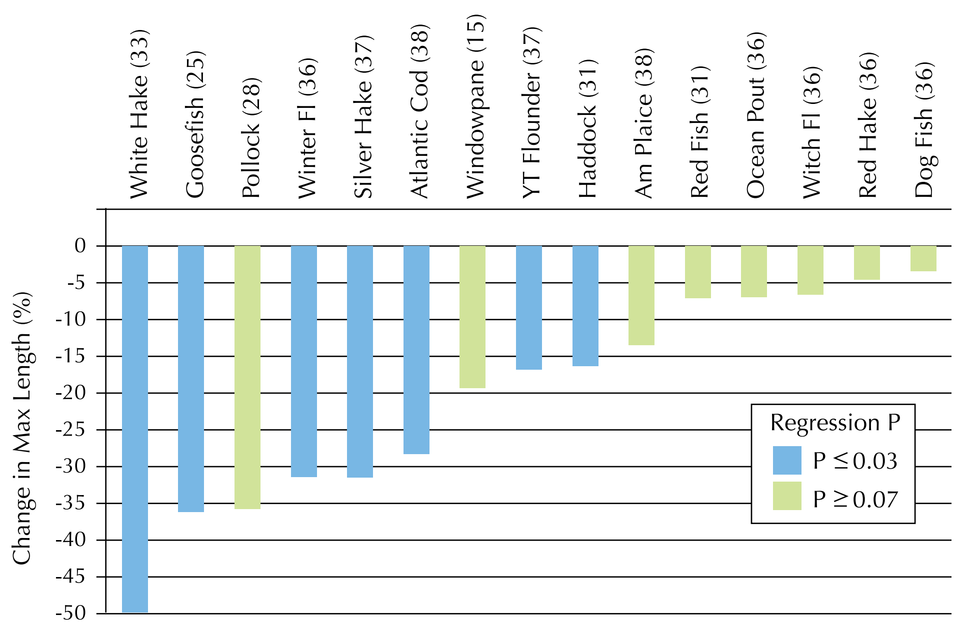


Figure 43. Reduction in maximum length of 15 species of ecologically and commercially important fish over a 38-year period (1963–2000) within the Stellwagen Bank sanctuary.

All species showed decreases in maximum length; those signified by the blue bars were statistically significant. The number in parenthesis following fish name was the number of trawl samples analyzed for the respective fish species identified (Crawford and Cook, in preparation).



For seven of these species (white hake, goosefish, winter flounder, silver hake, cod, yellowtail flounder, haddock), the decrease was significant. Estimated maximum length decreases for the seven species ranged from 15% to 49% for this period. The maximum length of white hake was reduced by nearly half (49%) and Atlantic cod was reduced by 27% over this period, for example. The average decrease for all 15 species combined was 20%. Results of the analysis presented next, in which the maximum length of some of these species appears to be increasing since the onset of fishery management actions, indicate that a contributing cause of the decrease in maximum length is the consequence of nearly four decades of heavy exploitation.

A subsequent analysis of the maximum length of fish caught in the sanctuary for a more recent time period (1990-2005) offers some cause for optimism for a subset of the species originally examined by Crawford (i.e., Atlantic cod, haddock, white hake, American plaice, winter flounder, witch flounder, and yellowtail flounder). Since the onset of fishery management actions in the 1990s, the maximum length of some species, particularly cod and haddock, appears to be increasing (Figure 44). Other species (particularly the flatfishes) show signs of a reversing trend in maximum size but are still of concern. The data analyzed are from the NOAA Fisheries Service research trawl surveys conducted within the sanctuary and serve to update the results of the analysis by Crawford presented above.

The finding of the great extent to which the size and (by implication) age structure of key commercial and ecologically important fish species has been truncated in the sanctuary compounds the likely population consequences of the BOFF effect, if it extends to these species as well. Related work with haddock suggests that it does (Wright and Gibb, 2005). The removal (i.e., absence) of large size classes among these key predatory species should also have a profound effect on the composition of their associated biological communities within the sanctuary due to ontogenetic diet shifts associated with predator morphology and/or habitat. Size-based diets are a common pattern in the Northeast shelf fish community and diet shifts have important implications for trophic dynamics and both sanctuary and fisheries management (Garrison and Link, 2000). In the case of piscivores (such as cod), the range of available prey generally increases with predator size related to increases in predator gape width (size of mouth), swimming speed and visual acuity (reviewed in Juanes, 1994).

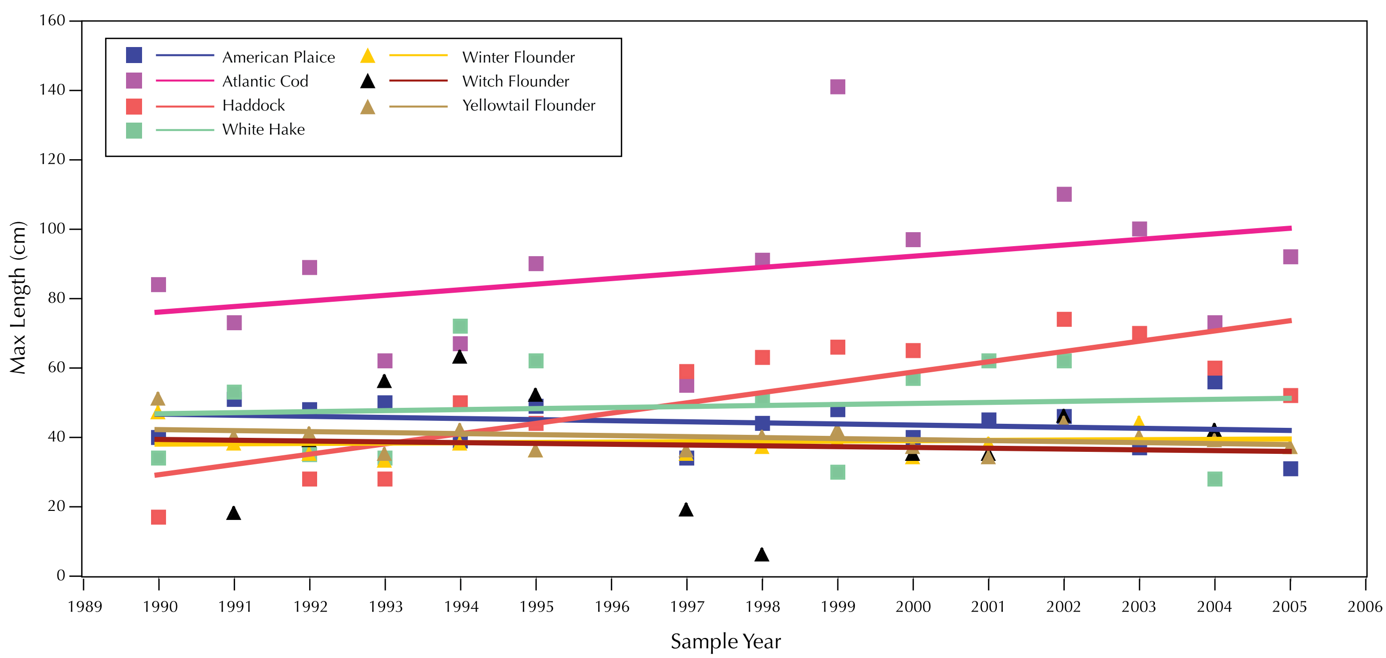
The truncation of old-growth age structure due to fishing can also have a profound effect on the genetic make-up and expression of traits within exploited fish populations. Selective fishing pressure on the larger (older) individuals of fishes over recent decades has caused the rapid evolution of decreased body size and fecundity of northern cod (Olsen *et al.,* 2004). An evolutionary change more troublesome than the reduction in body size and fecundity is the reduction of genetic diversity within fish species due to the harvesting of old-growth age structure. Marine fish populations are vulnerable to the loss of genetic variability, potentially leading to reduced adaptability and population persistence when the older members of the fish population are removed (Hauser *et al.,* 2002).

Notwithstanding potential selection for smaller average sizes at age, recent changes in average weights at age of GoM cod (Figure 45) strongly suggest environmental change as a causal mechanism. The magnitude of decreases in average size is much more rapid than any putative selective process could achieve, even with extraordinarily high trait heritability.

Historic Baselines

The Gulf of Maine Cod Project at the University of New Hampshire conducted a three-year survey and analysis of historical documents and manuscripts relevant to the marine historical ecology of the Stellwagen Bank sanctuary. The following summary of key findings derives from the final report of that study (Claesson and Rosenberg, 2009), which reinforces the long-term significance of the sanctuary's ecosystem and marine resources to the broader GoM system. At the same time, the study highlights the historical role of Stellwagen Bank's marine resources in the development and well-being of GoM coastal communities. While

Figure 44. Change in maximum length of a subset of fish species sampled in the Stellwagen Bank sanctuary during 1990–2005.



the study encompasses benthic invertebrates and fishes, the prevalent analysis is of fishes because of the rich statistical information gathered from the archives of the U.S Commission of Fish and Fisheries.

The study indicates that marine animal trophic level, richness, abundance and habitat quality in the sanctuary and the GoM declined sharply over an approximately 100-year period (1900-2000). The results of this research into the effects of climate factors such as sea surface temperature and the North Atlantic oscillation on these baseline shifts were uncertain. Therefore, the authors focused on documenting anthropogenic impacts, specifically, the effects of fishing on the sanctuary's marine animal populations and habitats. Indirect factors such as industrial pollution, river damming and reclamation of wetlands have interfered with spawning and migration of marine species. However, the direct impact of fixed- and towed-net fishing gears on Stellwagen Bank which has resulted in the removal of biomass and seafloor habitat disturbance was concluded to be the primary cause for declines in species richness and abundance within the sanctuary.

The following list summarizes the results of the quantitative and qualitative analysis of the historical record by Claesson and Rosenberg (2009):

a) Nearshore and microbank fish populations in the GoM including Stellwagen Bank were significantly deteriorated and had declined by ca. 1800;

b) Top predators in the sanctuary, such as halibut and swordfish, were overfished to near extirpation by the late 19th and early 20th centuries;

c) Steady decline in the trophic level of commercial fish species in the GoM began in the early 1900s with the advent of steam-powered bottom trawling;

d) Diversity of bottom-dwelling fish species in the western GoM appears to have declined significantly from ca. 1900 to 2000;

e) Maximum annual catch levels of historically important commercial fish species in the sanctuary have declined by nearly 50% from ca. 1900 to 2000; and,

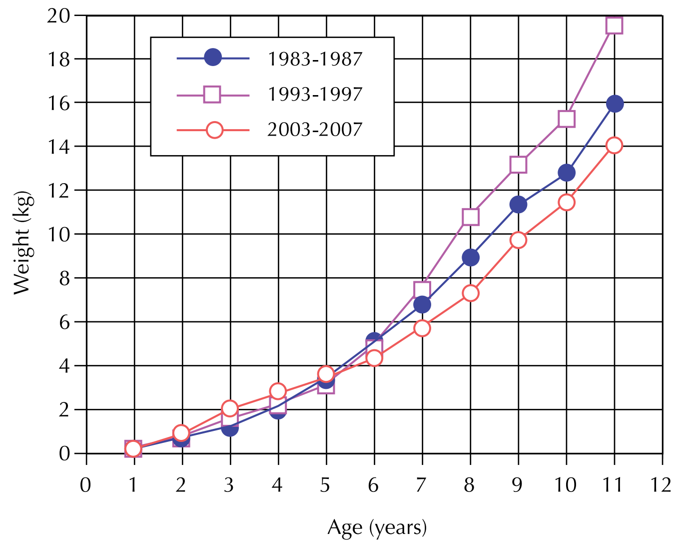
f) Proportional catch ratios of haddock to cod in the sanctuary have inverted in the last 100 years from 3:1 to 1:7, signaling resurgence in cod but a concomitant decline in haddock catches.

Management Implications

One of the principal objectives of this management plan is to protect and restore the ecological integrity of the sanctuary. In order to do this, the recent evidence discussed above suggests that old-growth age structure and large body-size classes be maintained in the population. As previously explained (Habitat Mediated Movement section of this document), 35% of Atlantic cod tagged in the sanctuary demonstrated a high degree of site fidelity (Lindholm and Auster, 2003; Lindholm *et al.,* 2007). Further, the majority of the cod tagged in the sanctuary area (tagging areas 124 and 132) by Howell *et al.,* (2007) were recaptured in the area where they were released. Additionally, a meta-analysis of 100 years of cod tagging studies across the North Atlantic showed a high rate (32%) of sedentary behavior for the species. These findings suggest that management directed at the sanctuary area alone (as opposed to the entire GoM) may be effective in meeting the sanctuary's objectives.

Figure 45. Observed average weight (kg) at age (years) for GoM cod for three five-year stanzas: 1983–1987; 1993–1997; and 2003-2007.

(Adapted from Figure 40.1 in NOAA, 2008.)



However, potential concentration of fishing effort at the sanctuary's boundaries could offset the protective value of the closed area to the degree that residency was temporary (Murawski *et al.,* 2005). Hence sanctuary policies must be coordinated with and complement policies of the NOAA Fisheries Service Northeast Regional Office and the New England Fishery Management Council. Generally, closures of areas without concomitant reductions in effective fishing mortality are insufficient to reduce fishing mortality on the population.

Old-growth age structure in long-lived fish (such as cod) can be maintained by three approaches (Berkeley *et al.,* 2004b): (1) lowering catch rates substantially, which can be economically infeasible; (2) implementing slot limits (release of both small and large individuals), which may be impractical due to capture mortality (e.g., via swimbladder expansion and barotraumas); and (3) implementing marine protected areas (MPAs) to ensure that at least part of the stock can reach old age and large size.

As indicated below under regulatory provisions, NOAA Fisheries Service has instituted regulations that are working to lower catch rates in the GoM region and established the WGoMCA in 1998 (although only overlapping 22% of the sanctuary area), hence implementing two of the three approaches identified that could help restore and maintain old-growth size and age structure of fishes in the GoM. The data series used to examine old-growth size structure in the sanctuary will continue to be extended to include the most recent data years available for all 15 species and analyzed to evaluate whether and to what degree these management actions are effective at increasing the maximum sizes of these ecologically important fish species within the sanctuary.

The identification of historic stable states and the services and benefits afforded by its productive and diverse ecosystem is critical to the restoration of the Stellwagen Bank sanctuary. The assessment of late 19th- and early 20th-century fisheries of Stellwagen Bank, as presented in Claesson and Rosenberg (2009), provides baselines for comparison to current ecosystem conditions in the sanctuary. Through this comparative analysis, long-term trends have been identified which may be used to direct future management decisions. For example, this research has shown significant declines in the biodiversity and abundance of fishes as well as major shifts in the composition of the Stellwagen Bank fisheries. These historic baselines are significantly different from the contemporary knowledge used to prepare the sanctuary *Condition Report* (NOAA, 2007) and buttress the need for management actions that improve current conditions and help restore the ecological integrity of the sanctuary. [For comparison of the historic and contemporary condition ratings refer to section VI. Summation, Table 24.]

Pressures

Commercial fishing with mobile gear, such as trawls and scallop dredges, together with fixed gear, such as bottom-tending gill nets and lobster pots, occurs extensively throughout the sanctuary. Commercial fishermen take species from four principal categories: groundfish, pelagics, other finfish and invertebrates. On average, 327 commercial fishing vessels per year fished in the sanctuary during 1996-2005 (see Commercial Fishing section of this document for details). Stressors resulting from commercial fishing include alteration of habitat and biological communities, removal of biomass, disturbance of feeding whales, entanglement of marine mammals, discharges of pollutants and destruction of historic resources. Other stressors, i.e., water quality, HABs, invasive species, are addressed in previous sections of this document.

The sanctuary is also a popular destination for recreational fishing boats. Recreational fishing by party, charter and private boats in the sanctuary targets primarily groundfish but also pelagic species such as bluefin tuna, shark and bluefish. On average, 69 party and charter boats per year fished in the sanctuary during 1996-2005 (see Recreational Fishing section of this document). Party boat and charter boat recreational fishing occurs over much of the sanctuary; however, the precise amount of private recreational use of the sanctuary has not been quantified. The recreational fishing fleet is estimated to take 25% of the Atlantic cod in the GoM (NEFMC, 2003). Stressors resulting from recreational fishing activities include targeted removal of large fish, fishing at times and places associated with spawning aggregations, discard mortality, disturbance of feeding whales, vessel strikes to whales, discharge of pollutants and destruction of historic resources.

Current Protection

Regulatory Provisions

Fishery resources in the Northeast, including in the sanctuary, are regulated by NOAA Fisheries Service with input from the NEFMC, the Mid-Atlantic Fishery Management Council (MAFMC) and the Atlantic States Marine Fisheries Commission (ASFMC). Some restrictions on fishing that affect the sanctuary have been put in place, including limited access programs and effort controls, rolling closures for groundfishing, catch and minimum size limits for individual species, and a large, permanent year-round habitat closure in the WGoMCA. See Sidebar for related considerations.

The latest approved Fishery Management Plan (FMP) developed by the NEFMC and the MAFMC is currently implemented by Amendment 13 to the Northeast Multispecies FMP (2004) (50 CFR Part 648). Other plans exist for the following species: Atlantic salmon; Atlantic sea scallop; American lobster (50 CFR Part 697); northeast multispecies and monkfish; mackerel, squid and butterfish; surfclam and ocean quahog; summer flounder; scup; black sea bass; Atlantic bluefish; Atlantic herring; spiny dogfish; Atlantic deep-sea red crab; tilefish; and the skate complex.

The Northeast Multispecies FMP establishes the following:

- Reduction in the number of Days at Sea
- Minimum size regulations for several major commercial and recreational species including but not limited to: monkfish, Atlantic cod, haddock, pollock, witch flounder, yellowtail flounder, American plaice and winter flounder
- Closures of spawning areas over Georges Bank, southern New England and the GoM
- New habitat closed areas over Georges Bank, southern New England and the GoM
- Increase in the mesh size of mobile trawl gear and gillnets
- Fish excluder devices and modified gear (raised footrope) for small mesh exempted fisheries
- Limits to hook size and number for hook gear
- Marking requirements for gillnet gear

In addition, federal lobster regulations (50 CFR Part 697) limit trap sizes and the number of traps allowed.

Under Amendment 13, the NEFMC and the MAFMC have also developed an updated FMP for Atlantic herring in coordination with the ASMFC; they also have developed a fishery management plan for the Arctic surf (or Stimpson) clam, for which commercial exploitation has been initiated in the Stellwagen Bank area (Amendment 13, 50 CFR part 648).

The northern shrimp FMP was developed by the ASFMC. The ASFMC is additionally responsible for striped bass and bluefish fisheries; the plan for the latter species is developed in cooperation with the MAFMC. The MAFMC is also charged with sole responsibility for management plans on summer flounder, butterfish, short and long-finned squid, surf clam, ocean quahog and mackerel.

Fishing for commercial bluefin tuna is regulated under the International Commission for the Conservation of Atlantic Tuna (ICCAT), as implemented via the Atlantic Tunas Convention Act of 1975. Quotas for bluefin tuna are determined by ICCAT. NOAA Fisheries Service allocates this quota by categories assigned to the four gear types employed in the fishery: hand-line, rod and reel, harpoon and purse seine net. The species is also caught incidentally by pelagic longline vessels.

Fishing for Atlantic striped bass in the sanctuary is prohibited by the general provisions set forth in 50 CFR 697.7(b). This section states that it is unlawful for any person to do any of the following: (1) fish for striped bass in the US EEZ [Exclusive Economic Zone]; (2) harvest any striped bass from the EEZ; (3) possess any striped bass in or from the EEZ (noted exceptions in areas of New York and Rhode Island); and (4) retain any striped bass taken in or from the EEZ. Boundaries of the Stellwagen Bank sanctuary fall entirely within the EEZ hence this regulation applies to the sanctuary.

Catch Share (Sector) Programs

There is growing interest in moving towards catch share programs in New England and away from traditional effort-based fisheries management approaches, such as regulating the number of days fishermen can fish or restricting access to certain areas during times of year when fish aggregate and/or spawn. Catch share programs are now in place in 13 federally managed fisheries in the United States. Sector management is a type of catch share program, where a group of fishermen are afforded a share of the total catch and more flexibility in making daily business decisions about how and when they want to fish.

The NEFMC in June 2009 approved the development of 17 new fishing sectors, and modification to two existing sectors, under the Northeast Multispecies Fishery Management Plan Amendment 16. Under proposed measures which are being reviewed by NOAA Fisheries Service, federal limited access groundfish permit holders have the option to either join a fishing sector or continue to fish under days at sea requirements. These sectors plan to fish widely throughout Georges Bank and the GoM, including the waters of the Stellwagen Bank National Marine Sanctuary.

On December 10, 2009, NOAA released a draft policy on the use of catch share programs in fishery management plans (http://www.nmfs.noaa.gov/sfa/domes_fish/catchshare/docs/draft_noaa_cs_policy.pdf). The draft NOAA policy encourages well-designed catch share programs to help rebuild fisheries and sustain fishermen, communities and vibrant working waterfronts. It is unclear at this time how implementation of these sectors will facilitate the realization of certain sanctuary management strategies (e.g., reducing seafloor habitat disturbance, fishery bycatch reduction).

Related Considerations

Fishing is not currently subject to regulation by the Stellwagen Bank sanctuary pursuant to the sanctuary Designation Document (Appendix B). In 1993 when the sanctuary was established, NOAA/NOS concluded that adequate legal mechanisms existed under the MFCMA to provide appropriate management of fisheries and that no supplementary fishing regulations under the NMSA were necessary (USDOC, 1993).

In the 17 years since sanctuary designation conditions have changed. As of the 4th quarter of 2009, 16 stocks require rebuilding within the New England fisheries; 16 stocks are overfished and overfishing is occurring in eight stocks (Status Determination Report, 2009 4th Quarter, NOAA Fisheries Service, NERO; http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm). Associated context is provided in Rosenberg *et al.*, (2006). Moreover, the condition of resource states in the sanctuary is now more fully characterized and is much better understood than in 1993, when the first management plan for the sanctuary was published by NOAA.

Importantly, for those stocks currently experiencing overfishing, the MFCMA calls for all overfishing to be eliminated by 2010. In terms of an ecosystem approach to management, NOAA must also consider the significant collateral effects of fishing on sanctuary resources that must be accounted for under the comprehensive resource protection objectives of the NMSA. These include biodiversity loss at the genetic, species and community levels; food web changes and shifts in community composition that occur through depletion of forage species and top level predators; the truncation of population size and age structures; and, degradation and loss of the sanctuary's biogenic habitats and living landscapes.

The congressionally mandated periodic review of sanctuary management plans allows national marine sanctuaries to adjust to better protect sanctuary resources. NOAA has determined that renewed consideration should be given to reduction of ecological impacts from fishing activities and mobile fishing gear in the sanctuary as described in the Ecosystem Alteration Action Plan in this document, for example. An explanation of the regulatory coordination tools available through the NMSA on fishery management issues in national marine sanctuaries is provided in Appendix H.

Seabirds

Status

Seabirds are defined as birds that spend a large proportion of their lives at sea, feeding either entirely or predominantly on marine organisms, and coming ashore for relatively short periods for resting or breeding (Schreiber and Burger, 2001). Most seabirds are assigned to one of three orders: the Procellariiformes (e.g., shearwaters, fulmars, petrels and albatrosses), the Pelecaniformes (e.g., gannets, pelicans, boobies and cormorants) or the Charadriiformes (e.g., gulls, terns, auks). Seabirds are usually numerically abundant, long lived (15-70 years) and feed at a variety of TLs (i.e., predators and scavengers). As such, seabirds can be very responsive to changes in their environment. The following background draws heavily from Pittman and Huettmann (2006).

The broad-ranging movements and longevity of seabirds mean that they track environmental changes at spatial and temporal scales that are otherwise difficult to monitor (Diamond and Devlin, 2003; Huettmann and Diamond, 2006). For example, seabird species are useful bioindicators by providing valuable information to define pelagic habitat types (Springer *et al.,* 1996) and assess ecosystem health (Furness and Greenwood, 1993). Changes in seabird distribution and abundance, as well as breeding success, growth rates, survival and diet composition, have been closely linked to regional climate variability (e.g., North Atlantic oscillations and El Niño/La Niña events) and global climate change (Aebischer *et al.,* 1990; Brown, 1991; Monaghan, 1992; Montevecchi and Myers, 1997; Schreiber and Schreiber, 1989;) and changes in prey abundance (Cairns, 1987; Diamond and Devlin, 2003; Hamer *et al.,* 1991; Garthe *et al.,* 1996). Seabirds also have the potential to function as indicators of pollutants, particularly since they rapidly bio-accumulate chemicals that are lipid-soluble such as organo-chlorines (e.g., DDT, PCBs) and organo-metals (e.g., methyl mercury) (Chapdelaine *et al.,* 1987; Furness and Camphuysen, 1997).

The GoM is locally and internationally recognized as an important area for seabirds, with seabird densities that are considerably higher than adjacent oceanic waters (Powers *et al.,* 1980; Powers, 1983; Powers and Brown, 1987; Platt *et al.,* 1995). The shallow banks and shelves, including Brown's Bank, Georges Bank, Stellwagen Bank, Cashes Ledge, Cape Cod and the Grand Manan region, have long been known to support large numbers of seabirds (Powers, 1983; Powers and Brown, 1987; Huettmann and Diamond, 2006). In its capacity as the U.S. partner of BirdLife International, the Massachusetts Audubon Society (Mass Audubon) has designated Stellwagen Bank an Important Bird Area (IBA). An IBA is a site that provides essential habitat to one or more species of breeding, wintering or migrating birds, and which supports high-priority species, large concentrations of birds, exceptional bird habitat, and/or has substantial research or educational value.

Species Frequenting the GoM

Many of the seabirds observed in the GoM are seasonal migrants that have traveled vast distances from remote islands in the south Atlantic where they nest (Brown, 1973). For example, Wilson's storm-petrel migrates to the GoM during summer from breeding sites in sub-Antarctic islands. Sooty shearwaters and greater shearwaters are also summer migrants to the GoM from breeding sites on several remote south Atlantic islands (Tristan da Cunha and Gough Island) and sub-Antarctic islands (Huettmann, 2000). Other birds, including some arctic terns and red phalaropes connect the GoM with southern and western Africa (Brown, 1979).

Black-legged kittiwakes and great cormorants are winter migrants, typically migrating from more northerly regions along with some auks, especially razorbills. Other seabirds migrate shorter distances (e.g., from Canada) to specific sites within the GoM that are considered to be important moulting grounds for immature birds (Huettmann and Diamond, 2000; Huettmann *et al.,* in press). Non-resident seabirds visiting the GoM typically exhibit a spring and fall arrival and departure pattern (Powers and Brown, 1987). Atlantic puffins from Maine and Canada are frequently observed feeding in the sanctuary during winter months. The majority of shearwater species in the region are migrants and breed outside the study area (Brown, 1988, 1990).

Seabirds that have established breeding colonies in the GoM region include Atlantic puffin, black guillemot, common murre, Leach's storm-petrel, razorbill, common eider and several species of cormorant, gull and tern. In fact, the islands of Maine provide the only breeding sites in the United States for Atlantic puffin and razorbill (one of the rarest breeding auks in North America) and provide some of the southernmost breeding sites for Leach's storm-petrel and common eider. These breeding sites prompted the U.S. Fish and Wildlife Service (GoM coastal program) to recognize approximately 300 "nationally significant" seabird nesting islands in the GoM.

Relationships with the Environment

Many seabirds have distinct utilization patterns associated with specific ocean currents and water masses, and the boundaries between those features, as well as finer-scale oceanographic and bathymetric features that affect prey dispersion and availability (Balance *et al.,* 2001; Daunt *et al.,* 2003; Schneider, 1990b, 1997). In most regions, oceanographic (e.g., sea surface temperature and chlorophyll concentrations) and bathymetric variables show a strong across-shelf spatial gradient that is associated with patterns of seabird distribution and prey abundance.

Seabird preference for shallow continental shelf waters versus deeper oceanic waters, proximity to shore, or to some distinct bathymetric feature (e.g., continental shelf edge) have been found to explain broad-scale patterns in abundance for a wide range of seabird species (Schneider, 1997; Wynne-Edwards, 1935; Yen *et al.,* 2004a, b). For example, Yen *et al*. (2004a, b) found that seabirds target regions of complex and steep topographies where oceanographic conditions lead to elevated productivity (fronts and upwelling zones) and increased prey retention.

The razorbills, murres and puffins (Alcidae), terns and some gulls (Laridae), fulmars, shearwaters and storm-petrels (Procellariiformes), gannets (Sulidae) and cormorants (Phalacrocoraciidae) are key components of the offshore ecosystem, where they form an important group of predators of small fish, squid and planktonic crustaceans. The primary prey items for most of these seabird species are small fish including Atlantic herring, sand lance, hake and mackerel, although they will also feed on cephalopods, crustaceans, annelids and some plant material (Powers *et al.,* 1980; Hall *et al.,* 2000; Diamond and Devlin, 2003).

Stomach content analysis of 156 individuals of nine seabird species (five species of Procellariiformes and four gulls, Laridae) collected at sea from the northeastern continental shelf showed that all species fed on fish, with sand lance being an important prey item for most marine birds throughout the year (Powers *et al.,* 1980). Squid were also a major prey item for many species, particularly greater shearwaters, while euphausiids (pelagic crustaceans) were an important component of the diet of Wilson's storm-petrel.

Seabird Utilization of the Sanctuary

An estimated 60 species of seabird were recorded within the GoM, based on sightings from the Manomet Bird Observatory (MBO) surveys (1980-1988). Nearly all of these, 53 species, were identified for the Stellwagen Bank sanctuary; they are listed by common and scientific name in Appendix J. Species rank based on frequency of occurrence was very similar between the sanctuary and the broader GoM, with the exception of gulls which, respectively, were more frequently and shearwaters, less frequently sighted within the sanctuary. In addition, there were five separate sightings of the federally endangered roseate tern in the GoM, one of which was recorded within the sanctuary. Since the surveys, MBO was renamed the Manomet Center for Conservation Sciences.

Predictive Modeling

The NOAA National Center for Coastal and Ocean Science (NCCOS) integrated the MBO seabird survey database covering the U.S. portion of the GoM with the PIROP (Integre des Recherches sur les Oiseaux Pelagiques) seabird survey database covering the Canadian portion of the GoM for predictive modeling purposes (Pittman and Huettmann, 2006). The combined database provides large sample sizes and exceptional spatial and temporal resolution for the GoM region and the northeastern U.S. continental shelf. This database was used to model and predict temporal patterns of seabird distribution and total abundance across a very broad spatial scale.

Monthly total abundance data for eight focal seabird species, corrected for effort, were compared to examine temporal patterns of abundance (Pittman and Huettmann, 2006). For this analysis, the GoM region was divided into 5 x 5 minute cells. Although the model presented a simplified estimate of monthly changes in seabird abundance, the temporal patterns of presence and absence for the GoM were clearly shown. This was true at the scale of the sanctuary area when seasonal summer-winter comparisons were made.

The sanctuary area supported all eight focal species in either one or both seasons. The sanctuary supported a higher number of species during winter months than summer months. In winter months, the maximum mean number of focal species (per cell) using the sanctuary was eight. Highest seabird diversity was recorded over the northern tip of Stellwagen Bank and southern Tillies Basin. In summer months, the maximum mean number of focal species (per cell) using the sanctuary was four, with highest mean number of species occurring over the central Stellwagen Bank area and Tillies Basin. Non-breeding summer migrants (greater shearwater and Wilson's storm-petrel) were particularly prevalent within sanctuary waters.

Patterns of prevalence indicated that auks used the sanctuary more in winter than summer. Highest auk prevalence was recorded in winter at the southern end of the Stellwagen Bank and northern tip of Cape Cod. Highest prevalence for auks in winter over the southern tip of Stellwagen Basin was also predicted in the model. Similar seasonal use patterns were found for razorbill, with absence in summer and intermediate level prevalence in the southern part of the sanctuary in winter. Greater shearwaters were more prevalent than auks in both winter and summer seasons, with sightings recorded from most cells within the sanctuary area. Tillies Basin supported highest prevalence of greater shearwaters, particularly in the summer months.

Northern gannets were widespread throughout the sanctuary in winter with highest prevalence in the south and central portions of the sanctuary. Northern gannets were also recorded in summer, although they were both less widespread and less prevalent than in winter. Wilson's storm-petrels were also distributed throughout the sanctuary in summer with highest prevalence over shallow waters on central Stellwagen Bank and over deeper waters of Tillies

Basin. Wilson's storm-petrels were not recorded within the sanctuary during winter months.

Standardized Survey

During July 1994–August 1995, a 14-month long study was undertaken by the sanctuary to quantify and map patterns of human and wildlife use of the sanctuary, including seabirds (D. Wiley and S. Highley, unpublished data). Each month data were collected along 10 standardized shipboard survey tracklines (strip transects of 400 m width) that crossed the sanctuary at 5 km (2.5 nm) intervals providing complete coverage of the southern two-thirds of the sanctuary that were surveyed. The 1994–1995 survey was repeated in 2001–2002 with area coverage at this later date including the entire sanctuary but excluded seabirds. (Refer to Wiley *et al.,* 2003 for details of the methodologies used.)

The distribution of data grouped by seabird family was analyzed to portray the grid density and spatial intensity of seabird use of the sanctuary. Data were binned into 5 x 5 minute grid cells for analysis, as done for the GoM region model discussed above. The analysis of the standardized survey data was done by NCCOS on behalf of the sanctuary during preparation for their larger scale GoM modeling. These results do not appear in their published work (Pittman and Huettmann, 2006).

Sightings totaling 5,825 seabirds of 34 species in nine families were recorded within the sanctuary during July 1994–August 1995 (Table 6). Their relative seasonal abundance grouped by family is summarized in Figure 46 for the calendar year July 1994–June 1995. This figure should be referred to in the subsequent descriptions of seasonality. The spatial distribution and density over all seasons for selected families is presented in a series of grid plots of the sanctuary that accompany the following family accounts (Figure 47).

The family Laridae (gulls, terns and jaegers) was numerically dominant over the year, being less abundant in the spring. Highest numbers were seen in vicinity of the northern and southern portions of Stellwagen Bank. Great black-backed gulls and herring gulls were most frequently seen.

The family Hydrobatidae (storm-petrels) was present only during spring (especially) and summer. Storm-petrels were sighted widely over Stellwagen Bank and area in spring, with highest numbers in both the northern and southern portions; but sightings in summer were entirely in the southern portion of the bank, especially the southwest corner and adjacent area.

The family Sulidae (gannets and boobies) was most numerous during fall (especially) and spring, although present in lower numbers over other seasons. Highest numbers were seen widely over and around Stellwagen Bank and Basin.

The family Alcidae (auks, murres and puffins) was present only during fall and especially winter. Numbers were seen widely over Stellwagen Bank and area in both seasons, but areas of greater concentration occurred in both the northern (especially) and southern portions of the bank in winter.

Table 6. Sightings totaling 5,825 seabirds of 34 species in nine families recorded in the Stellwagen Bank sanctuary during July 1994–August 1995.

Family	Common Name	Count
Laridae	Great Black-Backed Gull	1,516
	Herring Gull	1,431
	Black Legged-Kittiwake	276
	Common Tern	48
	Ring-Billed Gull	11
	Pomarine Jaeger	5
	Least Tern	4
	Laughing Gull	3
	Parasitic Jaeger	2
	Unidentified Gull	1
	Unidentified Jaeger	1
	Total	**3,298**
Hydrobatidae	Wilson's Storm-Petrel	1,100
	Leach's Storm-Petrel	4
	Total	**1,104**
Sulidae	Northern Gannet	510
	Total	**510**
Alcidae	Razorbill	219
	Unidentified Large Alcid	30
	Dovekie	14
	Atlantic Puffin	5
	Common Murre	5
	Black Guillemot	4
	Thick-Billed Murre	1
	Total	**278**
Anatidae	Common Eider	206
	White-Winged Scoter	37
	Black Scoter	12
	Surf Scoter	6
	Oldsquaw	2
	Total	**263**
Procellariidae	Greater Shearwater	176
	Sooty Shearwater	64
	Cory's Shearwater	6
	Manx Shearwater	5
	Northern Fulmar	5
	Total	**256**
Phalacrocacidae	Double-Crested Cormorant	54
	Great Cormorant	27
	Total	**81**
Gaviidae	Common Loon	21
	Red Throated Loon	1
	Total	**22**
Scolopacidae	Unidentified Phalarope	12
	Red-Necked Phalarope	1
	Total	**13**
	Total	**5,825**

The family Anatidae (ducks, geese and swans) was principally sighted during summer, fall (especially) and winter. Highest numbers were seen over Stellwagen Basin and the western margin of the bank.

Sightings of species in the remaining four families were relatively rare during this particular 12-month period. The Procellariidae (shearwaters and fulmars) were sighted in spring, summer (notably) and fall; they were not sighted in the winter. This family is customarily well-represented in the sanctuary, which is the case when the entire 14-month sampling period is considered (Table 6) rather than just the 12 months chosen for the seasonal analysis. This variability in sightings is discussed below.

