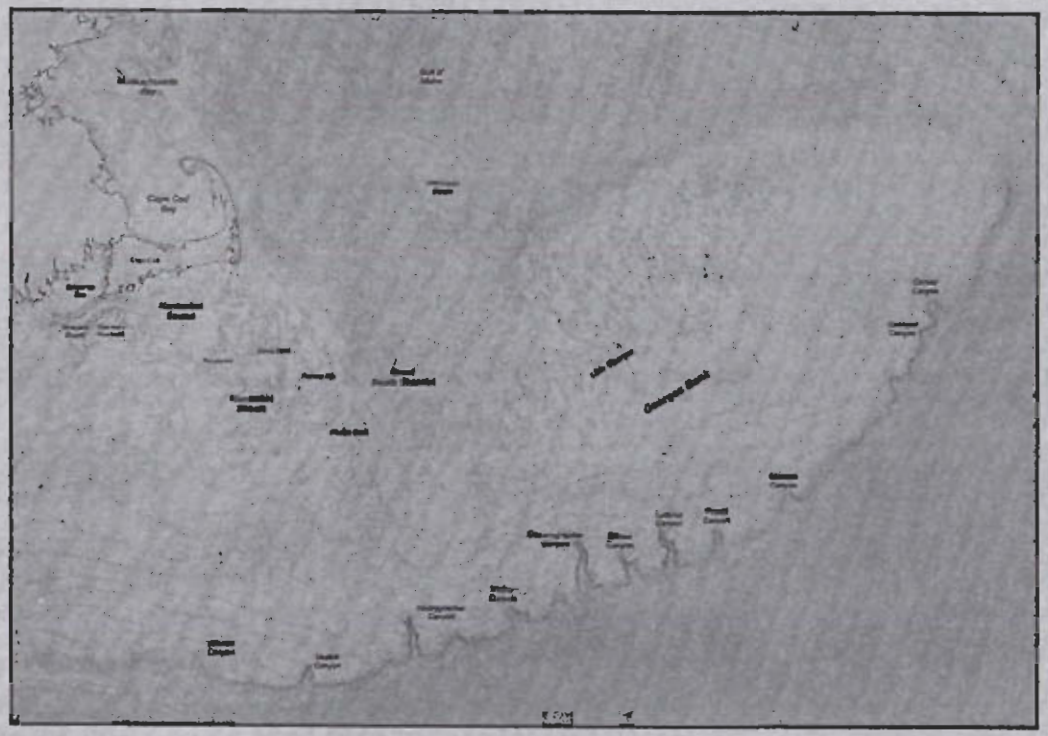

Toward an Ocean Vision for the Nantucket Shelf Region

Part I.
Review of the
Environmental Characteristics of the
Nantucket Shelf Region

Part II.
Management Options for
Resource Protection and Sustainable Uses

Provincetown Center for Coastal Studies
Provincetown, Massachusetts

January 2005

Toward an Ocean Vision for the Nantucket Shelf Region

Provincetown Center for Coastal Studies

Coastal Solutions Initiative

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Toward an Ocean Vision for the Nantucket Shelf Region

EXECUTIVE SUMMARY

…. *"User conflicts can and do arise when incompatible activities take place in the same area. A comprehensive offshore management regime is needed for the balanced coordination of all offshore uses."*

– U.S. Commission on Ocean Policy (June, 2004)

"U.S. ocean and coastal resources should be managed to reflect the relationships among all ecosystem components, including human and nonhuman species and the environments in which they live. Applying this principle will require defining relevant geographic management areas based on ecosystem, rather than political, boundaries."

– U.S. Commission on Ocean Policy (June, 2004)

"New ocean management structures are needed to promote consistent, coordinated ocean management policies and to ensure that the geographic divisions among federal and state management authorities support rather than prevent sound ecosystem management across a variety of jurisdictions"

– The Massachusetts Task Force Ocean Management(March, 2004)

Introduction

The ocean off the coast of Massachusetts has been the focal point for a growing number of activities and proposals in recent years. Proposals to construct the nation's first offshore wind power project have attracted recent attention; however other Massachusetts offshore waters have also been examined for potential energy facilities, offshore aquaculture sites, cable crossings, sand and gravel mining, oil and gas drilling, transportation routes and a variety of commercial and recreational activities. Ongoing issues include the implementation of fisheries management plans and marine mammal protection strategies.

The number of competing and often conflicting uses of the ocean has become problematic. Despite widespread interest in the development of renewable energy and aquaculture, proposals for these large-scale offshore facilities have revealed significant gaps in federal authority relating to the leasing of public underwater lands and permitting of offshore uses. Technological advances will undoubtedly continue to increase the number of prospective uses of ocean resources. In the face of these challenges, the ocean is an invaluable and vulnerable resource that merits a thoughtfully planned and balanced comprehensive management plan.

In 2003, the Provincetown Center for Coastal Studies issued a report entitled "*Review of State and Federal Marine Protection of the Ecological Resources of Nantucket Sound*," documenting previous initiatives to establish a clear and consistent science-based policy of resource protection that would be applicable across local, state and federal jurisdictions. Over a period of more than 30 years, specific actions toward this end have included the following:

- The state legislature in 1972 included Nantucket Sound in the Cape and Islands Ocean Sanctuary Act. This action was intended to provide full protection of the seabed and the Sound, which the state regarded as being within state jurisdiction, just as all of Cape Cod Bay is considered to be state waters. In the late 1980's, however, the U.S. Supreme Court ruled that the state had not proven its colonial claim to the entire Sound and that the waters beyond three miles from the mean low water mark were not under state jurisdiction, resulting in a "gap" in state jurisdiction in the center of Nantucket Sound.

- In 1980 the Massachusetts Attorney General and Secretary of Environmental Affairs nominated all of Nantucket Sound as a national marine sanctuary. In the nomination, various state agencies, including the Office of Coastal Zone Management and Division of Marine Fisheries, documented the region's ecological significance and its importance to such economic uses as fishing and tourism. The 1980 nomination envisioned a joint federal-state management of the sanctuary, similar in concept to the management plans now in place in the Florida Keys and California's Channel Islands.

- In response to three different oil and gas lease sales on Georges Bank proposed by the federal government in the late 1970's and early 1980's, Massachusetts repeatedly asserted its interests and role in decisions being made about the use of ocean resources off its coast.

- In 1983 a scientific panel commissioned by the National Oceanic and Atmospheric Administration included Nantucket Sound and other portions of the outer continental shelf south and east of Nantucket Sound in a short list of areas for future designation as a national marine sanctuary.

These actions were ahead of their time in recognizing the principle of *ecosystem-based management*. Ecosystem-based management of ocean and land resources is now widely accepted as the key to successful resource protection and management. Ecosystem-based management is the cornerstone of three recent major ocean public policy studies released in 2004: the Pew Oceans Commission, the U.S. Commission on Ocean Policy, and the Massachusetts Task Force on Ocean Management. In the words of the U.S. Ocean Commission:

> ***"U.S. ocean and coastal resources should be managed to reflect the relationships among all ecosystem components, including human and nonhuman species and the environments in which they live. Applying this principle will require defining relevant geographic management areas based on ecosystem, rather than political, boundaries."***

In this study, we have taken the principle of ecosystem-based management to the next logical step for Massachusetts by defining the "relevant geographic management areas" to include the state and federal waters south and east of Cape Cod, Martha's Vineyard, and Nantucket, out to the edge of the continental shelf. We refer to these areas collectively as the **Nantucket Shelf Region**. Our definition is based on the finding that these areas are inextricably linked by large-scale physical, biological, and ecological features and processes and share many important natural and socioeconomic features.

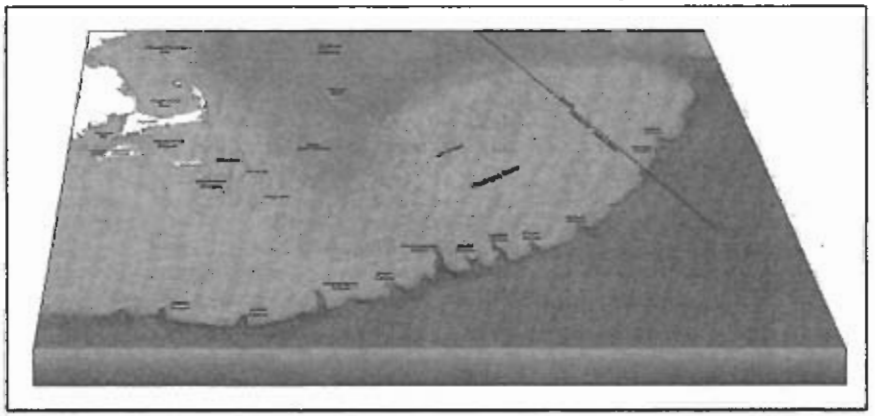
Part I of the report describes the ecological features that characterize this region and identifies issues and data gaps that warrant further scientific investigation to enhance our understanding of the region. Part II describes a number of management tools and techniques that may be useful as part of a comprehensive management scheme. In the following pages, the report describes the need for a common vision for the future of Nantucket Shelf and suggests some of the first steps in a planning process that could achieve and implement that vision.

Why Nantucket Shelf Region?

The Nantucket Shelf Region includes Vineyard Sound, Nantucket Sound, Nantucket Shoals, the continental shelf south of Martha's Vineyard, the Great South Channel, and Georges Bank. Scientific literature indicates that these areas form part of a large, shallow, coastal shelf eco-region that is characterized by a common geological origin, extremely dynamic sedimentary environment, tidally well-mixed water, high biological productivity, and unique ecological features. The Nantucket Shelf Region can be subdivided into three related ecosystems: *marine estuarine* (Nantucket Sound and Vineyard Sound), *offshore shoals* (Nantucket Shoals and Georges Bank), and *mid-shelf environment* (Great South Channel and the shelf area south of Martha's Vineyard).

The Nantucket Shelf Region serves as a dynamic transition zone between the Gulf of Maine Region to the north, which is influenced by the colder waters of the Labrador Current, and the warmer waters of the Middle Atlantic region and Gulf Stream to the south. This fundamental physical boundary between warm and cold water masses provides the setting for mixing and mingling of northern and southern species at the extreme ends of their geographic ranges, resulting in a zone of high biodiversity.

The Nantucket Shelf Region.



The Nantucket Shelf Region is one of the most heavily used ocean areas in the Northeast due to its bountiful natural resources, proximity to major population centers, and rich fishing grounds. It has a long and rich historic and cultural significance for the citizens of Massachusetts, and has high economic value for all of New England. At the same time, the area is increasingly subject to significant impacts from a myriad of human activities that threaten its quality, productivity and sustainability.

An incomplete patchwork of different federal and state ocean management jurisdictions currently exists in the Nantucket Shelf Region. The jurisdictional patchwork has a number of holes in it, in areas where preliminary (and sometimes old) scientific information suggests that the natural resources must be the same as in nearby protected areas. The absence of a single coordinating framework for ocean protection in the Nantucket Shelf Region has resulted in coastal and ocean protection that is inconsistent, with protection for some resources in one area and no protection for the same resources in an adjacent area.

This report finds that the Nantucket Shelf Region is of such ecological and socioeconomic importance that it should be the first offshore area in Massachusetts to benefit from a comprehensive ocean resources management plan. Comprehensive ocean management and protection is called for by the U.S. Commission on Ocean Policy, the Pew Oceans Commission and the Massachusetts Task Force on Ocean Management.

Development of an Ocean Resources Management Plan

The development of a successful and useful **Ocean Resources Management Plan** will largely depend upon 1) creating an effective planning process and 2) identifying key participants who can bring their knowledge, planning and management abilities to the table. A productive planning process will utilize the best available scientific information, identify and implement suitable tools, provide for the broadest public participation and input, build consensus among participants, and require commitment, cooperation and leadership from all interested parties.

One ocean management tool to consider is the designation of the Nantucket Sound Region as a "marine protected area", setting the stage for defined uses and activities. In the U.S., a Marine Protected Area (MPA), as defined by Executive Order 13158 (May 26, 2000) is "*any area of the marine environment that has been reserved by federal, state, territorial, tribal or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein.*" Many other countries use marine protected areas as an ocean and coastal management tool, and it is particularly suitable where there are many overlapping jurisdictions or where the region is large and encompasses many interests.

Although the term 'marine protected area' has only come into general use in the U.S. since Executive Order 13158, the concept includes a variety of areas created under such federal laws as the National Marine Sanctuaries Act, National Wildlife Refuge System Administrative Act, National Park Service Organic Act, and Magnuson-Stevens Fisheries Conservation and Management Act, among others. The public policy goals of each of the programs created by these laws vary, as do the management objectives within specific areas.

A national marine protected area designation could provide a comprehensive and flexible framework for the protection and management of the Nantucket Shelf Region, leading to better coordination and more effective management of its resources.

Another innovative ocean management tool highlighted in all three ocean studies is ocean zoning within the context of a marine protected area. Just as in land zoning, areas of the ocean could be identified for activities most compatible with the natural and socioeconomic values and carrying capacities of that area.