The family Phalacrocacidae (cormorants and shags) was sighted mostly during fall and especially spring; they were not sighted in the winter. The Gaviidae (loons and divers) were sighted in spring, summer and especially fall; they were not seen in winter. The Scolopacidae (sandpipers and phalaropes) were sighted only in summer.

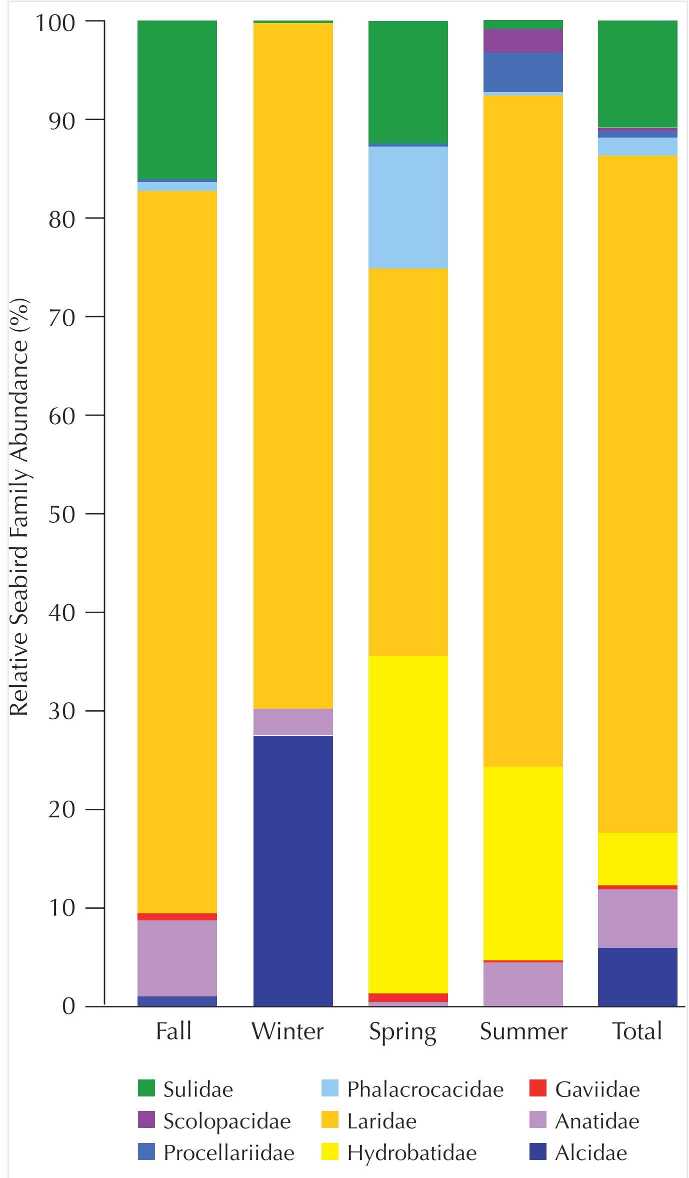
Sources of Variability

Variability in seabird sightings occurs seasonally and interannually within the Stellwagen Bank sanctuary. Comparison of the predictive modeling results over 1980-1988 (9-year period) at the scale of the GoM with the standardized survey sightings over 1994–1995 (1-year period) at the scale of the sanctuary demonstrates general agreement in seasonal presence or absence by species for some major groups. For example both analyses indicate that razorbills (auks) use the sanctuary more in winter and storm-petrels in summer.

However, the predictive modeling indicates that northern gannets are widespread in the sanctuary in winter, especially, and summer, whereas the standardized survey sightings made over a shorter time frame indicate that the family Sullidae (gannets and boobies) was most prevalent in fall especially and spring. Anecdotal observations from the sanctuary tend to support the fall-spring pattern as well. As noted above, seabirds are far ranging and environmentally facile; oceanographic climate and late or early seasonal turnover of sanctuary waters and associated productivity changes have the potential to influence seabird abundance patterns within relatively short time frames at the geographic scale of the sanctuary.

Figure 46. Relative seasonal abundance of seabirds within the Stellwagen Bank sanctuary for the calendar year July 1994–June 1995.

Data are individual sightings of species from the standardized survey grouped by family.



Standardized survey sightings in the sanctuary demonstrate that the relative abundance of seabird species can vary as much within the same month (August) between subsequent years (1994 and 1995) as between different months (August and February) in the same year (1995) (Figure 48). Great black-backed gulls accounted for the majority (60.1%) of the seabirds recorded in August 1994, while Wilson's storm-petrels made up the majority (76.7%) of the seabird sightings in August 1995. Likewise, while Wilson' storm-petrels made up 76.7% of the sightings in August (summer) 1995, razorbills made up 50.7% of the seabirds recorded in February (winter) that same year.

The combined use of predictive modeling and standardized surveys allows for the start of a comprehensive assessment and understanding of the seabird communities in the sanctuary. Results to-date indicate that while it is certain that a characteristic set of seabird species routinely use the sanctuary, and while there are demonstrated spatial patterns of seasonal use among the major groups, relative abundance among these species varies greatly and seasonal and interannual variability is high.

Pressures

Historically, the main threats to seabirds have been coastal development, predation by humans and other animals, removal of prey through fisheries activity and pollution of the marine environment. Drury (1973, 1974) describes the extensive harvesting of seabirds for food and feather in New

FIGURE 47. PART 1. SPATIAL DISTRIBUTION AND DENSITY OF SEABIRDS IN THE STELLWAGEN BANK SANCTUARY.

Data are individual sightings of species from the standardized survey for the period July 1994 – August 1995 grouped by family and aggregated over all seasons. Families included in the figure are: Laridae (gulls, terns and jaegers), Sulidae (gannets and boobies), Hydrobatidae (storm-petrels), Alcidae (auks, murres and puffins), Anatidae (ducks, geese and swans), and Procellaridae (shearwaters and fulmars). Data were analyzed by *ArcView's ArcMap* program.

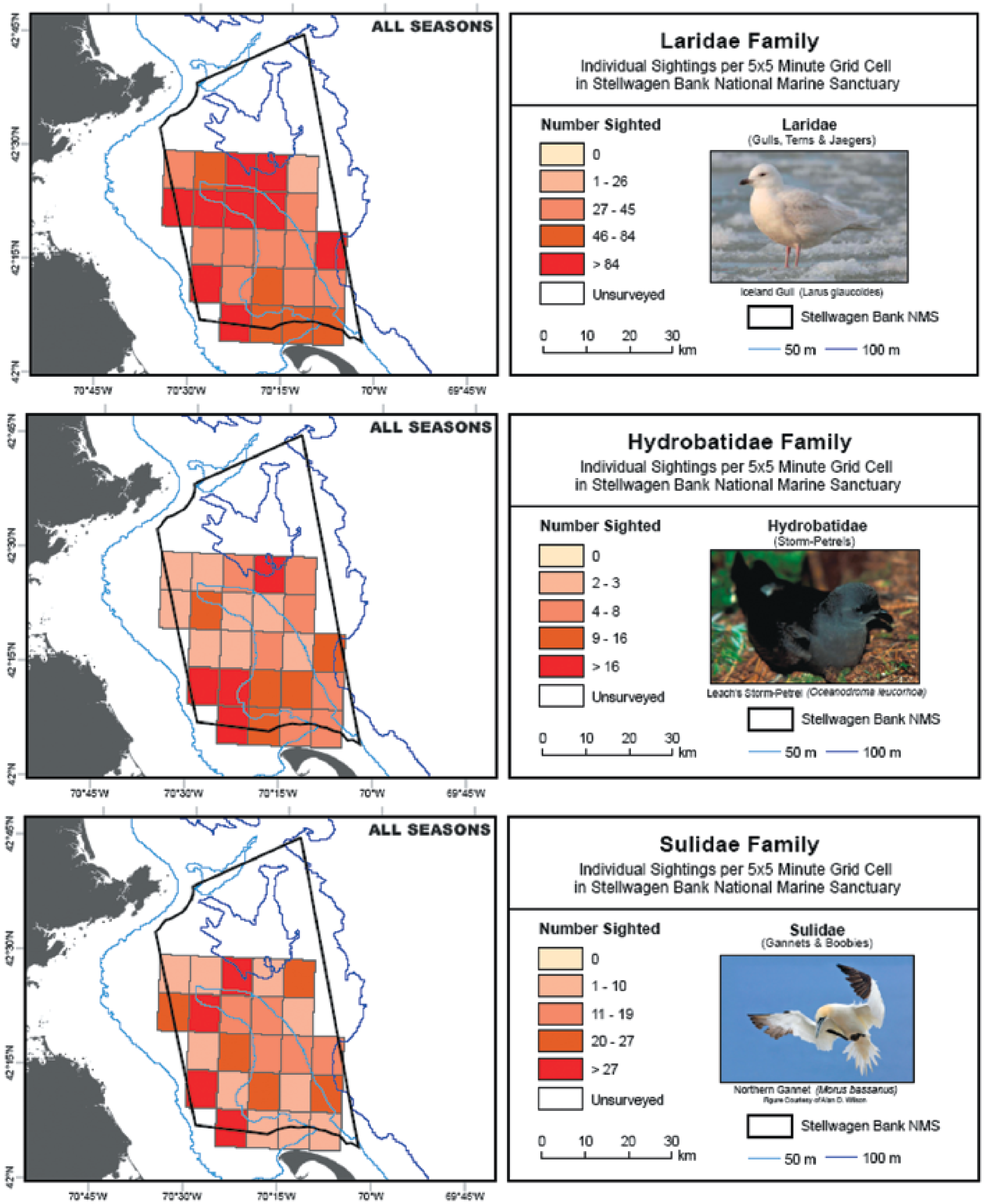
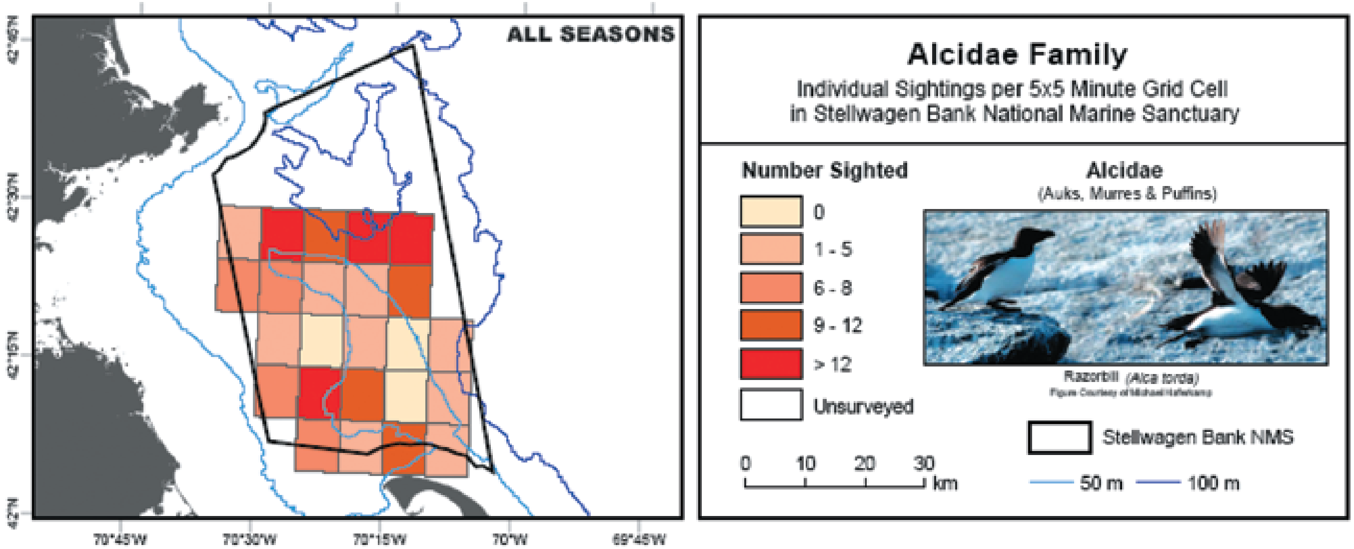
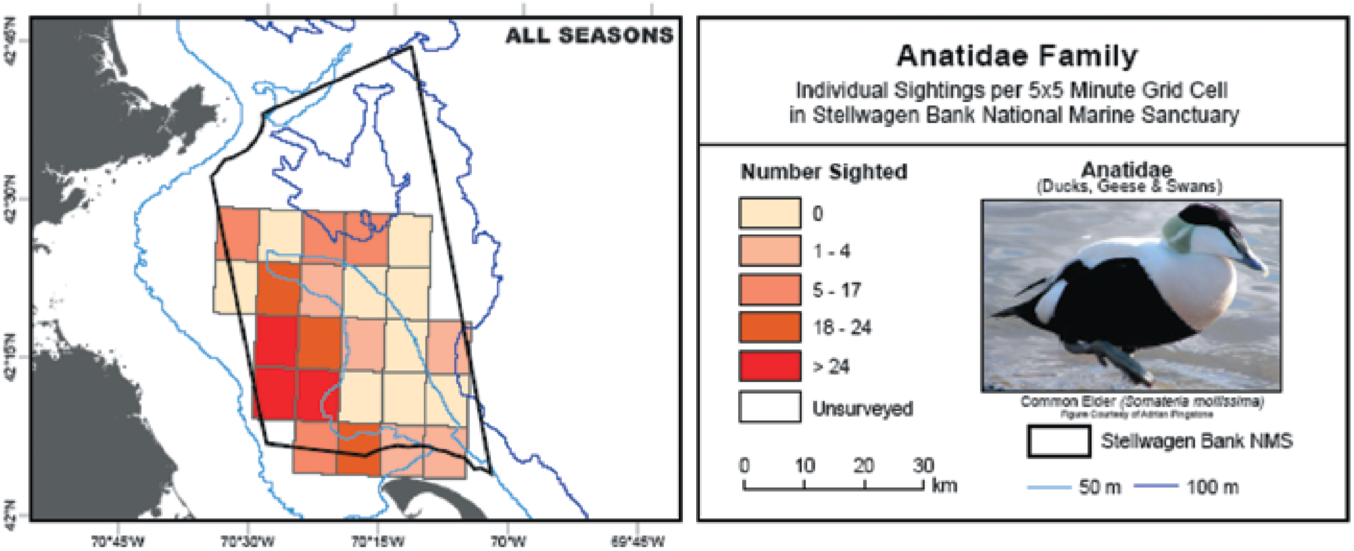
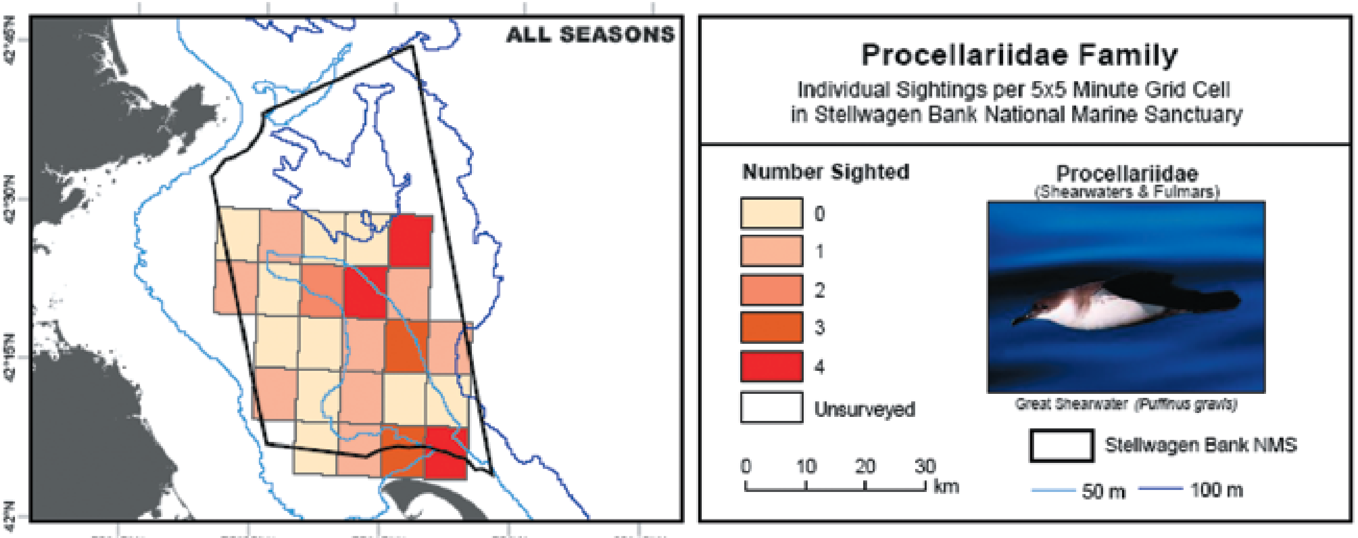


Figure 47. Part 2. Spatial distribution and density of seabirds in the Stellwagen Bank sanctuary.

Data are individual sightings of species from the standardized survey for the period July 1994–August 1995 grouped by family and aggregated over all seasons. Families included in the figure are: Laridae (gulls, terns and jaegers), Sulidae (gannets and boobies), Hydrobatidae (storm-petrels), Alcidae (auks, murres and puffins), Anatidae (ducks, geese and swans), and Procellaridae (shearwaters and fulmars). Data were analyzed by *ArcView's ArcMap* program.







England that resulted in extirpation of many seabird species even from remote outer islands by the turn of the 20th century. Great auks (*Pinguinus impennis*) were once frequently sighted in the GoM where some populations over-wintered, but were hunted to extinction by 1844. Great auk bones have been found in Massachusetts (Martha's Vineyard, East Wareham, Marblehead, Eagle Hill and Plum Island) and at least ten islands along the Maine coast (Burness and Montevecchi, 1992). Refer to the Sidebar for more information about the great auk.

Interactions between fisheries and seabirds have been well documented in many regions worldwide, with both increases and declines of seabird populations linked to patterns of fishing activity (Tasker *et al.,* 2000; Tasker and Furness, 2003; Votier *et al.,* 2004). Intense fishing activity can impact seabird populations through reduction of prey abundance and perturbation of prey population and community structure (Pauly *et al.,* 1998; Tasker *et al.,* 2000). Food web changes related to heavy fishing over many years have been found to adversely affect seabirds in the GoM (Lotze and Milewski, 2004). In addition, mortality related to entanglement with fishing gear has been reported.

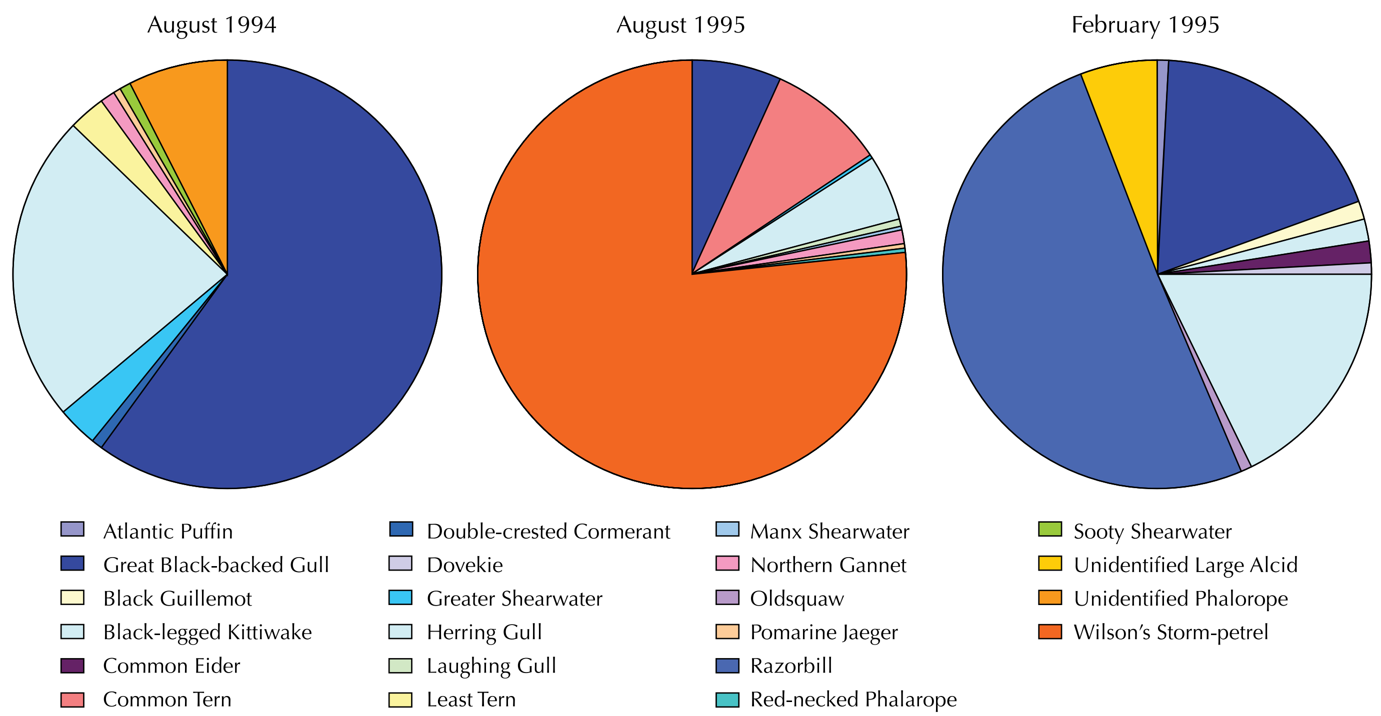
Based on NOAA Fisheries Service fishery observer data for 1994–2003, entanglement currently is not considered a major source of seabird mortality in the GoM or the sanctuary (Soczek, 2006). While occurring at a low rate, this study found that 88.6% of the overall observed seabird bycatch in the New England area was in the gillnet fishery, and shearwaters, particularly the greater shearwater, comprised 78.6% of all identified seabirds. This species is not currently classified as globally endangered or threatened (BirdLife International, 2004), but the potential for declines in the population have prompted its inclusion in the "Moderately Abundant Species with Declines or High Threats" category of the American Bird Conservancy's Green List (American Bird Conservancy, 2004) and in the "High Concern" category in the North American Waterbird Conservation Plan (Kushlan *et al.,* 2002).

Possibly the greatest threat for many seabirds (particularly terns and auks) in the GoM is from other seabirds, primarily gulls (Drury, 1965). Increases in fishery discards (offal and bycatch) and the spread of open landfills during the mid-1900s led to increased herring gull and great black-backed gull populations. This in turn led to greater pressure on other seabirds, particularly terns, through competition for prime nesting sites and increased predation by gulls on their eggs and chicks (Anderson and Devlin, 1999; Drury, 1965; Platt *et al.,* 1995).

Industrial contaminants are also a potential threat to seabird populations (Burger and Gochfeld, 2002). Elevated PCBs have been found in roseate tern chicks at Bird Island (Massachusetts) (Nisbet, 1981) and a wide range of metals has been found in common terns at breeding colonies in Massachusetts (Bureger *et al*, 1994). The impact of pollutants on seabirds, including sub-lethal effects, has not been adequately assessed for the GoM.

Analyses of changes in seabird populations in the Bay of Fundy (northern GoM) since European colonization have shown that approximately 50% of marine and coastal bird

Figure 48. Demonstrated high seasonal and inter-annual variability in the relative abundance of seabird species frequenting the Stellwagen Bank sanctuary based on standardized survey sightings data for the period July 1994–August 1995.



The Great Auk

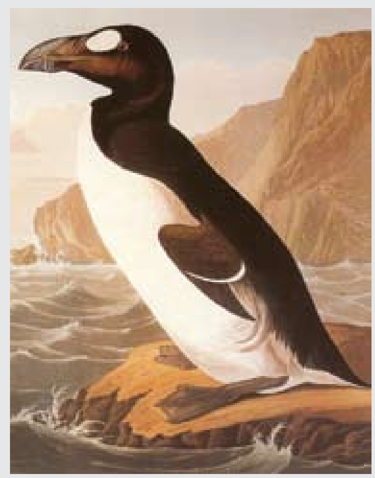
For 17th century European sailors to New England, the great auk (Figure 49) was a common and welcomed sight, indicating proximity to land. But by the middle of the 19th century the species had disappeared completely and forever (Eckert, 1963). While this once plentiful sea bird cannot return to life, the sad story of its extinction lives on as a stark reminder that humans do and have had a significant and sometimes permanent impact on the marine ecosystem of the Stellwagen Bank sanctuary.

The only flightless species of North Atlantic bird, the great auk was a noble animal of great speed and strength in the water. The largest of the alcids, the great auk was bigger than a goose in size and penguin-like in appearance. They were in fact the first birds to be called "penguins" (scientific name: *Pinguinus impennis)*, but their name was changed to great auk after scientists determined that they were not related to the birds of similar appearance in southern latitudes. One of their closest living relatives today is the razorbill which winters in large numbers in the sanctuary.

The great auk was a powerful and graceful swimmer, capable of diving to great depths in search of food. It made an annual migration in vast rafts of individuals swimming along the surface of the sea from summer breeding locations on or near Labrador, Newfoundland and points north and east, to winter feeding grounds on Stellwagen Bank, Georges Bank, and along the New England and Mid-Atlantic states. The birds spent most of their lives in the water—visiting land only to lay one egg per pair each year in massive breeding colonies.

Figure 49. Illustration of the great auk.

Adapted from painting by John J. Audubon titled "*Pinguinus impennis*—Great Auk."



But these terrestrial sojourns proved fatal for the great auk. Heavy bodies, small wings and flightlessness, the very qualities that adapted the great auks so well to their aquatic environment, coupled with the birds' tendency to group together in large numbers, made the animals easy prey for human visitors to the nesting colonies. First hunted for use as fish bait and food (fresh meat and eggs and salted meat for long voyages), the great auk later became economically popular for its oil and its feathers for fashion and for mattresses. The final chapter of its existence was closed by collectors searching for specimens for public and private museums, but the species was doomed by the time of the inauguration of President George Washington.

For generations, sailors and fishermen decimated the flocks, thinking that there would always be more. Even in the waning hours of the great auk's existence, scientists claimed there had to be additional stocks in the more northerly areas. We know now that they were very wrong. The naming of the sanctuary's research vessel in honor of this icon to local extinction is a constant reminder that the public must be ever-vigilant in protecting the resources of the Stellwagen Bank sanctuary.

species have been severely affected by human activity with several species extirpated and major colonies abandoned (Lotze and Milewski, 2004). With the exception of the great auk, re-colonization of abandoned breeding colonies has taken place for most species, albeit relatively slowly with estimated re-colonization time considered to take as long as 45 years for the common murre and 133 years for the northern gannet (Lotze and Milewski, 2002).

Current Protection

Sanctuary regulations (15 C.F.R Part 922 Subpart N) prohibit the taking of any seabird in or above the sanctuary, except as permitted by the Migratory Bird Treaty Act, as amended, (MBTA), 16 U.S.C. 703 et seq., and the Endangered Species Act (ESA), 16 U.S.C. 1531 et seq., or possessing within the sanctuary (regardless of where taken, moved or removed from), except as necessary for valid law enforcement purposes, any seabird taken in violation of the MBTA.

In addition where applicable, the MBTA, which implements conventions with Great Britain, Mexico, Russia and Japan, makes it unlawful except as permitted by regulations "to pursue, hunt, take, capture, kill… any migratory bird, any part, nest or egg" or any product of any such bird protected by the Convention (16 U.S.C 703).

Sea Turtles

Status

General Knowledge

Sea turtles are long-lived species that mature late in life and move great distances during their lifetimes, migrating hundreds or even thousands of kilometers between foraging and nesting grounds. They spend their lives at sea but return to land to reproduce.

Sea turtles are generally solitary creatures that remain submerged for much of the time they are at sea, which makes them extremely difficult to study. They rarely interact with one another outside of courtship and mating. Adult females nest in multiyear cycles, usually 2–4 years. They come ashore several times to lay hundreds of eggs during a nesting season in tropical waters. After about 50 to 60 days of incubation, the hatchlings emerge and head for the open ocean to begin life as pelagic drifters. This period is often referred to as the "lost years." In most cases, it is not known where the hatchlings go or how long this period lasts. While maturing over the course of several decades, sea turtles move in and out of a variety of ocean and coastal habitats. This open ocean existence often frustrates efforts to study and conserve them. Juvenile survival to adulthood is low.

Sea turtles serve important functions in the ecosystems in which they are found. For example, seagrass beds where green turtles graze regularly are more productive, nutrients are cycled more rapidly and the grass blades have higher protein content, thus benefiting other species. Some populations of sea turtles, whose feeding areas may be hundreds or even thousands of kilometers from their nesting beaches, serve an important role in nutrient cycling by transporting massive quantities of nutrients from the nutrient-rich feeding grounds (in colder waters of the North Atlantic) to typically more nutrient-poor coastal and inshore habitats in the vicinity of the nesting beaches (in tropical waters).

Occurrence in the Sanctuary

Seven species of sea turtles occur worldwide, four of which have been recorded in GoM: Kemp's ridley, leatherback, loggerhead and green. Only the leatherback and Kemp's ridley are seen with any regularity in the GoM. Leatherbacks and loggerheads have been the species most commonly reported in the sanctuary. Two families of sea turtles are represented in the sanctuary: the Dermochelyidae is represented solely by the unique *Dermochelys coriacea* (leatherback), which lacks the hard shell that characterizes the other sea turtles that make-up the family Cheloniidae. Three of the species recorded in the GoM are listed as endangered, and the fourth as threatened, under the ESA (Table 7).

Leatherback turtles have been sighted in the vicinity of the sanctuary in the spring and summer, and strandings have occurred in Cape Cod Bay spring, summer and fall. The predicted seasonality of leatherbacks is in the summer only. Loggerhead turtles have been sighted around the sanctuary in summer and strandings in Cape Cod Bay have occurred year-round. The predicted seasonality of loggerheads around the sanctuary is in the summer only. There have been no sightings of Kemp's ridley turtles around the sanctuary, though they have stranded in Cape Cod Bay winter, spring and fall. This species is not predicted to occur around the sanctuary throughout the year (Department of Navy, 2005; Shoop and Kenney, 1991). For additional information regarding sea turtle species accounts, visit URL http://www.iucn-mtsg.org/species/

Pressures

Sea turtles are transient visitors to the Stellwagen Bank sanctuary and there is very little documentation of human impacts to turtles in the vicinity of the sanctuary. In general, major threats to sea turtles in the U.S. include, but are not limited to: destruction and alteration of foraging habitats, incidental capture in commercial and recreational fisheries, entanglement in marine debris and vessel strikes. The NOAA Fisheries Service Observer Program documents fishing impacts to protected species and is the primary source for such information. NOAA Fisheries Service has not recorded any sea turtles taken in gillnets or otter trawls fished within the sanctuary since 1994 (NOAA Fisheries Service, unpublished data).

Table 7. Conservation status of sea turtles found in the Stellwagen Bank sanctuary and GoM region.

Common Name	Scientific Name	ESA Status
Kemp's Ridley	*Lepidochelys kempi*	Endangered
Leatherback	*Dermochelys coriacea*	Endangered
Loggerhead	*Caretta caretta*	Threatened
Green	*Chelonia mydas*	Endangered

Sea turtles die from eating or becoming entangled in non-degradable debris each year, including packing bands, balloons, pellets and plastic bags thrown overboard from boats or dumped near beaches and swept out to sea. Leatherbacks especially, cannot distinguish between floating jellyfish—a main component of their diet—and floating plastic bags.

Turtles are affected to an unknown, but potentially significant degree, by entanglement in persistent marine debris, including discarded or lost fishing gear including steel and monofilament line, synthetic and natural rope, and discarded plastic netting materials. Monofilament line is the principal source of entanglement for sea turtles in U.S. waters.

To effectively address all threats to marine turtles, NOAA Fisheries Service and the USFWS have developed recovery plans to direct research and management efforts for each sea turtle species. More information on threats to marine turtles is available at: http://www.nmfs.noaa.gov/pr/species/turtles/.

Current Protection

Sanctuary regulations (15 C.F.R Part 922 Subpart N) prohibit the taking of any marine reptile in the sanctuary, except as permitted by the ESA, as amended, 16 U.S.C. 1531 et seq., or possessing within the sanctuary (regardless of where taken, moved or removed from), except as necessary for valid law enforcement purposes, any marine reptile taken in violation of the ESA.

Sea turtles are given legal protection in the U.S. and its waters under the ESA, which lists the leatherback, Kemp's ridley and green turtle as endangered; the loggerhead is listed as threatened. This designation makes it illegal to harm, harass or kill any sea turtles, hatchlings or their eggs. It is also illegal to import, sell, or transport turtles or their products. NOAA Fisheries Service has jurisdiction over sea turtles in the water; USFWS has jurisdiction over sea turtles when they are on land.

Presently, all sea turtle species are listed in the International Union for the Conservation of Nature (IUCN) and Natural Resources Red List as endangered or vulnerable; included in Appendix I of the Convention on International Trade in Endangered Species (CITES) of Wild Fauna and Flora; and, all species are listed in Appendices I and II of the Convention on the Conservation of Migratory (CMS) Species of Wild Animals.

Marine Mammals

Marine mammals are a functional part of the biodiversity of the Stellwagen Bank sanctuary in a number of important ways, including their interdependence on seafloor and water column habitats and their predator-prey relationship to key forage species. They are a highly visible component of the species mix, which merits special consideration because of their charismatic attraction and universally protected or endangered status. They also are highly attuned to the acoustic environment and might be especially prone to harassment and behavioral disturbance due to human activity.

The major issues associated with marine mammals in the sanctuary are distinctly different from the issues otherwise associated with biodiversity conservation, such as biomass removal, changes in food webs and community composition, and disturbance or degradation of seafloor habitats and landscapes. Instead, marine mammal issues include entanglement in commercial fishing gear, vessel strikes from shipping, ocean noise, localized prey depletion, and marine pollution and contamination. However, the interactions with fishing and shipping are the key mortality factors for marine mammals (NOAA, 2007).

Of special note, the data set for humpback whales in the Stellwagen Bank sanctuary is the longest and most detailed study of baleen whales in the world. Matrilineal studies show evidence of four generations (1975–2006) of humpback use of, as well as inter-generational site fidelity to, the sanctuary as a feeding and nursery area. The newly-established sister sanctuary relationship between the Stellwagen Bank sanctuary and the Sanctuario de Mamiferos Marinos de la Republica Dominicana (Dominican Republic humpback whale sanctuary) is the first conservation management action worldwide to protect a migratory marine mammal species on both ends of its range (between sanctuary feeding/nursery grounds and the largest mating/calving grounds for humpback whales in the North Atlantic) by functionally linking two important nationally acclaimed marine protected areas.

Status

Cetaceans and Pinnipeds

The marine mammal fauna of the Stellwagen Bank sanctuary is diverse and has significant ecological, aesthetic and economic value. At least 22 species of marine mammals are known to occur in the waters over and around the sanctuary—six species of baleen whales (Mysticeti), eleven species of toothed whales (Odontoceti), and five species of phocid seals (Pinnipedia) (Table 8). For many of these species, the biological productivity of sanctuary waters provides primary habitat for feeding and other critical activities such as nursing. In fact, the sanctuary is one of the most intensively used cetacean habitats in the northeast continental shelf region of the United States (Kenney and Win, 1986).

Both cetaceans and pinnipeds are subject to a variety of human-related pressures, ranging from the visible impacts of human activities (e.g., vessel strikes, entanglements in fishing gear) to ubiquitous threats such as pollution, boat traffic and noise. In some instances, the impacts may be difficult to assess but may be particularly significant, especially for marine mammals that live in coastal areas or an environment that brings them into close contact with human activities.

Cetaceans

Cetaceans are divided between two suborders: the Mysticetes (baleen whales) and the Odontocetes (toothed whales). Representatives of both suborders are found in the sanctuary and throughout the GoM. Two morphological features distinguish cetaceans: mysticetes have baleen and two blowholes, and odontocetes have teeth and a single blowhole.

Baleen Whales

Baleen whales in the sanctuary range in maximum length from 6.4 m (26 ft.) for the minke whale to 30 m (100 ft.) for the blue whale. They have evolved baleen, instead of teeth, to feed upon zooplankton and small schooling fish. The plates of baleen form an efficient filtration system that separate prey from vast volumes of water taken into the mouth. Baleen whales typically forage throughout the water column, preying on species (such as sand lance, herring and copepods in the sanctuary) that are found from the surface to several hundred feet down. Humpback whales also are known to feed along the ocean bottom, scouring sand and gravel seafloor habitats that shelter sand lance; other species might also engage in similar behavior.

Within the sanctuary, the mysticetes are represented by six species arranged into two families, the Balaenopteridae (rorqual whales) and the Balaenidae (right whales) (Table 8). The Baleanopteridae are characterized by their sleek body form, generally, and the "rorqual" pleats on the underside of the mouth. This family includes the blue, fin, sei, minke and humpback whale, with the latter being alone in its own genus. The rorquals are 'gulpers,' feeding in discrete events, taking prey a mouthful at a time.

Table 8. Conservation status of 22 species of marine mammals sighted in the Stellwagen Bank sanctuary.

Group	Common Name	Scientific Name	MMPA Status	ESA Status
Baleen Whales (Mysticetes n=6)	Blue whale	*Balaenoptera musculus*	Protected under the MMPA	Endangered
	Fin or Finback whale	*Balaeneptera physalus*		Endangered
	Humpback whale	*Megaptera novaeangliue*		Endangered
	Sei whale	*Balaenoptera borealis*		Endangered
	Minke whale	*Balaenoptera acutorostrata*		
	North Atlantic right whale	*Eubalaena glacialis*		Endangered
Toothed Whales (Odontocetes n=11)	Sperm whale	*Physeter macrocephalus*	Protected under the MMPA	Endangered
	Long-finned Pilot whale	*Globicephala melaena*		
	Atlantic White-Sided Dolphin	*Lagenorhynchus acutus*		
	White-Beaked Dolphin	*Lagenorhynchus albirostris*		
	Harbor Porpoise	*Phocoena sp.*		
	Bottlenose Dolphin	*Tursiops truncatus*		
	Common Dolphin	*Delphinus delphis*		
	Striped Dolphin	*Stenella coeruleoalba*		
	Grampus (Risso's) Dolphin	*Grampus griseus*		
	Killer whale or Orca	*Orcinus orca*		
	Beluga	*Delphinus leucas*		
Seals (Pinnipeds n=5)	Harbor Seal	*Phoca vitulina*	Protected under the MMPA	
	Gray Seal	*Halichoerus grypes*		
	Harp Seal	*Pagophilus groenlandica*		
	Hooded Seal	*Cystophora cristata*		
	Ringed Seal	*Pusa hispida*		

The Balaenidae includes the North Atlantic right whale, characterized by its robust body with no dorsal fin, no ventral pleats and very long, narrow baleen. The right whales are "skimmers," grazing through patches of zoolplankton with their mouths open and continuously filtering prey as they swim. This skimming can be done at the sea surface, along the density gradient of mid-depth thermoclines or over the seafloor.

Besides the unique filtering system for feeding, most baleen whales share a number of broad characteristics in common. Most have wide geographic ranges and extensive migrations. They lack any known capability for sonar or echolocation. They often have a mating system in which both males and females are promiscuous. Often, they exhibit a relatively short period (less than one year) of maternal care with no strong kinship bonds aside from a mother and her new calf. They have large bodies requiring massive quantities of small prey. Despite these commonalties, the baleen whales of the sanctuary exhibit many differences. For more information, see species descriptions in Appendix. L.

Toothed Whales

Toothed whales observed in the sanctuary are represented by four families: Delphinidae (dolphins), Phocoenidae (porpoises), the Physeteridae (sperm whales) and Monodontidae (beluga whale). Of the eleven odontocete species that have been sighted in the sanctuary, common visitors include the white-sided dolphin, long-finned pilot whale and harbor porpoise (Table 8). From giants like the sperm whale to the diminutive harbor porpoise, sightings of odontocete species vary from year to year and may demonstrate cyclical or extralimital occurrences in the vicinity of the sanctuary.

As a rule, the odontocete diet consists of larger prey than that taken by the baleen whales. Unlike baleen whales, which often engulf large prey patches and ingest thousands or even millions of organisms at once, toothed whales usually feed by taking one item (such as a single fish) at a time. They often swallow their prey whole, and their teeth function to grip rather than to chew.

Unlike the baleen whales, the odontocetes usually do not make long annual migrations. Their seasonal responses tend to be onshore-offshore movements. Toothed whales are highly social animals, moving around in groups called pods. Different species and different populations within a species may vary in how these pods are organized. Some pods may be stable relationships between individuals over long periods of time; other pods may represent seasonal associations surrounding feeding or reproduction. For more information, see species descriptions in Appendix L.

Pinnipeds

True seals, or phocids, comprise one of three major families of pinnipeds (i.e., seals, sea lions and walrus). The term "pinniped" means "wing- or fin-footed" and refers to the family's modified front and hind appendages, which have a fin-like appearance. Members of the family Phocidae, called true or earless seals because they lack external ear flaps, are represented by five species in the sanctuary (Table 8). Of the five seal species found with any frequency in the Stellwagen Bank sanctuary, two (harp, hooded) are found only sporadically. The ringed seal is rare while gray and harbor seals can be found year-round, albeit generally in single sightings. Each species uses the sanctuary and nearby coast in different ways, but they do share many characteristics. Like toothed whales, pinnipeds have a broad diet including a wide variety of fishes, squid and other prey. For more information, see species descriptions in Appendix L.

Cetacean Habitat

The southern GoM, particularly the area of the Great South Channel, Stellwagen Bank and Jeffreys Ledge, supports the highest densities of baleen whales on the northeast U.S. continental shelf (Kenny and Winn, 1986). Additionally, critical habitat designation was established for the North Atlantic right whale in 1994 inclusive of the southwestern portion of the Stellwagen Bank sanctuary and Cape Cod Bay. The GoM (which includes sanctuary waters) is recognized as one of five geographically distinct feeding grounds for aggregations of endangered humpback whales in the western North Atlantic (Katona and Beard, 1990).

Cetaceans are capable of traveling large distances relatively rapidly, but also show distinctive site fidelity to specific feeding grounds and calving areas. Humpback, fin and right whales exhibit strong maternal fidelity to specific feeding grounds in the southern GoM (Clapham and Seipt, 1991). Weinrich found that individual humpback whales which visit Stellwagen Bank and Jeffreys Ledge as calves are more likely to return in subsequent years (Weinrich, 1998).

Hotspot for Prey Abundance

Sand lance are common in the GoM and prefer shallow areas of sandy bottom or fine gravel (such as Stellwagen Bank) for burrowing and spawning (Robards *et al.,* 1999). Herring use the seafloor for spawning (Stevenson and Scott, 2005). Sand lance and herring represent a vital link in the area's ecology, serving as a major food source for a variety of piscivorous species including invertebrates, many other fishes, numerous seabirds and a dozen species of marine mammals (Robards *et al.,* 1999; Stevenson and Scott, 2005). Within the Stellwagen Bank sanctuary, sand lance is a noted food source for humpback whales (Overholtz and Nicolas, 1979; Payne *et al.,* 1990; Hain *et al.,* 1995; Weinrich *et al.,* 1997; Weinrich *et al.,* 2000; Friedlaender *et al.,* 2009; Hazen *et al.,* 2009).

Sand lance occur within the Stellwagen Bank sanctuary at higher levels of abundance than in any other area of the southern GoM (Figure 50). The figure also depicts the high herring abundance that occurs in waters from just north of Cape Ann south to Cape Cod Bay, including the sanctuary, relative to other parts of the southern GoM. Sand lance distribution shows close association with sand and gravelly sand habitats, while herring distribution does not (Figure 50). The sanctuary and adjoining area is designated essential fish habitat (EFH)) for herring larvae, juveniles and adults under

Figure 50. Spatial distribution and density of key prey species for piscivorous cetaceans in the Stellwagen Bank sanctuary and the southern GoM.

Sand lance abundance is indicated in the top panel; herring abundance is indicated in the bottom panel. The spatial extent of sand and gravelly sand habitats is denoted in both panels. Data are from the NMFS Northeast Fisheries Science Center research trawl surveys for the period 1975-2000. Figure excerpted from Pittman *et al.,* 2006.

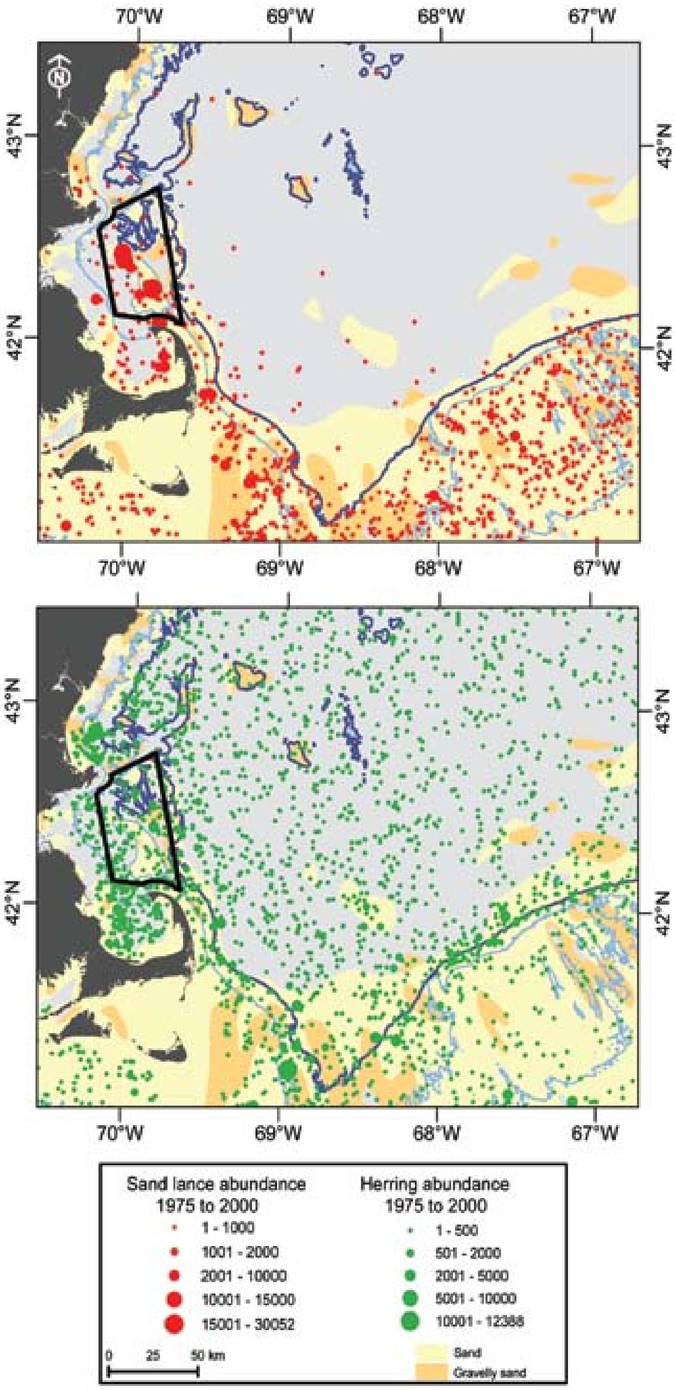
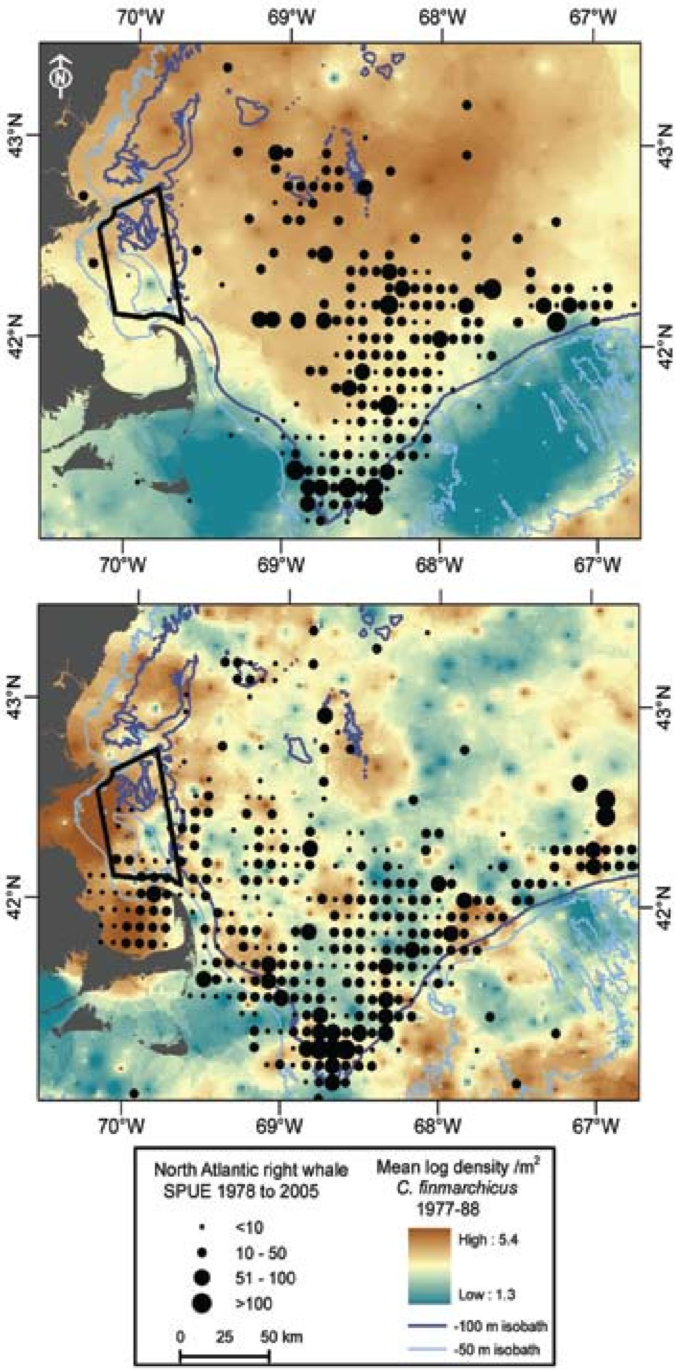


Figure 51. Overlay of spatial distribution of North Atlantic right whale relative abundance (sightings-per-unit effort: SPUE) on spatial distribution of *Calanus* copepods for the Stellwagen Bank sanctuary and the southern GoM.

Circles represent right whale SPUE; color shading represents density of copepods. Lower panel indicates spring season conditions; upper panel indicates summer season conditions. North Atlantic right whale SPUE data are for 1978-2005; copepod data are for 1977-1988. Figure excerpted from Pittman *et al.,* 2006.



the Magnuson-Stevens Fishery Conservation and Management Act (NEFMC, 2006).

The distribution and abundance of North Atlantic right whales are closely linked to the life history and spatial distribution of its main prey, the calanoid copepod *Calanus finmarchiscus*. *Calanus* early life stages coincide with the spring phytoplankton blooms on which they feed, particularly in Massachusetts and Cape Cod Bays, in waters overlapping or adjacent to the Stellwagen Bank sanctuary. This species of copepod also is prey for the sand lance, which in turn is important as prey for piscivorous baleen whales, as noted above.

Comparison of the spatial patterns of North Atlantic right whale abundance and *Calanus* abundance (all life stages combined) for both the spring and summer season shows a clear geographic shift in whale abundance that broadly tracks *Calanus* abundance hotspots (Figure 51). In spring (lower panel), these hotspots were located along the northern slope of Georges Bank, the Great South Channel, Cape Cod Bay and the western portion of the Stellwagen Bank sanctuary. In summer (upper panel), *Calanus* hotspots shifted offshore towards the central, southern GoM.

The margins of Stellwagen Bank are sites of high horizontal and vertical movement of both water and plankton due largely to the bank's exposure to GoM water circulation (Flagg, 1987). The interaction between physical oceanography and bathymetry creates environmental conditions that result in the aggregations of large numbers of planktivorous fishes, such as sand lance and Atlantic herring, which are key prey for humpback, fin and minke whales, as well as dolphins and porpoises. These same environmental conditions support an abundance of *Calanus* which are the primary prey of right whales. These environmental variables interact to establish the sanctuary as a hotspot for prey abundance.

Predictors of Cetacean Relative Abundance

Predictive modeling to explain patterns of cetacean relative abundance, based on sightings-per-unit-effort (SPUE) and on environmental data including bathymetry, substratum type, potential prey and oceanography, was used to explain spatial patterns of cetacean densities in the southern GoM for the period 1997–2005 (Pittman *et al.,* 2006). Analysis of the SPUE data was based on 34,589 cetacean observations. Model results were reported for spring and summer, which were least variable because the modeling techniques performed best for seasons with the highest cetacean abundance.

Prey availability or habitat indicators of prey availability were important predictors of distribution and density for important cetacean species which frequent the sanctuary. Sand lance abundance was a contributing factor in every case. Significant predictors of abundance for humpback, fin and minke whales in all cases included proximity to the 100 m isobath, sand and gravely sand, and mean (average) sand lance abundance. The 100 m isobath is the general lower depth limit of sand lance distribution and sand and gravely sand is preferred habitat for sand lance (Meyer *et al.,* 1979). Zooplankton abundance (all species combined) and abundance of the calanoid copepod *Calanus finmarchiscus,* were among the most significant predictors for the North Atlantic right whale abundance. Other significant predictors of right whale abundance included sand and gravely sand, and mean sand lance abundance. The combined abundance of sand lance, hake, mackerel and herring were among the significant predictors for Atlantic white-sided dolphin abundance.

Results of the predictive modeling also found that the 100 m isobath was a hotspot for herring, suggesting that humpback and fin whales may switch prey depending on local availability. Prey switching by these species has been noted between seasons (Macleod *et al.,* 2004) and inter-annually (Payne *et al.,* 1986; Weinrich *et al.,* 1997). In winter, there was a shift in the SPUE for humpback and fin whales from Stellwagen Bank to deeper waters over Tillies Basin and Jeffreys Ledge, both areas in or overlapping with the sanctuary and associated with abundant herring (Pittman *et al.,* 2006). This winter shift may result from decreased availability of sand lance prior to their spawning and decreased accessibility because sand lance spend more time buried in the sand during winter. A geographically similar but longer term shift from Stellwagen Bank to Jeffreys Ledge, and switch from sand lance to herring prey, was reported for humpback whales between 1988 and 1994 (Weinrich *et al.,* 1997).

Cetacean Occurrence

Southern Gulf of Maine

Using the SPUE database for 1997-2005, Pittman *et al.* (2006) calculated the occurrence and relative abundance of cetaceans within the southern GoM. Among baleen whales, the Stellwagen Bank sanctuary was used most heavily by humpback and fin whales and to a lesser degree by minke whales, all of which are piscivorous and feed on sand lance and herring in the sanctuary (Figure 52a). North Atlantic right whales and sei whales, both of which feed primarily on plankton, also used the sanctuary although occurrence was higher for right whales (Figure 52b). The occurrence of toothed whales in the sanctuary was highest among Atlantic white-sided dolphins, but included pilot whales as well (Figure 52b).

A comparison of the spatial distribution patterns for all baleen whales and all dolphins and porpoises in the southern GoM showed that both groups have very similar spatial patterns of high- and low-use areas (Figures 53 and 54). The baleen whales, whether piscivorous or planktivorous, were more concentrated than the dolphins and porpoise. They utilized a corridor that extended broadly along the steeply sloping edges in the southern GoM, indicated broadly by the 100 m isobath. The Stellwagen Bank sanctuary supported a high abundance of cetaceans throughout the year. The waters on and around the sanctuary also support high cetacean richness (number of species) (Pittman *et al.,* 2006).

Figure 52a. Spatial distribution and relative abundance of key cetacean species in the Stellwagen Bank sanctuary and the southern GoM based on interpolation of SPUE for the period 1970–2005.

Data are aggregated for all seasons. Species depicted include the humpback whale, fin whale, minke whale, North Atlantic right whale, sei whale, Atlantic white-sided dolphin and pilot whale. Figure adapted from Pittman *et al.,* 2006.

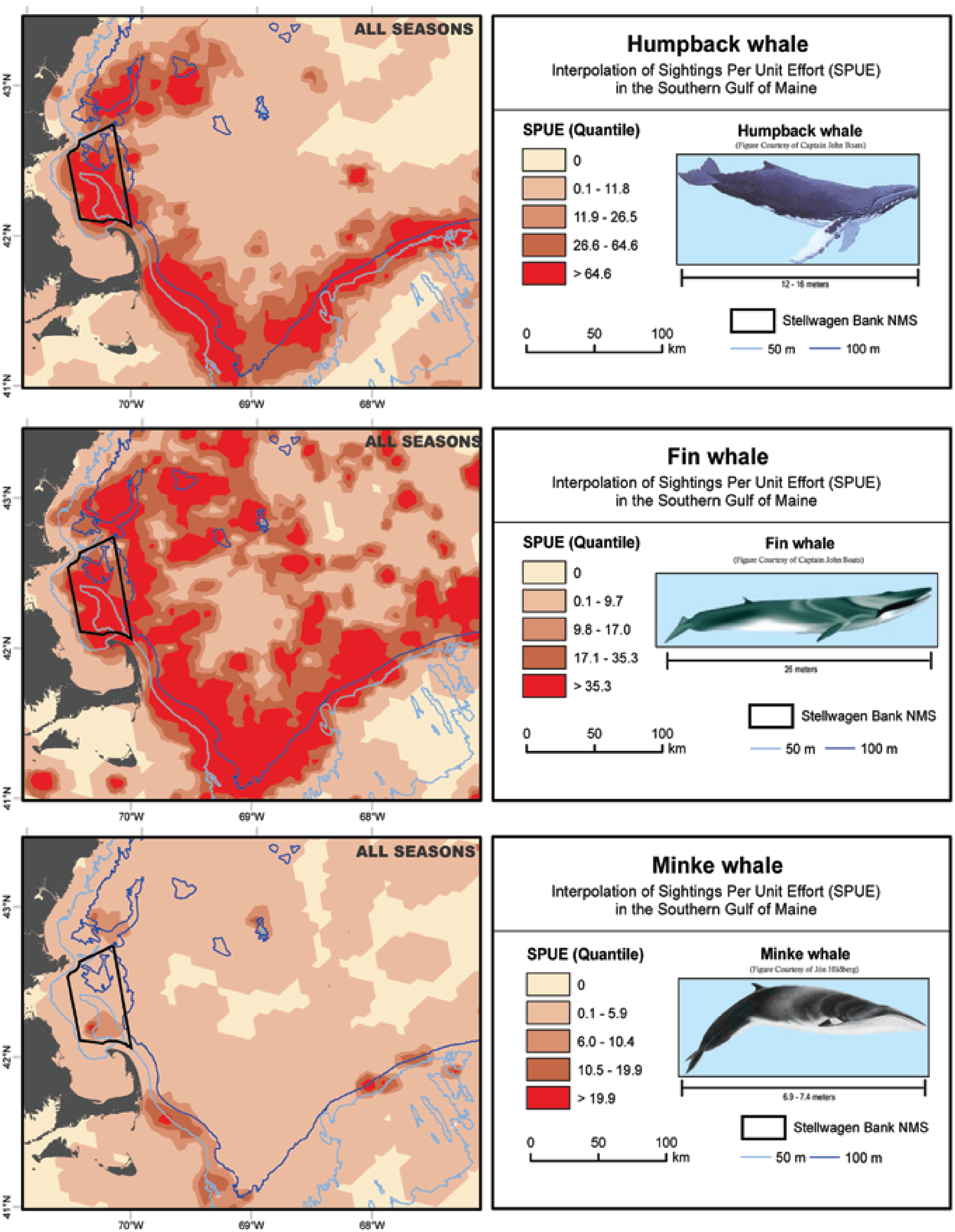


Figure 52b. Spatial distribution and relative abundance of key cetacean species in the Stellwagen Bank sanctuary and the southern GoM based on interpolation of SPUE for the period 1970–2005.

Data are aggregated for all seasons. Species depicted include the humpback whale, fin whale, minke whale, North Atlantic right whale, sei whale, Atlantic white-sided dolphin and pilot whale. Figure adapted from Pittman *et al.*, 2006.

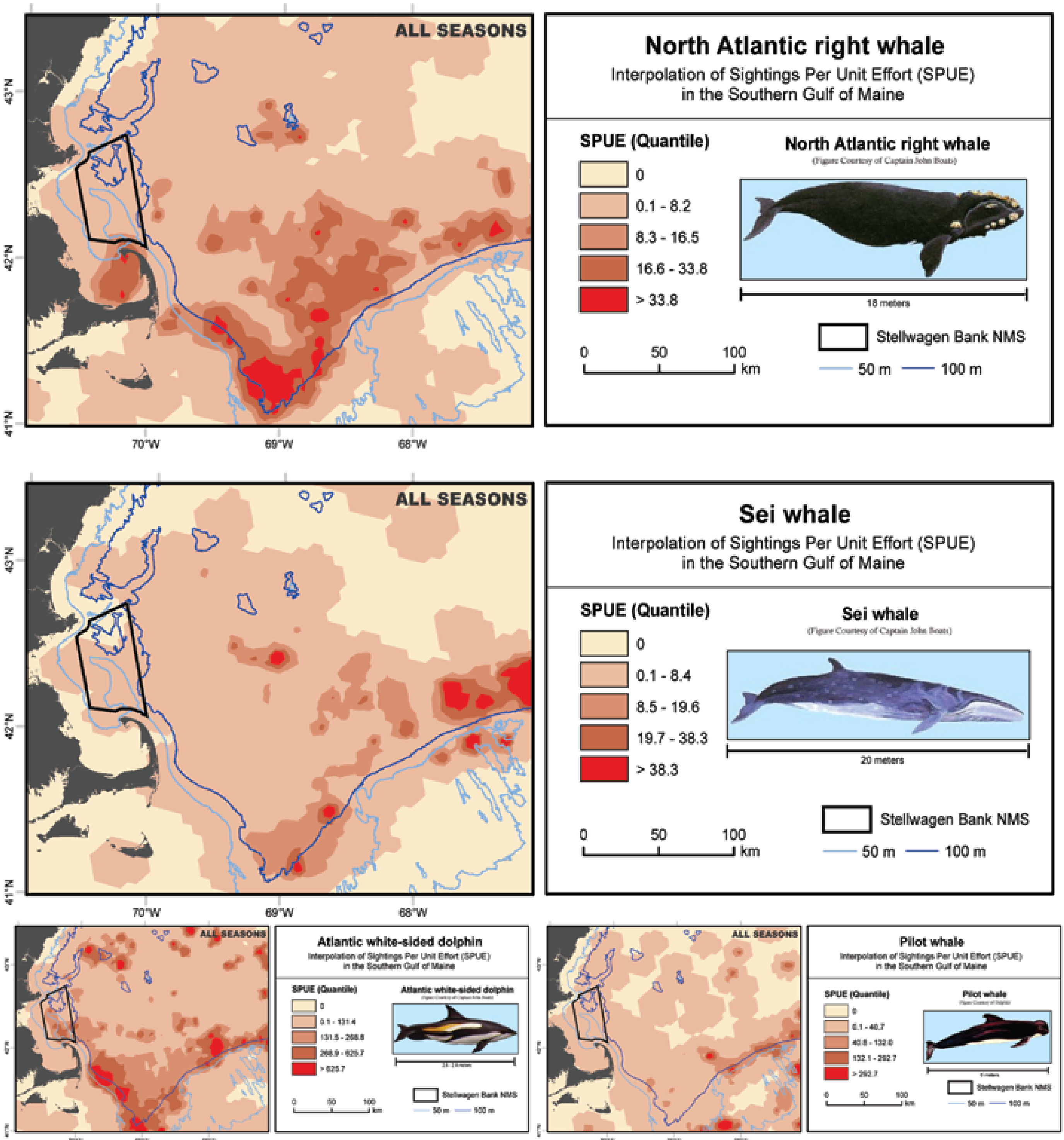


Figure 53. Seasonal patterns of interpolated SPUE data for all baleen whale species in spring, summer, fall and winter and all seasons combined for the Stellwagen Bank sanctuary and the southern GoM (1970–2005).

Figure excerpted from Pittman *et al.,* 2006.

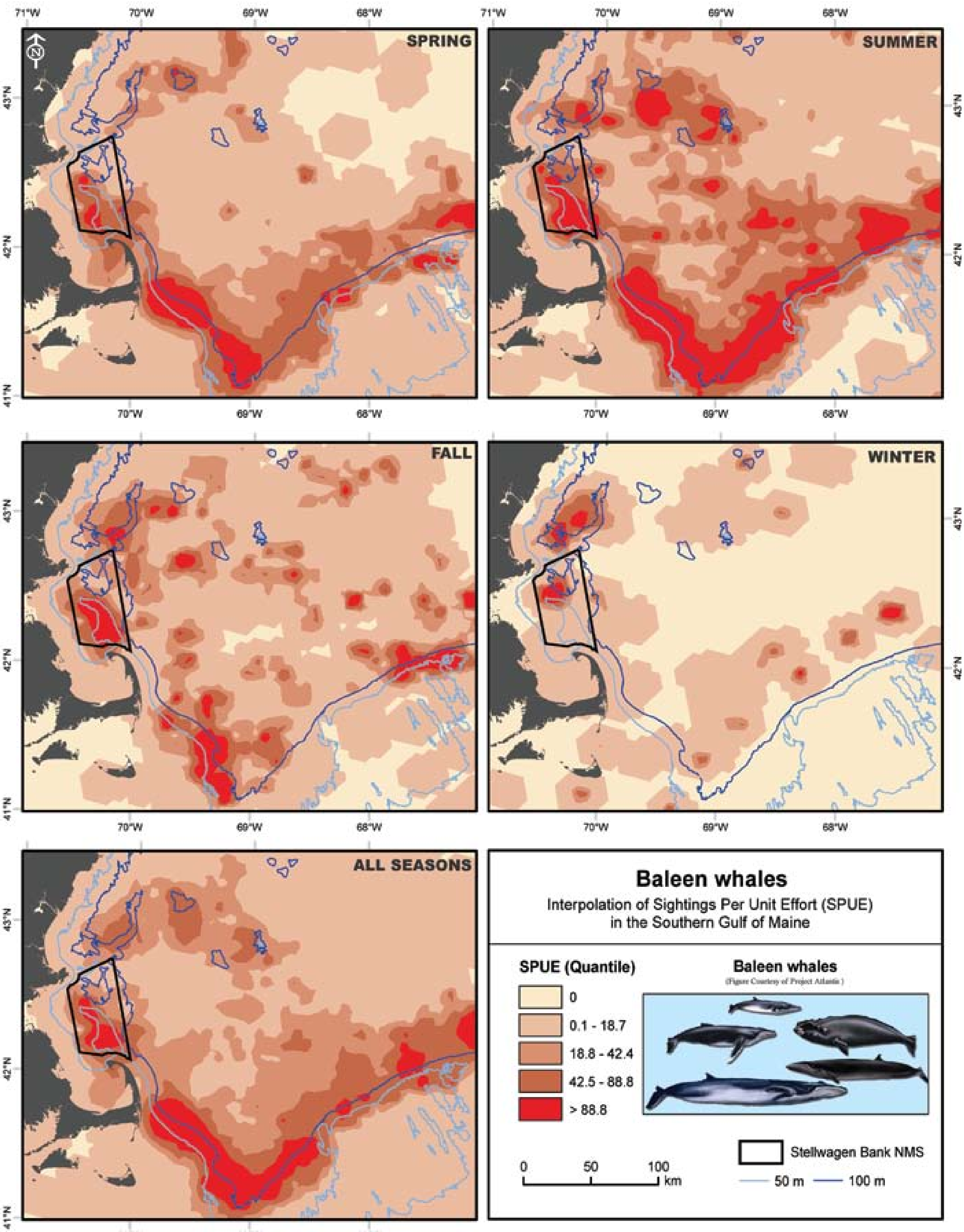
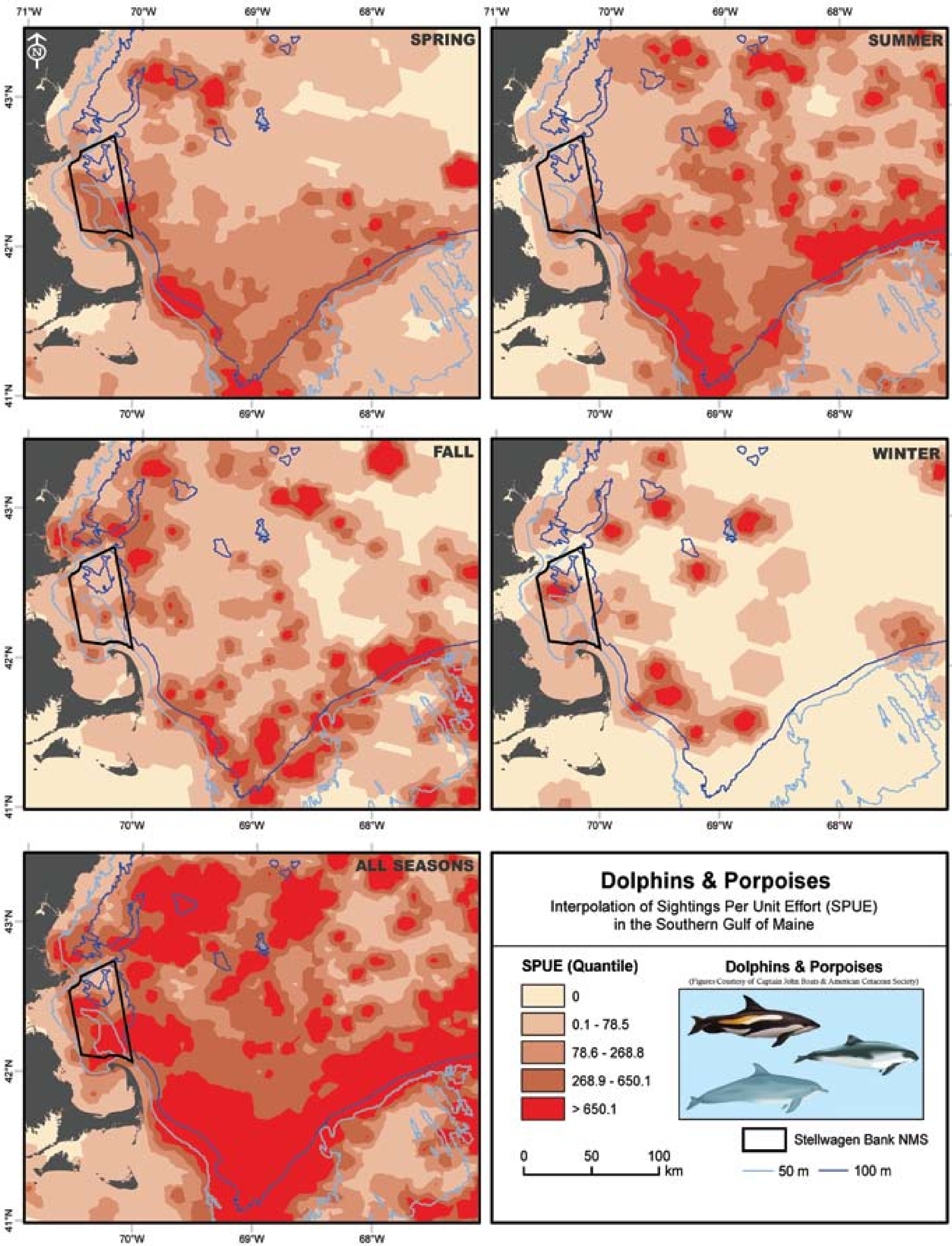


Figure 54. Seasonal patterns of interpolated SPUE data for all dolphins and porpoises in spring, summer, fall, winter and all seasons combined for the Stellwagen Bank sanctuary and the southern GoM (1970–2005).

Figure excerpted from Pittman *et al.,* 2006.



Stellwagen Bank Sanctuary

Direct knowledge of the relative occurrence and spatial/temporal distribution of cetaceans in the Stellwagen Bank sanctuary was derived from two sources: non-standardized data collected aboard whale watching vessels and standardized surveys conducted by the sanctuary. Whale watch sightings data were provided by the Provincetown Center for Coastal Studies and the Whale Center of New England. Whale watching trips targeted high use areas where companies expected to see the largest number of whales, particularly humpbacks. The database is robust in that it consists of multiple daily trips occurring from April through October, has been continuous over 25 years (1979–2004), and consists of over 255,000 sightings of animals. However, effort is not equally distributed throughout the sanctuary.

Standardized surveys of the entire sanctuary for a 12-month period were conducted from July 2001–June 2002 (Wiley *et al.,* 2003). This survey provided equal effort in all parts of the sanctuary, but was of a limited time span (one year) and sample size (528 sightings of 2,124 animals). Use of both databases provides a richer understanding of the relative occurrence and spatial/temporal distribution of cetaceans in the sanctuary. Relative use of the sanctuary by species and seasonal trends were based only on the 12-month standardized survey data.

Among baleen whales, the Stellwagen Bank sanctuary was used most heavily by humpback whales, followed by minke, fin and right whales (Figure 55). Among humpback whales, Robbins (2007) determined that the sanctuary is preferentially used by juveniles (nursing) and reproductively mature/active (pregnant and lactating) females. The occurrence of toothed whales in the sanctuary was highest for white-sided dolphins, followed by harbor porpoise and pilot whales (Figure 56). In general, the sanctuary was dominated by baleen whales during the summer period and toothed whales during the winter (Figure 57).