As one example, sustainable fisheries management within the Nantucket Shelf Region is highly desirable. Human uses of the area include recreational and commercial fishing and shellfishing, which are important to the local economy. The Nantucket Shelf Region also provides important nursery and migration habitat for commercially and recreationally important fish species. These socioeconomic and ecological values can both be protected through careful management for sustainable fisheries rather than prohibition. While sustainable fisheries management under the mandate of the Magnuson-Stevens Act is currently the guiding management tool for Georges Bank, only a congressional moratorium prevents exploration for oil and gas. This inconsistency of public policy represents a continuous threat to the fishery.

As a second example, areas used by endangered species for breeding and nesting should be protected as critical habitat areas. In particular, nearly the entire North American population of roseate terns passes through the Cape and Islands region and stops in Monomoy to nest and feed. While Monomoy is managed as a national wildlife refuge and more than 90% of the refuge is protected as a national wilderness area, far less protection applies to nearby state and federal waters. Terns also fly to Buzzards Bay, which is included in EPA's National Estuary Program. Existing critical habitat areas such as the Great South Channel (protected especially for the right whale) may also be linked ecologically. However, designation of the entire Nantucket Shelf Region as a critical habitat would probably not be warranted.

A guiding body is needed to conduct the planning process that would result in an Ocean Resources Management Plan for the Nantucket Shelf Region. This report builds on another key recommendation of the U.S. Commission on Ocean Policy by recommending the creation of a **Nantucket Shelf Regional Coordinating Committee**. The Nantucket Shelf Regional Coordinating Committee would be charged with developing a comprehensive plan for the protection, preservation, and sustainable use of the abundant resources of the Nantucket Shelf Marine Protected Area; and furthermore, to create a detailed implementation plan that emphasizes coordination of existing authorities and agencies and provides specific recommendations about additional legislative, regulatory or scientific steps that are required to fully achieve its mandate.

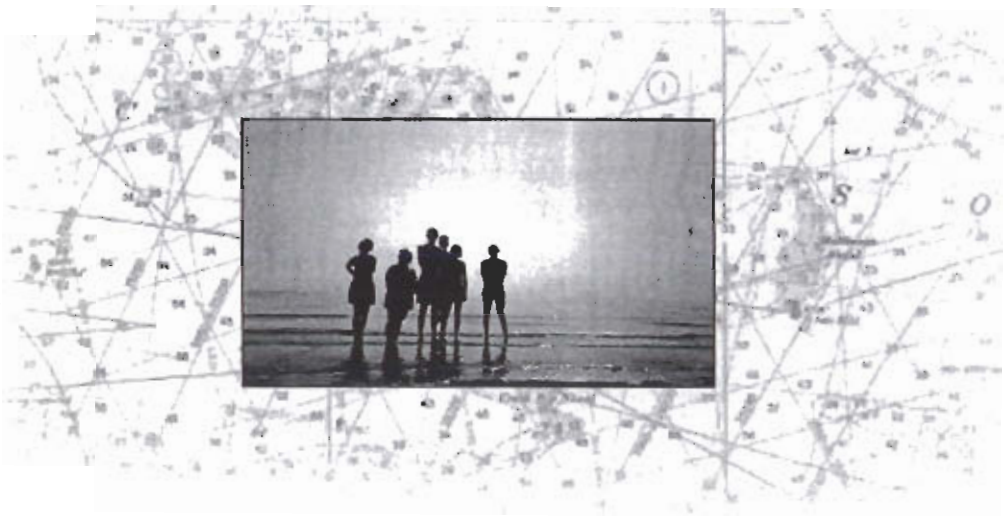
Various models for public process already exist, including those provided by the National Estuary Program, National Estuarine Research Reserves, and National Marine Sanctuaries. Generally, these models call for steering committees comprised of both technical and non-technical components (e.g., scientists, resource managers, coastal decision makers, citizens, businesses, resource users, etc.). The public process involves public meetings of the steering committee, stakeholders, the public, and representatives of relevant agencies.

The Nantucket Shelf Regional Coordinating Committee could be administered jointly by the federal National Oceanic and Atmospheric Administration (NOAA) and the state Executive Office of Environmental Affairs (EOEA). The active participation of the three Regional Planning Agencies (Cape Cod Commission, Martha's Vineyard Commission, Nantucket Planning and Economic Development Commission) would represent local and regional interests and highlight the land-ocean linkages. The Massachusetts Coastal Zone Management Program (CZM) within EOEA and linked closely to NOAA would bring valuable coastal and ocean planning, policy and technical expertise.

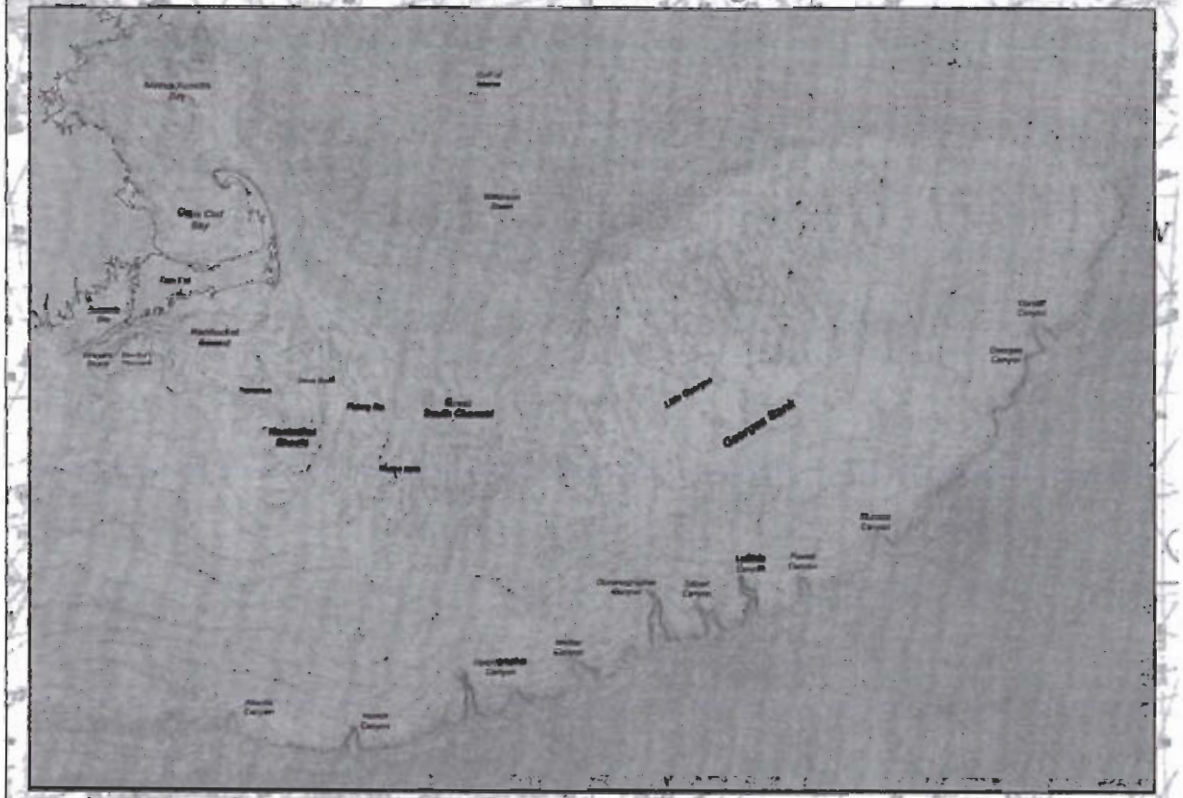
Lastly, management of the Nantucket Shelf Marine Protected Area will require both short-term and long-term process studies and long-term monitoring studies of geology, oceanography, biology, ecology, and climate. The creation of a **Nantucket Shelf Ocean Observatory** program is recommended to serve as a regional science and outreach source of information.

A great deal of work has already been completed that supports the ocean vision outlined in this report. The two national ocean commissions and state task force on ocean management have laid the groundwork for a more comprehensive ocean resources management system. The numerous existing but disjointed protected areas within the Nantucket Shelf Region signify the richness and diversity of the ecosystem. The regional planning agencies and state coastal zone management program are familiar with the socioeconomic and environmental interests of the region. However, the lack of a single unifying management and protection framework hampers coordinated management of the region.

The designation of the Nantucket Shelf Region as a marine protected area (MPA) would acknowledge its special environmental and economic values and provide a needed unifying framework; and the creation of a Nantucket Shelf Regional Coordinating Committee charged with the responsibility for developing a comprehensive ocean resources management plan, are the next two logical steps toward realizing a sustainable ecosystem-based vision for the Nantucket Shelf Region.



The Nantucket Shelf Region



Considerably more scientific and socioeconomic research is needed to develop a specific ocean zoning approach. However, an initial zoning concept for the Nantucket Shelf Region, based on available information, might include four zones as follows:

Ocean Zone 1: Including the state and federal waters south of Cape Cod and around the islands of Nantucket and Martha's Vineyard, including Nantucket and Vineyard Sounds and Buzzards Bay. This area is characterized by aesthetic and cultural values, active recreational boating and fishing, marine science and education, increasing coastal development, a coastal economy that is heavily dependent on the natural resources and scenery, and an often-disjointed network of existing coastal protected or managed areas, including the Cape Cod National Seashore, Monomoy National Wildlife Refuge and Wilderness Area, Waquoit Bay National Estuarine Research Reserve, Mashpee National Wildlife Refuge, and the Massachusetts Cape and Islands Ocean Sanctuary.

Ocean Zone 2: Nantucket Shoals and Georges Bank. These two areas share many ecological and socioeconomic features, such as: shallow sandy benthic habitat; high-energy environment; important fisheries habitat; distance from land; ecological transition area between the Great South Channel and the two shoals; moderate recreational use; high cultural value; and a hazard to shipping. Georges Bank is actively managed for fisheries and fishery closures are in effect in some areas. The threat of oil and gas drilling in Georges Bank remains.

Ocean Zone 3: Great South Channel. This area is important for both ecological reasons (feeding ground for endangered right whales and humpback whales, fish, and high productivity) and socioeconomic reasons (commercial shipping). The area contains a federal critical habitat for endangered Northern Atlantic Right Whales, and the fishery is seasonally closed.

Ocean Zone 4: Outer Continental Shelf. This area includes the large area of continental shelf south of Martha's Vineyard, Nantucket Shoals, and the Great South Channel out to the edge of the continental shelf. It is characterized by its open ocean character, highly dynamic water processes, moderate recreational value, fisheries habitat, and low to moderate risk for shipping. Relatively little is known about the ecological values of this area.

Part I.
Review of the Environmental Characteristics of the Nantucket Shelf Region

1. BACKGROUND

Seen from space, the great sweep of Cape Cod and its submerged banks and shoals are one of the most prominent geographic features of the Northeastern coast. Cape Cod and the islands of Martha's Vineyard and Nantucket represent only the highest points of a much larger peninsula that has been drowned by the rising sea as Ice Age glaciers melted. The submerged areas include Nantucket Shoals, Nantucket Sound, Vineyard Sound, Georges Bank, and Stellwagen Bank (Figure 1).

In fact, Nantucket Sound, Vineyard Sound, Nantucket Shoals, the Great South Channel, the continental shelf south and west of Martha's Vineyard, and Georges Bank form one continuous shallow continental shelf environment which shares a common geological origin (Emery, 1987). This larger cape, much of which is submerged now, forms much of the continental shelf off the Massachusetts coast and juts out into the North Atlantic Ocean. In this literature review, this area will be called the "Nantucket Shelf Region".

This prominent geographic feature has long been known as a major biogeographic transition zone, an area where southern species of plants and animals meet and mix with northern species. Cape Cod and nearby shelf areas form the southern boundary of the Gulf of Maine, a huge, highly productive shelf sea dominated by the cold Labrador Current flowing south from the Canadian Arctic and subject to intense cooling during the winter. The Nantucket Shelf Region also forms the northern boundary of the Middle Atlantic region that is warmed by warm core rings from by the northward flowing Gulf Stream. This region represents a major biogeographic boundary for land plants, fishes, invertebrates, and many other species of plants and animals.

Nantucket Sound has been the subject of much attention recently, due to a proposed wind farm. An earlier proposal in the 1980's to protect Nantucket Sound suffered from a lack of scientific information to support protection. Now, two decades later, due to the pressures posed by human uses of Nantucket Sound, advances in coastal research, and advances in resource management and protection, it is time to reevaluate the current state of scientific information concerning the area in order to reevaluate our management of the area.