A comparison of both databases revealed similar patterns of spatial distribution and density (Figure 58). Baleen whales in particular tended to cluster on the northwest and southwest portions of Stellwagen Bank with a secondary cluster on the southeast section of the Bank. A three-dimensional visualization of the spatial distribution of these whales over 25 years further illustrates this finding (Figure 59). A common feature of each of these areas of high use is a substrate dominated by sand and gravelly sand, seafloor habitat types which support concentrations of sand lance. Standardized survey data revealed an additional high use area on the southern portion of Jeffreys Ledge (Figure 58).

Humpback Whale Foraging Behavior

The Stellwagen Bank sanctuary is leading a multi-institutional tagging project investigating the underwater foraging behavior of humpback whales to understand how they use habitat and interact with fishing gear and shipping. Tagged whales carry a computerized package developed at the Woods Hole Oceanographic Institution (WHOI) that continuously records pitch, role, heading and depth (Johnson and Tyack, 2003). Tag-derived data are mapped in four dimensions using GeoZui4D software, allowing scientists to create virtual whales that move like the tagged animals. GeoZui4D is a software application developed at the University of New Hampshire (UNH) for interacting with time-varying geospatial data (Ware *et al.,* 2006), such as that provided by the whale tags. Tag data were also viewed in TrackPlot (Ware *et al.,* 2006; Wiley *et al.,* 2005) to provide a static 3-D representation of spatial patterns in whale movement.

Figure 60 illustrates behavior that is typical of the high interrelated use of both seafloor and water column habitats by humpback whales feeding in the sanctuary based on the tagging results of 15 individuals in July of 2006. Sand lance prey fields were simultaneously mapped acoustically in areas adjacent and parallel to the whale tracks, confirming their presence in large numbers (Figure 61). Acoustics offer a minimally invasive technique for collecting continuous along-track data on biomass at fine horizontal and vertical spatial scales throughout the water column (Simmonds and MacLennan, 2005). The whale tracks were mapped over the sanctuary's seafloor multi-beam sonar image, which indicated that the whales were feeding over sand and mud which is sand lance habitat. More extensive treatment of this research is provided in Friedlaender *et al.* (2009) and Hazen *et al.* (2009).

The depth versus time series recorded for the subject whale shows how and when it uses the water column, demonstrating pronounced shifts in lengthy bouts of repeated dives (Figure 60). During hours of daylight, dusk and early evening (1400 hr to 2100 hr) the whale spent its time in an alternating series of frequent short duration dives to the seafloor followed by extensive time spent in the upper water column and at the surface. During the ensuing hours of darkness and pre-dawn (2120 hr to 0440 hr) the whale spent its time in long duration dives to the seafloor. Bouts of predominantly near-surface activity resumed with the return of daylight. These findings of diurnal foraging patterns are generally supportive of those of Goodyear (1989), who also conducted tagging studies of feeding humpback whales on Stellwagen Bank during times of high sand lance abundance. Sand lance make daytime migrations into the water column where they form schools and feed, returning to the seafloor at night (Casey and Myers, 1998), a behavior that corresponds to the whale's diel (24-hr period) use of these habitats.

Two types of foraging behavior were characteristic of how humpback whales differentially used water column and seafloor habitats in the sanctuary (Friedlaender *et al.,* 2009). During the "daylight" sequence, whales engaged in repeated bubble-net feeding near the sea surface in which individual or multiple animals exhale, encircle and corral sand lance in the water column. By diving below the level of schooling sand lance, the whales presumably can better detect their prey contrasted and profiled against the sky as well as prevent their prey from fleeing to shelter afforded by the seafloor. During the "darkness" sequence, whales engaged in repeated bouts of bottom feeding where they

Figure 55. Relative occurrence of fin, humpback, minke and right whales in the Stellwagen Bank sanctuary.

Data are based on standardized surveys from July 2001–June 2002 (303 sightings of 361 animals). Adapted from Wiley *et al.*, (2003).

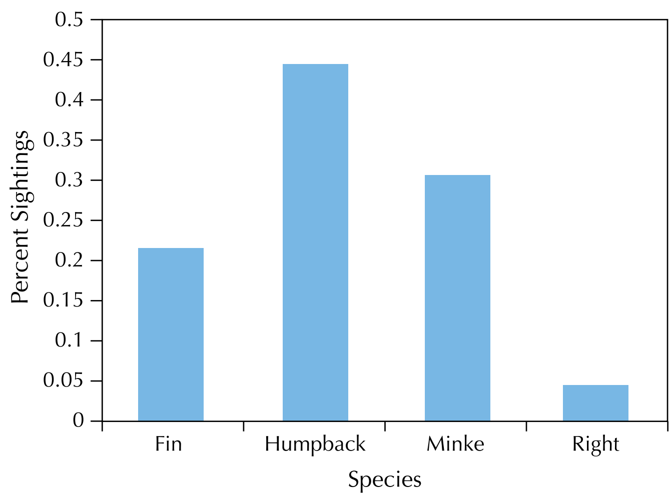


Figure 56. Relative occurrence of harbor porpoise, white-sided dolphins and pilot whales in the Stellwagen Bank sanctuary.

Data are based on standardized surveys from July 2001–June 2002 (162 sightings of 1,708 animals). Adapted from Wiley *et al.*, (2003).

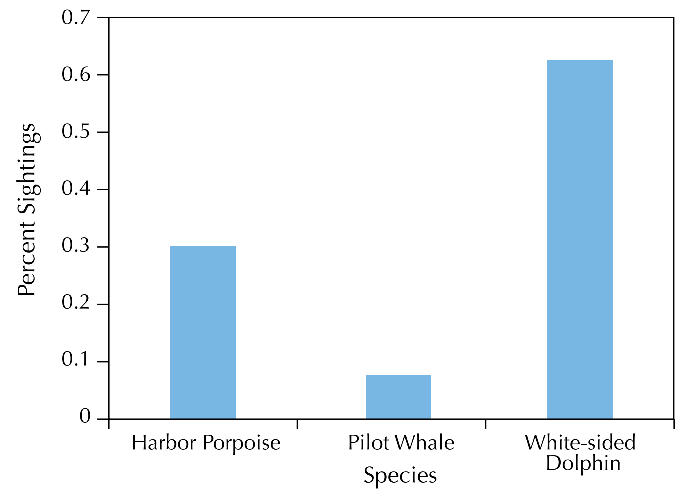


Figure 57. Frequency of Cetacean Sightings within Stellwagen Bank sanctuary by month. Data are from standardized surveys from July 2001–June 2002.

Adapted from Wiley *et al.*, (2003).

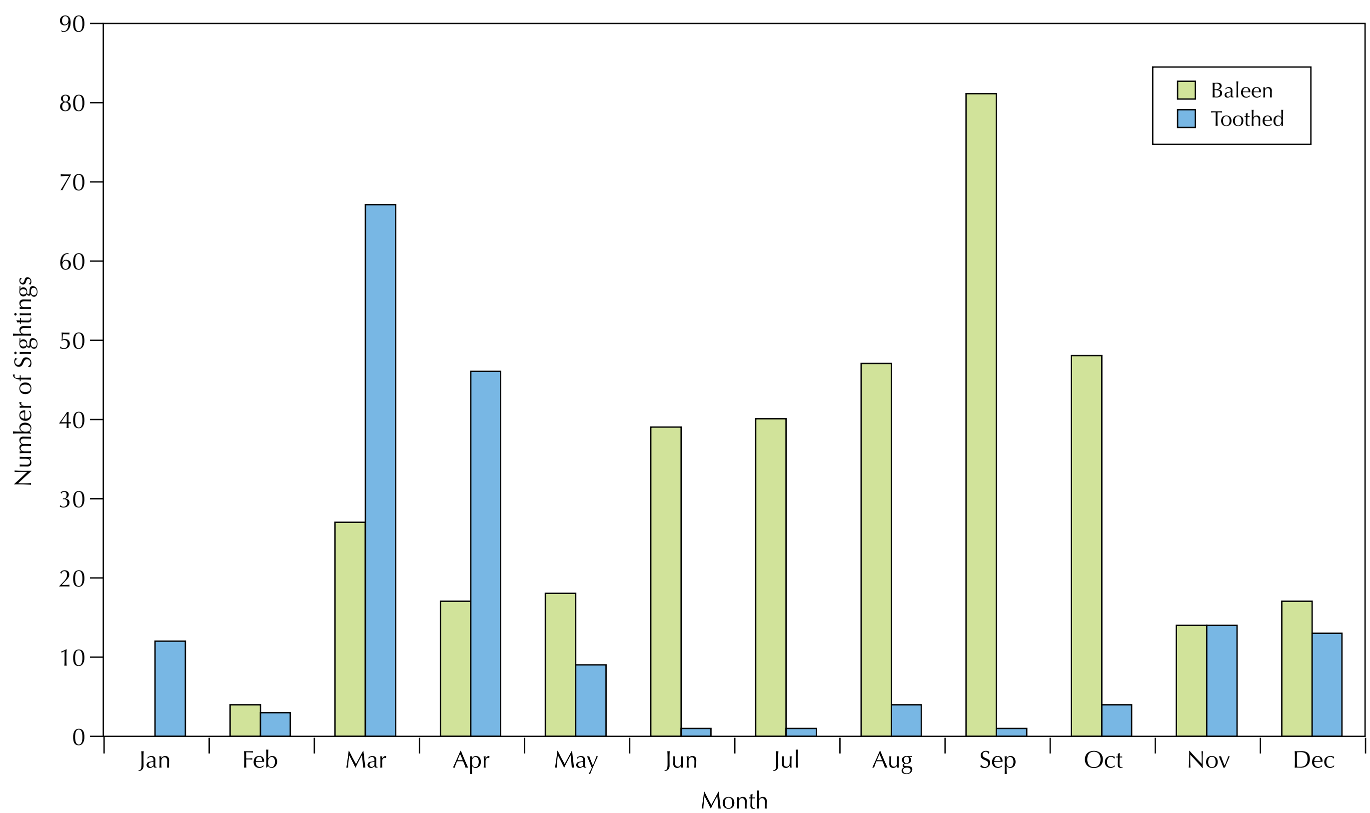
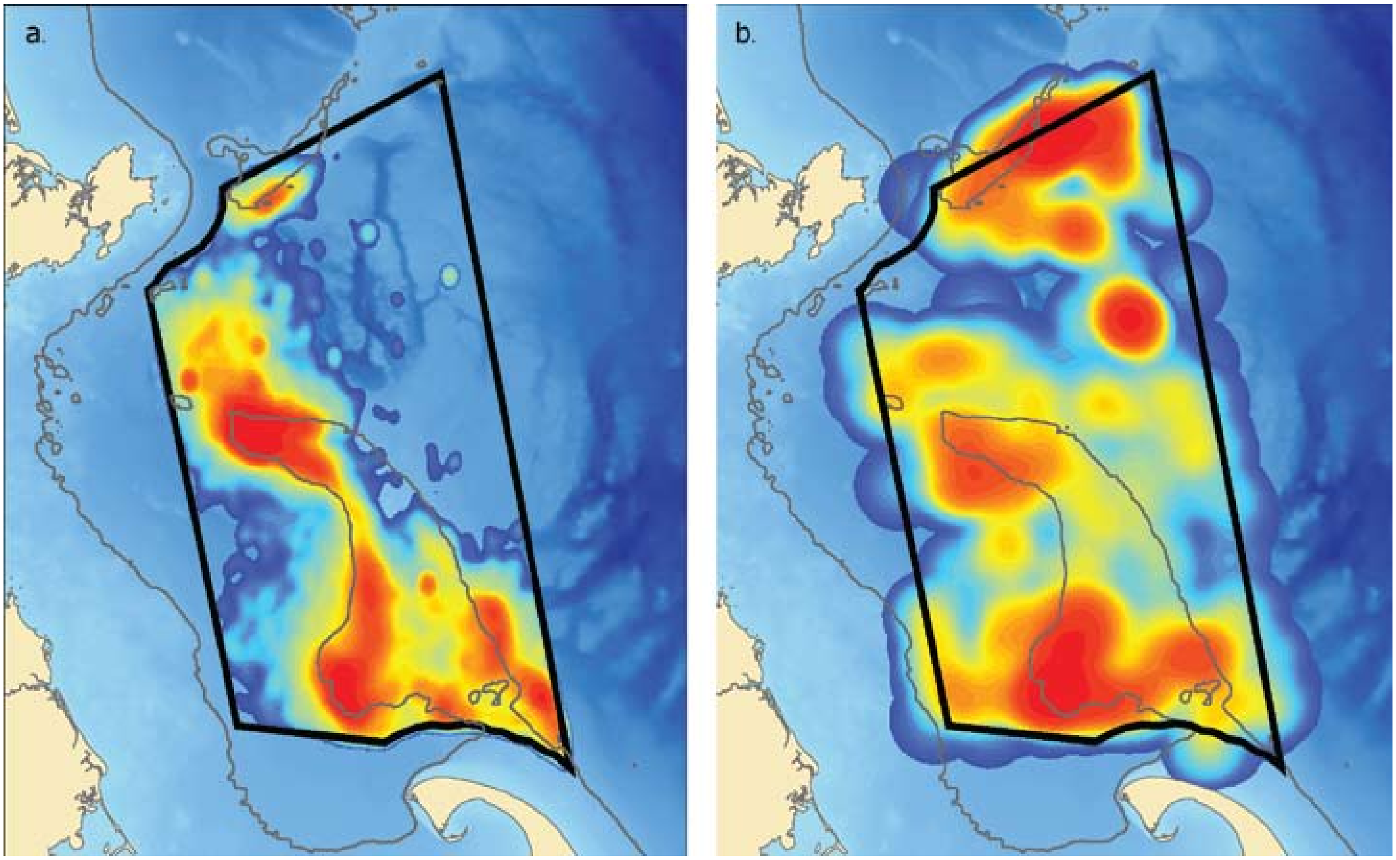


Figure 58. Comparison of the spatial distribution of baleen whales within the Stellwagen Bank sanctuary from whale watch and standardized survey data.

Whale watch data (a.) are non-standardized observations made during April through October from 1979-2004 (n = ~255,000). Survey data (b.) are based on standardized surveys from July 2001–June 2002 and include animals not identified to species (352 sightings of 413 animals). Survey data are adapted from Wiley *et al.,* 2003. Whale watch data were collected by the Provincetown Center for Coastal Studies and the Whale Center of New England. The two illustrations are Kriged density plots of information from both data sets using a 5,000 m search radius analyzed by ESRI ARCGIS.



turn on their side to scour the sandy bottom while feeding on sand lance burrowed in the seafloor. Each of these characteristic behaviors is illustrated in Figure 60. Results from Friedlaender *et al.* (2009) suggest that surface feeding activities in humpback whales are based primarily on visual prey detection and secondarily on the presence of prey over a certain threshold level in the water column.

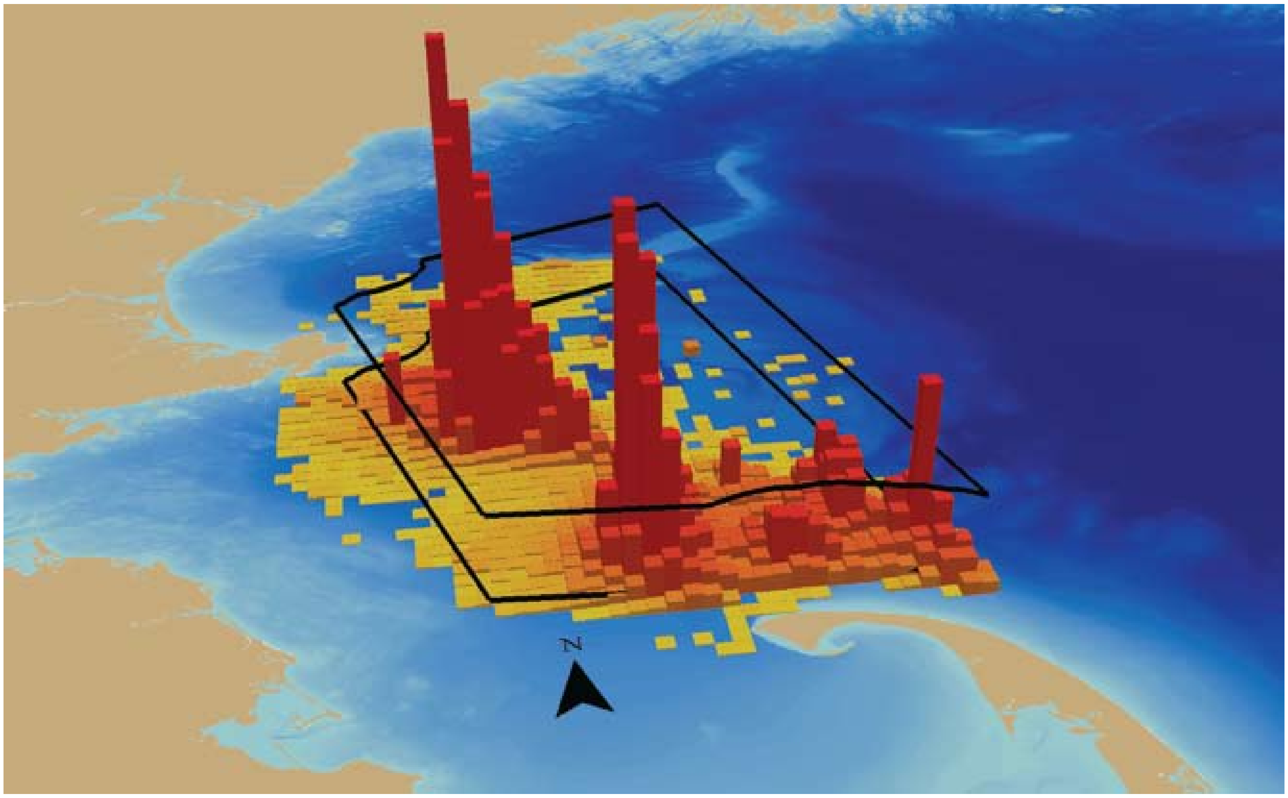
Hazen *et al.* (2009), in fact, show that humpback whales on Stellwagen Bank maximize their foraging efficiency when surface feeding by preferentially targeting dense, vertically oriented patches of sand lance. Hazen *et al.* (2009) found that whale surface feeding was significantly affected by prey school shape. Surface feeding occurred more often around prey schools with a large area, taller height and shorter length. Longer schools were often associated with a thin layer (less than 2.5m tall) in the water column, potentially more difficult or less cost-effective to consume. Using generalized additive models (GAM) and classification and regression tree models (CART), Hazen *et al.* (2009) observed that surface feeding was more likely above acoustically detected prey densities of -65 dB, affirming that there were thresholds in surface-feeding behavior in the sanctuary.

Measured sand lance schools reached up to 4km in length and vertical thickness up to 30m; mean school length was 139 m and mean height was 7.9 m (Hazen *et al.,* 2009). Examples of such schools are shown mapped in Figure 61. This visualization of actual data depicts the linear transect through a series of prey patches in the sanctuary and provides a 2-dimensional portrayal of 3-dimensional prey aggregations (i.e. length, width, vertical thickness). Diver-based observations of sand lance school characteristics and behavior near the seafloor at Stellwagen Bank are described in Meyer *et al.* (1979). Because the spatial characteristics of prey fields is an important determinant of the optimality of humpback whale foraging, maintenance of prey patch integrity needs to be considered in sanctuary management.

While this tagging research was directed at humpback whales foraging on sand lance in the sanctuary, the same surface feeding behavior is expected to extend to humpback whales feeding on Atlantic herring (*Clupea harengus*) in the sanctuary. Humpback whales in the western North Atlantic are documented to use bubbles (including "nets") to feed on herring (Haine *et al.,* 1982; Weinrich *et al.,* 1992) and sanctuary researchers have witnessed bubbles being used

Figure 59. A three-dimensional visualization of the spatial distribution of baleen whales within the Stellwagen Bank sanctuary (1979–2004).

Data are non-standardized observations from whale watching vessels operating from April through October (n = ~255,000) and collected by the Provincetown Center for Coastal Studies and the Whale Center of New England.



by humpback whales to capture herring in the portion of the sanctuary overlapping Jeffreys Ledge. Bubble-net feeding by humpback whales on herring and other epipelagic prey (e.g., krill) in southeast Alaska is well documented (Juraz and Juraz, 1979; D' Vincent *et al.,* 1985; Sharpe, 2001).

Laboratory experiments have determined that Pacific herring, *Clupea harengus pallasi*, exhibit strong avoidance to bubbles and could be contained within a circular bubble net (Sharpe and Dill, 1997). Sonar measurements of water depth at which humpback whales begin bubble-net feeding on herring in southeast Alaska (mean 17.1 m) (Sharpe, 2001) is very similar to the depth (approximately 20m) at which humpback whales begin bubble-net feeding on sand lance in the sanctuary (e.g., Figure 60 this document). Based on Sharpe's (2001, Chapter 4) detailed descriptions, the underwater behavior of humpback whales bubble-net feeding on herring in southeast Alaska is similar to how humpback whales bubble-net feed on sand lance in the sanctuary (Friedlaender *et al.,* 2009; Hazen *et al.,* 2009).

Conservation Status

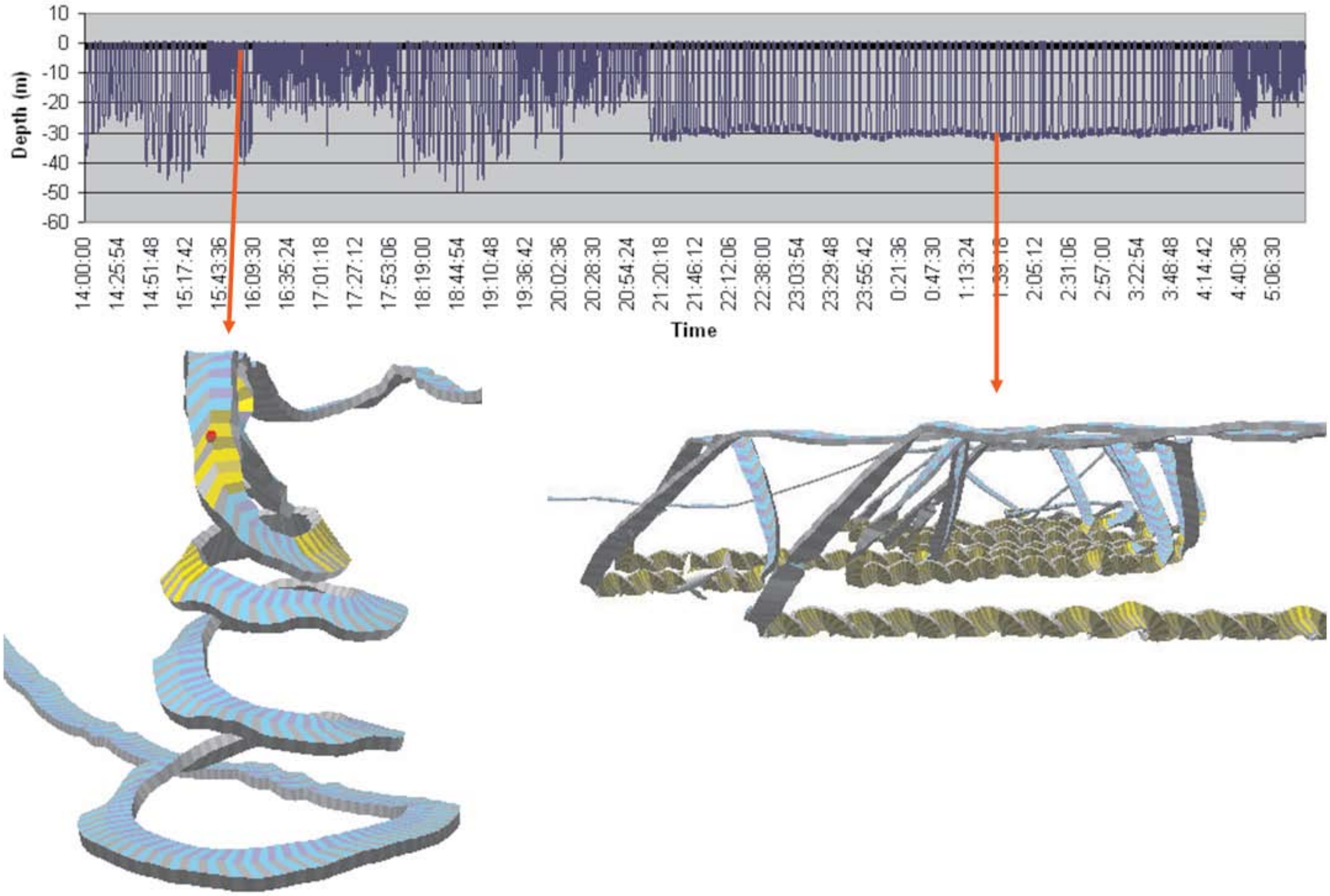
All marine mammal species are protected under the MMPA; five baleen whale species frequenting the Stellwagen Bank sanctuary are listed as endangered under the ESA (i.e., blue, fin, humpback, sei and North Atlantic right whale) (Table 8). The North Atlantic right whale population continues to be depleted (NOAA, 2006); the best estimate of the size of the population is 300 to 350 animals. Earlier models indicated that this population was likely declining rather than remaining static or increasing (Caswell *et al.,* 1999). More recent models that estimate survival rate from re-sightings data collected during 1980-2004 indicate that the median population growth rate is about 1% (Pace *et. al*, 2007). However, the models also revealed that this population has almost no capacity to absorb additional mortality. Because the primary causes of premature mortality among right whales are anthropogenic, mainly ship strikes and fishing gear entanglements, recovery of the right whale population is contingent upon reducing the effects of these activities on the species (Pace *et al.,* 2007).

Pressures

Habitat loss, habitat degradation and competition for prey are recognized as key threats to cetaceans worldwide (Reeves *et al.,* 2003). Known or potential threats to the survival of marine mammals are due to the increasing pressures of human activity in and around the sanctuary and the marine mammals' dependence on resources that are also used intensively by humans. Marine mammals are vulnerable to disturbances caused by ship noise, industrial activity and other acoustic inputs to the marine environment, collisions with powered vessels and entanglements with fishing gear. Other types of human activities (e.g., water pollution) occur that may influence living resource quality

Figure 60. A time/depth plot of the diving behavior of a tagged humpback whale in the Stellwagen Bank sanctuary over a 15-hour period in July of 2006.

The animal used complex spiral bubble maneuvers in the water column to corral fish (presumed sand lance) during daylight and exhibited bottom side-roll behavior at night. Ribbon tracks used to visualize behavior were created using TrackPlot (Ware *et al.,* 2006). Data are from Wiley *et al.* (unpublished).



(e.g., reduced availability of prey). High levels of chemical contaminants in the tissues of cetaceans may be affecting the animals' immune and reproductive systems (Reeves, 2003).

There are undoubtedly more threats than are presently recognized, and even the most basic information on cetacean mortality caused by human activity is limited due to funding restraints, under-reporting and the lack of directed scientific effort. Moreover, the total impact of the various threats cannot be predicted by simply summing their effects as though they were independent. For example, the immunosuppressive effects of environmental contaminants (Lahvis *et al.,* 1995) with range shifts of pathogens caused by global warming and ship ballast transport (Harvell *et al.,* 1999) could increase the susceptibility of cetaceans to emergent diseases. While research is underway to better identify emerging threats, cautionary measures should be taken to moderate or eliminate the relevant and acknowledged anthropogenic input factors (Reeves, 2003).

Behavioral Disturbance

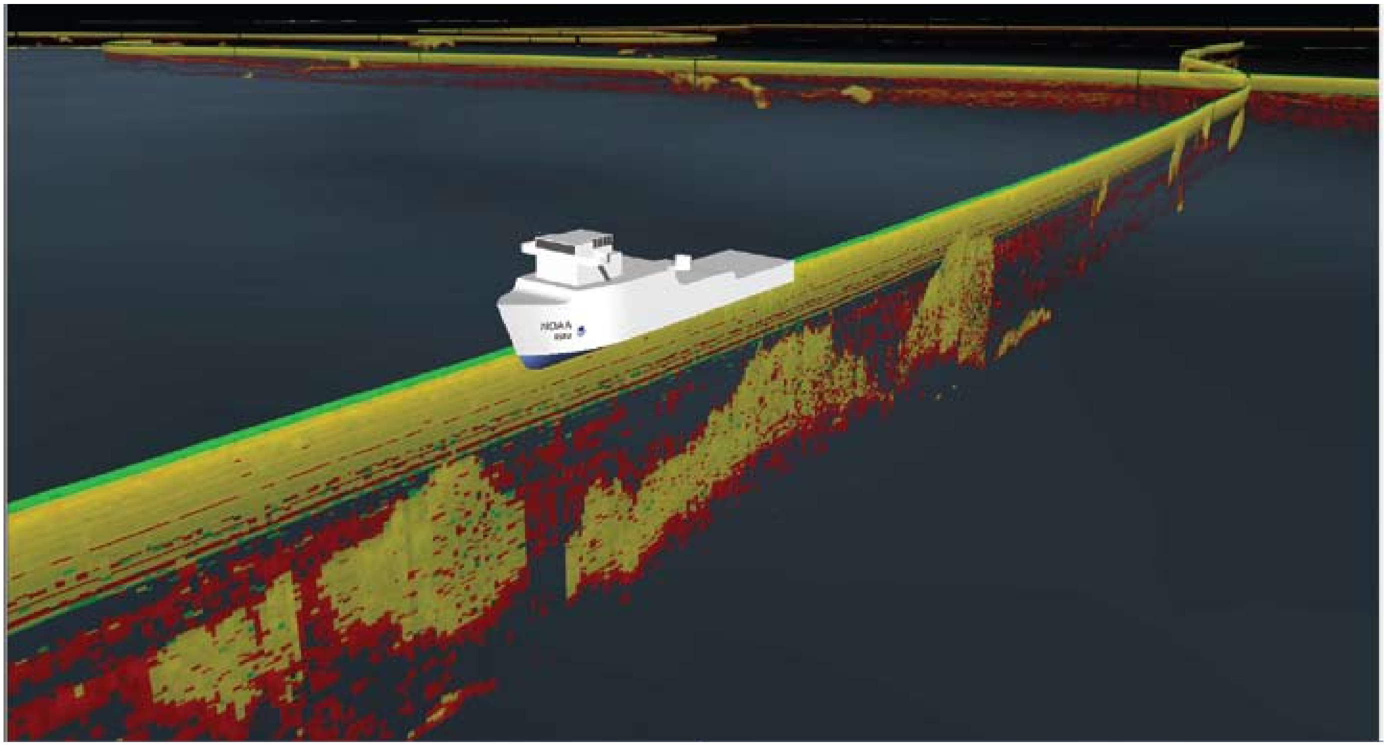
There are numerous ways in which marine mammals are disturbed or potentially disturbed by human activities within or around the Stellwagen Bank sanctuary. These include activities associated with vessels, aircraft flying over the sanctuary, fishing activities and underwater noise from the high number of vessels passing through and nearby the sanctuary.

Whale Watching

Whale watching tours began in New England in 1975, and within a decade the regional whale watching industry became the largest in the United States and one of the largest in the world (Hoyt, 2001). Twelve to fifteen commercial whale-watch companies operate regularly scheduled trips on as many as 22 vessels that make multiple trips daily to the sanctuary, from April through October, out of six Massachusetts ports. A sampling of tracks from whale watch vessels representing all companies and all ports were recorded in 2003 during whale watch trips to the sanctu-

Figure 61. Visualization showing the NOAA Ship *Nancy Foster* acoustically mapping sand lance prey fields in the Stellwagen Bank sanctuary.

The horizontal band is the zone of cavitation caused by the ship's propellers and is an artifact. Prey fields are evident below this zone: yellow = higher density; red = lower density. Visualization portrays actual data. Image: UNH/SBNMS.



ary and adjoining areas (Figure 62). With the exception of vessels departing from Newburyport, the northernmost port depicted, virtually all whale watching trips were made to the sanctuary and almost all of these were made to northern and southern Stellwagen Bank, where whales historically are most abundant (Figures 58 and 59). More than one million people visit the sanctuary yearly aboard these platforms (Hoyt, 2001).

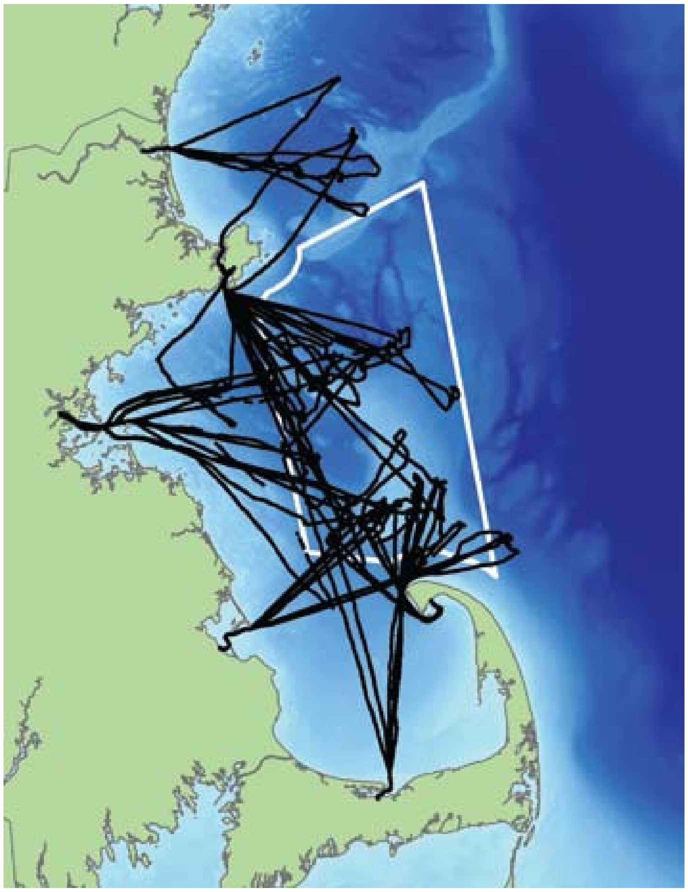
There is growing awareness however, that cetacean tourism can have a downside (Corkeron, 2004; Lusseau, 2004). Intensive, persistent and unregulated vessel traffic involving multiple approaches and erratic paths that focuses on animals while they are resting, feeding, nursing their young or socializing can disrupt those activities, and possibly cause short and long-term problems for targeted populations. Impact studies worldwide have shown changes in ventilation rate, avoidance behavior, displays of annoyance and changes in habitat use ((Donovan, 1986; Baker, 1988; Corkeron, 1995; Williams *et al.,* 2002; Lusseau, 2004; Scheidat *et al.,* 2004). Underwater noise of whale watching boats can potentially affect whales (Erbe (2002). The concerns are further compounded by the increase in popularity of whale watching, not just on commercial vessels, but also privately-owned recreational vessels. In both cases, instances occur where numerous boats surround a single whale or group of whales, disturbing the animals and at the same time detracting from the quality of the tourist experience.

If behavioral disturbance is repeated above a certain threshold, it could lead to impairments in an individual's breeding, social, feeding and resting behavior. If enough individuals are so affected, this could contribute to secondary deleterious effects on a population's long-term reproductive success, distribution or access to preferred habitat (Fair and Becker, 2000; Bejder and Samuels, 2003; Higham and Lusseau, 2004). Using data primarily from sightings (1980-2005) in the Stellwagen Bank sanctuary, Weinrich and Corbelli (2009) found that whale watch exposure did not correlate with reduced reproductive success in humpback whales. While it is reassuring that disturbance from whale watching was not affecting the reproductive success of these whales, finding such a population effect would be an extreme consequence of the activity and may not be the most appropriate objective to manage for in a National Marine Sanctuary.

This situation reinforces the importance of determining the proper metric for both determining management goals and measuring impact. Reproductive failure would be an extreme impact resulting from the culmination of an accumulation of lesser stressors. It may be appropriate for the sanctuary to take actions that reduce known stressors to assure the general well being of whales using the sanctuary, even if research results haven't shown drastic cumulative population level effects. Further, some of the results reported by Weinrich *et al* (2009) showed a confounding relationship with the importance of the sanctuary as a major feeding

Figure 62. GPS tracks of 36 commercial whale watching trips from six major whale watching ports in Massachusetts that were monitored by onboard observers during the summer and fall of 2003.

Vessels were from the 12 major companies that operate regular schedules and each company was monitored approximately three times.



One important aspect of the Northeast region whale watch guidelines is a series of recommended vessel speeds within various distances from the whales: less than or equal to 13 knots at a 1–2 nm distance to whales (zone 3); less than or equal to 10 knots at a 1–0.5 nm distance to whales (zone 2); and less than or equal to 7 knots within 0.5 nm distance to whales (zone 1). Details of the approach guidelines can be found at the following web address: http://www.nero.noaa.gov/shipstrike/info/guidetxt.htm or Appendix M. The industry considers these guidelines to be more stringent than approach guidelines/regulations in other regions, where distance restrictions exist but no speed restrictions have been established. The industry has used these guidelines to argue against the need for additional restrictions such as speed regulations in the sanctuary. A recent study conducted in the sanctuary indicates that compliance with the speed portion of the guidelines by the commercial whale watch fleet was extremely low and that speed exceedances were excessively high (Wiley *et al.,* 2008).