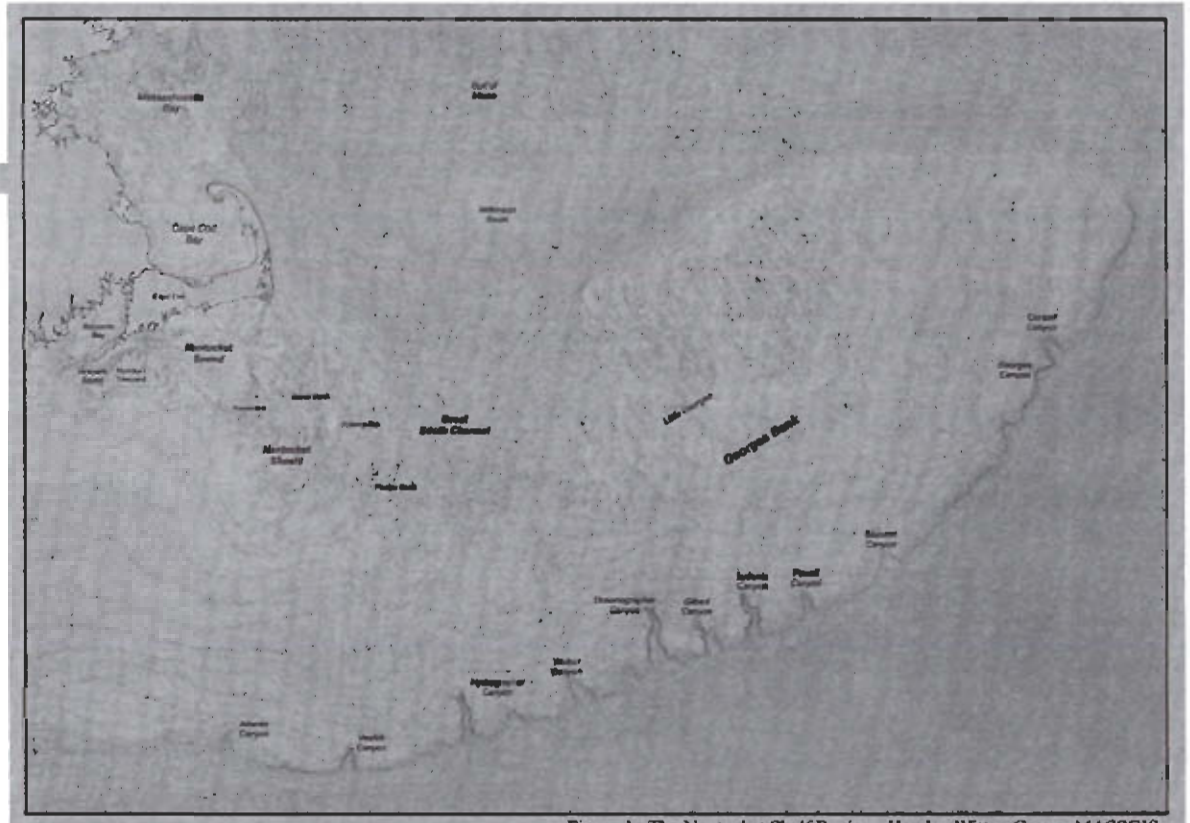


Figure 1. The Nantucket Shelf Region. Horsley Witten Group, MASSGIS

This broad area of continental shelf most likely shares many physical, chemical and biological processes. But do we know what these are? Studies of Nantucket Sound relating to a proposed wind energy project typically focus on the area of the proposed project and on Nantucket Sound itself. Such a narrow focus may miss important features. Before one can evaluate the need for marine protection, one first needs to understand the largescale ecological and natural values of a region.

Ecosystem-based resource protection and management is not new to land managers. But for ocean managers, this is a new concept. An ecosystem-based approach first identifies the important or unique ecological features of a region. The characterization of the ecological values of a region is then used as the basis for designing appropriate measures for protection or management of these ecological features.

There are few comprehensive studies of Nantucket Sound, Nantucket Shoals, or indeed of the Nantucket Shelf Region, from the broader vantage point of an entire shelf ecosystem, such as the comprehensive studies of Stellwagen Bank (Valentine et al., 2001; Ward, 1995; Auster et al., 2001; Pett and McKay, 1990; U.S. Department of Commerce (NOAA) 1993; USGS 1998), Georges Bank (Backus, 1987; Emery, 1987; Twichell, 1987; Walsh et al., 1987; Butman, 1987; Collie et al., 1997; Franks and Chen, 2001; USGS 2001; Valentine and Lough, 1991), the Great South Channel (Kenney and Wishner, 1994) or the Gulf of Maine (Brooks, 1992; Christensen, 1989; Durbin et al., 1994; Oldale et al., 1973; Greenberg, 1983; Bigelow, 1927). Information gaps are significant, and thus a review of scientific information concerning important natural features and processes of this area must be based upon comparison with nearby better-studied areas, inference or extrapolation based on scientific knowledge of similar processes or features elsewhere. Nevertheless, there are distinctive features of the Nantucket Shelf Region which deserve to be considered for management or protection.

Part I of this report is meant to provide an objective review of the state of scientific knowledge concerning the Nantucket Shelf Region. The goals of Part I are to:

- Review and summarize existing scientific knowledge concerning the major physical, biological and ecological processes of the Nantucket Shelf Region;
- Identify data gaps and evaluate their significance; and
- Provide a factual, objective basis for further discussion of the values of the Nantucket Shelf Region in Part II of this report.

Part II of this report describes existing marine protection and management approaches, and describes criteria for evaluating whether a given marine area should be protected or not. Part II is meant to foster discussion of the values of this region and whether this area or portions of it should be protected or managed.

2. HOW THIS STUDY WAS DONE

A key goal of this review is to provide an accurate, objective summary of information concerning the Nantucket Shelf Region. This review therefore utilizes only published, peer-reviewed scientific sources of information (i.e., scientific articles, books, reports, maps, abstracts, and scientific and technical studies or reports produced by or for government agencies). On occasion, books dealing with a specific topic from a layman's point of view, such as nature guides or an in-depth essay or study of a topic, are used. Maps, figures, and diagrams from the original sources are included; very few diagrams were created specifically for this review. This was done to provide transparency and to demonstrate the original source of the information.

In this review, emphasis was put on identifying largescale processes and features of the region. Thus, the review is not intended to be a comprehensive and in-depth review of all the features of this region.

Significant scientific data gaps are identified. Whenever possible, their significance is evaluated according to best professional opinion and existing available scientific or technical literature. If hypotheses, conjectures, speculations, or questions are posed, they are clearly identified and are based on similar processes or phenomena documented elsewhere, and best professional opinion.

The report begins by briefly describing distinct geographic areas in the Nantucket Shelf Region, and then proceeds to describe major physical and ecological features of the region. The second part of the report evaluates marine protection criteria and models.

Fishing boat on Nantucket Sound, photo NOAA library

3. GEOGRAPHIC AREA OF THIS REVIEW

In this review, the broad shallow shelf area covered by Nantucket Sound, Nantucket Shoals, the Great South Channel and the area south of Martha's Vineyard is called the Nantucket Shelf Region. The goal of this review is to identify largescale physical and ecological processes characteristic of the Nantucket Shelf Region. Information concerning such regional processes covers a wide geographic area that includes the entire shelf region east and south of Cape Cod, extending to the edge of the continental shelf between 100 meters and 200 meters depth. The review draws upon information concerning Nantucket Sound, Nantucket Shoals, the Great South Channel, Vineyard Sound, Georges Bank, the nameless area of continental shelf south of Martha's Vineyard, and the continental shelf area encompassing these geographic regions.

Each of these geographic areas is briefly described below.

Nantucket Sound is defined as the roughly triangular area of continental shelf that lies between the southern shore of Cape Cod (between Monomoy and Mashpee), and the islands of Martha's Vineyard and Nantucket (Figure 1). Nantucket Sound constitutes a small, shallow marine basin whose edges are formed by the islands of Nantucket, Martha's Vineyard and Monomoy, the submerged shoals associated with these islands, and by the Cape (U.S. Department of Commerce, Coast and Geodetic Survey Chart No. 1209, 1970). At its western end, Nantucket Sound merges with Vineyard Sound.

Nantucket Shoals is a broad area of shallow sandy shelf that extends south, southeast and east of the island of Nantucket. The area has a complex, dunelike topography that reflects the strong tidal currents. On the crest of the shoals and in the troughs between them are small linear sand waves that are largely at right angles to the dune crests, although some of the larger sand waves on the crest of the shoals parallel the current. In this area, the shoals consist of reworked glacial sediments that have been deposited over a silt bed of unknown thickness containing Eocene plant spores and pollen (Uchupi and Austin, 1987). Phelps Bank, nearly 50 miles southeast of Nantucket, represents the most seaward extent of the Shoals, with water depths of 40 to 60 meters. Nantucket Shoals is truncated by the Great South Channel to its east and southeast.

The Great South Channel is a submarine valley that runs in a north-south direction, out of the Gulf of Maine, cutting its way between the hilly mass of Georges Bank on the east and the high sandy plateau of Nantucket Shoals on the west. At its shallowest, the channel formed by this underwater valley is about 50 meters deep. The valley links Wilkinson Basin in the southern Gulf of Maine, where water depth exceeds 150 meters, with the continental shelf southeast of Nantucket Shoals. The terminus of the Great South Channel is on the outer shelf near Hydrographer Canyon (Uchupi, 1965).

Ships approaching or leaving the Gulf of Maine or Massachusetts Bay use the Great South Channel to skirt the treacherous shallows of Nantucket Shoals and Georges Bank. The Great South Channel is also one of the major spring feeding grounds for the western North Atlantic population of a critically endangered species of whale, the Right Whale (*Eubalaena glacialis*). The Right Whale congregates by the dozen in this area, because their favorite food source, a copepod, typically undergoes a spring population explosion in this area. The South Channel Ocean Productivity Experiment, or SCOPEX, was designed to evaluate the productivity in this area (Kenney and Wishner, 1994).

South of Martha's Vineyard, there is a broad expanse of shelf that is characterized by the lack of shallow offshore shoals. This southern New England shelf area slopes down gradually to the edge of the continental shelf above Atlantis Canyon, at a depth of about 120 meters. Here, the gradient steepens, dropping 300 meters in a distance of a little over 50 kilometers, to the continental slope below (Uchupi, 1965).

Georges Bank is a shallow elongate bank on the continental shelf east of New England (Figure 1), with water depths ranging from 3 to 150 meters. The area covered by Georges Bank is roughly 40,000 kilometers squared (km^2). It is bordered on the north by the deeper waters of the Gulf of Maine, while the Atlantic Ocean forms the southern margin (Valentine and Lough, 1991). Tidal currents flow dominantly northwest and southeast. Georges Bank is eroding since no new sediment is reaching it from the continent. Sand is winnowed from Georges Bank by strong tidal and storm currents, leaving behind gravel "pavement" in the northeastern area, and coarse sand-gravel in the middle portion (Valentine and Lough, 1991). Sand ridges 20 to 30 meters high exist on the crest of the bank in the northeastern area, formed by rapid currents, much as strong winds deposit sand dunes if enough sand is present (Twichell et al., 1987).

The water over Georges Bank is well-mixed due to the strong currents and waves, and form a distinct water body separated by oceanographic fronts from the stratified water of the Gulf of Maine and the Atlantic Ocean. These different water masses have different temperatures, salinity, nutrient concentrations, and differ in their capacity to support phytoplankton and zooplankton and the animals that feed upon these (Valentine and Lough, 1991).

Georges Bank was once a rich fishery due to its shallow, well-mixed, highly productive waters, but the fisheries are now depleted due to overfishing. By the late 1980's, many Georges Bank fishery populations such as cod, haddock, herring, and scallops had declined, while others such as skate and dogfish populations had expanded rapidly (NOAA, 1991, in Valentine and Lough, 1991).

Between Georges Bank and the New York Bight, there are 10 major submarine canyons leading from the shelf into the slope environment. These are, going from north to south: Corsair Canyon, Lydonia Canyon, Gilbert Canyon, Oceanographer Canyon, Welker Canyon, Hydrographer Canyon, Veatch Canyon, Atlantis Canyon, Block Canyon, and Hudson Canyon (Uchupi, 1965; Shepard and Dill, 1966; reviewed in Pratt, 1973).

Typically these submarine canyons are relatively straight canyons with a V-shaped profile reflecting their origin as stream-cut valleys, with sloping walls that may be as steep as 30 degrees in places. Sedimentary rock and semi-consolidated sediments are frequently exposed on the canyon walls, creating a terraced pattern (Pratt, 1973).

Submarine canyons are widely believed to result from stream erosion of the continental shelf during periods of low sea level during glacial periods (Ross, 1968). At its lowest, sea level would have been about 300 meters lower than today's sea level, exposing the continental shelf to the air and to terrestrial erosion processes (Emery, 1987).

Silts are the predominant sediment in the floors of these downward-sloping canyons, carried there by intermittent strong currents flowing down the shelf and into the heads of the canyons (Pratt, 1973; Butman, 1988). At the bases of the canyons, on the continental slope at depths of over 2000 meters, there are depositional fans, or deltas, of fine-grained silts. Currents flowing down the canyons were documented by early studies (Trumbull and McCamis, 1967; Ross, 1968; and Dillon and Zimmerman, 1970) and by later studies (Butman, 1988).

4. GEOLOGY

The Nantucket Shelf Region has been submerged by the sea and reemerged as dry land many times. This area was a continental shelf for many millions of years prior to the onset of glaciation in the Pleistocene. Before the Pleistocene, parts of the shallow continental shelf were above sea level and consisted of a coastal zone of plains and low hills that gradually became lower toward the east, where an ancient shoreline stood (Strahler, 1966). See Figure 2 for a geological time scale (Raup and Stanley, 1978).