Observations in this study were made on 46 commercial whale watching trips in 2003 and 2004 that occurred in and around the sanctuary; all of the principal whale watching companies were represented. Results indicate that whale watching vessels often ignored speed zone guidelines and the degree of non-compliance increased as distance from the whale(s) increased (Table 9). The overall level of non-compliance based on distance traveled by the whale watch vessels (data from all speed zones combined) was 78%. The maximum vessel speed recorded in zone 1 (where the level of non-compliance was lowest and boats were closest to whales) differed little from the maximum vessel speed recorded for the entire whale watch trip (Figure 63).

When the magnitude of the whale watching activities in the sanctuary is viewed in context of the critical role the habitat, potentially masking subtle effects of whale watch exposure on the inclusive fitness of individual whales.

Working with the whale watching industry and non-profit conservation organizations, NOAA established voluntary whale watch guidelines in the Northeast region in 1999 following a sharp increase in whale watch vessel speeds and collisions with three whales, at least one of which was fatal (Weinrich, 2005). The guidelines (operational procedures) were first developed in 1984 by an *ad hoc* committee of whale watch naturalists, captains and scientists (Beach and Weinrich, 1989). The intent of the guidelines is to avoid harassment, behavioral disturbance and possible injury or death to large whales by both commercial and recreational vessels. While the guidelines are voluntary and difficult to enforce, NOAA Office of Law Enforcement enforces the intent of the guidelines through the take and harassment provisions of the ESA and MMPA. These guidelines are less restrictive than the majority of other guidelines or regulations world-wide (Carlson, 2007), which often contain a 100 m minimum approach distance.

Table 9. The level of non-compliance with the speed portion of the NOAA whale watching guidelines based on the monitoring of 46 commercial whale watching trips operating in and around the Stellwagen Bank sanctuary during 2003–2004.

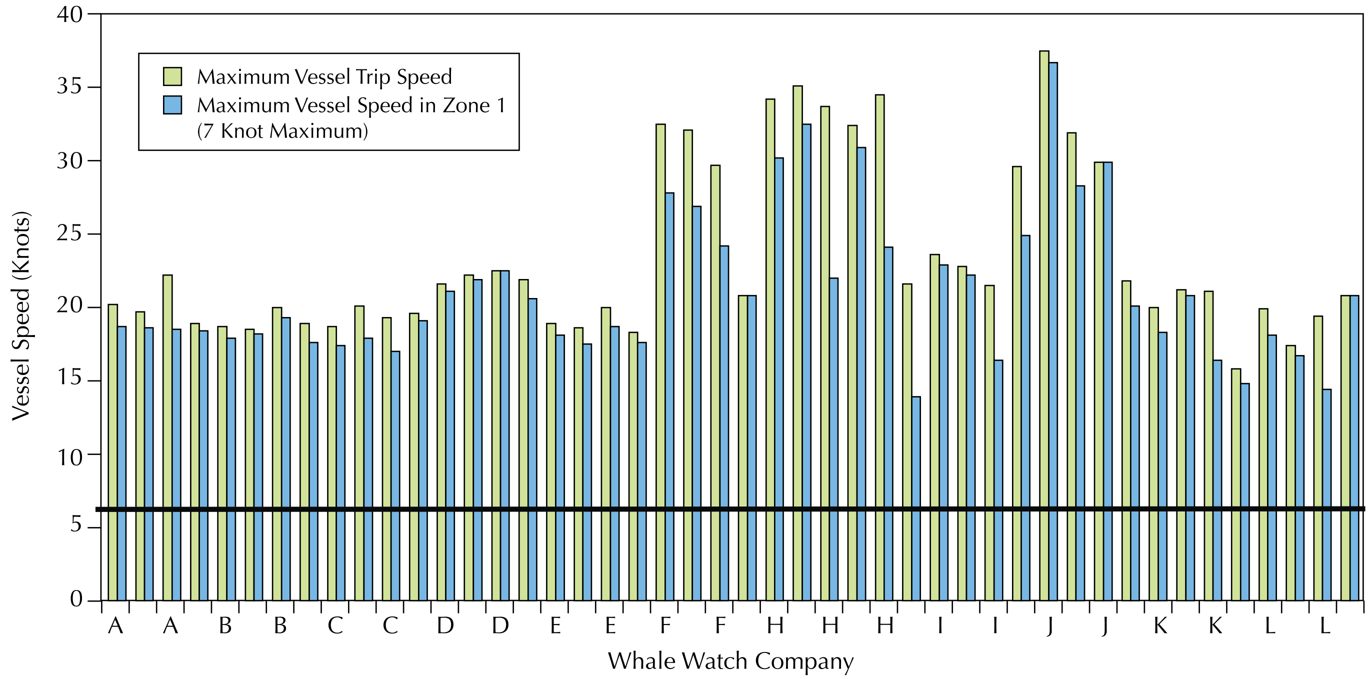
GPS receivers onboard each vessel provided information on the vessel's track and speed. Non-compliance was registered when a vessel's speed exceeded that specified by the guidelines. For each speed zone, a vessel's non-compliant level was calculated by comparing the distance the vessel traveled out of compliance to the total distance traveled in that zone. The industry's non-compliant level was calculated by summing the total non-compliant distances for all vessels traveling in a zone and comparing that to the total distance traveled by all vessels in that zone.

Zone Number	Suggested Speed (Knots)	Industry Non-compliant Level (%)	Non-Compliant Range for All Trips (%)
1	≤ 7	62	33–84
2	≤ 10	93	67–100
3	≤ 13	92	61–100
Overall		**78**	**33–100**

(≤) less than or equal to

Figure 63. Comparison of a vessel's maximum recorded trip speed and its maximum recorded zone 1 speed for 46 commercial whale watching trips representing 12 companies operating in and around the Stellwagen Sanctuary in 2003 and 2004.

In general, all vessels attained speeds well above the 7 knots (horizontal black line in figure) specified by the guidelines for zone 1 and reached near maximum trip speeds in zone 1. This indicates that operators were not following speed guidelines meant to safeguard whales. Speed data were derived from GPS devices and collected by unannounced and inconspicuous observers. Speed zones around whales were identified by those observers using military grade binoculars with a digital compass and laser rangefinder to position whales. ESRI ARCGIS was used to create speed zones around the whales for purposes of calculation.



sanctuary serves as a major feeding and nursery area for several endangered species of whales, particularly humpback whales (Robbins, 2007), combined with the minimally restrictive approach guidelines and lack of compliance where measured (Wiley *et al.,* 2008), the subject animals would seem to be at risk from the effects of whale watching. The high degree of non-compliance and the magnitude by which the recommended speeds in each zone were exceeded by whale watching vessels indicate that the guidelines cannot be relied upon as a voluntary measure to reduce the risk of behavioral disturbance or vessel strike to whales in the sanctuary and that regulation should be considered. Such regulation would be aligned with NOAA's Ship Strike Reduction Program. The MMBD AP proposes several strategies that address this issue (AP: MMBD 1.1).

Ocean Noise

There is growing evidence that noise in the ocean has increased dramatically over the past 50 years (Andrew *et al.,* 2002; MacDonald *et al.,* 2006). Over the past few decades the shipping contribution to ambient ocean noise has increased by as much as 12 dB, coincident with a significant increase in the number and size of vessels comprising the world's commercial shipping fleet (Hildebrand, 2009). As the primary source of low frequency ocean noise is commercial shipping (Wenz, 1962), noise is expected to increase most dramatically in areas experiencing increased commercial shipping such as access-ways for growing ports. Although pre-industrial ambient noise estimates are not available for the Stellwagen Bank sanctuary, growth in the Port of Boston continues to be accompanied by increases in large vessel traffic transiting the sanctuary.

In a 2006 study conducted within the sanctuary, noise produced by large commercial vessels was at levels and within frequencies that warrant concern regarding the ability of endangered whales to maintain acoustic contact within greater sanctuary waters (Hatch *et al.,* 2008). The high use patterns in the Stellwagen Bank sanctuary have led to it being a case study to address noise management in a spatially explicit context, and has resulted in the conclusion that noise generated by transportation networks that extend far beyond sanctuary boundaries must be managed to conserve its resources (Hatch and Fristrup, 2009). Effective noise control policies must be developed through partnerships among transportation and resource management agencies, surmounting differences in missions and historical precedents.

Increasing ocean noise is problematic given growing evidence that some underwater sound sources can negatively impact sensitive marine species (NRC, 2003). For example, some marine mammal populations have been documented to respond to sources by altering their breathing rates, spending more time underwater before coming up for air, changing the depths or speeds of their dives, shielding their young, changing their song note durations and/or swimming away from the affected area (Richardson *et al.,* 1995; NRC, 2005). In addition, high intensity underwater sounds can cause temporary or permanent hearing loss in marine mammals, which in a few cases has been associated with animals becoming disoriented and stranding (NRC, 2005).

Finally, but perhaps most importantly for the sanctuary as indicated above (Hatch *et al.,* 2008), increasing ocean noise may "mask" signals produced by acoustically-active marine animals to communicate with conspecifics (NRC, 2003). Such masking would decrease the distance over which signals could be received by conspecifics, thus limiting their utility as reproductive, feeding and/or navigation behaviors. Acoustic masking from anthropogenic noise is considered a threat to marine mammals, particularly low-frequency specialists such as baleen whales (Clark *et al.;* 2009). Although there has been much less research on the impacts of noise on non-mammalian marine animals, many fish and marine invertebrates also utilize sound to communicate (e.g., haddock in the sanctuary, Van Parijs *et al.,* 2009).

Given the importance of sanctuary waters to several vocally-active and endangered marine mammals (e.g., humpback, fin, sei and North Atlantic right whales), conducting research and developing a policy framework to minimize human-induced underwater noise is a cautionary guiding principle in the management plan (AP: MMBD.2). In implementing this principal, the Stellwagen Bank sanctuary is serving as the research venue of an ambitious multi-year passive acoustic project aimed at developing a suite of tools to monitor and map ocean underwater noise over a mesoscale region (for more project details see Hatch and Fristrup, 2009). A variety of reports and reviews have highlighted the fact that marine protected areas such as the Stellwagen Bank sanctuary can represent "test beds" to evaluate the efficacy of methods to continuously monitor underwater noise (Van Parijs and Southall, 2007) and create policy to regulate anthropogenic sources (McCarthy, 2004; Cummings, 2007; Firestone and Jarvis, 2007; Haren 2007; Scott, 2007).

Tuna Fishing

Tuna fishing consists of a variety of gear types and methods including harpoon, hook and line (trolling, jigging, anchored chumming, or casting lures to surface feeding fish) and purse seine. The target species is principally bluefin tuna, which is often attracted to the same forage base (sand lance and Atlantic herring) as piscivorous marine mammals such as endangered humpback and fin whales, minke whales and dolphins and porpoise. To help find tuna, fishermen often search directly for the prey and sometimes use surface feeding whales and birds as indicators of tuna availability and location (Sacco, 2008). Indirectly, commercial whale watch boats are used as proxies in the search for feeding whales. As a result, there is a high co-occurrence of baleen whales where tuna fishing occurs in the sanctuary (Figure 64), and the potential for interaction and disturbance is correspondingly high (Figure 65).

During 2006-2009, there were 37 reports filed on tuna fishing/whale altercations (mostly whales being hooked with and trailing tuna fishing gear) in the sanctuary that resulted in 22 enforcement cases (NOAA OLE, personal communication). Most of these cases resulted in the issuance of warnings, which count as a first offense should the vessel be encountered repeating the violation. Several of these cases could lead to further enforcement actions under the MMPA and ESA. In 2009, the Stellwagen Bank sanctuary, in partnership with NOAA OLE and NOAA Fisheries Service Highly Migratory Species Division and Protected Resources Division, ran a series of advertisements in On the Water magazine and television show that alerted fishermen to this problem. This outreach effort is planned to continue in 2010.

In addition to the direct effect of hooking the whales, there is a serious related indirect effect that can impair NOAA's programmatic response to a larger problem. The observation of a hooked whale trailing tuna fishing tackle in 2007 prompted calls from so many whale watch patrons, that it clogged the whale disentanglement hotline jeopardizing its effectiveness (S. Landry, PCCS, pers. comm., 2007). The hotline serves to notify and mobilize the disentanglement team of an entangled whale, usually in fixed fishing gear such as gillnets and lobster trawls. See Entanglement section that follows for expanded treatment. Since whale watch boats may be in close proximity to whales where viewing is enhanced, this public response has the potential to recur as long as whales are sighted adorned with tuna fishing gear.

In most other regards, entanglements with tuna fishing gear are cryptic and hard to detect at a distance, hence the number of reports is likely a fraction of the actual number of whales impacted. Disentanglement is not possible because of the light weight of the fishing gear which provides no purchase to the cutting tools routinely used in such an operations. In 2009, entanglement of a seabird (shearwater) in tuna fishing tackle also was documented. Sanctuary regulations prohibit the taking or possessing of any seabird, in or above the sanctuary, in violation of the MBTA.

Other Activities

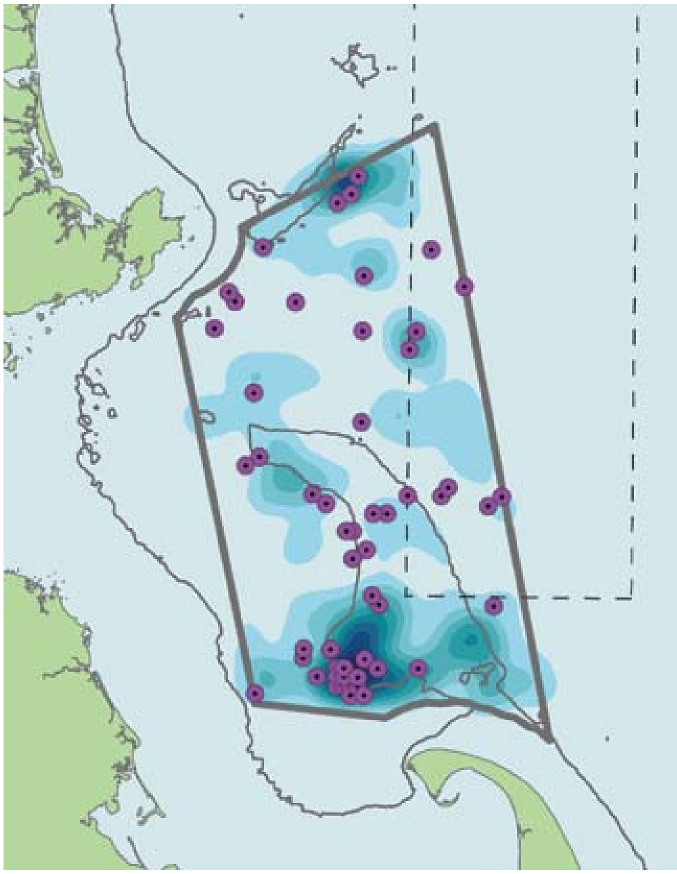
Additional activities that impact whale behaviors include watercraft approaching whales too closely, vessels disrupting critical feeding behaviors (such as transiting through bubble clouds or bubble nets) and potential disturbance by aircraft, specifically fixed-wing aircraft, helicopters and airships (APs: MMBD 1.2, 1.3 and MMBD.3).

Vessel Strikes

Research indicates that approximately 10% of the vessel/whale collisions recorded world-wide were reported from the Stellwagen Bank sanctuary area (including Cape Cod Bay and Boston Harbor) and that the sanctuary area is a "hot spot" for vessel strikes along the eastern U.S. seaboard (calculated from Jenson and Silber, 2003) (Figure 66). Data indicate that about 39% of the reported strikes result in mortality or serious injury (Anon, 2004). Species struck include four endangered species (humpback, fin, sei and North Atlantic right) and one protected species (minke).

Figure 64. Co-occurrence of baleen whales and tuna fishing in the Stellwagen Bank sanctuary during July 2001–June 2002.

Whale distribution is represented as a Kriged density plot of sightings data from the standardized survey using a 5,000 m search radius and analyzed by ESRI ARCGIS. Dots indicate locations where bluefin tuna were caught based on Fishing Vessel Trips Reports (VTR) for the same period. Source: NOAA Fisheries Service VTR data selected for the sanctuary area. The VTR database is discussed in the Human Uses section under Commercial Fishing – data types and sources.



Vessel types involved in the strikes of these whales include large commercial ships, commercial whale watch vessels and private recreational-type boats. Historical records demonstrate that the most numerous, per capita, ocean-going strikes recorded among large-whale species accrue to the North Atlantic right whale (Vanderlaan and Taggart, 2006). Where possible, reducing the co-occurrence of whales and vessels is likely the only sure means of reducing ship strikes (Silber *et al.,* 2009).

Vessel Speed

Jenson and Silber (2003) documented 27 reported vessel/whale collisions that occurred in the greater Stellwagen Bank area over a 22-year period (1980-2002) with a general increase in strikes occurring between 1984 and 2001. The annual mean cruising speed of commercial whale watch vessels in the Stellwagen Bank sanctuary over the related 25-year period (1980-2004) increased from 11 kts to 28 kts, with maximum speeds doubling from 20 kts to 40 kts; the

Figure 65. Photograph of a hooked humpback whale in the Stellwagen Bank sanctuary trailing tuna fishing tackle.

Credit: Provincetown Center for Coastal Studies.

Figure 66. Approximate location of ship strikes to baleen whales along the eastern seaboard of the U.S. including the Stellwagen Bank sanctuary from 1979–2002.

Note high occurrence in and around the sanctuary where indicated by arrow. Positions inferred from Jensen and Silber (2003).

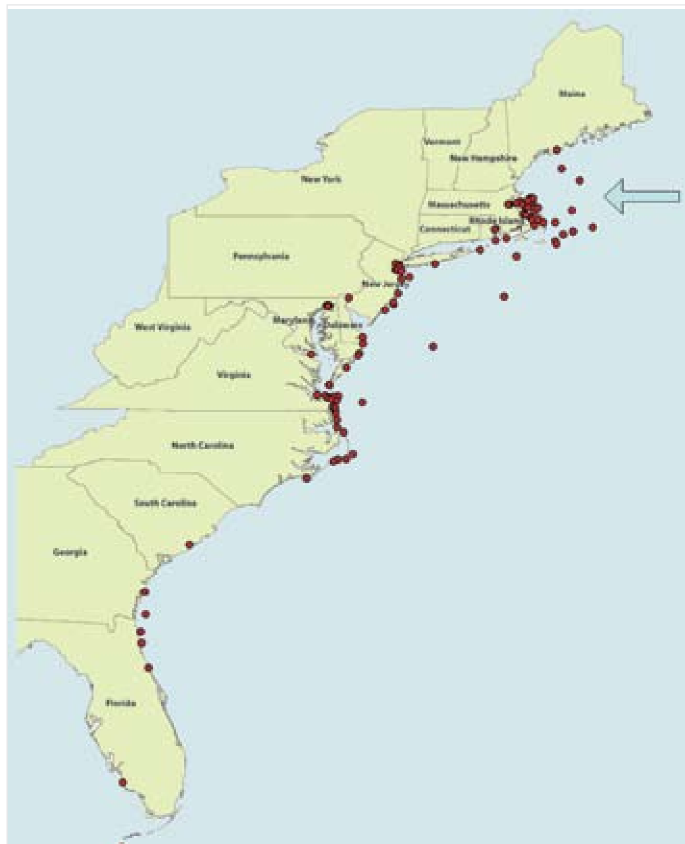


Figure 67. Historical trends (1980–2004) in the cruising speed (annual minimum, maximum and mean) of commercial whale watch vessels operating within and around the Stellwagen Bank sanctuary.

Reported strikes of whales due to collision with the whale watch boats are also indicated in the year that they occurred. Data for 1980-2002 were gathered by naturalists on whale watch cruises and provided by the Whale Center of New England; data for 2003-2004 were gathered by data loggers integrated with GPS receivers during the sanctuary study of industry compliance with NOAA whale watch guidelines (Wiley *et al.,* in press).

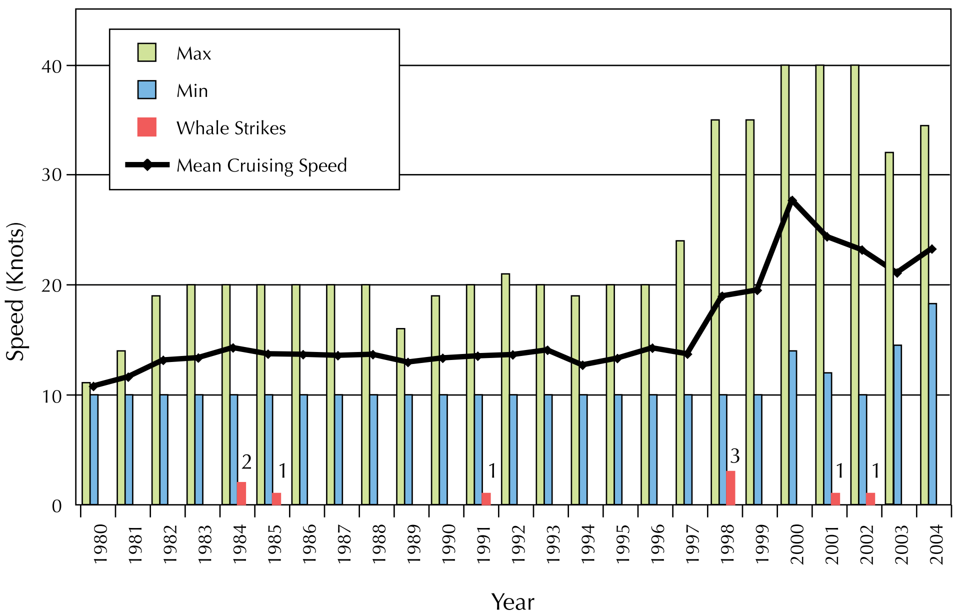
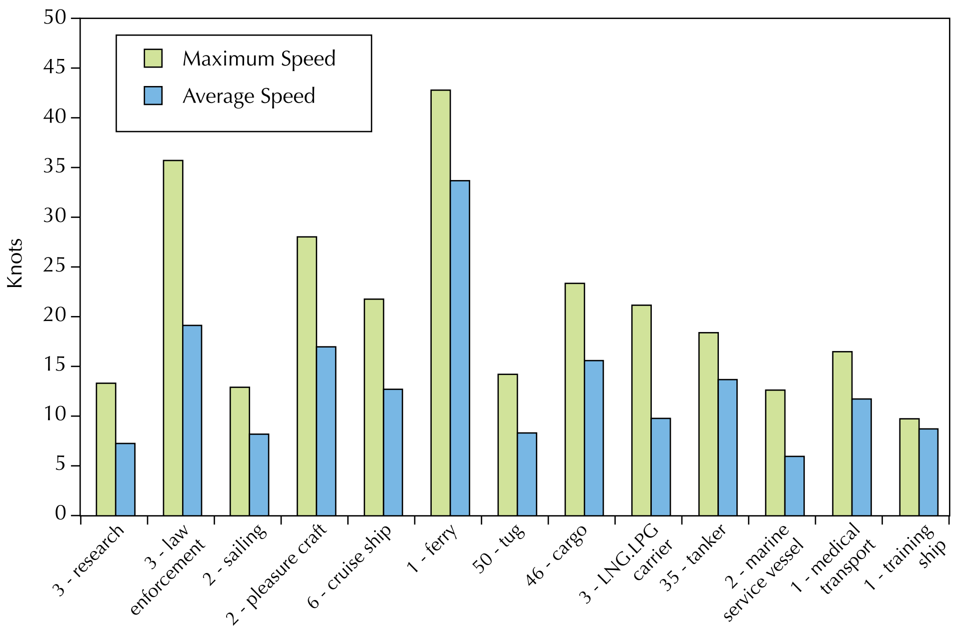


Figure 68. Maximum and average speed in knots for all (156) tracked commercial vessels transiting the Stellwagen Bank sanctuary during the months of April and May 2006 using the USCG's AIS.

The number of vessels of each type tracked within this time frame is indicated along the bottom axis.



higher speeds began in 1998 (Figure 67). The annual rate of strikes by these whale watch vessels during 1998-2004 (5/7 = 0.714) was 3.2 times greater than during 1980-1997 (4/18 = 0.222). [Note: There were no reported strikes between 2005 and 2009, which lowers the rate during 1998-2009 (5/12 = 0.417). However, that rate of strike is nearly twice (1.9 times) the rate during 1980-1997 when vessel speeds were lower.]

Vanderlaan and Taggart (2007) calculate that the greatest rate of change in the probability of a lethal injury to a large whale (any species) due to vessel strike occurs between vessel speeds of 8.6 kts and 15 kts; the probability drops below 50% at 11.8 kts and approaches 100% above 15 kts. The increased vessel speed by commercial whale watch vessels operating in the sanctuary places whales at greater risk of being struck and raises the probability of lethal injury. Increase in size and speed of vessels generally has resulted in a corresponding increase in the number of vessel strikes (e.g., Laist *et al.,* 2001; Taggart and Vanderlaan, 2003; Pace and Silber, 2005).

To further characterize speed of commercial vessels transiting the sanctuary, records from the USCG Automatic Identification System (AIS) were analyzed for the months of April and May 2006. The AIS data were collected as part of a collaborative effort between the Stellwagen Bank sanctuary and the USCG (see below). One hundred and fifty-six AIS-tracked vessels transited the sanctuary during these two months. Tug and tows, cargo ships and tankers made up 86% of the total traffic volume (Figure 68). Cargo ships were recorded to be transporting a wide variety of container types, while the majority of tanker traffic specialized in mineral resource and chemical transport. The highest average speeds recorded (all greater than 15 kts) were reported for a single large passenger ferry, motorized pleasure craft and law enforcement vessels; these and cruise ships, cargo and

LNG carriers all showed maximum speeds greater than 20 kts. An evaluation of the impact of ship speed limitations and the relationship to whale mortality within the sanctuary is underway (e.g. Thompson *et al.,* 2009).

Vessel Traffic

Collisions with large commercial ships constitute the majority of human-caused North Atlantic right whale mortalities (see Sidebar). NOAA Fisheries Service and the USCG established the Mandatory Ship Reporting System (MSRS) in July 1999 to reduce this threat (Figure 69). Under this system, all commercial ships, 300 gross tons or greater, are required to report to a shore-based station when entering into critical habitat areas (i.e., Great South Channel). Analysis of relative ship traffic density (kilometers of ship track per square kilometer) representing MSRS data from the first three years (1999-2002) of the northeast Mandatory Ship Reporting System indicates that five major high-use corridors of vessel traffic pass directly through the sanctuary (Ward-Geiger *et al.,* 2005).

The Stellwagen Bank sanctuary has worked in partnership with the USCG to adapt the AIS, originally developed for tracking vessels in real time to reduce the risk of vessel collisions, as a means to analyze vessel traffic patterns across the sanctuary. The AIS is a national shipboard broadcast system operating in the VHF maritime band. Compliance is mandatory for all vessels 300 gross tons or more, vessels carrying 150 or more passengers, and some other types of commercial shipping such as tug and tow (http://www.navcen.uscg.gov/enav/ais/default.htm). Together with the USCG, the sanctuary has established a network of receivers on Cape Ann, Scituate and Cape Cod that provides complete coverage of the sanctuary and adjoining area.

The AIS data portrayed in Figure 70 indicate that the sanctuary, because of its proximity to the Port of Boston, receives more commercial shipping traffic than any other location within U.S. jurisdiction in the GoM. These data are for the months of April and May 2006. While the overall traffic pattern displayed is similar to that indicated by the MSRS data, the AIS data have the advantage of being automatic and thus free of voluntary reporting bias, of representing all vessel tracks and not just one-way traffic upon entering critical habitat areas, and of documenting the entire vessel path actually traveled, not just the straight line distance inferred from initial point of reporting and arrival at destination. Vessel reports include information about vessel type and behavior, such as speed and course, and cargo carried.

ON THE BRINK OF EXTINCTION—the North Atlantic Right Whale

The North Atlantic Ocean has been home to the North Atlantic right whale (*Eubalena glacialis*) for eons. The Basques began hunting North Atlantic right whales in Europe in 1150, taxed by royal decree, and continued for nearly 600 years. By the 1500s, the Basques had exterminated the right whale population on the eastern side of the North Atlantic Ocean. In the latter part of the 16th century, Basque whalers expanded their hunting grounds westward to North America, particularly to the waters off southern Labrador.

Eventually, New England shore-based whalers dominated the local industry, seeking oil and baleen for energy and commercial products. Their catches of right whales peaked in the early 1700s, but Yankee whalers continued to pursue this species whenever opportunity afforded. The last animals to be taken intentionally were a mother and calf off Madiera in 1967, although the species had been afforded protection from hunting since an international agreement signed in 1935. This species had been the "right" whale to take because of its proximity to coasts and its high oil content making the whale positively buoyant so that it floated when killed.

Despite seven decades of protection from whaling, the North Atlantic right whale population has not rebounded. Today only a remnant of the population survives, no more than 350 whales clustered in calving and feeding grounds along the eastern seaboard of North America. Only occasional right whale sightings in the Gulf of St. Lawrence or in the waters between Iceland, Greenland and Norway give echoes of their once substantially greater range.

A critical factor in the right whale's population decline is human-induced mortality. Right whales are frequently struck and killed by ships or become fatally entangled in fishing gear, because their migratory routes overlap with major fishing areas and heavily trafficked shipping lanes along the east coasts of the United States and Canada. They are also more frequently killed and entangled because they spend most of their time at the surface, feed at the surface and travel slowly compared to other whales. In addition, the whales are not reproducing consistently or fast enough to increase their numbers—perhaps because of disease, pollutants, poor food supplies or genetic insufficiencies. Right whales reach reproductive maturity at a late age relative to other whales (>9 yrs), produce one calf every 3-6 yrs (a lower frequency than other whales) and only 50% of the calves survive the first year.

An area consisting of Cape Cod Bay and the southernmost portion of the sanctuary was designated a right whale critical habitat in 1994 because of its significance as a feeding area for right whales, which are resident primarily from January through early May. More than half the total population has been sighted in the area since studies began of right whales in the 1980s. Results of ongoing acoustic monitoring of the Stellwagen Bank sanctuary indicate that this species frequents the sanctuary to a greater extent than previously understood.

Figure 69. Mandatory ship reporting system (MSRS) data from 1999–2002 showing tracks of large commercial vessels traversing the Stellwagen Bank sanctuary.

Tracks depict only incoming traffic and represent only the straight line projected path of ships as they enter the MSRS zone, hence the straight lines. Only half of the actual traffic is illustrated, because vessels leaving the port are not required to report upon their departure. Tracks going north-south are ships or tugs in tow that are transiting through the Cape Cod Canal. The Boston Transportation Separation Scheme (TSS) (outlined in purple) is a voluntary shipping lane established by the International Maritime Organization (IMO) (data courtesy of NOAA Fisheries Service).

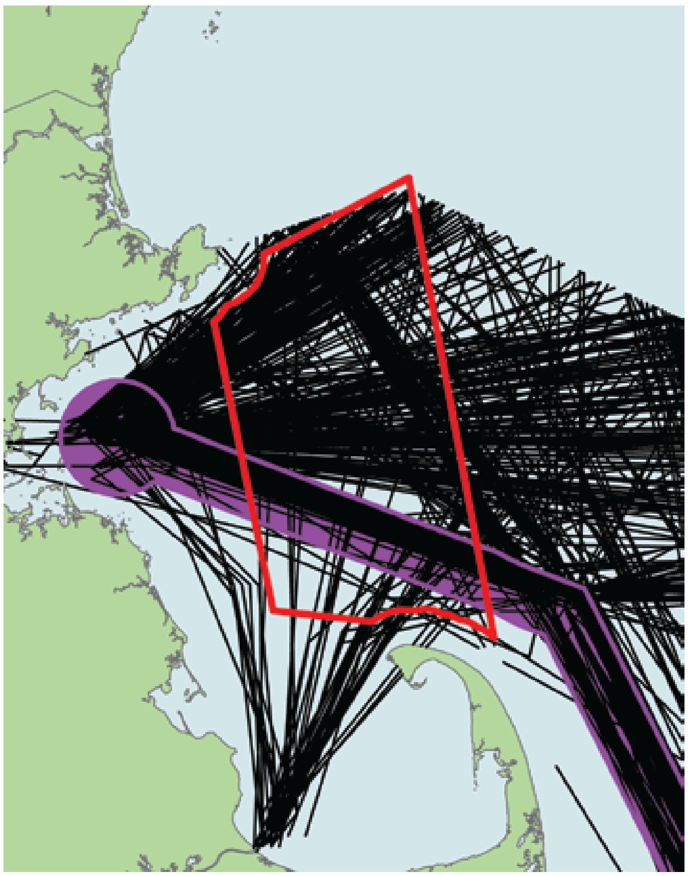
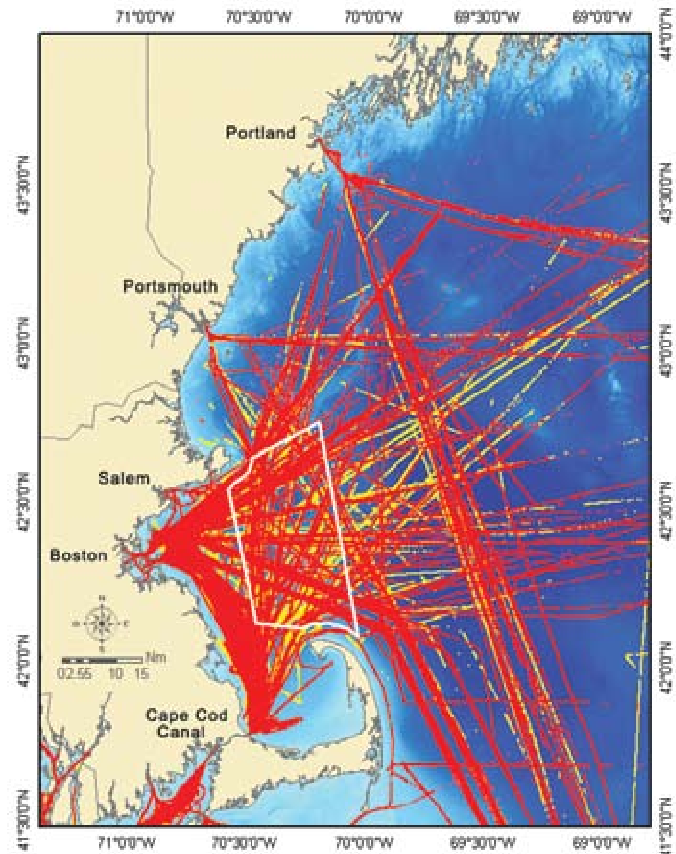


Figure 70. Ship tracks in the Stellwagen Bank sanctuary and western GoM for the months of April and May 2006 derived from the USCG AIS.

The data consist of more than 36 million position records generated along vessel paths at several second intervals from a total of 916 ships. Yellow represents the April tracks overlain by the May tracks in red.



A more extensive analysis of AIS data conducted over the entire 2006 calendar year indicated significant differences in temporal and spatial use of the sanctuary by large commercial ships (Hatch *et al.,* 2008). Tankers carrying oil and natural gas were marginally significantly more common in fall and winter than in spring and summer, while passenger carriers (cruise ships, ferries, sailing vessels, and pleasure craft) were significantly more common in the summer and fall than in the winter and spring. The spatial distribution of vessel types was also found to be non-uniform within the sanctuary (Figure 71). Tankers, cargo ships and passenger vessels (e.g., cruise ships) predominantly used the Boston shipping lanes, while service and research vessels were less concentrated and tug/tow activity was concentrated in the western and northern sanctuary.