The landforms that we call Cape Cod, Nantucket, and Martha's Vineyard did not come into being until very recently, during the last or Wisconsin stage of glaciation which began some 50,000 to 70,000 years ago (Strahler, 1966). These modern landforms result from the deposition of boulders, cobbles, gravel and sand as terminal moraines and ice-contact deposits formed as the glaciers were receding. Below this veneer of glacially-deposited sand, gravel and boulders lies a series of ancient landscapes, stacked like the layers of a cake.

Shoals off Nantucket. photo MASSGIS

The information concerning these ancient, pre-Pleistocene landscapes comes from seismic reflection profiling studies of the sediments and rocks underlying Nantucket Sound and nearby regions, performed in the 1970's and 1980's (O'Hara, et al., 1976; O'Hara and Oldale, 1980; O'Hara and Oldale, 1987). The seismic reflection profiling studies by O'Hara and Oldale were conducted in order to assess sand and gravel resources, evaluate the environmental impacts of offshore mining of sand and gravel and of offshore disposal of solid waste and dredged materials, to identify and map offshore geology and to determine the geologic history of this area of the shelf. These seismic reflection studies provide a significant portion of the total scientific knowledge that we have concerning Nantucket Sound.

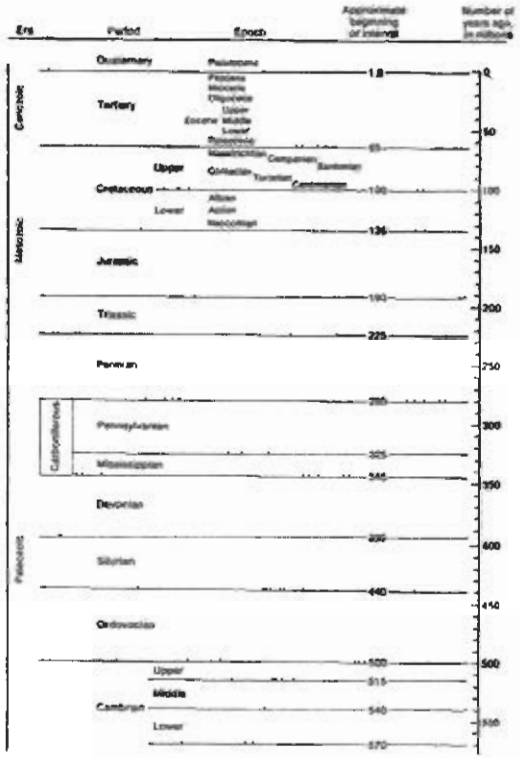


Figure 2. Geological Time Scale.
From Raup and Stanley (1978)

4.1. Pre-Cretaceous Landscape

Beneath Nantucket Sound, the oldest, deepest rocks are believed to be of Mesozoic age or older, formed before the Cretaceous Period. The bedrock is crystalline basement rock that represents the North American continental plate. Sedimentary rock is deposited on top of the crystalline basement. During the Mesozoic Era, as the North American continental plate moved apart from the European and North African continental plates, the Atlantic Ocean widened, in a tectonic process called rifting. The sedimentary rocks formed from sediments deposited in a shallow sea that covered the continental shelf, which were later consolidated into solid rock by metamorphic processes (Oldale et al., 1973).

The Mesozoic landscape sloped gently towards the south, and was cut by streams and rivers that flowed south and southeast towards the opening Atlantic Ocean. These rivers flowed down from the North American continental highlands.

4.2. Late Cretaceous and Early Tertiary Coastal Plain

During the last part of the Mesozoic (Late Cretaceous) and continuing into the early Tertiary, coastal sediments were deposited in a thick layer on the bedrock shelf, thickening towards the ocean. These coastal plain sediments included both consolidated and unconsolidated sands and silty clays containing some gravel (Oldale et al., 1973). The coarse grain size of these sediments suggests that they were deposited underwater in a nearshore shallow environment, perhaps much like offshore conditions today.

In Nantucket Sound, there is an unconformity between portions of the Pre-Cretaceous bedrock and later Late Cretaceous-Tertiary sediments, indicating that portions of the ancient bedrock were exposed to erosion. The eroded fragments of pre-Cretaceous crystalline rock ended up as part of the Late Cretaceous coastal plain deposits.

4.3. Late Tertiary and Pleistocene River Valleys

During the late Tertiary and early Pleistocene, the area of Nantucket Sound was filled by coastal plain sediments. A major unconformity shows that this landscape underwent massive erosion. The erosion of this landscape is perhaps best seen in an extensive erosional scarp, or eroded cliff, that faced north, which is now buried beneath the more recent glacial sediments of Nantucket Sound. This buried eroded cliff runs east-west and extends from eastern Georges Bank to western Long Island Sound. Evidently, the area south of this scarp was a highland or range of hills that eroded. The streams and rivers that flowed north into the valley representing the proto-Nantucket Sound had their headwaters in this range of coastal hills that ran from west to east for hundreds of miles, parallel to the Atlantic coast. (O'Hara and Oldale, (1987).

Similarly, the plains to the north of the proto-Nantucket Sound valley were eroded by numerous streams and rivers that flowed south (Figure 3) and then out of the east to the Sound, towards the area of the present-day Great South Channel. These streams cut long, linear southwest- trending valleys that flowed towards the center of Nantucket Sound. Some of these streams, in the northern part of Nantucket Sound, may have cut down to the underlying pre-Cretaceous bedrock, exposing that ancient rock.

Drainage from the proto-Nantucket Sound was towards the east. The east-flowing river (outside the area in Figure 3 mapped by O'Hara and Oldale) broke through the line of hills at a water gap and then flowed south across the exposed continental shelf to the Atlantic Ocean. The Great South Channel may have been the water gap that allowed drainage of the Nantucket Sound area towards the sea (O'Hara and Oldale, 1987). The Great South Channel may also have drained the western Gulf of Maine (Oldale et al., 1973). Today, the Great South Channel still connects the southern Gulf of Maine with the North Atlantic, but the Late Tertiary watersheds that drained into it and the low line of hills which it breached are now buried beneath Pleistocene glacial sediments of Nantucket Sound and Cape Cod and flooded by the rising sea.

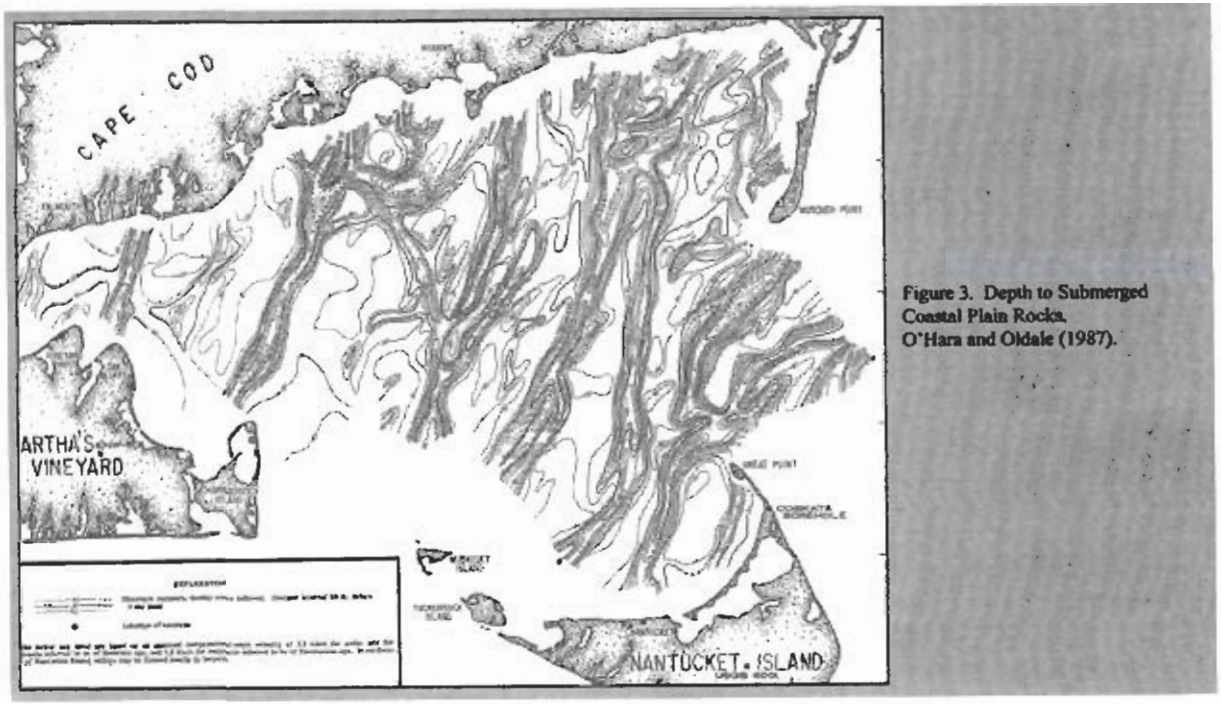


Figure 3. Depth to Submerged Coastal Plain Rocks, O'Hara and Oldale (1987).

4.4. Pleistocene Glaciation and the Formation of Cape Cod and the Islands

The continental glaciers that formed present-day Cape Cod and the Islands were but small outliers of the great Laurentide Ice Sheet, the massive glacier that covered northern North America during the Pleistocene. This massive ice sheet, 10,000 feet thick or more at its greatest, flowed out from its center at Labrador towards the continental shelf. In eastern North America, the ice mainly flowed south and east.

The direction of flow of the Pleistocene glaciers that crept down from the north was probably influenced by the preexisting linear valleys cut by the south- and north-flowing streams during Late Tertiary times. Like grooved pavement, the valleys probably acted to entrain the glacial ice, which would have settled deep into the valleys (O'Hara, 1981b). The Late Tertiary linear valleys may have helped to determine the shape of the Nantucket Shelf region by influencing the direction of flow of the Pleistocene glaciers.

The landforms of Cape Cod, Nantucket, Martha's Vineyard, Nantucket Shoals, the Great South Channel, and much of Georges Bank were formed by glacial processes in the last Ice Age, the Wisconsin stage. Nantucket and Martha's Vineyard were formed by the bulldozer action of glaciers pushing sediments ahead as the Laurentide Ice Sheet flowed south from New England and Canada.

Such sediments deposited in front of a glacier are called terminal moraines. A terminal moraine also receives the sediments that are carried by the ice and deposited as the glacier melts at its terminus. A terminal moraine typically reflects the shape of the end, or terminus, of the glacier that molded it. When the glacier retreats, it leaves behind the terminal moraine.

The terminal moraines that form the high spines of Nantucket and Martha's Vineyard were formed by distinct lobes of glacial ice. The Nantucket Sound lobe marked the farthest advance of glacial ice in the Nantucket Shelf region (Figure 4, from Strahler, 1966). Long Island and Block Island were also formed at the same time and in the same manner (Strahler, 1966). Cape Cod was not yet formed. Nantucket and Martha's Vineyard are therefore older than the Elizabeth Islands and the Buzzards Bay and Sandwich Moraines, which were deposited later, during the second stillstand of ice (Strahler, 1966).

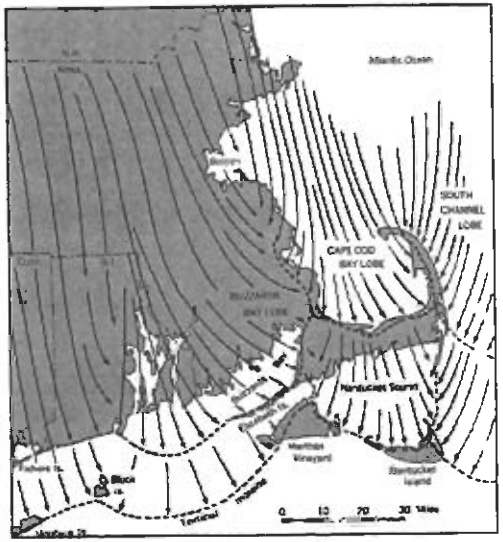


Figure 4. This map of southeastern New England shows by arrows the directions of flow of ice of the Wisconsin Stage as well as the two positions of ice standstill (dashed lines). (Based on a map in Woodworth and Wigglesworth's Geography and Geology of the Region Including Cape Cod, 1934). From Strahler (1966).

About 18,000 years BP, the glaciers began melting and retreated northward, and then halted. This second ice margin position, or stillstand, was held for several thousand years. Now the ice margin of the Cape Cod Bay lobe and the Buzzards Bay lobe ran through a line defined by the recessional moraines of the Elizabeth Islands and Cape Cod, in particular the Buzzards Bay Moraine and the Sandwich Moraine, which were deposited then. Meltwater streams eroded the moraines and washed sediment down to form the broad, gently sloping glacial outwash plains that form most of the southern and eastern portions of Cape Cod. A glacial lake formed in Nantucket Sound at the melting edge of the retreating ice sheet (Gutierrez et al., 2003).

In Nantucket Sound, glacial drift sediments were deposited in the narrow linear valleys that existed before the Pleistocene glaciation. Thicknesses of these Pleistocene glacial drift sediments reach over 100 meters in some of the deeper valleys, and thin to 10 meters or so in areas that were high (see Figure 5, O'Hara and Oldale 1987).. The current bathymetry of Nantucket Sound (see Figure 6, from O'Hara and Oldale, 1987) reflects a combination of glacial and post-glacial sediment deposition processes.