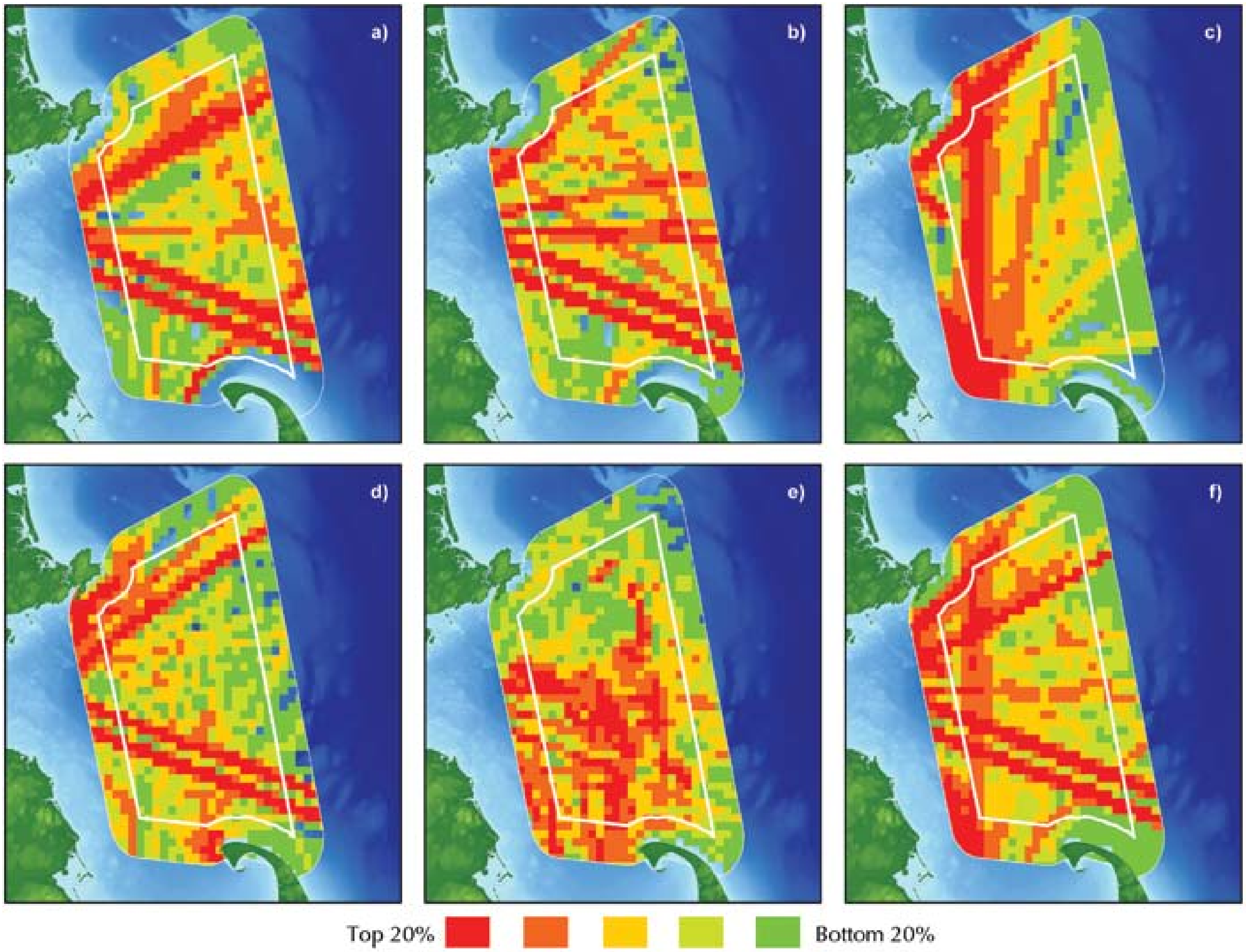
The main Boston shipping channel transects historic whale high-use areas across southern Stellwagen Bank. All cetacean species that frequent the sanctuary and surrounding waters exhibit space-use patterns with areas intensively utilized by boat traffic for fishing, commercial shipping, military shipping and recreational activity. The MMVS AP proposes several strategies to address these issues including re-routing shipping lanes (AP: MMVS.1) and instituting voluntary speed restrictions for vessels other than large commercial ships to mitigate vessel strikes to marine mammals (AP: MMVS.2).

Entanglement

The Stellwagen Bank sanctuary and adjoining area is a hot spot for observations of fishing gear entanglements with whales in the GoM (Figure 72). The area in and around the sanctuary has a high use of fixed gear vessels (gillnet, lobster and other trap/pot fisheries) (Figure 73). Figure 73 is reflective of a model that predicts chance encounters between whales and fixed fishing gear. Analysis of scars on humpbacks and right whales in the GoM region indicate that between 50% and 70% of the animals have been entangled at least once in their lives and between 10% and 30% are entangled each year (Robbins and Mattila, 2004).

Figure 71. Spatial distribution of commercial vessel types transiting the Stellwagen Bank sanctuary in 2006.

Distributions of five vessel types (a-e) and all (except fishing) vessels (f) within the sanctuary in 2006, with (a) all tankers (including liquefied natural gas; n = 162), (b) all cargo ships (n = 144), (c) all tug/tows (n = 113), (d) all passenger vessels (including cruise ships, sailing boats, fast ferries and private yachts; n = 87), and (e) all service and research vessels (n = 31). Figure adapted from Hatch *et al.,* 2008.



Chronically entangled whales lose blubber reserves making them more likely to sink when they die, thus it is believed that gear-induced mortality is underestimated more than ship kills. A study of the morbidity and mortality of chronically entangled North Atlantic right whales indicates that gear entanglement is a major animal welfare issue as well as being an obvious conservation concern (Moore *et al.,* 2000).

Co-occurrence between various marine mammal species and types of fishing gears capable of entangling them are of priority concern in the sanctuary. Such co-occurrence varies on a spatial and temporal basis and Wiley *et al.* (2003) calculated a Relative Interaction Potential (RIP) index to identify hotspots of potential whale entanglement in the sanctuary (Figure 74). This risk analysis predicts that the highest possibility of entanglement within the sanctuary should occur around the southwest and northwest corners of Stellwagen Bank.

The risk of whale entanglement in the sanctuary increases in areas where whales and fixed fishing gear co-occur, as indicated by the shading with the darkest area representing the top quartile of risk (Figure 74). For the study period of July 2001–June 2002, all three sightings (100%) of entangled whales occurred within or in the immediate vicinity of top-quartile cells. For the period 2000–2002, 85% (11 of 13) of entangled whales were found within or in the immediate vicinity of top-quartile cells.

Tagging data indicate that humpback whales can be extremely active at or within a few meters of the seafloor for many hours (Figure 75) and that bottom feeding is an important strategy (Wiley *et al.,* 2005). Therefore, fishing gear anywhere in the water column presents an entanglement risk to the animals. In 95% of flat-bottomed dives in the four humpback whales tracked in this study, the animals exhibited a characteristic “side-roll” behavior along the seafloor (Figure 75). Side rolls involved the animal rolling laterally more than 40 degrees from dorsal and holding that posi-

Figure 72. Sighting locations of whales reported entangled in fishing gear in the Stellwagen Bank sanctuary and GoM between 1985 and 2006.

Note: entangled whales can tow gear for long distances and the location of reported sightings might or might not be the original site of entanglement. Source: Provincetown Center for Coastal Studies.

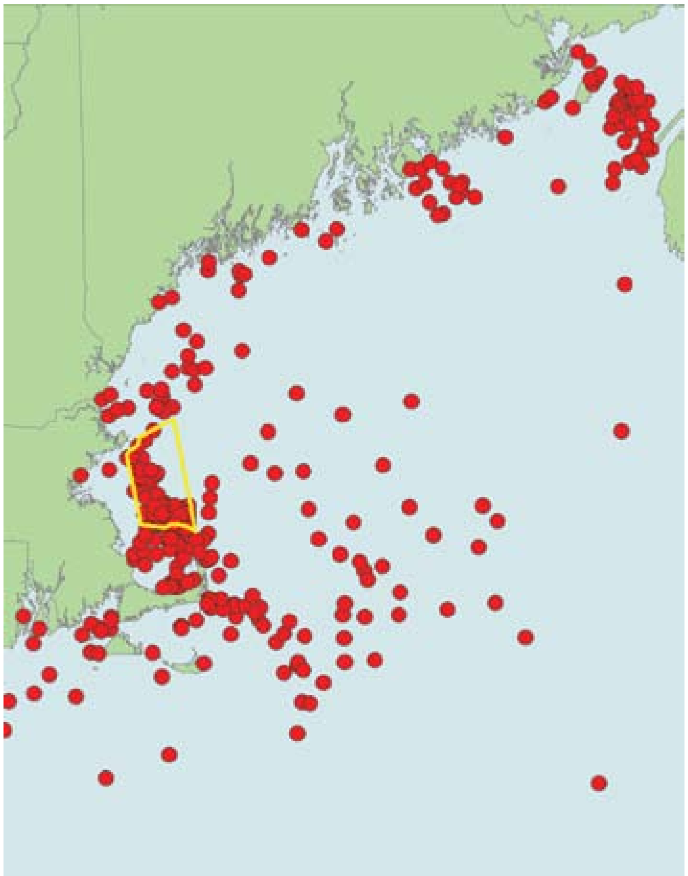
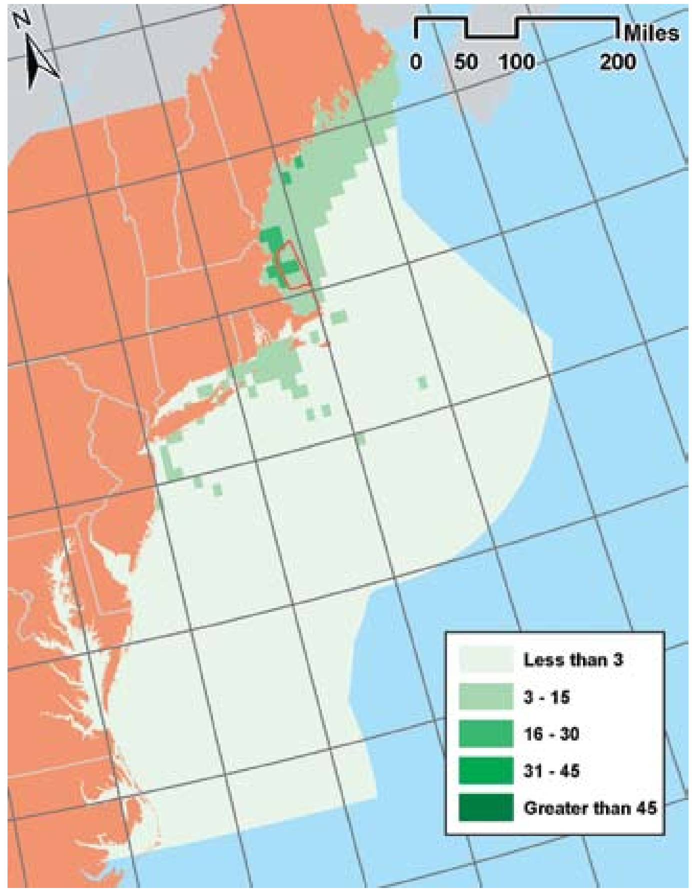


Figure 73. Distribution and density of number of active fixed gear fishing vessels (gillnet, lobster, and other trap/pot fisheries) from Virginia to Maine during 2004.

Graphic based on VTRs and federal lobster permit data analyzed by 10 x 10 minute grid cell. Analysis does not include state-only permitted vessels and as a result likely underreports some fixed gear effort, notably lobster pot fisheries. Source: Industrial Economics, Inc./NOAA Fisheries Service, NERO.



tion for a consistent duration, usually more than 10 seconds and less than a minute. The consistency of the behavior is evident from the bimodal distribution of body orientation measurements.

Side-roll behavior is presumed mouth-open feeding during which whales turn on their side to scour the sandy bottom and engulf sand lance burrowed in or located along the seafloor. This behavior indicates that the likelihood of entanglement by open mouth and protruding appendages (flippers and tail) would be elevated during bottom feeding bouts in areas with co-occurrence of fixed fishing gear strung across the ocean bottom. In a study of 30 cases of entangled humpback whales (Johnson *et al.,* 2005), the most common point of gear attachment was the tail (53%) and the mouth (43%) which seems to affirm this inference.

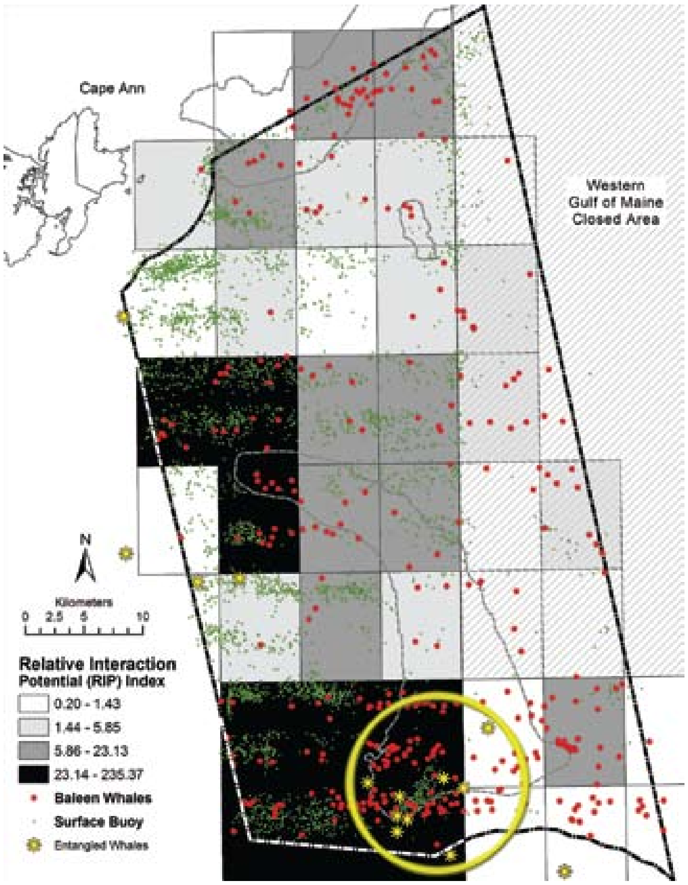
The immediate effects of entanglement include mortality by drowning as well as serious and minor injuries such as lacerations. Long-term effects can include deteriorating health and susceptibility to disease, crippling deformation and impaired body function, and decreased competitive and reproductive ability. Marine mammal species reported in the sanctuary that are most susceptible to entanglement include baleen whales, harbor porpoises, white-sided dolphins and harbor seals.

Most cetacean bycatch in the sanctuary (and the GoM) is associated with the sink gillnet fishery, although entanglements have also been documented in lobster pots, purse seine and bottom trawl gear (Smith *et al.,* 1993; Johnson *et al*, 2005). The incidental catch of harbor and harp seals, harbor porpoise and Atlantic white-sided dolphin has been documented for gillnet fisheries in the GoM (Gilbert and Wynne, 1987; Waring *et al.,* 1990; Smith *et al.,* 1993; Waring *et al.,* 2008). Derelict fishing gear (i.e., "ghost nets") is also suspected to cause entanglement.

Reducing incidental mortality in fisheries through time/area closures, gear modification, and disentanglement rescue and release efforts are management solutions to address entanglement problems. The Harbor Porpoise and Atlantic Large Whale Take Reduction Plans provide for time/area closures and gear modification in the sanctuary area (NOAA

Figure 74. Relative Interaction Potential (RIP) index showing the potential for interaction between baleen whales and fixed fishing gear in the Stellwagen Bank sanctuary, by 5-minute square area.

The index was calculated by multiplying the total number of fixed gear surface buoys within a 5-minute square by the total number of whales sighted in that square. Data were collected from July 2001 through June 2002 for calculation of the index. Yellow symbols depict where entangled baleen whales were sighted during 2000-2002. (Source: adapted from Wiley *et al.,* 2003)



2006b; NOAA 2007a). Because the sanctuary is a hot spot for observed entanglements as discussed above, it is an ideal location to focus disentanglement efforts for large whales.

Reduced Forage Base

Sand lance (*A. dubius*) are not commercially fished within the sanctuary (refer to subsection EA.3 Action Plans in this document for expanded discussion of sand lance as prey). However, the sand lance (*A. marinus*) is the target of the largest single-species fishery in the North Sea with the total allowable catch (TAC) being set at 1 million tons per year (ICES, 1998). The Department of Fisheries and Oceans Canada has identified sand lance (*A. dubius*) as one of the major unexploited fish resources of the northwest Atlantic (http://www.dfo-mpo.gc.ca/zone/underwater_sous-marin/SandLance/sandlanc_e.html). While there is yet no fishery for sand lance in the GoM, if one were to develop the Stellwagen Bank sanctuary area would certainly be targeted because of its historical high level of sand lance abundance. Sand lance occur within the sanctuary at higher levels of abundance than in any other area of the southern GoM (Figure 50 this document).

Atlantic herring accounted for the greatest volume by species landed from the Stellwagen Bank sanctuary during 1996–2005 (refer to subsection on commercial fishing in the Status of Human Uses section of this document for data source and details). On average 7.0 million pounds (3,180 mt) of herring were harvested annually from the sanctuary by commercial fishing during 1996–2005 (Table 10). The availability of herring, particularly as a functional prey substitute for sand lance, may be a factor in determining the local abundance of whales, dolphins and other wildlife in the sanctuary. The local depletion of herring by fishing is a related concern. See Sidebar for further explanation of local depletion. Much of the following discussion pertains to herring because an active fishery for this prey species occurs within the sanctuary.

The distribution of commercial herring landings in the sanctuary during 1996–2005 is presented in Figure 76. Landings were greatest around Jeffreys Ledge and parts of Stellwagen Bank. A variety of gear types, including mid-water pair trawls, mid-water otter trawls, and purse seines, was used between 1996 and 2001, but thereafter most herring catches have been taken by pair-trawling (Figure 77). While seasonally and annually variable, the herring catch from the sanctuary area in the fall-season fishery (August - November) can be high as evidenced in 2005 (Figure 78, Table 10). An indication of the variability in catch distributions for 1996, 2000 and 2004 are presented in the Final Amendment 1 to the Atlantic Herring Fishery Management Plan (http://www.nefmc.org/herring/planamen/final_herring_al.htm).

According to recent stock assessments, herring are currently not overfished and no overfishing is occurring (http://www.nefmc.org/herring/index.html). The inclusion of biological interactions and their impacts in stock assessments and multi-species models is an important step in predicting sustainable yields and developing realistic estimates of biological reference points for key prey species (ICES, 1989; Overholtz *et al.,* 1991; Hollowed *et al.,* 2000; Read and Brownstein, 2003). Although such interactions have not been formally included in the current assessment or in the herring FMP, a buffer (a 29,000 mt difference between Allowable Biological Catch and Optimum Yield), has been included in recent Total Allowable Catch specifications packages for Atlantic herring. In 2006, the biomass of the Gulf of Maine-Georges Bank herring stock complex was estimated to be slightly greater than 1 million metric tons, and about 60% higher than the MSY stock biomass level.

The fishery for herring harvests the same size groups that predators (whales, dolphins) consume, and this overlap could result in competition if herring was a limiting resource (Overholtz *et al.,* 2000); fishermen seeking pelagic species (such as herring) adopt the same foraging strategy as natural predators (Bertrand *et al.,* 2007). Tradeoffs between these two sources of removal may need to be addressed, but this does not necessarily imply an 'either-or' situation (Over-

LOCAL DEPLETION

The term local depletion is commonly used in the scientific literature, books, popular magazines, fishery management plans and even the U.S. Federal Register. The term has been applied in relation to a large number of species worldwide that includes finfishes (e.g., Fritz, 1999; ASMFC, 2009), elasmobranchs (e.g., Walker, 1998), shellfishes (e.g., Salomon *et al.,* 2007; Saunders *et al.,* 2009) and zooplankton (e.g., Wetterer, 1988). It has also been applied to a wide variety of processes including recolonization, individual interactions, population interactions, animal behavior, fisheries and metapopulation dynamics (e.g., Armstrong *et al.,* 1994; Benoit *et al.,* 2002; Jackson *et al.,* 2002; Planes *et al.,* 2005; Wilson *et al.,* 2006; Conners and Munro, 2008; Wiggert *et al.,* 2008).

Despite liberal use of the term, a preliminary search of the recent primary literature and regional fishery management plans finds no operational definition within individual studies/plans or across studies/plans (e.g., predator-prey interactions versus metapopulation dynamics) (J. Stockwell, Gulf of Maine Research Institute, personal communication, 2009). As used in this document, the meaning of "local depletion" is reduction in local prey abundance (i.e., availability) by fishing to below levels that allow whales and other marine life to feed optimally or near maximally within the sanctuary.

The concern for local depletion within the SBNMS derives from recent genetic and otolith microchemical studies which indicate that marine stocks have complex spatial structures at much smaller scales than previously assumed. The important implication of these findings is that a decline in fish abundance in one area may not be replenished quickly or inevitably from another area. Thus, averaging stock assessments among areas may result in localized overfishing (Francis *et al*, 2007). This creates the concern that local depletion of a fish stock or portion thereof could occur within the bounds of the SBNMS and adjacent area.

Data requirements to discern local depletion can be much different from those routinely used for regional population surveys. Alternative sampling methodologies and means of analysis (i.e. modeling) may need to be formulated and directly applied. At the spatial scale of the sanctuary, novel protocols may be especially important in resolving issues of competition between fisheries and upper trophic level predators, such as whales. Battaille and Quinn (2006) estimate local depletion of walleye pollock in the eastern Bering Sea as the slope of logarithmic catch-per-unit-effort (CPUE) versus cumulative effort from the fishery. The general trend of local depletion was detected often in their study. Their results help to better understand the linkage between the Steller sea lion decline and the trawl fishery for walleye pollock over the last few decades.

Local depletion can transcend the direct effects on exploited populations by impacting the prey base for fish predators, increasing bycatch of non-target species and destruction of habitat. The ecological implications of local depletion, including competitive interactions that could preclude re-colonization and the prospect of reduced functional resiliency for example, have not been examined at the scale of the sanctuary.

holtz and Link 2008). This possibility should be evaluated in the sanctuary.

The decline of high-order marine predators (common dolphin, bluefin tuna, swordfish) feeding on epipelagic prey in the central Mediterranean is consistent with the hypothesis of prey depletion, likely resulting from intensive exploitation of local fish stocks, particularly anchovies and sardines (Bearzi *et al.,* 2005). [Of note, this study was done in a 480 km^2 portion of the area included by the Greek Ministry of the Environment in the Natura 2000 network ("Sites of Community Importance") under the 9243 EEC "Habitats" Directive (Frantzis, 1996), hence in an ecologically important area akin to the sanctuary]. Modeling of minke whale abundance and herring fishery catches in the North Atlantic ecosystem suggests that interactions may be linear and inverse (Schweder *et al.,* 2000), i.e. whale abundance goes down as herring catches go up Of consequence is the fact that baleen whales (humpback, fin and minke) require a minimum threshold level of prey density to successfully forage (Piatt and Methven, 1992; Hazen *et al.,* 2009) and that humpback whales depend on the spatial characteristics and density of prey schools to maximize their efficiency when surface feeding (Hazen *et al.,* 2009).

Prey patchiness tends to increase with mean prey density, so depletion of prey stocks by fishing may rapidly reduce numbers of suitable prey aggregations. Marine mammals are typically aggregated prey patch foragers. Thus local changes in prey abundance may be more important than changes across the entire stock range, i.e., GoM. Management to avoid depletion of the prey fields composed of herring and sand lance in local areas of critically important foraging habitat for marine mammals, such as the sanctuary, may be needed. Also the sanctuary is a hotspot for prey abundance (see Figure 50 and associated text). An important characteristic of pelagic forage fish hot spots is their persistence, allowing predators to predict their locations and concentrate search efforts to enable optimal foraging (Gende and Sigler, 2006). Significant fishing down of prey aggregations in the Stellwagen Bank sanctuary would diminish the reliability and functional utility of this important attribute of the sanctuary.

While reductions in prey abundance might not always be sufficient to directly cause a predator species population to decline *per se*, such reductions can cause shifts in predator species distribution which affects local predator abundance. Local changes in humpback whale abundance and distribution in the western North Atlantic have been correlated with variation in prey availability (Payne *et al.,* 1986; Weinrich *et al.,* 1997). A nega-

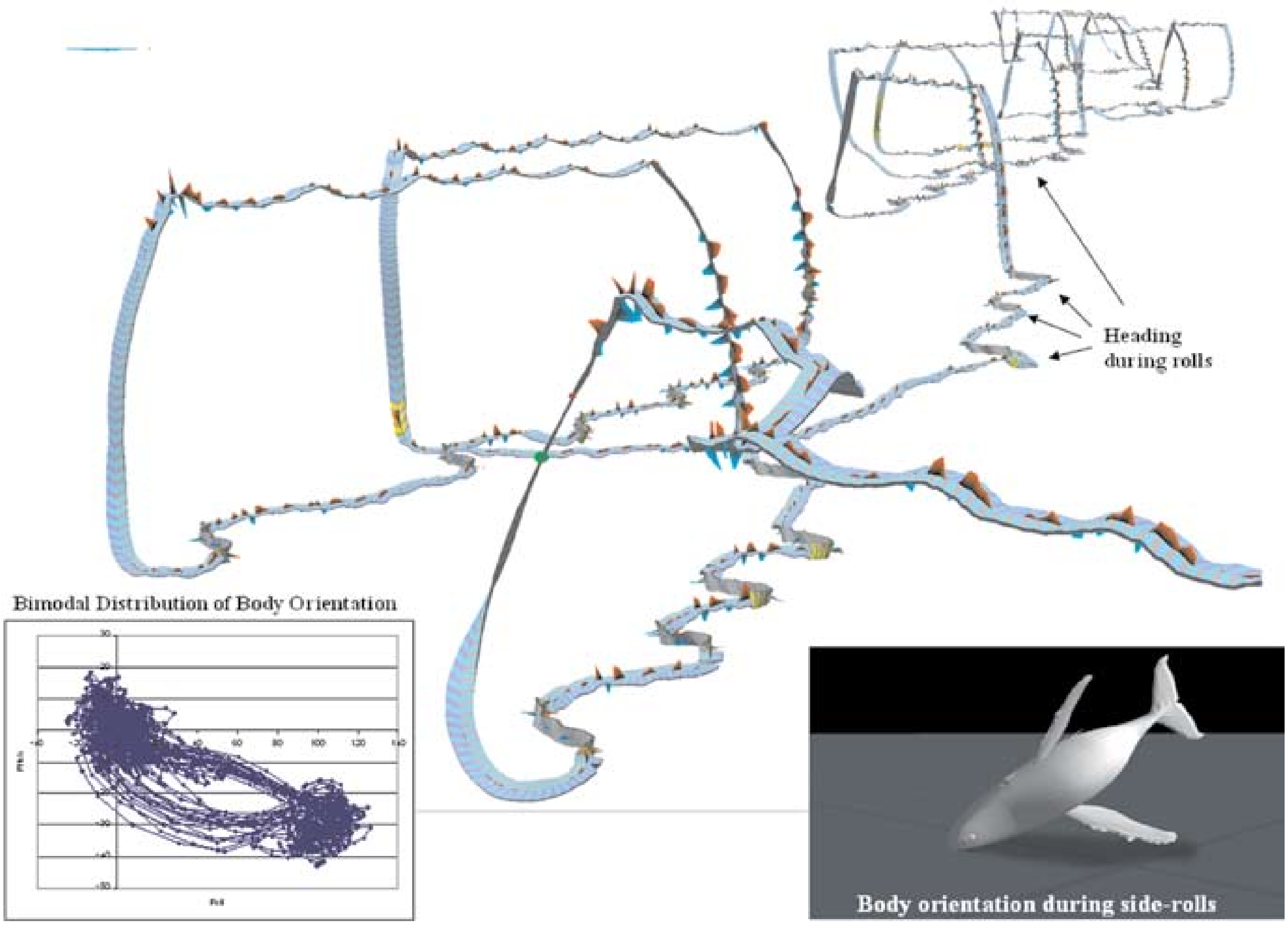
Table 10. Herring landings (millions of pounds) from the Stellwagen Bank sanctuary by gear type (1996–2005).

Gear Type	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total	% Total
Pair Trawl, Midwater	95	4,060	8,083	3,098	1,060	1,676	7,383	1,881	3,407	13,057	**43,800**	**62.5**
Otter Trawl, Midwater	2,627	2,761	4,162	2,064	0	1,406	430	0	0	3,971	**17,421**	**24.9**
Purse Seine	2,680	1,274	710	3,682	60	0	0	80	0	0	**8,486**	**12.1**
Other *	358	3	4	8	0	0	0	2	4	0	**378**	**0.5**
Total	**5,760**	**8,098**	**12,958**	**8,852**	**1,120**	**3,082**	**7,813**	**1,963**	**3,411**	**17,028**	**70,085**	**100.0**

* Other includes: otter trawl, bottom, fish; gill net, sink; hand line/rod & reel; otter trawl, shrimp; and mixed gear.

Figure 75. Three-dimensional ribbon track of a tagged humpback whale showing extensive interdependent use of seafloor and water column during foraging along the bottom.

Twists in the ribbon correspond to side rolls by the animal. Also shown is the bimodal distribution of body orientation (0,0: normal dorsal superior swimming position; 100,30: body rolled ~100° and pitched down ~30°) and a visualization of the body roll and pitch used during suspected bottom feeding. Ribbon tracks were developed by Colin Ware (University of New Hampshire). (Adapted from Wiley *et al.,* 2005).

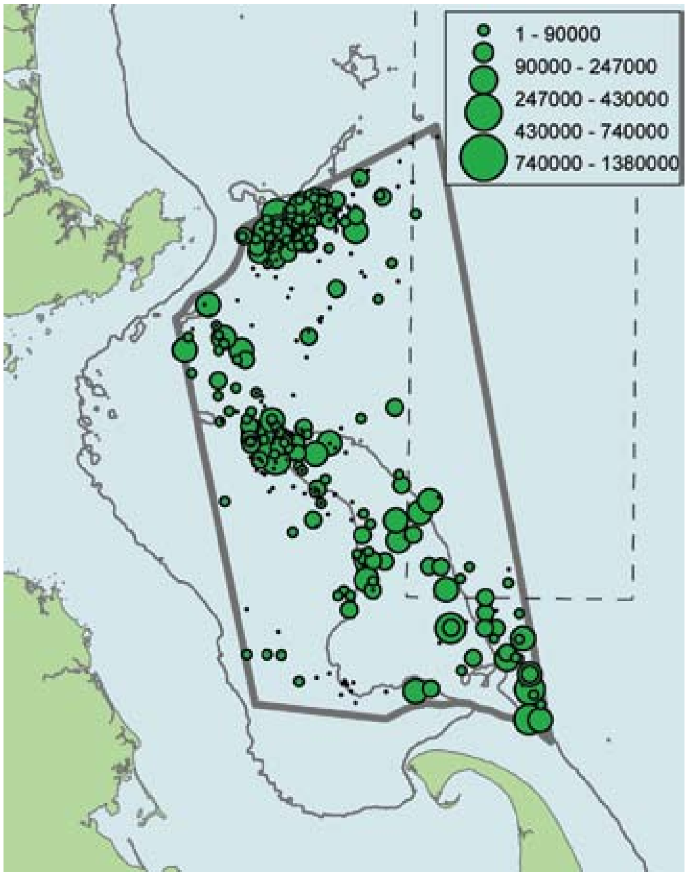


tive relationship was apparent between the relative abundance of herring and sand lance in the GoM and humpback whale movements from the GoM to eastern Canada when prey densities dropped (Stevick *et al.,* 2006). This study also found that humpback whales exhibited high levels of site fidelity to specific feeding grounds and that the duration of stay at, and tendency to return to, each feeding ground was related to relative prey density.

A recent study (Robbins 2007) determined that despite inter-annual variation, the sanctuary is a site of persistent humpback whale aggregations, and that the sanctuary is preferentially used by juveniles and reproductively mature/active females. These natal groups typically play important roles in large mammal population dynamics because of their sensitivity to environment and/or population density (juveniles) and importance to population growth (adult

FIGURE 76. SPATIAL DISTRIBUTION OF COMMERCIAL HERRING FISHING IN THE STELLWAGEN BANK SANCTUARY DURING 1996–2005.

Area of circle is proportional to pounds of herring caught and landed from that location. Source: NOAA Fisheries Service VTR data selected for the sanctuary area.



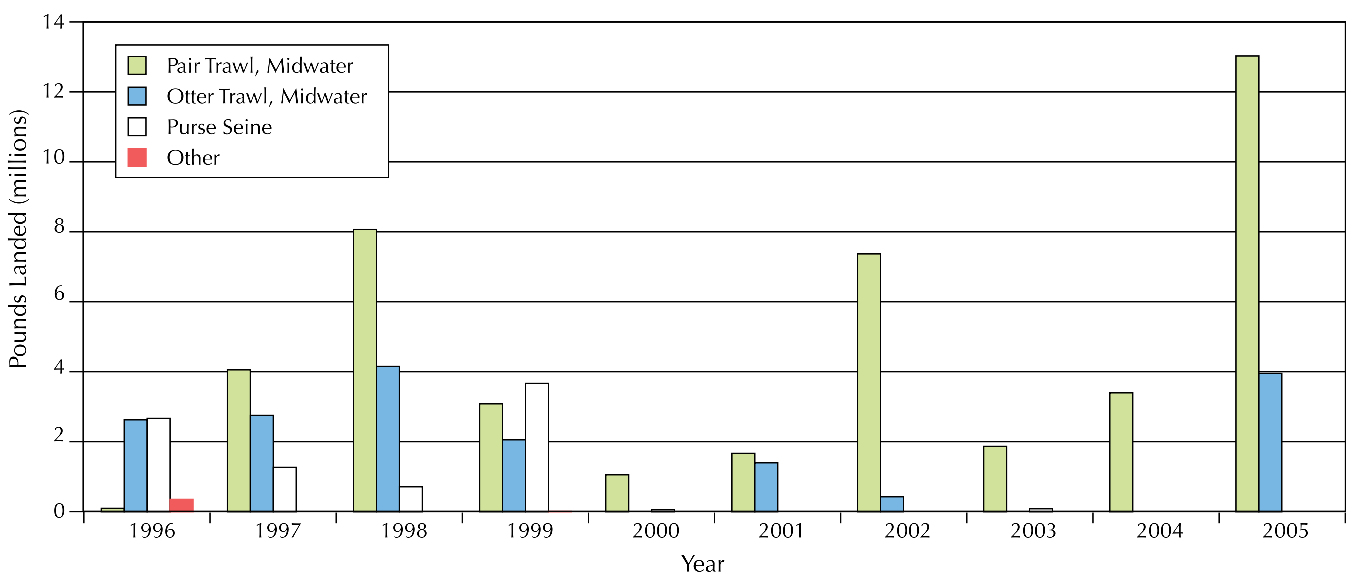
females). Thus, the preferential and persistent use of the sanctuary by these components of this endangered whale population suggests that management actions specific to the sanctuary may benefit the population as a whole (Robbins 2007). Additional research may be useful in confirming the importance of these factors. While less data exist for other species, similar conditions might exist. For example, Agler *et al*. (1993) found that fin whales in the southern GoM had higher reproductive rates than those in the northern areas.

Prey availability can effect survival among components of these humpback whale natal groups. Robbins (2007) found that sand lance and/or mackerel abundance in the season following weaning were the model factors that best explained annual variation in survival of humpback whale calves in the GoM. Much of the data underlying these analyses came from the sanctuary area. Model support for a sand lance effect explaining the annual variation in calf survival was 1.62 times greater than for mackerel. Atlantic herring abundance did not reliably predict calf survival. Using logistic regressions to predict humpback whale calf survival to age 1 and whether the calf survived to age 2, Weinrich and Corbelli (2009) found that sand lance abundance was a significant predictor for calf survival to both ages. Data for these regressions were derived largely from the sanctuary area. Additionally, breeding success of seabirds can be highly sensitive to sand lance abundance (Furness and Tasker, 2000). While the latter study was conducted in the eastern North Atlantic, some of the same seabird species that frequent the sanctuary were included in this analysis.

Herring and sand lance are keystone prey species that constitute a major segment of the forage base of the sanctuary. The species that may be affected by the harvest of herring or the potential harvest of sand lance include those (e.g., whales, cod, bluefin tuna) central to supporting tourism and recreation in the sanctuary, which are activities that gener-

FIGURE 77. HERRING LANDINGS IN POUNDS BY FISHING GEAR TYPE AND YEAR FROM THE STELLWAGEN BANK SANCTUARY DURING 1996–2005.

Source: NOAA Fisheries Service VTR data selected for the sanctuary area.



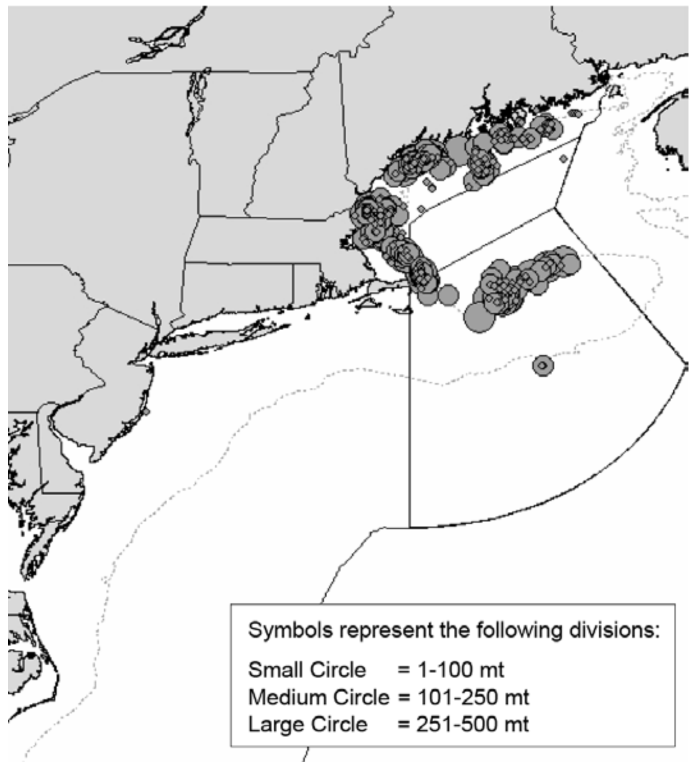
ate direct sales far greater in value than the ex-vessel landings of the herring *per se*. For example, annual direct sales value for commercial whale watching in the sanctuary was approximately $24 million in 2000 (Hoyt, 2001); ex-vessel value for herring landings from the sanctuary that year was $64 thousand (Fishing Vessel Trip Report [VTR] data, NOAA Fisheries Service); ex-vessel value for herring landings from the sanctuary for the decade (1996–2005) was $5.4 million (Table 15, Commercial Fishing section of this document). Cost-benefit analysis could be useful in evaluating the tradeoffs between these two sources of marine revenue.