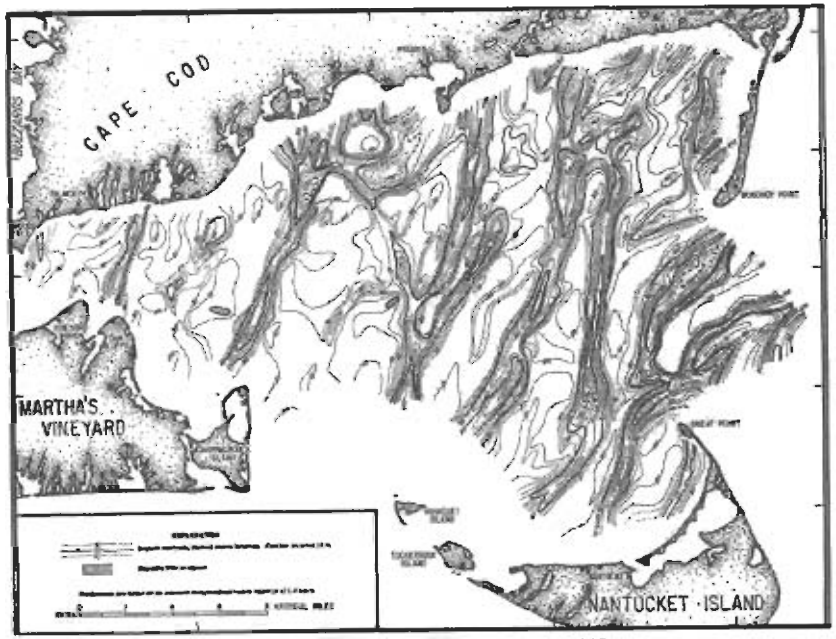


Figure 5. Thickness of Glacial Drift Deposits. O'Hara and Oldale (1987).

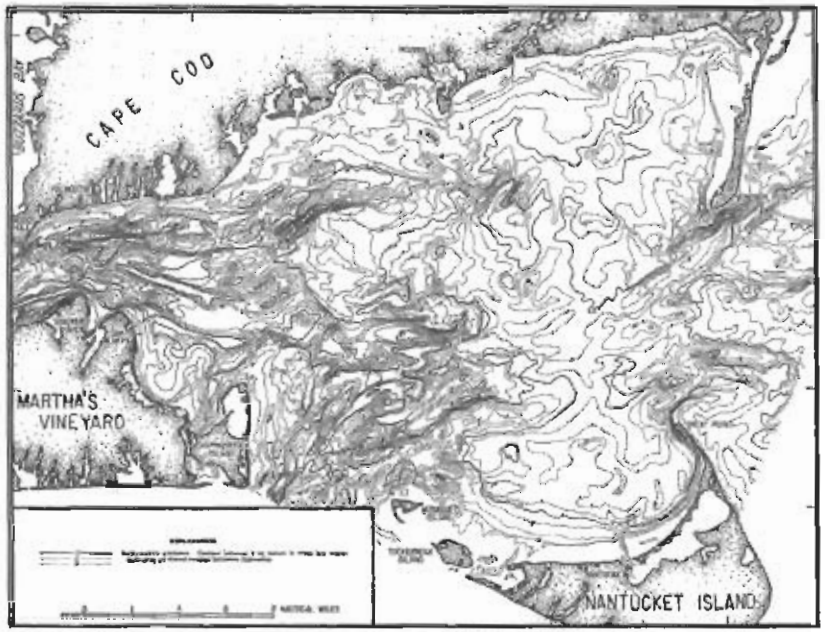


Figure 6. Existing Sea Floor Topography. O'Hara and Oldale (1987).

The area of the Great South Channel, which may have been a Tertiary water gap in an east-west line of coastal hills (O'Hara and Oldale, 1987), was covered by a different glacial lobe, the Great South Channel Lobe (Strahler, 1966). The intersection between the South Channel Lobe and the Nantucket Sound ice lobe coincides with the eastern edge of Nantucket Sound. Today, water depths are still shallow at the eastern edge of Nantucket Sound, because of the ridge of glacial sediments deposited in the gap between the Great South Channel ice lobe and the Nantucket Sound ice lobe (Figure 6, from O'Hara and Oldale, 1987).

4.5. Relative Sea Level Rise

During glacial times, sea level was nearly 300 to 500 feet (100 to 160 meters) lower than today's levels, because of the huge amount of seawater locked up in glacial ice. The Nantucket Shelf region was exposed land (Figure 7, from Emery, 1987). The shoreline was much closer to the edge of the continental shelf than its present position, which today is near the 200-meter depth contour (Uchupi, 1965). During a glacial period of low sealevel, water depths would have quickly deepened to hundreds of meters a short distance offshore.

During this period of exposure to sun, wind and rain, the continental shelf received precipitation, underwent weathering and erosion, and drained towards the sea, (Strahler, 1966). Fresh groundwater accumulated in the subsurface of the exposed Nantucket Shelf region (Kohout et al., 1977). Streams and rivers cut down through the exposed sediments of the continental shelf, heading for the edge of the continental shelf only miles away. The submarine canyons, such as Oceanographer Canyon, that plunge off the edge of the continental shelf were probably formed during this lowstand, carved out by the great glacial rivers that entered the sea closer to the edge of the continental shelf.

What animals and plants lived here? The animals and plants and habitats of this coastal glacial ecosystem probably would have resembled a present-day Arctic coastal ecosystem, but there is scant information from the Nantucket Shelf region from this brief emergent period. Mastodon teeth and bones have been recovered (Emery).

About 12,000 years ago, rapid global warming caused the glaciers to shrink rapidly and sea level to rise (Strahler, 1966). The rapid warming event caused a rapid retreat of the glaciers, and meltwater streams eroded and carried sediment out to form glacial outwash plains. Nantucket Sound remained a lake until about 9,500 years BP, when sea level was 30 meters below its present level (Uchupi et al., 1996). Beginning about 7,600 years BP, rising sea level drowned the lake and the shoreline migrated inland as the sea inundated the coastal valleys and plains (Gutierrez et al., 2003). By about 1,000 years BP, sea level reached its approximate present level. Since then, sea level continues to rise at the rate of approximately one foot per century over the past century, and it is expected to rise at least 19 inches over the next century (IPCC, 2002).

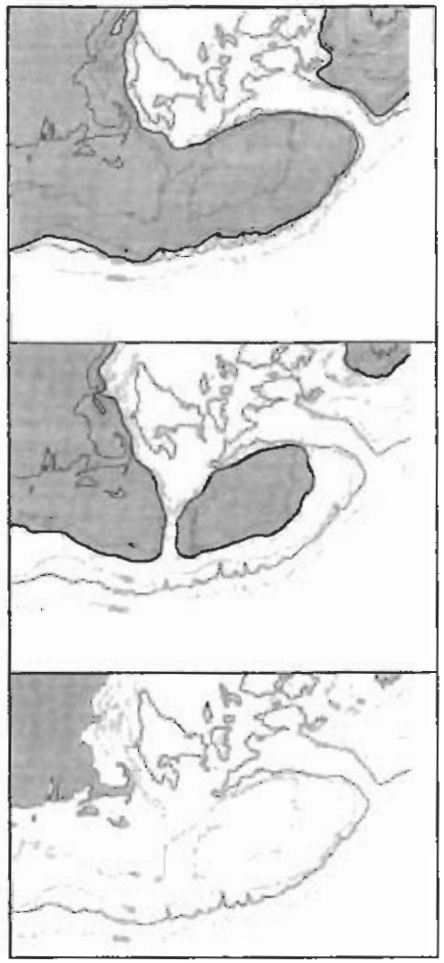


Figure 7. Georges Bank during the past 16,000 years (BP = Before Present): (top) Georges Cape (14,000 years BP), (middle) Georges Island (11,500 years BP), and (bottom) Georges Bank (present) formed as sea level rose at the end of the Pleistocene epoch. Emery (1987).

4.6. Sedimentary Environments

Sediments in the Nantucket Shelf Region are of the type that geologists call clastic, that is, formed by the disintegration of rock into small particles. Water, waves, wind, erosion, abrasion, temperature extremes and the weathering action of soil microorganisms break down rock into sediment particles. These sediments are then carried into the sea by rivers and streams. Clastic sediments have been deposited in this area of the continental shelf for many millions of years, beginning in the late Cretaceous.

New England and areas to the north do not have massive coral reefs or reefs built up of other limestone-forming invertebrates. Biogenic sediments, or sediments that are deposited by algae, reef-forming corals and other invertebrates that secrete limestone, are uncommon in this region. Unfortunately for coral reef-lovers, the cool temperate waters are not favorable for growth of carbonate-secreting, reef-forming animals, since the minerals they secrete are not stable for long due to the cool temperatures, which tend to dissolve carbonate.

Other biogenic sediments, such as opal-like silica, are deposited by diatoms, a type of microscopic algae. Diatoms are common in offshore waters and in the Gulf of Maine, and can form spring and summer blooms. There is, however, no information on biogenic silica production in the Nantucket Shelf Region.

Clastic sediments can have many different compositions reflecting the parent rock. The more resistant and long-lived sediment grains consist of the harder rocks and minerals such as quartz, rutile, ilmenite, garnet, and other tough igneous and metamorphic minerals derived from the weathering of granite, gneiss, diorite, and basalt. Such sediment grains of more resistant minerals tend to weather more slowly to form gravel, sand, silt and clay. Softer sediment grains of feldspar, soapstone, schist, and other soft minerals and rocks tend to weather more quickly into fine-grained clays. Limestone (carbonate) and basalt can also weather to form gravel, sand, silt and clay.

The clastic sediments of the continental shelf of New England reflect the nearby parent rocks and sediments, namely, the pre-Cretaceous igneous and metamorphic bedrock of the North American continent, younger sedimentary rocks and sediments from the Tertiary period, and even more recent Pleistocene glacial drift carried from many areas of the Northeast. Although one may find pebbles or cobbles of limestone or basalt, extensive sand deposits composed of limestone or basalt are not common in New England because massive limestones and basalt are not common rocks in New England.

Sediment grain size is an important attribute in the marine environment. The size of a sediment grain may seem irrelevant to us. However, to a tiny invertebrate living on or beneath the sediments or a fish laying eggs on the bottom, sediment grain size is a critically important feature. Fish feed upon the many invertebrates that live in and on the sediments. Some invertebrates prefer to live in or on muds, while others prefer sand. Certain fish and shellfish prefer gravels and sands to muds, silts or clays.

Sediment grain size depends on the type of parent rock, the length of time the sediment grain has been weathering, how far the sediment grain has been carried by water or wind (relating to abrasion time), and the wave and current energy in an area. Bigger waves and faster currents with more energy can move larger sediment grains than smaller waves or slower currents. A fast current can winnow out the fine silts and clays and sands, leaving behind coarser gravels, pebbles and cobbles. Currents that slow down deposit their sediment loads because they no longer have enough energy to keep moving sediment grains.

4.7. Benthic Habitat Mapping

National Marine Sanctuaries are marine and coastal areas of special biological significance. The National Marine Sanctuary System, administered by NOAA, requires seabed and habitat maps to serve as a basis for managing sanctuary resources and for conducting research. Also, since the decline of the Northeast fisheries, the need to understand, identify and protect essential fish habitat has become critical.

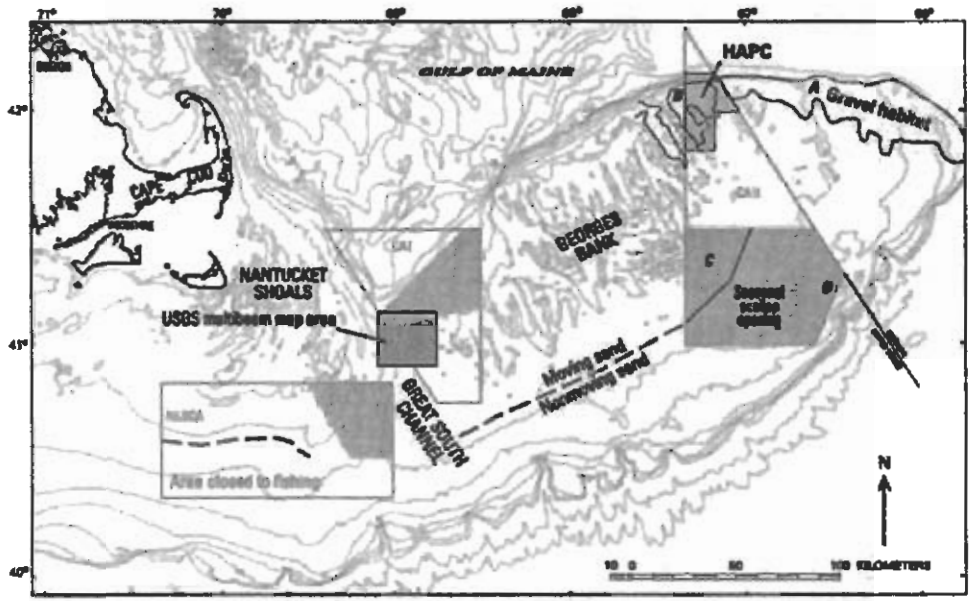


Figure 8. Benthic habitat mapping of Georges Bank, using multisensor approach. From USGS Fact Sheet FS-061-01.

As a result, geologists and biologists of the U.S. Geological Survey, the National Marine Fisheries Service and National Marine Sanctuaries System of NOAA, and universities have conducted detailed studies of the physical and biological characteristics of benthic habitats in a number of National Marine Sanctuaries and important fishing grounds. These marine habitat geology and fish ecology studies were conducted to study the interplay of geologic factors and biological habitat needs of species, and to better understand how physical habitat influences the survival and success of important fish and shellfish species (Valentine et al., 2001; Valentine and Lough, 1991; Lough et al., 1989; Collie et al., 1997; Auster et al., 2003; USGS Fact Sheet 078-98, May 1998; USGS Fact Sheet FS-142-00, December 2000; USGS Fact Sheet FS-061-01, July 2001).

Using multibeam bathymetry and sidescan sonar, underwater video, underwater photography, and sediment sampling at thousands of stations, marine scientists are mapping underwater topography, sedimentary bedforms (sand dunes, sand waves, ripples, channels), sediment grain size, benthic fauna, and the behavior of fish and invertebrates, the effects of habitat disturbance by storms, fishing gear and moving sand, and habitat preferences among different fish and invertebrate species. The multisensor mapping approach can document habitat characteristics at many size scales, ranging from several to many square miles (megahabitat), hundreds to tens of meters (local habitat), and several meters down to several centimeters (microhabitat).

Seabed mapping surveys have been carried out in Stellwagen Bank National Marine Sanctuary (NMS), and Georger Bank to define and map biological habitats, assess natural and human disturbance of habitats, and identify areas where contaminants might accumulate (Valentine, Cochrane and Scanlon, MTS Journal, Vol. 37, No. 1, p. 10-17).

In Georges Bank, several years of such studies show that: (USGS Fact Sheet FS-061-01; Valentine and Lough, 1991)

- Herring spawning sites are located on gravel bottom only where currents are strongest;
- Juvenile cod survive best on gravel habitat, especially where sponges, tube worms, and other attached species (epifauna) increase the complexity of the seabed, possibly because predation is reduced (juvenile cod are less visible against gravel bottoms and where there are other organisms that provide cover);
- Attached species are not able to colonize gravel habitat that is buried occasionally by moving sand, depending on periodicity;

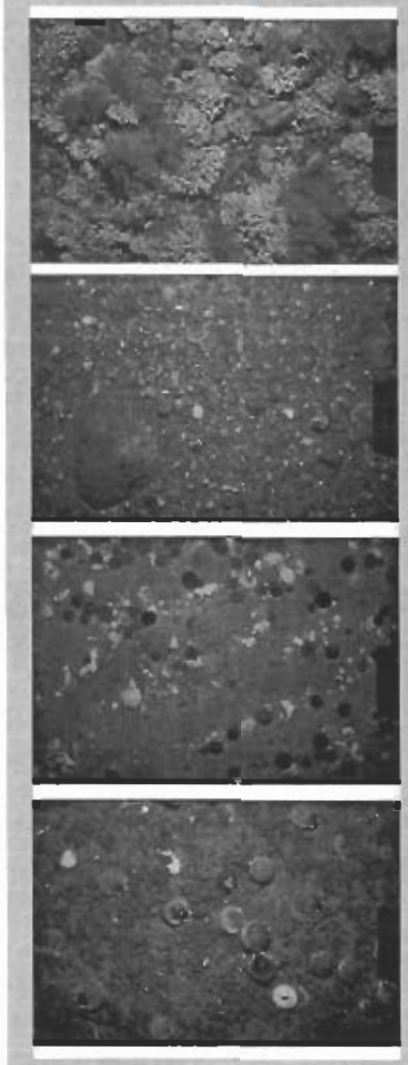


Figure 9. Photographs of the seabed showing some typical Georges Bank habitats. See Figure 10 for locations. A, Undisturbed gravel habitat with epifauna of tube worms and other attached species. B, Gravel habitat disturbed by scallop dredges and lacking epifauna. C, Moving sand habitat (strong bottom currents) with sand dollars in ripple troughs. D, Non-moving sand habitat (weak currents) with sea scallops.
USGS Fact Sheet FS-061-01.

- Dredging and trawling on gravel habitat remove epifauna and decrease habitat complexity, but fishing gear apparently has less long-term impact on sand habitat, especially where sand is moved by bottom currents, depending on periodicity;
- Scallops prefer habitats of gravel and nonmoving sand (weak bottom currents);
- Closure of large areas to fishing allowed depleted sea scallop populations to increase markedly in 4 to 6 years;
- Some sand-dwelling flounder species possibly prefer moving sand (strong bottom currents), but others prefer nonmoving sand habitats.

Figures 8 and 9 show the location of the benthic habitat mapping studies on Georges Bank, and examples of benthic habitat (from USGS Fact Sheet FS-061-01).

In Georges Bank and in Stellwagen Bank National Marine Sanctuary, multisensor studies at several thousand stations have provided information on the different habitats present, including the value of sediment bedforms (i.e., sand waves and ripples, troughs) for fish habitat, species preferences for sediment grain size, damage to benthic habitats from mobile fishing gear, the value of undisturbed seabed as habitat for fish and other organisms, and the beneficial fishery habitat effects of removing disturbances to allow the seabed to recover from impacts (Auster et al., 2003; Auster et al., 2001; Auster et al., 1996; Valentine et al., 2001). Examples of benthic habitats and habitat disturbance are shown in Figures 10, 11, 12 and 13 (from USGS Fact Sheet 1998).

Multisensor methods have proved extremely useful in monitoring the effects of fishing gear on benthic habitats and essential fish habitat. Combined with studies of benthic invertebrates and benthic production, sidescan sonar and benthic imaging have shown that mobile fishing gear (trawlers and dredgers) significantly reduces benthic productivity and biomass of Atlantic sea scallops, sea urchins, and polychaete worms on eastern Georges Bank; when such impacts ceased for several years, benthic productivity increased by factors of 5 to 10 or more (Hermsen et al., 2003). On Stellwagen Bank, similar surveys showed that mobile fishing gear altered the physical habitat by removing sedimentary structures (sand waves, depressions) and by removing benthic organisms that provide structural habitat complexity (e.g., sponges, hydrozoans, bryozoans, amphipod tubes, shell aggregates, holothurians, crabs, etc.). Reduced habitat complexity can result in increased predation on juvenile fish and ultimately reduce recruitment (Auster et al., 1996).

In eastern Georges Bank, large sand waves, analogous to underwater sand dunes, have formed in response to rapid storm and tidal currents with speeds ranging from 10 to 100 centimeters per second. Sand waves usually lie at right angles to the direction of the prevailing current.

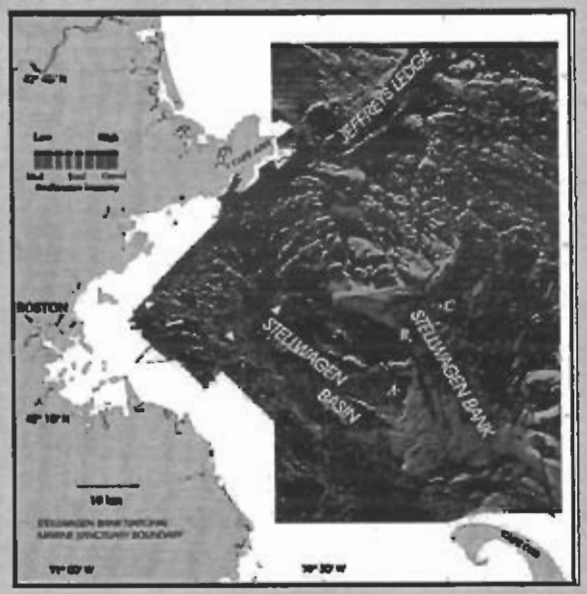


Figure 10. Sun-illuminated map of Stellwagen Bank National Marine Sanctuary and Massachusetts Bay with backscatter intensity draped over the topography. Red indicates high-backscatter material including coarse sand, gravel, and rock; green indicates sand; blue indicates mud. Within each backscatter color interval, the intensity varies from dark to light depending on the sun illumination. The image illustrates the wide variety of sedimentary environments in this region of the coastal ocean. The transitions between sediment types are often very sharp. Topographic features observed here were formed for the most part by glacial processes. Glacial ice containing rock debris moved across the region, sculpting its surface and depositing sediment to form basins, knolls, banks, and other features. Later many of the smaller features were formed during a final period of ice stagnation and melting. Today, the sea floor is mainly modified by storm currents and waves from the northeast. These currents erode sand and mud from the shallow banks and transport them into the basins. Stellwagen Bank and Jeffreys Ledge are shallow banks (20-40 m water depth) covered with sand and gravel. Stellwagen Basin (80-100 m) is floored with mud. In deeper water (85-140 m) in the northeastern part of the image, a fine hummocky pattern on the sea floor was created by gouges (5-10 m deep and up to 120 m wide) caused by icebergs that grounded in the muddy sand at the close of the last period of glaciation. Present and past disposal sites (white arrows) are characterized by high-backscatter material and are especially distinct when the background material is fine grained sediment, such as in Stellwagen Basin. The easternmost arrow points to the presently active Massachusetts Bay Disposal Site. The yellow rectangle in the western part of the map is the location of the new ocean outfall that will discharge treated sewage effluent from the Boston metropolitan area into Massachusetts Bay. USGS Fact Sheet 078-98 (May 1998).

Figure 11. A view of the SEABOSS from below (with base plates removed; see fig. 2). Photograph by Dann Blackwood, USGS. The instruments are as labeled: A, forward-looking video camera; B, lights for forward-looking video camera; C, downward-looking video camera; D, lights for downward-looking video camera; E, 35-millimeter still camera; F, strobe light for still camera; G, modified Van Veen grab sampler; H, depth sensor; I, junction box; J, parallel lasers for scale; K, angled laser for range. From USGS Fact Sheet FS-142-00 (December 2000).

Figure 12. An oblique view of the SEABOSS on deck between stations. Photograph by Dann Blackwood, USGS. From USGS Fact Sheet FS-142-00 (December 2000).

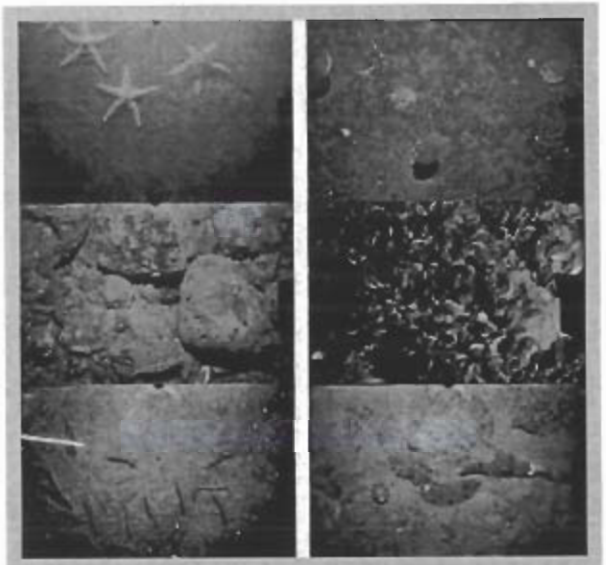


Figure 13. Examples of still photographs taken of different habitats with the SEABOSS during USGS studies. Area shown in each photograph measures about 51 to 76 centimeters. A. Four starfish together on a muddy bottom in the New York Bight. B. Juvenile scallops swimming over a sandy bottom on Georges Bank. C. A boulder mound in western Massachusetts Bay that is providing habitat for lobster and fish. D. Mussels clustered on bedrock in Niantic Bay in Long Island Sound. E. Sand lance schooling over coarse sand in the Stellwagen Bank National Marine Sanctuary. F. A goosefish camouflaged on a muddy sand bottom in the Stellwagen Bank National Marine Sanctuary. From USGS Fact Sheet FS-142-00 (December 2000).

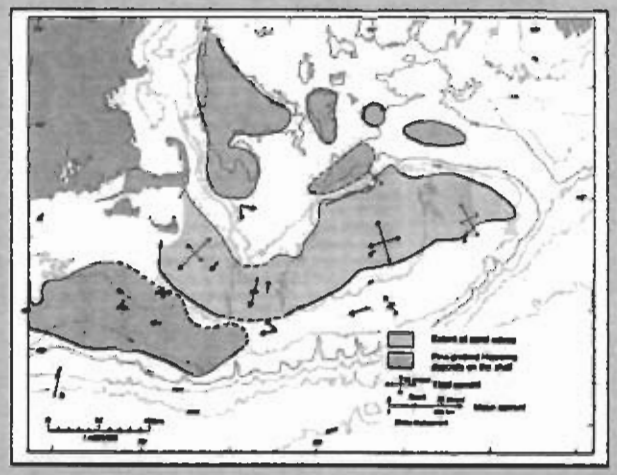


Figure 14a. Summary map showing tidal currents, mean currents, area of sand waves, and locations of fine-grained Holocene deposits. From Twichell et al. (1987).