Biodiversity plays a key role in ecological integrity in that it promotes ecosystem resilience and stability (Tilman *et al.,* 1996; Duarte, 2000) via ecosystem function and biological redundancy within functional groups (Walker, 1992). Walker (2009) suggests that one way to preserve ecological integrity is to focus on the conservation of those species that represent an ecosystem function for which there are few or no other species. Maintenance of ecological resilience and stability is thus further rationale to protect key forage species within the sanctuary. If one forage organism (e.g. sand lance) has low abundance one year, or over a period of time, then it is important that the sanctuary have in place conservation measures to ensure that there is an adequate population of the other forage species (e.g. herring) to maintain that ecosystem function.

Because it is difficult to predict the effects of climate change, especially in complex marine ecosystems, precautions must be taken in places of special importance like the sanctuary. Richer biodiversity, because of the functional redundancy and compensation it affords, supports more resilient ecosystems (Ehlers *et al.,* 2008). See subsection on Functional Relevance under Biodiversity Explained (this plan) for introduction of this concept. Climate change may affect one species of a functional prey group more adversely than another, which is why it is important, especially in times of environmental uncertainty, to maintain multiple species populations that can perform similar ecosystem functions.

Figure 78. Seasonal distribution of Atlantic herring catch in the northeast region during the 2005 fishing year.

Note: A significant part of the catch distribution in the fall fishery (August – November) included the sanctuary area. Solid lines demarcate herring management area boundaries. See also Figure 80 in this regard. Figure excerpted from NEFMC, 2006.



Pollution and Chemical Contaminants

The environment of the Stellwagen Bank sanctuary provides feeding and nursery areas for humpback, fin, sei, minke and North Atlantic right whales, the latter being the most critically-endangered of all large cetacean species. Cetaceans are key predators of small fish and zooplankton and they exhibit low fecundity relative to many other marine animals. These biological characteristics, coupled with their sensitive dependence on specific prey types, mean that cetaceans also function as important bioindicators of the health and productivity of marine ecosystems (Reijnders *et al.,* 1999; Greene *et al.,* 2003).

Pollution in the form of dredge spoils, ocean dumping and disposal, and noise, as well as chemical contaminants may affect the health and survival of baleen whales (Perry *et al.,* 1999; Reeves *et al.,* 2000; Rolland *et al.,* 2005). Sand lance is a key species within the sanctuary and serves as the primary prey of humpback whales and other baleen whales in the sanctuary. The populations of key species, such as sand lance, are highly variable, and fluctuate widely from year to year, with concomitant effects on consumers, such as whales. Although contaminant concentrations have not been determined for prey species (e.g., sand lance) to date, predator-prey relationships are important pathways to consider when evaluating possible adverse effects of contaminants on the health of marine mammals.

In addition to point-source pollution that may affect food webs (e.g., chemicals from discharge sites and dumping), the atmospheric transport of contaminants represents a global danger (Reeves, 2003). Exceptionally high levels of chemical contaminants in the tissues of cetaceans may be affecting the animals' immune and reproductive systems (Reeves, 2003). For example, Weisbrod *et al.,* (2001) found elevated levels of organochlorine in pilot whales and Atlantic white-sided dolphins from the southern GoM, with the later considered to have bioaccumulated hazardous concentrations of polycholorinated biphenals (PCBs) and chlorinated pesticides. In addition, a wider range of PCBs and pesticides have been detected in baleen whale species, including the endangered right whale, although concentrations were not considered hazardous (Weisbrod *et al.,* 2000).

Cetacean exposure to marine biotoxins associated with harmful algal blooms (HABs) has been documented in the GoM (Doucette *et al.,* 2006). The dinoflagellate genus *Alexandrium*, which produces paralytic shellfish poisoning (PSP), blooms at the time of right whale abundance. The trophic transfer of marine toxins has been hypothesized to be a contributing factor to the poor recovery of the North Atlantic right whale, although neither chronic nor sublethal effects are known for cetaceans (Durbin *et al.,* 2002). Similarly in 1987, 14 humpback whales washed ashore dead and decomposed along Cape Cod Bay and Nantucket Sound. The cause of this unprecedented stranding of large baleen whales was attributed to a naturally occurring neurotoxin called saxotoxin or STX (Geraci *et al.,* 1989). Additionally, marine debris pollution (e.g., from ingestion of plastic bags) and its impact on marine animal populations is a global problem, which is extremely difficult to evaluate (Laist *et al.,* 1999).

Current Protection

The protection of marine mammals in the sanctuary is provided through the following laws, regulations, and guidelines:

- National Marine Sanctuaries Act (NMSA) of 1972 (16 U.S.C. Part 922 1431 et seq.)
- SBNMS Regulations (15 CFR § Subpart N)
- Marine Mammal Protection Act (MMPA) of 1972
- Endangered Species Act (ESA) of 1973
- NOAA Voluntary Whale Watch Guidelines

Sanctuary regulations prohibit the taking or possessing (regardless of where taken, moved or removed from), except as necessary for valid law enforcement purposes, of any marine reptile, marine mammal or seabird in or above the sanctuary, except as permitted by the Marine Mammal Protection Act, as amended, (MMPA), 16 U.S.C. 1361 et seq., the Endangered Species Act, as amended, (ESA), 16 U.S.C. 1531 et seq., and the Migratory Bird Treaty Act, as amended, (MBTA), 16 U.S.C. 703 et seq. Five species of baleen whales are endangered (Table 8).

The MMPA and ESA prohibit the "taking" of a marine mammal (i.e., "harass, hunt, capture or kill") without authorization. The relevant definition of the term "harassment" means any "negligent or intentional act which results in the disturbing or molesting of marine mammals" causing by disruption of "behavioral patterns, including, but not limited to migration, breathing, nursing, breeding, feeding, sheltering" {16 U.S.C. 1362(13)}. All marine mammals are federally "protected" by the MMPA and most large whales are further listed as "threatened or endangered" under the ESA.

Behavioral Disturbance

NOAA regional whale watch *guidelines* are intended to prevent harassment and possible injury or death to large whales by both commercial and recreational vessels (Appendix M). The North Atlantic right whale is protected by separate State and Federal *regulations* that prohibit approach within 500 yards (457 m) of this species (50 CFR 222.32) (Appendix N). Any vessel finding itself within the 500-yard buffer zone created by a surfacing right whale must depart immediately at a safe slow speed. The only vessels allowed to remain within 500 yards of a right whale are vessels with appropriate research permits, commercial fishing vessels in the act of hauling back or towing gear, or any vessel given prior approval by NOAA Fisheries Service to investigate a potential entanglement. Except for the North Atlantic right whale, no federal rule regulates how vessels behave around whales in the northeast region.

The Stellwagen Bank sanctuary has no overflight restrictions governing airplane activity. To date, guidelines or legislation regarding sound (acoustic) energy and the need to manage it appropriately do not exist. NOAA Fisheries Service published a notice of intent on 11 January, 2005, in the Federal Register (70 FR 1871) to prepare an EIS to analyze the potential impacts of applying new criteria in guidelines to determine what constitutes a "take" of a marine mammal under the MMPA and ESA as a result of exposure to anthropogenic noise in the marine environment.

Vessel Strike

NOAA issues ship speed advisories using NOAA-based communications to help reduce ship strikes to North Atlantic right whales. The NOAA National Weather Service issues right whale advisories and speed advisories on NOAA weather radio when aggregations are sighted. Advisories are voluntary and apply to areas where right whales sightings have been confirmed; they indicate that neither navigational nor human safety is to be jeopardized as a result of reduced speeds or other maneuvers to reduce the risk of striking a whale. Speed advisories have also been integrated into many NOAA publications. Ships reporting into the Mandatory Ship Reporting System receive an automated message indicating precautionary measures to be taken to avoid hitting whales, including speed advisories (Ward-Geiger *et al.,* 2005).

In December 2008, NOAA implemented regulatory measures, as part of the NOAA Ship Strike Reduction Program, designed to significantly reduce the likelihood and severity of collisions with right whales while also minimizing adverse impacts on ship operations. The regulations require vessels greater than or equal to 65 feet in overall length and subject to the jurisdiction of the U.S., or entering or departing a port or place under the jurisdiction of the U.S., to reduce speed to 10 knots or less within specific Seasonal Management Areas (SMAs) along the US east coast (50 CFR 224.105). The SMAs include the areas and times where right whales occur predictably from year to year. There are certain exemptions to the speed restrictions for navigational safety, as well as Federal vessels and law enforcement vessels. The rule is set to expire on December 9, 2013. These regulations, pursuant to rulemaking authority under MMPA section 112(a) (16 U.S.C. 1382(a)) and ESA 11(f) (16 U.S.C. 1540(f)), are also consistent with the purpose of the ESA "to provide a program for the conservation of [...] endangered species" and "the policy of Congress that all Federal departments and agencies shall seek to conserve endangered species [...] and shall utilize their authorities in furtherance of the purposes of [the ESA]." Previous efforts to reduce occurrence of North Atlantic right whale deaths and serious injury from ship strikes had not been sufficient to recover the species.

On December 12, 2006, the International Maritime Organization approved a proposal submitted by the USCG on behalf of NOAA to narrow and move the Boston area Traffic Separation System (TSS) (i.e., the shipping lanes that cross the sanctuary to and from the Port of Boston) 12 degrees to the north (Figure 79). The proposal was developed by the Stellwagen Bank sanctuary in collaboration with NOAA Fisheries Service, NOAA General Counsel (International) and the USCG. The lane shift greatly reduces the risk of vessels striking whales—by up to 81% for all whales (humpback, fin, minke, northern right) and by up to 58% for the critically endangered right whale—while minimally impacting shipping interests. The conservation benefit is realized by moving the TSS away from areas of historical high use by whales over prime feeding habitat. This management action implements strategy AP:MMVS.1 recommended in this document.

On December 14, 2009, President Obama's Interagency Ocean Policy Task Force released its "Interim Framework for Effective Coastal and Marine Spatial Planning" (CEQ, 2009). In that report, NOAA's successful effort to reconfigure the Boston TSS within the Stellwagen Bank sanctuary served as the signature example of the potential benefits of coastal and marine spatial planning for the White House Council on Environmental Quality.

Entanglement

Besides MMPA and ESA mandates, a number of existing regulations and plans designed to reduce the risk of marine mammal entanglement in the Northeast apply to, but are not specific to, the sanctuary. Regulations that are most applicable to marine mammal entanglement within the sanctuary are those pertaining to trap/pot fisheries and gillnet fisheries. Examples are:

- Federal lobster trap limits
- Lobster trap gear identification
- Lobster trap maximum size
- Trap/pot gear restrictions
- Lobster trap gear configuration
- Special restrictions on critical habitat areas
- Reconfiguration of anchored gillnet gear
- Multispecies sink gillnet regulations (aimed at rebuilding overfished groundfish stocks)
- Seasonal and rolling closure areas
- Gear stowage requirements

The Atlantic Large Whale Take Reduction Plan (NOAA, 2007) addresses broad-based gear modifications and special management areas to reduce serious injury and mortality of right, humpback and minke whales due to incidental interactions with commercial fisheries.

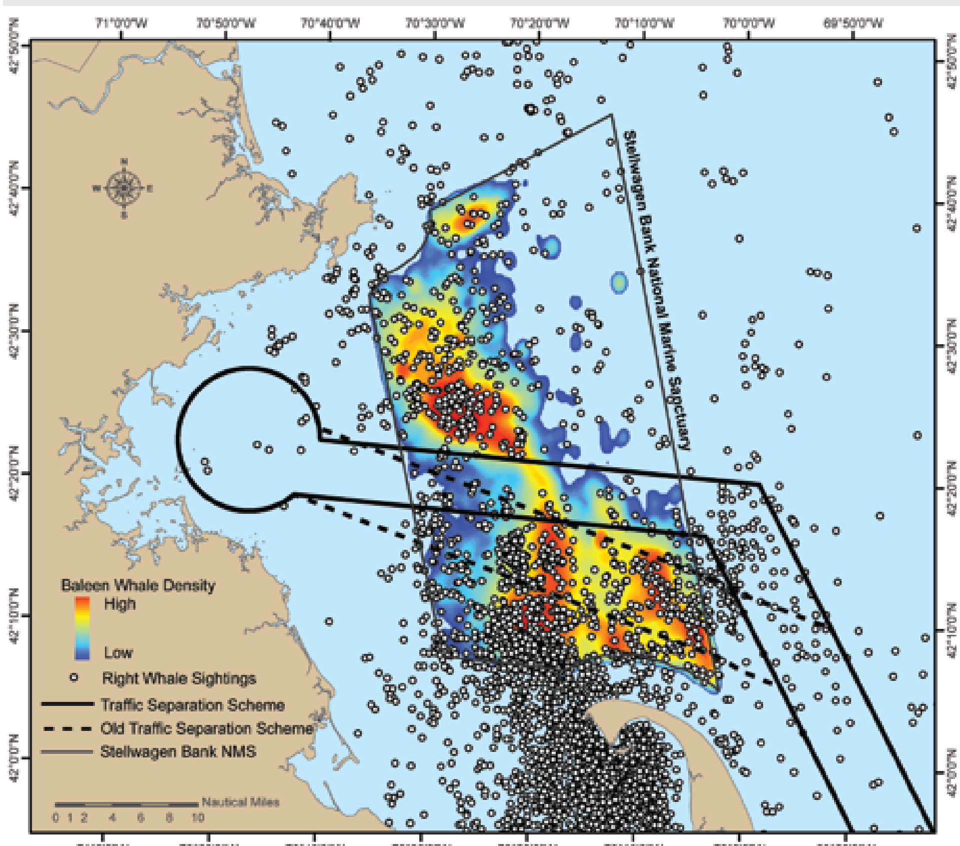
Reduced Forage Base

Sand Lance

Sand lance (*A. marinus*) are the target of the largest single-species fishery in the North Sea (ICES, 1998). The Department of Fisheries and Oceans Canada has identified sand lance (*A. dubius*) as one of the major unexploited fish resources of the northwest Atlantic (http://www.dfo-mpo.

Figure 79. Realignment of the shipping lanes (TSS) into the Port of Boston by the International Maritime Organization to reduce the risk of ship strikes to baleen whales in the Stellwagen Bank sanctuary.

Analysis based on non-standard whale sightings (n=~255,000) from commercial whale watching vessels from 1979-2004 overlain with right whales sightings (circles) from the Right Whale Consortium database (n=5,675). Kriged density plots of whale watch derived sightings were produced using a 5,000 m search radius analyzed using ESRI ARCGIS; whale watch data were collected by the Provincetown Center for Coastal Studies and the Whale Center of New England.



gc.ca/zone/underwater_sous-marin/SandLance/sandlanc_e.html). While there is not a fishery for sand lance in the GoM, if one were to develop the sanctuary area would certainly be targeted because of its historical high level of sand lance abundance. While narrow and elongated in shape, sand lance are susceptible to capture in small mesh nets.

The regulations governing fishing in the GoM primarily stem from the Northeast (NE) Multispecies Fishery Management Plan (FMP). The FMP states that no vessel may fish with trawl gear in the GoM, including the sanctuary, with smaller than 6.5″ square or diamond mesh at its codend (50 CFR part 648.80(a)(3)(i).) The intention of this regulation is to ensure that undersized regulated[1] groundfish and other small fish are not targeted by vessels fishing for groundfish.

Vessels participating in an exempted fishery or using exempted gear may fish with smaller than 6.5″ mesh under limited circumstances. To become exempted from the NE Multispecies FMP minimum mesh size requirement, a fishery must meet the requirements specified at §648.80(a)(8). These regulations state that a fishery may become exempted when "there are sufficient data or information to ascertain the amount of incidental catch of regulated species, if the Regional Administrator, after consultation with the NEFMC, determines that the percentage of regulated species caught as incidental catch is, or can be reduced to, less than 5 percent, by weight, of total catch, unless otherwise specified in this paragraph (a)(8)(i), and that such exemption will not jeopardize fishing mortality objectives."

An exemption (§648.80(a)(8)(i)) to the 5-percent incidental catch requirement would only be authorized if the Regional Administrator and the NEFMC have considered the "status of the regulated species stock or stocks caught in the fishery, the risk that this exemption would result in a targeted regulated species fishery, the extent of the fishery in terms of time and area, and the possibility of expansion in the fishery."

In order to acquire sufficient data to ascertain the amount of interaction with regulated species, exemptions from the minimum mesh size and/or the possession requirements for existing exempted fisheries would be required. The exempted fishery permit (EFP) process requires public notice and comment period, in accordance with §600.745, and compliance with the National Environmental Policy Act (NEPA). An EFP would be required because fishery development is not considered scientific research. EFPs are limited in scope, and an EFP is issued for no longer than one year. If the research requires more time, the EFP would have to be renewed through the entire process, including additional public notice and comment.

Four exempted fisheries or fishing areas that overlap the sanctuary are currently active. All of the exempted fishing areas currently restrict vessels to possessing only certain species, of which sand lance are excluded and not permitted for retention.

1. Small Mesh Northern Shrimp Fishery Exemption (§648.80(a)(5))

This fishery is exempted throughout the whole GoM during the Northern GoM shrimp season (as specified by the Atlantic States Marine Fisheries Commission). The minimum mesh size for this exempted Northern shrimp fishery is not specified. However, the fishery is primarily prosecuted north of the sanctuary off the coast of Maine. This fishery also requires the use of a Finfish Excluder Device (FED). The FED is intended to keep finfish from entering the codend of a shrimp trawl net and the parallel bars are to be spaced not more than 1″ apart.

2. Raised Footrope Trawl Whiting Exempted Fishery (§ 648.80(a)(15))

This fishery overlaps a small portion of the southern-most part of the sanctuary. The minimum mesh size for this exempted whiting fishery is 2.5″ square or diamond mesh throughout the codend. This exempted area is only open to small mesh fishing from September 1 through November 20 of each year.

3. Midwater Trawl Gear Exempted Fishery (§648.80(d)), and

4. Purse Seine Gear Exempted Fishery (§648.80(e))

These fisheries are exempted throughout the Gulf of Maine/Georges Bank Exemption Area (as defined in §648.80(a)(17)) for the entire year. There is no minimum mesh size; however, midwater trawl and purse seine vessels typically fish with nets similar to the whiting fishery, i.e., 13/4″ to 3.5″ mesh.

While sand lance are excluded from the list of species permitted for retention, there is no regulated minimum mesh size in the two exempted fisheries most likely to capture sand lance, i.e., midwater trawl and purse seine. Both of these fisheries are prosecuted in the Stellwagen Bank sanctuary. Based on the federal observer program database, there is no evidence of sand lance bycatch in these fisheries.

If a fishery for sand lance were to be developed, presuming that the fishery would require smaller than regulated mesh, it would first have to proceed through the EFP process. If the research meets the requirements of the exempted fishery process described above and in §648.80(a)(8), including demonstration of less than 5% incidental catch of regulated groundfish, development of the fishery would then have to progress through the regional fishery management council process and then, potentially, into the Federal rulemaking process, including public notice and comment. Compliance with NEPA and all other applicable laws would be required. At such time, the Regional Administrator would make a determination based on a variety of factors including, but not limited to, juvenile mortality of regulated NE multispecies, sacrifices in yield that will result from that mortality, the ratio of target species to regulated species, status of stock rebuilding and the recent recruitment of regulated species.

1 The term "regulated groundfish" is defined at §648.2 as "the subset of NE multispecies that includes Atlantic cod, witch flounder, American plaice, yellowtail flounder, haddock, pollock, winter flounder, windowpane flounder, redfish, and white hake, also referred to as regulated NE multispecies."

While perhaps difficult in practice, a sand lance fishery that did not interact with groundfish technically could be allowed, if it met the requirements described above and as specified at §648.80(a)(8), including empirical evidence that there was not, in fact, interaction with regulated NE multi-species in excess of 5% bycatch. NOAA Fisheries would not have to conduct a stock assessment prior to granting approval for an experimental sand lance fishery that would require an EFP. However, if an FMP were developed or sand lance were incorporated into an existing FMP, full requirements of the MFCMA would need to be fulfilled. Given the complexity of the EFP process, and to ensure full protection for this critical component of the sanctuary's forage base, consideration should be given to a direct prohibition on fishing for sand lance in the Stellwagen Bank sanctuary.

Atlantic Herring

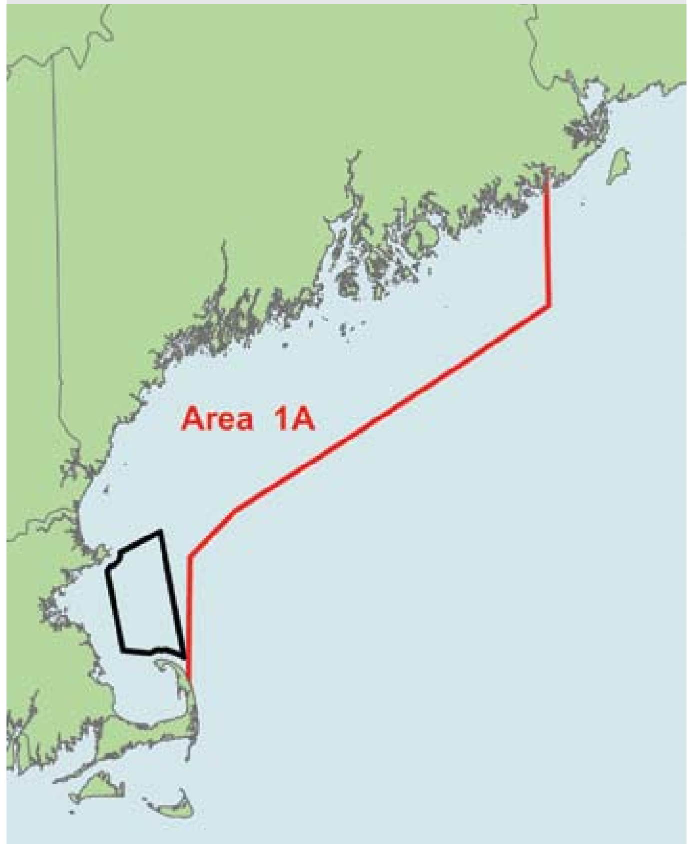
Final Amendment 1 to the Atlantic Herring Fishery Management Plan was developed by the NEFMC and submitted to NOAA Fisheries Service on May 3, 2006. Notice of the final rule implementing Amendment 1 was published on March 12, 2007 (72 FR 11252). Of significance to the Stellwagen Bank sanctuary is how the commercial herring fishery impacts the forage base of the sanctuary particularly in regard to Area 1A which entirely overlaps the sanctuary (Figure 80). Area 1A regularly produces the greatest share of the herring landings.

Relative to the 2005/2006 total allowable catches (TACs) of herring, the 2007 fishery specifications reduced the Area 1A TAC by 10,000 mt (17%), modified the seasonal split of the Area 1A TAC, and increased the Area 3 TAC by 5,000 mt. Domestic annual harvest for the fishery was set at 145,000 mt, domestic annual processing was set at 141,000 mt, and there was no specification for either total allowable level of foreign fishing or total joint venture processing. The 2007 fishery specifications provided the opportunity for total U.S. fishery landings to increase about 35% above recent (1995–2005) levels.

However, when implementing multi-year specifications for 2007–2009, NOAA Fisheries Service determined that the 2008 and 2009 specifications should include an additional reduction in the Area 1A TAC with a corresponding increase in the Area 3 TAC. As a result, the Area 1A TAC was reduced another 5,000 mt to 45,000 mt, and the Area 3 TAC was increased another 5,000 mt to 60,000 mt. All other specifications remain the same for 2008 and 2009. In addition, the research set-aside program became effective in 2008, and 3% of each management area TAC has been set-aside to support herring-related research. The information in this and the previous paragraph is from the NEFMC (2006) "Herring Fishery Specifications for the 2007–2009 Fishing Years."

At its meeting on November 17, 2009, the NEFMC reduced the overall herring TAC from 145,000 mt, in place during 2007-2009 to 91,200 mt. This decision was based on the lack of certainty about the abundance of the herring stock, consideration that the herring stock is projected to decline over the next several years, and the finding that heavy fishing in some areas of the GoM could be depleting the inshore spawning stock components. As a result, TAC allocations by harvest areas were adjusted further and the Area 1-A TAC was reduced to 26,546 mt. This decision awaits NOAA Fisheries Service enactment into regulation.

Figure 80. Location of the Stellwagen Bank sanctuary relative to Area 1A in the herring fishery management plan.



From the perspective of the sanctuary, the key component of the series of actions taken is the 10,000 mt reduction in 2007, the additional 5,000 mt reduction specified for 2008 and 2009, and the further 18,454 mt reduction established in 2009 for the 2010-2012 Area 1A TAC. Cumulatively, these reductions amount to appreciably more than the total average annual landings (3,180 mt) of herring caught in the sanctuary over 1996–2005 and is more than the highest single year landings in the sanctuary to date (7,726 mt) made in 2005. Additionally, the purse seine/fixed gear-only area proposed in Amendment 1 was implemented in 2007. Vessels using single and paired mid-water trawls are prohibited from fishing for Atlantic herring in Area 1A from June 1 through September 30 during each fishing year. All gear types are allowed to harvest herring from Area 1A from October 1 through May 31.

While the numeric level of reduction seems appropriately scaled to address the concern of diminished prey base in the sanctuary, that concern would only be fully addressed if the TAC were harvested entirely outside of the sanctuary (for reasons explained in the subsection on Reduced Forage

Base and under Action Plan Objective EA.3). The shape and spatial integrity of prey fields as well as thresholds for prey density are determinants of the optimality of humpback whale foraging on sand lance in the sanctuary (Friedlaender *et al.* 2009; Hazen *et al.,* 2009). If these findings extend to whales foraging on herring in the sanctuary, both conditions would potentially be degraded by herring fishing. Also, the ecological importance of functional redundancy of prey opportunities within the sanctuary should be evaluated. And while adjustments have been made to be precautionary, the calculations underlying the determination of the TAC do not include explicit estimates of herring consumption by whales or other key predators in the sanctuary.

Maritime Heritage Resources

Office of National Marine Sanctuaries (ONMS) regulations define "historical resource" as any resource possessing historical, cultural, archaeological, or paleontological significance, including sites, contextual information, structures, districts and objects significantly associated with or representative of earlier people, culture, maritime heritage, and human activities and events. Historical resources include "submerged cultural resources" and also include "historic properties," as defined in the National Historic Preservation Act.

The term "historical resource" as used in the ONMS regulations also encompasses pre-Columbian Native American archaeological sites; therefore, the ONMS's Maritime Heritage Program prefers the term "maritime heritage resource." "Maritime heritage resource" is defined as any shipwreck or other site or object that is of archaeological, historical, or cultural significance found in, on or under the submerged lands, including sunken State craft.

Maritime heritage resources in the Stellwagen Bank sanctuary require management as mandated by the historical resource provisions of the NMSA, sanctuary regulations, and the Federal Archaeological Program. Additionally, maritime heritage resources contribute to biodiversity conservation by serving as substrate for epibenthic organisms and shelter for fishes and invertebrates.

Status

Uncounted Native American and historic archaeological sites lie within the Stellwagen Bank sanctuary. Over ten thousand years ago, portions of the sanctuary's seafloor were dry land supporting a diverse array of flora and fauna and potentially Paleoindian peoples. In the more immediate past, the sanctuary's position at the mouth of Massachusetts Bay places it astride the historic shipping routes and fishing grounds for such historic ports as Gloucester, Salem, Boston, Plymouth and Provincetown. These ports have been centers of maritime activity in New England for nearly 400 years. As a result of man's long association with the sea, the sanctuary contains a broad cross-section of this nation's maritime heritage. To date, the only archaeological resources identified in the sanctuary are shipwrecks.

The Stellwagen Bank sanctuary has been actively pursuing maritime heritage research since 2000. The sanctuary has relied heavily on a partnership with NOAA's National Undersea Research Center at the University of Connecticut (NURC-UConn) to access appropriate tools, including side scan sonar, remotely operated vehicles (ROVs) and skilled pilots, to investigate maritime heritage resources. The sanctuary has also benefited greatly from the generosity of independent researchers, such as John Fish and Arnold Carr of the company American Underwater Search and Survey, who have provided locations or information about sanctuary maritime heritage resources.

The sanctuary's research has been focused along two paths: locating maritime heritage resources and characterizing those resources. Prior to 2000, the sanctuary was unaware of the precise location of any such sites within its boundaries. Since 2000, the sanctuary has conducted yearly remote sensing research projects utilizing side scan sonar to survey the seafloor and identify potential maritime heritage resources. These surveys have mapped 139.4 square kilometers (53.8 square miles) of the sanctuary's seafloor, or approximately 6.4 percent of the sanctuary's total area.

As sanctuary researchers located potential maritime heritage resources, they began to characterize the resources utilizing the appropriate technology. Maritime heritage resources shallower than 130 feet were investigated with SCUBA (Self-Contained Underwater Breathing Apparatus) divers, who recorded diagnostic features with still and video photography, measurements and scaled drawings.

All maritime heritage resources deeper than 130 feet were investigated with an ROV carrying lights and cameras. Under direction from archaeologists, a ROV pilot navigated the robot around the archaeological sites, imaging diagnostic features and artifacts with digital still and video cameras. Some maritime heritage resources were characterized during a single ROV dive, while others have not been fully characterized after several ROV dives. In particular the large size of several sanctuary shipwrecks, notably the *Portland* and *Frank A. Palmer/Louise B. Crary,* and conservative ROV navigation used to avoid entangling fishing gear on these sites, have resulted in a lengthy process of ongoing site characterization.

Beginning in 2003, the sanctuary instituted a monitoring program for the steamship *Portland* and *Frank A. Palmer/Louise B. Crary*. Annually between 2003 and 2006 and again in 2009, sanctuary researchers returned to the sites with an ROV to monitor artifacts and structures for change. At both shipwreck sites, researchers noted changes to artifact assemblages and the vessels' wooden structure. The sanctuary also periodically revisits other maritime heritage resources to document site changes. The Stellwagen Bank sanctuary has adopted a policy of *in situ* preservation as its preferred preservation method for maritime heritage resources. This policy is recognized by the international community through the United Nations Education, Scientific, and Cultural Organization (UNESCO) Convention on the Protection of Underwater Cultural Heritage's objectives and general principles. While the U. S. is not a signatory to the convention, NOAA has formally recognized the convention's annex rules as best-practice for underwater archaeological research.

Maritime heritage resources begin to deteriorate shortly after submersion in a saltwater environment. The physical and chemical oceanographic aspects of the ocean, such as waves, currents, salinity, and pH erode and corrode cultural material, while biological and biochemical activities of organisms, such as wood-boring mollusks and bacteria, contribute to the natural deterioration of archaeological sites. The specific environment in which an archaeological site is located greatly influences how rapidly the site will deteriorate. The sanctuary's low energy deep muddy basins preserve archaeological sites much longer than the much more dynamic top of Stellwagen Bank. Additionally, the composition of submerged artifacts greatly affects how long the item will remain in the archeological record. In general, organic material, such as wood and fabric, does not last as long as iron, brass or ceramics.

Archaeological sites reach equilibrium with the environment after a period of deterioration. Corrosion products enclose ironwork, slowing oxidation. Likewise, anoxic sediment covers hull remains greatly reducing biological and biochemical consumption. Archaeological sites can last for thousands of years, as evidenced by classical Greek shipwrecks found in the Mediterranean Sea. Even though these ancient shipwrecks have deteriorated significantly since their deposition, the sites maintain archaeological integrity and can be invaluable gateways to learn about past human activities. Disturbance by anthropogenic activities can upset this natural equilibrium and accelerate disintegration.

Native American Resources

Ancient geologic and glacial processes once exposed the sanctuary's seafloor to the sun, allowing it to support flora and fauna that may have been utilized by the Paleoindian peoples (Barber, 1979). Around 12,000 years ago, groups of migratory humans, known as Paleoindians, inhabited southern New England. The retreat of the Laurentide ice sheet 21,000 to 16,000 years ago allowed these people access to Stellwagen Bank and Jeffreys Ledge, which rose above the surrounding ocean as a result of lower sea levels and the rebound of the Earth's crust after the retreat of the heavy ice sheets (Funk, 1978; Barber, 1979).

Although no archaeological evidence of Paleoindian inhabitation has been found in the sanctuary, sea level models suggest that dry land remained accessible to the Paleoindians for a thousand years. During this time, people likely utilized the bank to hunt for land mammals, as a base for fishing and hunting marine mammals, and for gathering shellfish and vegetation (Barber, 1979). The possibility of finding Paleoindian cultural remains on Stellwagen Bank is supported by the recovery of mastodon skeletal remains by local fishermen (Carr, 1990). Further geologic study, site modeling, and sampling will be necessary to determine the potential for locating Native American cultural remains in the sanctuary (Bell, 2009; Coleman and McBride, 2008).

Rising sea levels inundated Jeffreys Ledge and Stellwagen Bank around 10,000 years ago, displacing any Native Americans living within the area to the edges of Massachusetts Bay, but not diminishing their usage of marine resources. Native Americans developed complex societies in New England during the approximately 12,000 years of human habitation prior to the arrival of Europeans. At the time of European contact Penobscot, Abenaki, Pequot, Massachusett, Narragansett, Wampanoag and Confederated River tribes inhabited the region surrounding Massachusetts Bay. These coastal tribes utilized the marine environment as their ancestors had, but it is unlikely that they ventured into the sanctuary's waters considering the wealth of resources close to shore. The arrival of Europeans in New England dramatically amplified the sanctuary's human usage.

Historic Resources

As a result of four centuries of vessel traffic through the sanctuary, several hundred historic vessel losses are recorded in the sanctuary's vicinity. Primary causes of vessel loss (shipwrecks) in the sanctuary fall into four broad classes: (1) acts of war—naval engagements, piracy, law enforcement; (2) natural forces—storms (gales/hurricanes); (3) human error—poor seamanship, fire, collision; and (4) abandonment—for the reasons stated above, plus vessel condition and economic reasons (Fish, 1989). The sanctuary's minimum depth of 20 m (65 ft.) means that no vessel was lost in the sanctuary as a result of grounding or stranding. Vessels reported lost to either of these two causes are not considered to lie within the sanctuary.

The ambiguity of location given for most maritime disasters, and particularly for sanctuary shipwrecks, precludes accurate statements about the quantity of sanctuary shipwrecks. In general, a presumed nearest landfall is assigned when the shipwreck does not occur at a recognized landmark, i.e., on shore, on rocks, near a buoy marker or lightship. References such as off-Provincetown, off-Cape Ann, off-Massachusetts Coast, or off-New England, or "left port never to be heard of again," are frequently the only description of shipwreck locations that may be in the sanctuary. Additionally, for most colonial writers, places of loss were far less important to record than the persons and property that were lost.

Government data collection has been primarily aimed at identifying and locating man-made and natural objects that are hazards to navigation. These locations within the sanctuary are approximated and not verified, because they do not pose a hazard to navigation. Further, reliable location information is often in private hands (sport divers, researchers, fishermen), for whom personal interests generally preclude making the information public.

Most available published sources of shipwreck information concentrate on "romance of the sea" and/or major calamities and disasters; their audience is typically popular and not scholarly. Many of these works are laundry lists of shipwrecks, often published without sources. Further, many works reflect a certain selective presentation of facts, such as including only larger vessels or those carrying "valuable" cargo. Archival research has revealed a dramatic increase in the reporting of vessel losses in the sanctuary beginning around 1850 to the present. Over 95% of the vessel losses uncovered by archival research date from that period While maritime traffic dramatically increased during the later half of the nineteenth century, incomplete reporting of earlier shipwrecks has likely skewed results to favor the last 150 years of sanctuary history.

Vessels

Since the sanctuary began investigating its maritime heritage resources in 2000, archaeologists have located forty shipwreck sites. Thirty-five sites are historic shipwrecks and five are modern shipwrecks. Historical records indicate that several hundred more vessels sank within the sanctuary or its vicinity. Past research expeditions have used remote sensing technology, such as side scan sonar and ROVs, to locate and identify shipwreck sites. Archaeologists have also used SCUBA to investigate shallower shipwreck sites, such as the 5-masted coal schooner *Paul Palmer* that caught fire and sank off Provincetown in 1913.

In 2002, a team of NOAA scientists confirmed that a sanctuary shipwreck was the side paddle wheel steamship *Portland*. The wooden hulled steamship, built in 1889 by the New England Shipbuilding Company of Bath, Maine, for the Portland Steam Packet Company, ran between Portland, Maine, and Boston, Massachusetts, from 1890 to 1898 (Figure 81). At 85.6 m (281 ft.) long, the steamship was one of the largest and best-appointed vessels afloat in New England during the 1890s. The steamship sank with all hands on November 27, 1898 during a fierce storm, thereafter known as the "Portland Gale." Historians believe that nearly 200 people lost their lives.

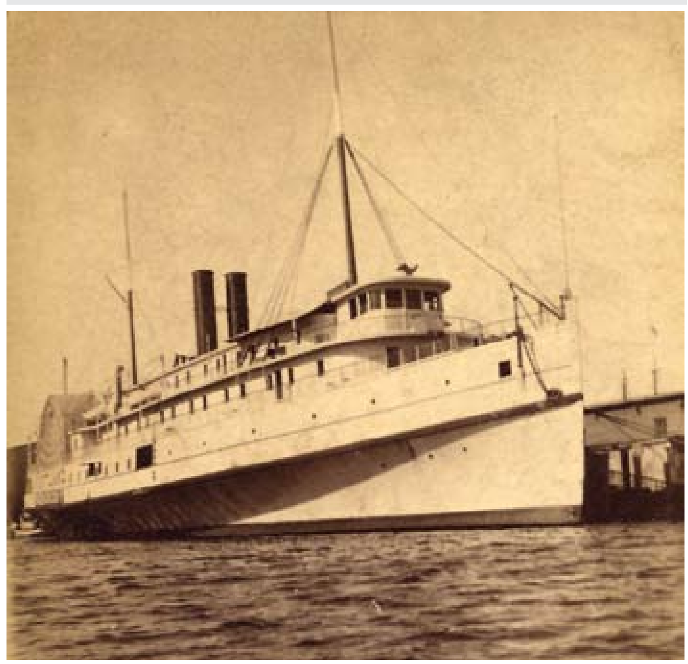
The *Portland*'s remains include its upright and intact wooden hull, which survives from the main deck level down to the keel (Figure 82). Machinery assemblages such as the boilers, paddle flanges and shaft, steam engine, walking beam and wooden A-frame are articulated and in their original positions. Smaller cultural artifacts such as plates and cups lie scattered inside and outside the hull (Figure 83). The *Portland's* hull is draped with fishing nets and provides substrate for sponges and anemones. In 2005, the *Portland* was listed on the National Register of Historic Places.

Another visually spectacular shipwreck site is the wrecks of the 83.5 m (274 ft.) long 4-masted schooner *Frank A. Palmer* (Figure 84) and 81.4 m (267 ft.) long 5-masted schooner *Louise B. Crary* (Figure 85), which sit upright on the seafloor connected at their bows after colliding (Figure 86). Both vessels were built at the turn of the century in Bath, Maine, for the coal trade between the Chesapeake Bay and New England. While enroute to Boston, Massachusetts, from Hampton Roads, Virginia, with coal cargos, the *Frank A. Palmer* and *Louise B. Crary* collided on December 17, 1902. Eleven of the twenty-one sailors onboard the schooners perished during the accident or while awaiting rescue in a lifeboat. Both schooners are intact from keel to main deck and have portions of their masts still standing. Surveys have encountered cultural artifacts within the remains of the Frank A. Palmer captain's cabin (Figure 87). In 2006, the *Frank A. Palmer* and *Louise B. Crary* were listed on the National Register of Historic Places.

In addition to the *Frank A. Palmer* and *Louise B. Crary*, archaeologists located and investigated several other collier sites with varying degrees of preservation. Similar in size to the *Frank A. Palmer*, the shipwreck of the 5-masted schooner *Paul Palmer* exemplifies the differences in site preservation as a result of the wrecking event and the environment in which the shipwreck lies (Figure 88). While sailing south from Maine to the Chesapeake in ballast, the schooner's forecastle caught fire off Highland Light in 1913. Flames quickly engulfed the schooner, thwarting efforts to extin-

Figure 81. Historic photograph of the steamship *Portland* from 1891. The *Portland* sank with all hands during the Portland Gale in November 1898.

Courtesy: LARC.



guish the flames with the schooner's pumps. The vessel's crew escaped the fire by boarding a tug that approached the schooner to help fight the blaze. Burned to the waterline, the schooner sank on top of Stellwagen Bank. In 2007, the *Paul Palmer* was listed on the National Register of Historic Places.

Today, the *Paul Palmer's* remains consist of its wooden hull, intact to the turn of the bilge, keelsons, a pile of anchor chain and the schooner's windlass (Figure 89). Ship fittings, such as bitts, a davit, anchors and rigging components, lie throughout the site. While the fire likely destroyed much of the vessel's hull, the dynamic environment on top of Stellwagen Bank caused the schooner's structure to degrade faster than the more static environment in which the *Frank A. Palmer* rests. The schooner's degradation has also been hastened by impacts from commercial fishing. Evidence of these impacts was graphically demonstrated by a trawl net wrapped around the shipwreck's windlass. NOAA divers removed the net in 2006. The sanctuary has documented recent commercial fishing impacts in the form of broken timbers and displaced anchors.

Other collier shipwrecks represent much smaller vessels more typical of the sailing vessels that plied the East Coast during the nineteenth and early twentieth centuries. The archaeological preservation of these smaller collier shipwrecks varies widely. One 32 m (100 ft.) long vessel is near-

Figure 82. The steamship *Portland*'s location in the sanctuary was confirmed by NOAA scientists in 2002.

Depicted here is a side scan sonar image of the *Portland* showing it sitting upright on its keel with boiler uptakes and walking beam engine projecting above the main deck. Courtesy: Klein Sonar Associates, Inc.

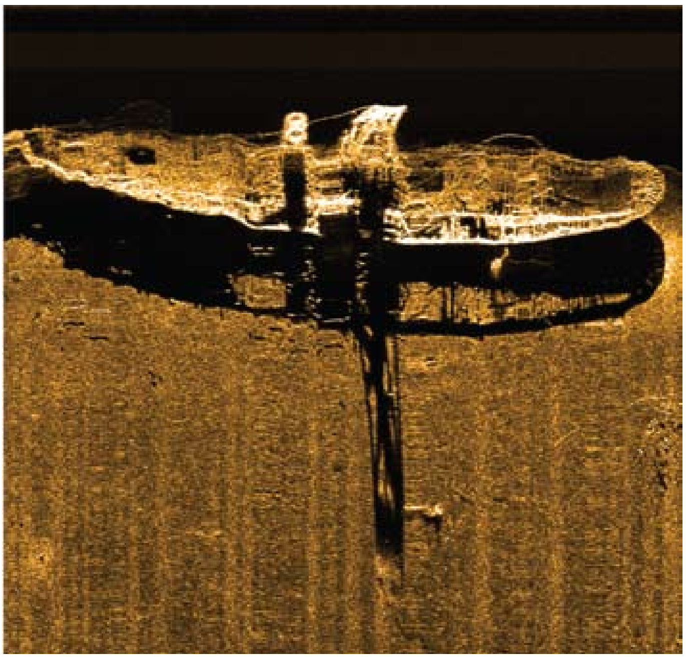


Figure 83. Fragile teacups and dishware in the galley survived the *Portland*'s plummet to seafloor in 1898.

The shipwreck is listed on the National Register of Historical Places and is the best preserved of any New England "night boat" found to date. Source: NOAA/SBNMS, NURC-UConn, and the Science Channel.

Figure 84. Historical photograph of the 4-masted coal schooner *Frank A Palmer*.

The Maine built *Frank A. Palmer* was the longest 4-masted schooner ever built. Courtesy: Maine Maritime Museum.

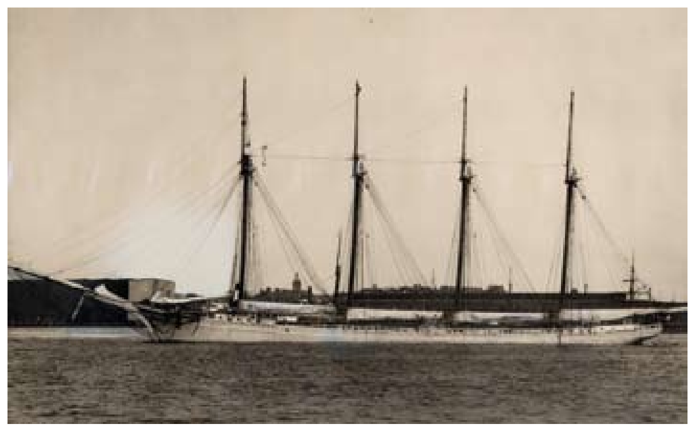


Figure 85. Historical photograph of the 5-masted coal schooner *Louise B Crary*.

In 1902, the *Louise B. Crary*'s mate miscalculated his tack causing his vessel to strike the *Frank A. Palmer*'s bow. Courtesy: Maine Maritime Museum.

Figure 86. NOAA scientists confirmed the location of the schooners *Frank A. Palmer* and *Louise B. Crary* in the Stellwagen Bank sanctuary in 2002.

Depicted is a side-scan sonar image of the two intact vessels, connected at their bows, in the same orientation in which they sank. Source: NOAA/SBNMS and NURC-UConn.

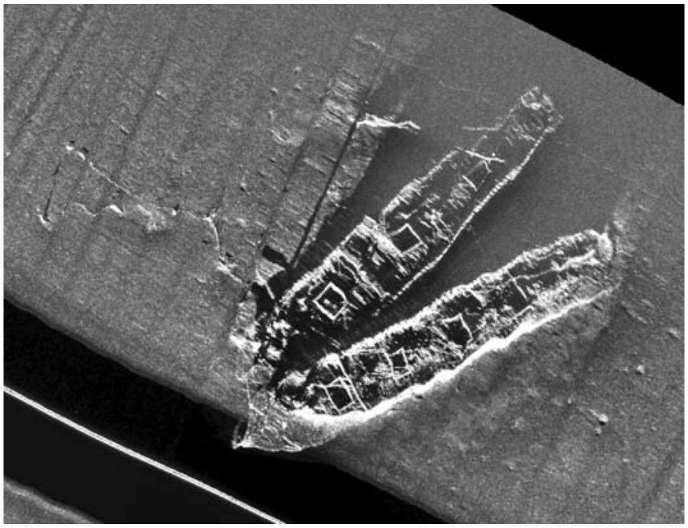


Figure 87. The *Frank A. Palmer*'s stern cabin contains the remains of the captain's sink and toilet.

The *Frank A. Palmer* and *Louise B. Crary* are listed on the National Register of Historic Places and are the best preserved examples of New England coal schooners in the archaeological record located thus far. Source: NOAA/SBNMS and NURC-UConn.

Figure 88. Historical postcard of the 5-masted coal schooner *Paul Palmer* offloading coal in New Hampshire.

The *Paul Palmer* caught fire and sank off Cape Cod in 1913 while en-route to Virginia. Courtesy: LARC.

Figure 89. The *Paul Palmer* rests on top of Stellwagen Bank with its wooden frames and hull planking protruding up from the sand.

Substantial information can be learned about the role coal schooners played in the growth of New England by examining *Paul Palmer*'s archaeological remains. Source: NOAA/SBNMS.

ly intact up to its deck level. Site features include copper-alloy sheathed hull planking, wooden hanging knees, and a variety of ship fittings and artifacts (Figure 90). In contrast, the hull remains of another collier are only represented by eroded frames protruding centimeters from beneath a pile of coal 35 m (114.8 ft.) long. Very few ship fittings and no smaller artifacts were found on this site (Figure 91). Both vessels were likely two-masted schooners that carried a variety of cargos, but happened to be loaded with coal when they sank. While both vessels lie in water of similar depth, the more intact vessel lies in an area that is less frequently fished by bottom trawl gear.

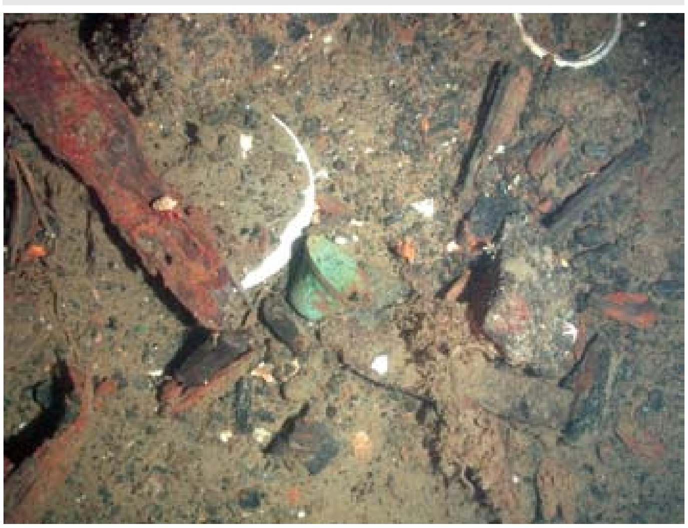
The granite industry is another coastal trade represented by a sanctuary shipwreck. Almost all that remains of this sailing vessel is its cargo of granite slabs. These slabs vary in size, ranging from blocks measuring 2 m long by 0.5 m wide, to others stretching over 3 m long. Approximately 40 slabs were contained within the vessel's hold (Figure 92). The most common slab shape measures 3 m long by 2 m wide with a manhole bored into its center. Blocks of this variety were used to cover sewer basins that captured the drainage from street gutters. The uniform shape of the manholes suggests that a large diameter drill was used to bore the hole, a technology first used in the second half of the 19th century.

After colliers, the second most common variety of shipwreck located thus far in the sanctuary is 20th century commercial fishing vessels. Of these, wooden-hulled eastern rig draggers represent the majority. 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 the wrecking event and/or damage incurred from the impact of nets and trawl doors of successive generations of fishing vessels.

Sanctuary research has identified one of the eastern rig dragger shipwrecks as the *Joffre* (Figure 93). Launched from Arthur D. Story's Essex, MA shipyard in 1918, the auxiliary fishing schooner was built to prosecute the mackerel seine fishery. Within a year, *Joffre* transitioned to groundfishing for halibut, cod, and haddock. *Joffre* operated as a dory trawler until 1939, when its new captain sought to enter the rapidly growing Acadian redfish fishery. Modified with a trawl winch and gallows frames, the eastern rig dragger landed large catches of redfish to supply the growing demands for fish protein brought about by the Second World War. *Joffre* was returning to Gloucester, MA from a groundfishing trip when it caught fire and sank in 1947. Archaeological investigation has revealed the dragger's scorched hull, fishing gear, and large diesel engine partially buried in the seafloor off Cape Ann. In 2009, the *Joffre* was listed on the National Register of Historic Places.

Figure 90. Artifacts, such as the brass hand bell and ceramic dishes seen here, are well preserved on this wooden hulled shipwreck with a coal cargo.

The sanctuary is studying this vessel to discover its identity and learn about life onboard a merchant sailing vessel in the New England coasting trade. Source: NOAA/SBNMS and NURC-UConn.



Aircraft

At least one aircraft crash site is believed to be located within the sanctuary. Divers reported finding a P-38 Lightning on the western edge of Stellwagen Bank. Fishermen also report recovering military aircraft parts from a site north of Stellwagen Bank (B. Lee, pers. comm., 2004). This material may originate from a six-engine B-47 jet bomber that crashed off Gloucester in February 1957.

Pressures

Sanctuary shipwrecks below the zone of storm wave disturbance (~85 m) generally reside in a depositional environ-

Figure 91. The coal cargo depicted in this photograph covers the remains of a shipwreck.

Bottom trawling has destroyed the vessel's structure above the sediment and removed all the durable artifacts, such as anchors and iron fittings. Source: NOAA/SBNMS and NURC-UConn.

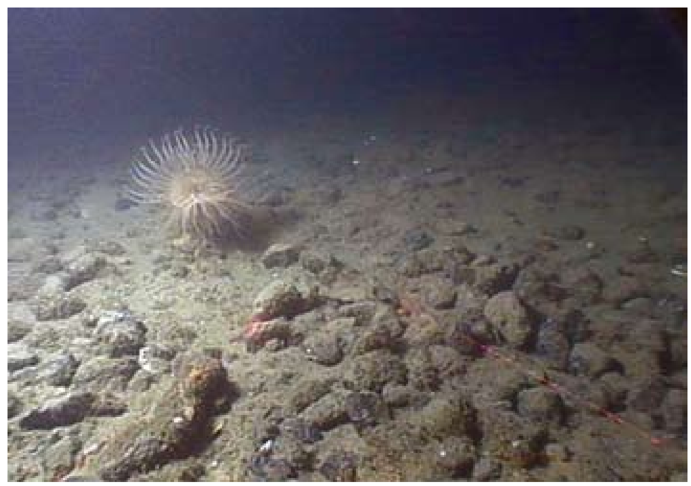
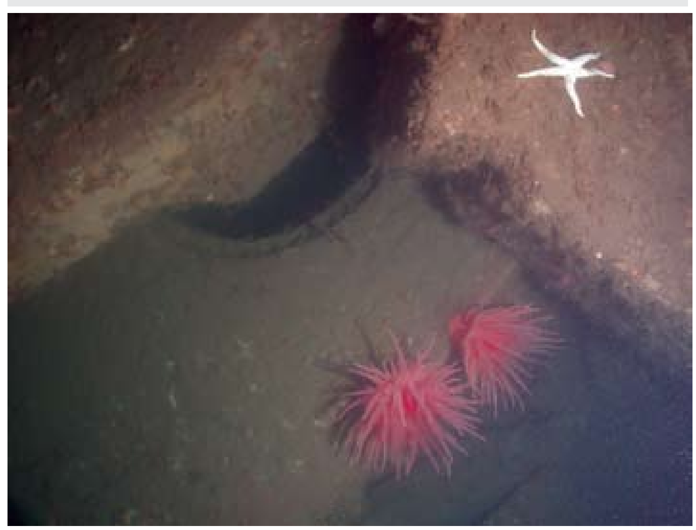


Figure 92. This shipwreck's granite block cargo was destined for use in the construction of sidewalks and sewer systems.

Granite transportation supported a large fleet of sailing vessels during the 19th and early 20th centuries. Source: NOAA/SBNMS and NURC-UConn.



ment of little natural disturbance. Consequently, the chief impacts to archaeological sites in this realm result from fishing activities. The sanctuary's maritime heritage resources have been adversely impacted by fishing activities and are highly susceptible to future damage due largely to two factors: structural materials and fishing impacts. Nearly all maritime heritage resources located to date are wooden-hulled shipwrecks and much of the sanctuary's seafloor is regularly accessed by a variety of fishing gears. While the sanctuary's cold deep water helps preserve the shipwreck's organic structure, wooden hulls slowly degrade over time becoming very fragile. The ongoing characterization of the sanctuary's maritime heritage resources continues to reveal the results of past damaging interactions between historic shipwrecks and fishing gear. Other potential anthropogenic pressures on maritime heritage resources include SCUBA diving and remote sensing.

Fishing

Interactions between fishing gear (mobile and fixed gear as well as hook and line) and many of the sanctuary's maritime heritage resources have resulted in the degradation of the shipwrecks' archaeological integrity, reduction of their historical/archaeological significance, and diminishment of their aesthetic qualities. Currently, reference material mainly focuses on the impacts of fishing on marine habitats and the environment (Dorsey and Pederson, 1998; Smith *et al.,* 2003; Tudela, 2004). Marine archaeological literature has not yet adequately addressed fishing impacts to maritime heritage resources (Foley, 2006; Garcia *et al.,* 2006; Brennan, 2009; Sakellariou *et al.,* 2007; Ballard, 2008).

Many recreational and commercial fishermen intentionally target shipwrecks due to the higher density of fish typically found around structures that rise above the surrounding seafloor. By targeting these non-renewable resources, irreparable damage is done. A single impact from fishing gear can cause extensive damage, compromising the information contained within the archaeological site.

Depending upon the fishing technique and character of the shipwreck, fishing gear may interact with a site momentarily and then continue along without getting hung up or the gear may become tangled on the shipwreck, and then ultimately abandoned. The lost gear provides direct evidence of the interaction between fishing and maritime heritage resources. Nineteen historic shipwrecks located within the sanctuary exhibit entangled fishing gear. The discarded gear presents a serious safety and operations hazard to SCUBA divers and remote sensing equipment, such as side scan sonars, ROVs and Autonomous Underwater Vehicles (AUVs). The nets, lines and cables from lost gear close off completely or limit the site's accessibility to archaeologists, recreational SCUBA divers and the interested public. Derelict fishing gear also presents an entanglement hazard to marine life.

Mobile Gear Impacts

Mobile fishing gear (otter trawls, beam trawls, shellfish dredges) has had the greatest impact on maritime heritage resources. Mobile fishing gear components have been found on fifteen historic shipwrecks. These towed nets or dredges, often weighing hundreds of pounds, roll or are dragged across the seafloor. When the net encounters a wooden shipwreck rising above the seafloor, it interacts with the shipwreck in one of three ways:

(1) The gear breaks apart the shipwreck's structure;

(2) The gear rolls over the shipwreck, damaging the fragile structure; or

(3) The gear catches on the shipwreck, stopping the vessel. If the gear can be pulled free it usually results in partial destruction of the shipwreck. Oftentimes, pieces of the

Figure 93. The eastern rig dragger *Joffre* exemplifies the many changes in fishing techniques and technology that occurred during the 20th century.

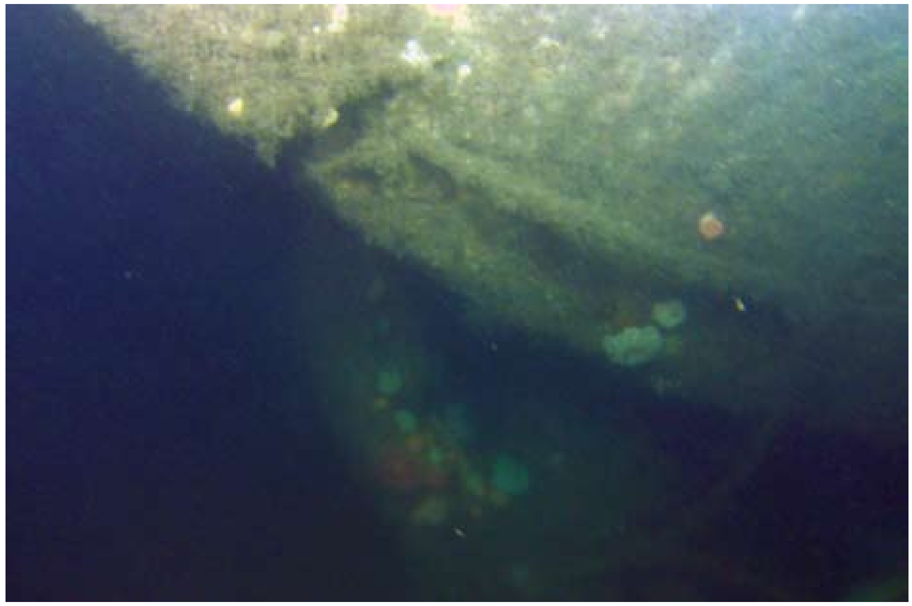
This style of fishing trawler, once common to the waters of Massachusetts Bay, is a transitional design bridging the gap between earlier wooden schooners and modern-day steel trawlers. Source: Atlantic Fisherman, November 1943. Courtesy: Maine Maritime Museum.

net are left behind. Less frequently, the gear is so entangled with the shipwreck's structure that entire nets and even trawl doors are lost.

Considerable damage to the shipwreck's structure results in all three situations. In addition, trawl nets and dredges often remove artifacts from the site. Fishermen frequently snag and recover anchors, windlasses, pumps and other assorted ship fittings. The removal of this material is particularly harmful to the site's archaeological integrity. In many cases, fishermen using mobile gear seek to avoid shipwrecks so that they do not "hang" their gear. Alternatively, some choose to tow their gear as close as possible to the structure to catch fish inhabiting the shipwreck. This latter behavior has the potential to damage or destroy artifacts surrounding the shipwreck, damage the shipwreck through contact with the trawl doors or dredge, and potentially damage or entangle the main shipwreck structure.

Figure 94. Wire rope associated with a trawl net cuts into the steamship *Portland*'s bow.

The negative impacts of commercial fishing activities are well documented on the wreck of the Portland. Source: NOAA/SBNMS and NURC-UConn.



Two examples of negative mobile fishing gear impacts are found on the steamship *Portland* and the schooner *Paul Palmer*. The Portland has a complete otter trawl net, including rollers and a trawl door, wrapped around its bow and starboard side. The wire tow rope has cut deeply into the steamship's stempost, while one of the trawl doors lies on the main deck (Figure 94). The net is tangled with and extends nearly the length of the starboard side forward of the boiler uptakes. More wire rope is draped across the top of the boiler uptakes. The trawl net has damaged portions of the wreck and greatly hampers the sanctuary's ability to archaeologically investigate the shipwreck. The net and its wire tow rope present a severe entanglement risk for the ROV vehicle used to study the site.

The schooner *Paul Palmer* also had a trawl net wrapped around its bow. The net and rollers were entangled with the site's windlass and chain pile, and likely altered the orientation of the windlass when it was snagged (Figure 95). The net posed an entanglement hazard for SCUBA divers and marine life. NOAA divers removed the net in September 2006.

Fixed Gear Impacts

Fixed fishing gear (gillnets and lobster trawls) has also negatively impacted sanctuary maritime heritage resources. Fixed fishing gear components have been found on ten historic shipwrecks. The initial placement of the gear may damage a resource if the gillnet anchor or lobster pot falls directly on a maritime heritage resource or its associated artifacts. However, the greatest damage results when fishermen attempt to recover their gear. If the gear has not already become entangled in the shipwreck's structure, pulling the gear to the surface can ensnare it. Once gear is firmly entangled, a fisherman will likely use the full power of his or her net or pot hauler and boat to free the gear. The high tension exerted on the lines easily snaps fragile wooden structure.

Entangled fixed gear continues to degrade the shipwreck by blocking access to the resource. SCUBA divers and ROV operators cannot safely approach ensnared gillnets and researchers are unable to document the resource and share the information with the public. Entangled gillnets negatively impact the *Frank A. Palmer* and *Louise B. Crary*. In particular, a gillnet enshrouds the *Louise B. Crary's* bow covering the forecastle and forward deck house preventing archaeological examination (Figure 96). A gillnet also stretches between the two schooners preventing the archaeological examination of the collision point.

Hook and Line Impacts

Hook and line gear has been found on five historic shipwrecks. Hook and line bottom fishermen often target wrecks to catch the fish inhabiting the shipwrecks' structure. Fishing boats often anchor to maintain position, risking anchor damage to the shipwreck and any surrounding debris fields. Heavy lead jigs, weighing up to two pounds are repeatedly raised and lowered to attract fish and heavy lead sinkers of 24 oz or more may be used with baited hooks (Figure 97). A single party boat can carry fifty or more fishermen simultaneously using such gear. When a jig or sinker comes into contact with a maritime heritage resource, it has the potential to break fragile artifacts made from glass or ceramics.

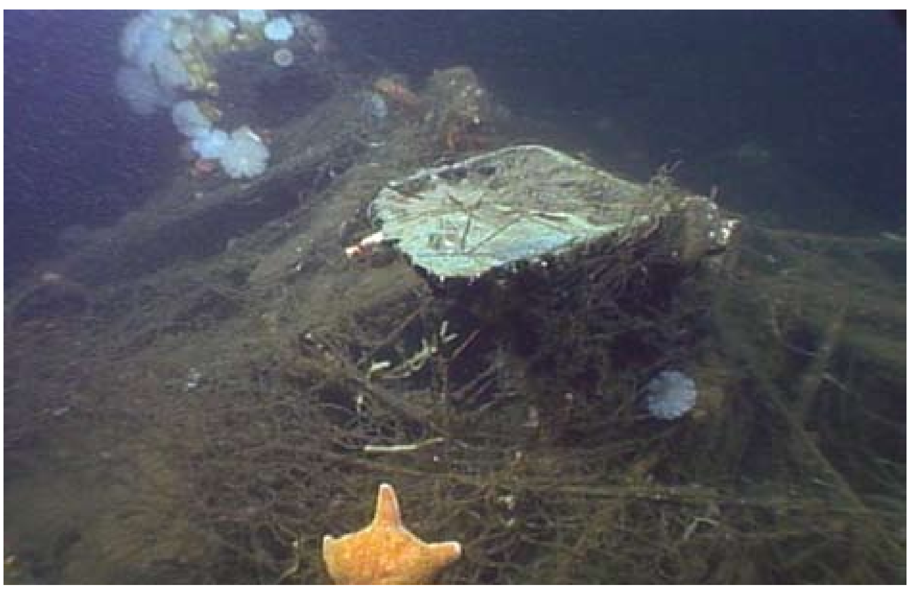
Frequently, fishermen snag their tackle on the shipwreck's structure. Attempts to free the line may damage the resource. If the jig or baited hook is firmly stuck, the fisherman will break or cut the line, which may then fall across the ship-

Figure 95. This large trawl net was once wrapped around the schooner *Paul Palmer*'s windlass, where it was a hazard to SCUBA divers and marine life.

In 2006, NOAA divers removed the net to facilitate the documentation of the schooner's windlass. Courtesy: Tane Casserley, NOAA Maritime Heritage Program.

Figure 96. Gillnets cover the schooner *Louise B. Crary*'s bow.

The fishing gear entangled in this shipwreck prevents archaeologists from documenting most of the wreck's bow area and main deck space. Source: NOAA/SBNMS, NURC-UConn and the Science Channel.



wreck. Lost fishing line limits access to a shipwreck in much the same way as a trawl net or a gillnet does. Additionally, single strands of fishing line are difficult to see underwater, making entanglement of an ROV or a SCUBA diver a possibility.

An example of the impact of lost fishing line on a shipwreck is found on the *Frank A. Palmer*. A 2004 archaeological investigation of the site encountered no lost fishing lines crossing the aft deckhouse space. Returning to the same area in 2005, researchers found several fishing lines crossing the area (Figure 98). The lines prevented the researchers from maneuvering their ROV into the area to investigate the artifacts contained within the cabin. Additionally, an unseen fishing line fouled a ROV thruster, preventing its operation, jeopardizing its recovery, and forced the dive's termination.

Diving

While SCUBA diving will not necessarily damage a historic shipwreck, certain diving practices and activities have the potential to impact its archaeological integrity (Edney, 2006). In comparison to the rocky shorelines and near shore waters of Massachusetts, the sanctuary has been visited by considerably fewer SCUBA divers. However, many divers have communicated their interest in visiting the sanctuary's shipwrecks. When SCUBA diving is conducted in the sanctuary, the dive location is usually a shipwreck.

The techniques and practices, both above and underwater, associated with SCUBA diving on a shipwreck may negatively impact the site if not done with care and resource preservation in mind. While attempting to access a shipwreck, a dive boat may drag its anchor across the seafloor and through the shipwreck's debris field. Similarly, the vessel's anchor may also snag on the shipwreck's hull, fragmenting it. Anchors or down weights dropped from a boat can plummet directly onto a fragile wooden hull and/or the associated artifacts, causing damage. Repetitive anchoring on, or securing a down line to, a maritime heritage resource can increase its rate of structural deterioration and reduce the shipwreck's archeological significance.

Once underwater, divers' actions can be low-impact, such as observing or photographing the shipwreck and associated marine life. However, high-impact activities such as souvenir collecting remove artifacts and reduce the shipwreck's archaeological integrity. Divers who remove tightly secured artifacts often damage or destroy larger areas of the shipwreck. While prohibited by sanctuary regulations, artifact collecting still occurs in National Marine Sanctuaries (*Craft, Ferguson, Jernigan, King, Parrott, Stocks, and Wilson v. NOAA*, 6 O.R.W. 150 United States Department of Commerce, 1990; *Craft, Ferguson, Jernigan, King, Parrott,* *Stocks, and Wilson v. NPS, NOAA, and National Marine Fisheries*, 34 F.d 918. United States Court of Appeals, 1994). Artifact collecting also deprives future SCUBA divers of the excitement of exploring an "untouched" shipwreck.

Other high-impact activities, which may be more pervasive on shipwrecks where collecting is illegal, involves divers "hand fanning" sediment off artifacts or moving artifacts around a shipwreck to create "artifact displays" that no longer represent the past activities of a shipwreck's passengers and crew. Artifacts lose provenance once moved or removed from a site and are no longer able to provide the same amount of information about past events. Ultimately, artifacts that are repeatedly disturbed deteriorate more quickly and artifacts recovered from the marine environment face rapid deterioration if not properly conserved and thus lose their ability to inform the present about the past.

Figure 97. Jigs are evidence of hook and line fishing activity on the schooner *Paul Palmer*.

Lost fishing gear poses a hazard to divers and degrades the archaeological integrity of the shipwreck. Source: NOAA/SBNMS.

Remote Sensing

Underwater remote sensing technology allows individuals to explore the marine environment without personally entering the water. Technologies vary from side scan sonar to remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs). Most remote sensing technologies are not designed to physically interact with maritime heritage resources and can do damage if unintentional contact is made.

Towed sensors, such as side scan sonars, drop cameras and magnetometers, can cause damage by striking or becoming entangled in a maritime heritage resource. Damage to the resource is then exacerbated when a remote sensing operator attempts to free an entangled piece of expensive marine technology. Remotely operated vehicles are designed to operate in proximity to maritime heritage resources and are capable of interacting with the resources using manipulator arms. Remotely operated vehicle operators can remove or disturb archaeological resources in a manner similar to divers.

Figure 98. Braided and monofilament fishing line is caught around the *Frank A. Palmer*'s steering wheel.

Fishing line stretched across the schooner's stern prevents the complete documentation of this area, which would provide important information about the vessel's crew. Source: NOAA/SBNMS and NURC-UConn.

Entanglement risks for ROVs are especially great in the Stellwagen Bank sanctuary due to derelict fishing gear entangled on shipwrecks. Freeing an ensnared ROV will likely damage a maritime heritage resource. Submersibles, manned underwater vehicles, pose the same hazards to maritime heritage resources as ROVs; they are also at risk of entanglement endangering the operators within the vehicle.

Current Protection

The sanctuary's mandate to protect and manage maritime heritage resources arises from various federal regulations and laws. The sanctuary boundary encompasses an 842-square mile area of seafloor outside of the territorial sea of Massachusetts Bay and does not overlap with the jurisdiction of the Commonwealth of Massachusetts.

The protection of maritime heritage resources is provided through the following laws and regulations:

- Antiquities Act of 1906
- Historic Sites Act of 1935
- Archaeological and Historic Preservation Act of 1960
- National Historic Preservation Act (NHPA) of 1966 (16 U.S.C. § 470 et seq.)
- Department of Transportation Act of 1966 (section 4(f))
- Presidential Order 11593 of 1971
- Archaeological Resources Protection Act of 1979
- National Environmental Policy Act (NEPA) (Section 101(b)(4))
- National Marine Sanctuaries Act (NMSA) of 1972 (16 U.S.C. § 1431 et seq.)
- Stellwagen Bank National Marine Sanctuary Regulations of 1992 (15 C.F.R Paer 922 Subpart N)

The NMSA mandates that the ONMS manage maritime heritage resources in a fashion that protects the resources while facilitating compatible public and private use of the resources. ONMS regulations enacted to carry out this mandate incorporate all laws and regulations of the Federal Archaeological Program, specifically the National Historic Preservation Act of 1966 (NHPA). Section 110 of the NHPA requires the ONMS to undertake a heritage resource inventory, develop a management program for each sanctuary site, and nominate potentially eligible maritime heritage resources to the National Register of Historic Places. Section 106 of the NHPA directs the ONMS to take into consideration the effects of its undertakings on historic properties and to mitigate the negative effects of its undertakings. Furthermore, the ONMS is required to consult with Massachusetts' State Historic Preservation Officer and if necessary, the Advisory Council on Historic Preservation, on undertakings that have the potential to effect historic properties.

Current sanctuary regulations prohibit moving, removing or injuring, or attempting to move, remove or injure a sanctuary historical resource except as an incidental result of traditional fishing operations. These regulations also prohibit drilling into, dredging or otherwise altering the seabed of the sanctuary; or constructing, placing or abandoning any structure, material or other matter on the seabed of the sanctuary, except as an incidental result of an anchoring vessel, traditional fishing operations; or the installation of navigational aids. Lastly, sanctuary regulations prohibit possessing within the sanctuary (regardless of where taken, moved or removed from), except as necessary for valid law enforcement purposes, any historic resource.