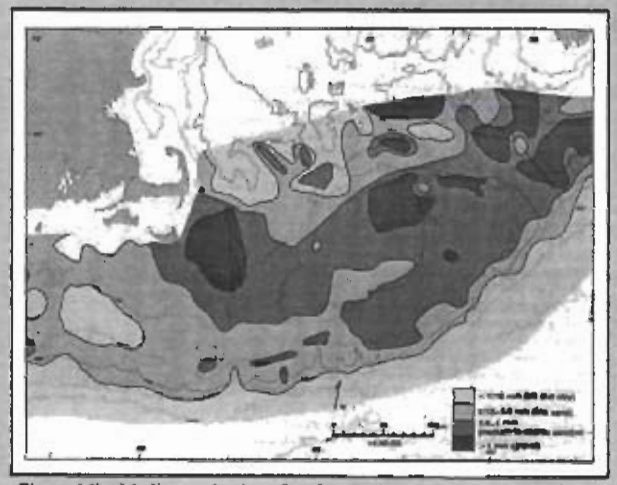


Figure 14b. Median grain size of surface sediments in the Georges Bank area. (Schlee (1973), modified). From Twichell et al. (1987).

They are formed much as desert sand dunes are formed, by a current that carries sand grains forward and then drops the sand grains as the current slows in travelling up the face of the growing dune. The sand waves on Georges Bank reach amplitudes (height from bottom to top of a sand wave) of up to 25 meters (75 feet) with a wavelength of 50 to 300 meters between wave crests, although most are 1 to 10 meters in height with correspondingly smaller wavelengths (Twichell et al., 1987). Megaripples are smaller sand waves that have heights of less than 1 meter and wavelengths of 1 to 15 meters between wave crests. Sand waves may move or migrate at a rate of 12 meters per year, while portions of sand waves may move as much as 60 meters per year (Twichell et al., 1987).

Sand waves and megaripples are absent where surface tidal currents are less than 40 centimeters per second and typically are found in water that is less than 60 meters deep. Sand waves and sand ripples exist in the Great South Channel and on Nantucket Shoals, where surface tidal currents exceed 60 centimeters per second, where sand waves are 5 to 10 meters high (Figures 14a and 14b, Twichell et al., 1987). In the floors of the troughs or depressions between sand wave crests, gravel lag deposits are often found, representing larger heavier particles left behind when the lighter finer sand is swept forward by currents to form the sand waves. Sand waves may build up on both sides of the crests where the ebb tidal current and the flow tidal current are roughly equivalent in speed, in which case the crest of the waves may lie obliquely at an angle to the direction of the ebb and flow tidal currents (Twichell et al., 1987).

Similar but smaller sand waves and sand ripples occur on Stellwagen Bank, where the tidal currents are weaker, reaching speeds of 20 to 30 centimeters per second (Auster et al., 2003; Valentine et al., 2001). Using the Seabed Observation and Sampling System (SEABOSS), researchers have found that silver hake, a predator species that feeds on fish and squid, prefer sand wave habitat, possibly because it provides shelter from current flows and from larger predators (Auster et al., 1995; Valentine, 2000). Furthermore, fish size was related to sand wave morphology as well as current velocities, and prey. Studies like this that integrate underwater landscapes with ecology provide far more useful information for resource managers than studies that address only one issue at a time.

These results show that seabed mapping provides resource managers with information on where the best benthic habitat may exist in an area, and how benthic habitat can be impacted by mobile fishing gear. Seabed mapping can be used to monitor long-term use and recovery of benthic habitats over large areas. Seabed mapping has proved highly useful for making management decisions involving commercial and recreational fishing, habitat disturbance, engineering projects, tourism, and cultural resources (USGS and NOAA/National Marine Sanctuary Program, 2003). Seabed mapping is one of the most essential and invaluable tools for understanding, managing and protecting marine habitats. This cannot be overemphasized.

In Nantucket Sound, the USGS has collected information on sediment grain size, using sediment sampling (Figure 15). This study, performed by USGS scientists Larry Poppe and Chris Polloni, is one of the few recent scientific studies centering on Nantucket Sound (Poppe and Polloni, 2000). Their broad survey shows that sand predominates over most of the area, with occasional pockets of silty clay (e.g., in the oval basin west of Nantucket). Gravel deposits also occur as long linear east-west ridges at the eastern end of Vineyard Sound (western end of Nantucket Sound) and gravel also forms mounds here and there around the margins of Nantucket Sound. Yet the Stellwagen studies demonstrate how complex the seafloor geology and habitat are, and how even thousands of sediment samples are inadequate to describe the seafloor environment.

4.8. Issues and Data Gaps

Multisensor seabed mapping techniques have not been applied to studying the benthic habitats of Nantucket Sound, or Vinetard Sound, Nantucket Shoals or large areas of the Great South Channel or Georges Bank. Given the proximity to government scientific agencies and research institutions, this is surprising, but the information gap is probably due to the fact that neither of these areas is located within a marine sanctuary, and the fisheries that once existed in Nantucket Sound have been depleted. This information gap is an important one.

As a result, we know little about the benthic habitats that may be present in Vineyard and Nantucket Sounds and Nantucket Shoals, except indirectly through fisheries information and sediment grain size mapping. We know nothing about the potential impacts to benthic habitat in these areas from mobile fishing gear, which has been documented in the Gulf of Maine (Auster et al., 1996). This is one of the most significant data gaps identified in this literature review.

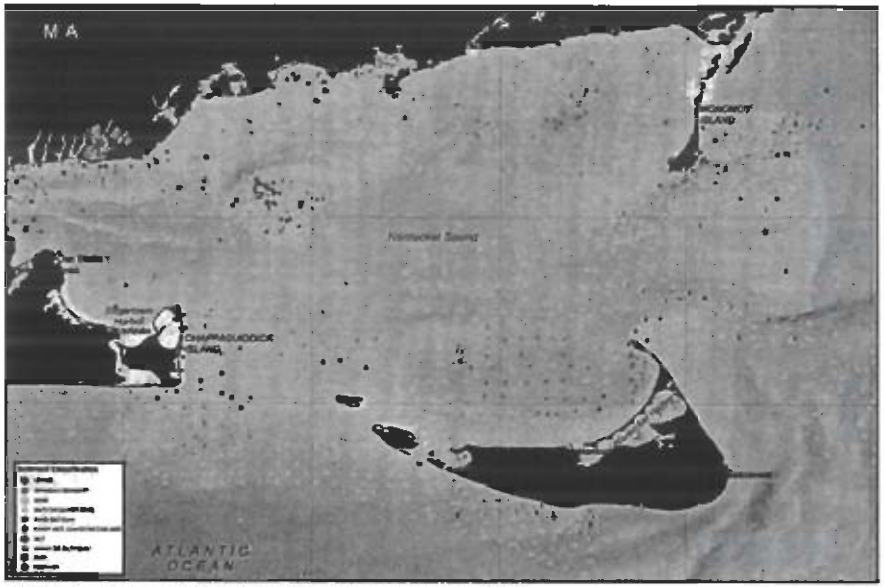


Figure 15. Sediment Grain Size. From Poppe and Polloni (2000).

Sand waves and ripples provide important habitat for fish on Georges Bank and Stellwagen Bank. Do sand waves exist in Nantucket Sound? If so, do the troughs between sand waves, or the gravelly ridges mapped by Poppe and Polloni (2000), provide essential fish habitat? A sidescan sonar study was performed for a proposed wind energy project describes sand waves (Cape Wind Farm DEIR); however, the sidescan sonar data were not provided in the DEIR, and so the existence of such sand waves cannot be confirmed. However, given the tidal currents in the Nantucket Sound and Nantucket Shoals areas (see section on Circulation), underwater sand waves probably do occur. Mapping such sedimentary bedforms would be important for mapping essential fish habitat and benthic habitat.

Are the long gravel and sand ridges remnants of glacial deposits, or are they deposits formed by winnowing by the strong tidal currents? These sand ridges and shoals are probably completely the result of tidal currents, but this is an area that needs further study. The length and east-west orientation of these features suggests that these features are associated with the terminal moraines formed by the retreating ice, since they are roughly parallel with the glacial ice front. It does not seem likely that they are submerged drumlins, like the east-southeast submerged drumlins found in Massachusetts Bay, which reflect the flow direction of the ice sheet in that region (Oldale et al., 1994), because the flow direction of the ice sheet in the Nantucket Sound region was probably north-south. Uchupi and his colleagues found that the sediments of Nantucket Sound represent a complex history related to the inundation of the area as sea level rose during the latest Holocene transgression (Uchupi et al., 1996).

In short, while the sedimentary and benthic habitats of Georges Bank and Stellwagen Bank and portions of the Great South Channel have been studied in depth, only the structural geology, glacial history, and sediment grain size of Nantucket Sound and Nantucket Shoals have been studied to any extent. Benthic habitat of Vineyard Sound, Nantucket Sound and Nantucket Shelf have yet to be characterized at the level of detail of the Stellwagen Bank studies.

5. BATHYMETRY

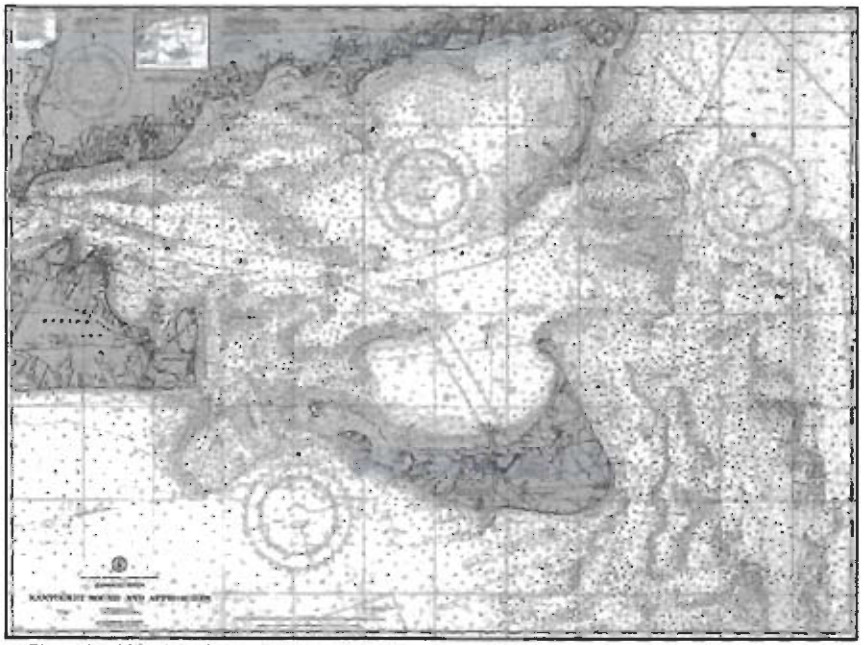


Figure 16. NOAA Bathymetric Chart. U.S. Department of Commerce, Coast and Geodetic Survey Chart No. 1209, 1970.

5.1. Bathymetry Charts

Existing NOAA navigational charts provide bathymetry of the Nantucket Shelf region. Such charts are developed for navigational purposes. A 1970 NOAA bathymetry chart of Nantucket Sound is shown in Figure 16 (U.S. Department of Commerce, Coast and Geodetic Survey Chart No. 1209, 1970). Such maps are useful for largescale assessment, but may be less suitable for evaluating benthic habitat values due to the scale of mapping.

Bathymetric maps show the topography of Nantucket Shoals and Nantucket Sound is best characterized as irregular and broken, with ridges that are both linear and irregularly sinuous, mounds, and plateaus, with channels between these topographic highs. The largest expanses of water that could be called basins are situated in two areas: 1) an oval basin just west of the island of Nantucket, surrounded on three sides by Tuckernuck Shoal, Tuckernuck Bank, and the long horn of Nantucket's spit, and 2) An irregular basin, lying between the above mentioned basin, Lewis Bay on Cape Cod, and Monomoy Island (U.S. Department of Commerce, Coast and Geodetic Survey Chart No. 1209, 1970).

Water depths in Nantucket Sound vary from less than half a meter (1 foot) to approximately 23 meters (70 feet), relative to mean low water (Coast and Geodetic Survey Chart No. 1209, 1970). The deepest areas of Nantucket Sound are found approximately 3 nautical miles due south of Waquoit Bay, at the western end of Nantucket Sound adjacent to Vineyard Sound; approximately 4 nautical miles south of West Bay, approximately 8.5 nautical miles south of West Bay; immediately south of the southern end of Monomoy Island (Butler Hole); several small areas north of Nantucket; and in Muskegat Channel lying off the southeastern end of Martha's Vineyard. With the exception of one or two small areas north of Nantucket, most of these deeper areas lie within long, elongate basins that are probably associated with areas of rapid current flow that have helped to shape these features. Their orientation corresponds with the major directions of tidal current flow into and out of Nantucket Sound (see Section on Physical Oceanography).

5.2. Issues and Data Gaps

A study of how and whether bathymetry has changed over time, throughout the Nantucket Shelf Region, does not appear to have been done. This is important to know because changes in bathymetry and sediment transport can affect benthic habitats. Such a study would also shed light on changes in circulation in response to climate change, the effects of major storms on sediment movement and distribution, and the effects of shallow nearshore sediments on abating storm wave energy.

High-resolution bathymetry data would provide a necessary foundation for many other studies, such as habitat mapping, and for resource management.

Long-term studies of bathymetry would also be useful for evaluating whether sand transport from the shelf to nearshore regions can occur via waves, tides and currents; this is a little-studied area of coastal geology, since most attention typically has focused on sand transport from nearshore to shelf regions. A recent workshop on coastal change addressed such issues and the need for developing an ocean observatory system (Workshop on "The Moving Shoreline: Coastal Change in Response to Rising Sea Level, April 26 – April 29, Woods Hole Oceanographic Institution, Rob Evans, Department of Geology and Geophysics, Conference Chairman).

Research data buoys ready for deployment.
photo: NOAA library

6. PHYSICAL OCEANOGRAPHY

Physical oceanography is the science of the movement of the sea. It deals with circulation, tides, waves, currents and the physical processes that cause the ocean to move. Physical oceanographers in particular seek to understand why and how the ocean moves, and are therefore most interested in processes. Examples of important processes include:

- Advection (mixing of different water masses);
- Stratification (formation of layers of water with different properties);
- Buoyancy (tendency of a less dense body of water to rise relative to a denser body of water);
- Tides (created by the constantly changing gravitational attractions of moon, sun and earth as these move relative to each other);
- Gradient-driven flow (water flows down to a lower area due to gravity);
- Coriolis force (the earth's daily rotation under a body of water causes that water body to slowly spin clockwise or counterclockwise); and
- Interactions between some or all of the above processes.

These major physical oceanographic processes can affect the chemistry, ecology, geology, and climate of a region. Very often, understanding the physical oceanography of an area, one can predict the chemistry, ecology, sedimentation, and erosion of a region. Physical oceanographers rely upon field measurements of the properties of water: current velocities, tidal ranges, wave heights, water temperature, salinity, density and so on. Such data is combined with knowledge of basic physical processes that cause water masses to move. Computer mathematical models are created to understand how water masses move and change over time, based on selected processes and field data. The results of such models are compared with observations to see whether the models accurately match observed conditions.

Scientific knowledge concerning the physical oceanographic processes of the Nantucket Shelf Region is patchy. Much is understood about the physical oceanography of the Gulf of Maine (and by extension Nantucket Shoals and the eastern margin of Nantucket Sound) and Georges Bank. In a general sense and at a large scale, the physical oceanography of the New England continental shelf is well understood. Specific areas have been studied more than others, for example, the off-shelf currents leading down to the submarine canyons at the head of the continental slope (see studies by Brad Butman and others).

However, a major information gap exists where Nantucket Sound and Vineyard Sound are concerned, largely due to the lack of modern detailed and focused scientific studies aimed at understanding the physical oceanographic processes in these areas. We probably know more about the physical oceanography of Georges Bank, Stellwagen Bank, and the Gulf of Maine than we do about our own backyard, Nantucket Sound and Vineyard Sound.

Research data buoy deployment.
photo: NOAA library

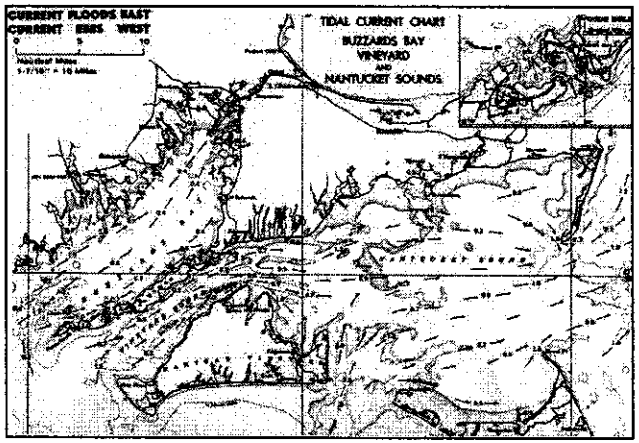


Figure 17. Tidal Current Chart. Buzzards Bay, Vineyard and Nantucket Sounds. 3 hours after flood starts at Pollock Rip Channel or 1 hour after low water at Boston. Velocities shown are at Spring Tides. See Note at bottom of Boston Tables: Rule-Of-Thumb for Current Velocities. (Pollock Rip Ch. is SE of Monomoy Point). From Eldridge (2003).

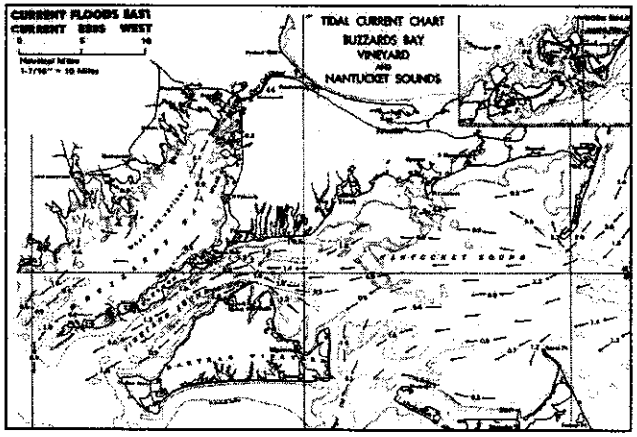


Figure 18. Tidal Current Chart. Buzzards Bay, Vineyard and Nantucket Sounds. 3 hours after EBB starts at Pollock Rip Channel or 1 hour after high water at Boston. Velocities shown are at Spring Tides. See Note at bottom of Boston Tables: Rule-Of-Thumb for Current Velocities. (Pollock Rip Ch. is SE of Monomoy Point). From Eldridge (2003).

6.1. Vineyard Sound, Nantucket Sound and Nantucket Shoals

The tidal range in Vineyard Sound and Nantucket Sound is relatively small, ranging from 1.5 to 3 feet in various areas, with lower tidal ranges occurring on shorelines facing the open ocean and higher tidal ranges occurring in coastal embayments and other semi-enclosed areas. Nantucket Sound and Vineyard Sound receive little river runoff; therefore, despite the low tidal range, their circulation is dominated by strong (upwards of 2 knots) reversing semi-diurnal tidal currents (Bumpus et al., 1973). The net drift movement of water is towards the east, amounting to about 200 cubic meters per tidal cycle, or about 5 percent of the total easterly and westerly tidal flow (Bumpus et al., 1971). Salinity ranges from 30 to 32.5 parts per thousand. There is little or no vertical stratification of the water column due to the turbulent mixing by tidal current over the uneven bottom of the sounds, and meet Pritchard's definition of a Type D vertically homogenous estuary (Pritchard, 1955).

In Vineyard Sound and Nantucket Sound, the ebb tide current flows to the west while the flood tide current flows to the east, towards the Great South Channel (Figures 17 and 18, Eldridge, 2003). During the ebb tide, a tidal current flows south between Nantucket and Martha's Vineyard, through Muskegat Channel, into the Nantucket Shoals region, reversing during the flood tide. Average maximum current velocities range from 2 knots (103 centimeters per second) on flood tides in Pollock Rip Channel southeast of Monomoy, to 4.5 knots (231 centimeters per second) on flood tides in Woods Hole channel, at the western end of Vineyard Sound and sometimes exceeding 7 knots (360 centimeters per second) in the latter area (Eldridge, 2003). On Nantucket Shoals, tidal currents also dominate water movement and surface tidal currents exceed 60 centimeters per second (Twichell et al., 1987).

These tidal current speeds are much faster than the minimum current speed needed to form sand waves and megaripples, which is 40 centimeters per second (Twichell et al., 1987), so where there is plenty of sand available, it is likely that sand waves and megaripples have formed in Vineyard Sound and Nantucket Sound. Since the ebb and flood tide currents are almost equally strong (easterly flow is slightly greater), it would not be surprising to find sand waves that have built up sand on both sides of the wave crest, as occurs in Georges Bank (Twichell et al.,1987). However, no scientific studies of sedimentary bedforms and benthic habitat in Nantucket Sound or Vineyard Sound have been done, as mentioned previously.

6.2. Gulf of Maine

The Gulf of Maine is a marginal sea that is nearly isolated from the Atlantic Ocean by Georges Bank, Browns Bank, the Great South Channel ridge, and Cape Cod. Its waters are cold, chilled by both the Labrador Current and by severe winter cooling brought about by the gulf's location in the lee of the North American continent and isolation from the warmer deeper waters of the North Atlantic Ocean (Brooks, 1992). The gulf contains three major basins with varying depths: Wilkinson Basin (275 meters deep), Jordan Basin (275 meters deep), and Georges Basin (379 meters deep).

The main connection between the Gulf of Maine and the Atlantic Ocean is the Northeast Channel, a glacially-scoured drowned valley with a sill depth of 230 meters. At this sill depth, deeper Atlantic slope water can enter the Gulf of Maine. The Great South Channel is shallower and only allows limited exchange of water with the upper layers of the Atlantic, with a sill depth of about 70 meters, despite the fact that it is a low point in the submarine ridge that runs from Nantucket Shoals to Georges Bank (recall its former role as a water gap in pre-Pleistocene times, according to O'Hara and Oldale (1987)).

Non-tidal circulation in the Gulf of Maine is basically counterclockwise, with a smaller clockwise gyre in the eastern gulf, and counterclockwise circulation in the western and southern gulf (Brooks, 1992). Flow around the edge of Georges Bank is clockwise. At the extreme southern end of the Gulf of Maine, water flow diverges from the main gulf counterclockwise circulation and follows the edge of the Nantucket Shelf region south and then west (Figures 19 and 20 from Bigelow (1927) and Brooks, 1992). The divergence is an area where upwelling of deeper nutrient-rich water occurs in response to the diverging water masses, and is thus an area where production should be higher.

The contour-hugging current flows around Nantucket Shoals, along depth contours of 20 meters or greater, bending around the Shoals much as a ship might avoid the Shoals. In the spring and summer, surface currents become stronger as heating and stratification increase, while during the winter the gyre-like circulation weakens and the surface water inside the gulf drifts slowly seaward over the banks (Brooks, 1992).

In the nearshore areas of the Gulf of Maine, fresher waters are less salty and dense, and during the summer form a thin layer on top of the saltier, denser Atlantic ocean water entering the gulf through the Northeast Channel (which is called Maine Bottom Water). In the winter, due to intense cooling of water at the surface of the ocean, chilled water sinks and forms an intermediate layer of water called Maine Intermediate Water, which by its sinking causes the overturn or mixing of nearly two-thirds of the water column.

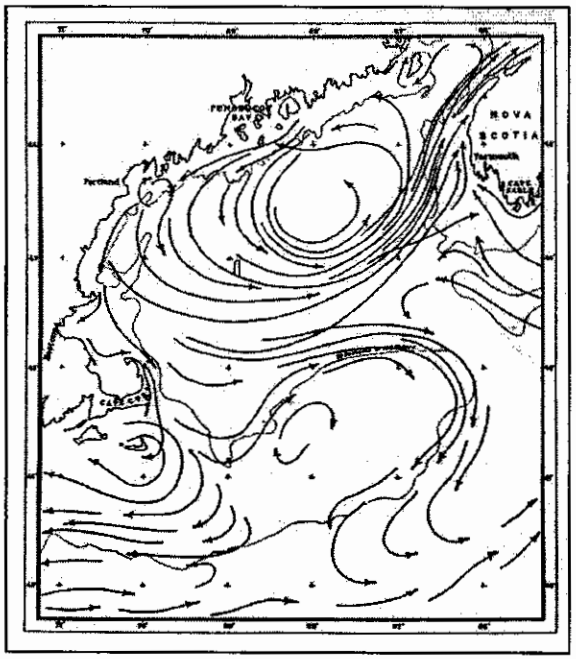


Figure 19. Bigelow's (1927) classical circulation schematic for the Gulf of Maine region in summer months, based on multiple experiments with surface drift bottles, hydrography, and plankton distributions. Bigelow (1927) and Brooks, (1992).

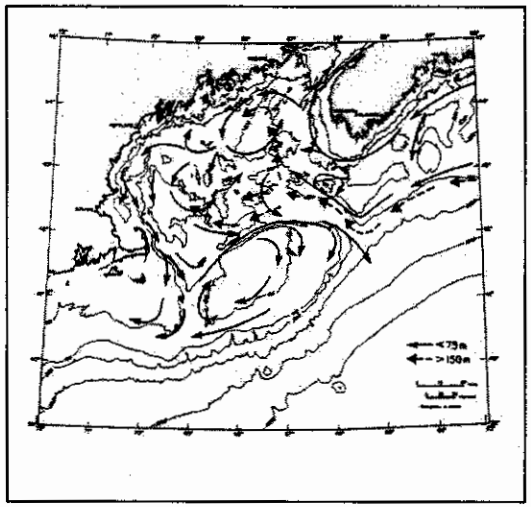


Figure 20. Schematic map of the summer subtidal circulation in the Gulf of Maine. The circulation is separated into a near surface component (at depths below 150 m; dashed lines) showing the flow of dense salty slope water. The net deep inflow of slope water entering the Gulf of Maine through the Northeast Channel is mixed vertically by several mechanisms (e.g., coastal upwelling, seasonal overturning, boundary mixing) and leaves the Gulf of Maine in the flow above 100 m. No comparable map exists for the circulation during other seasons. Brooks (1992).

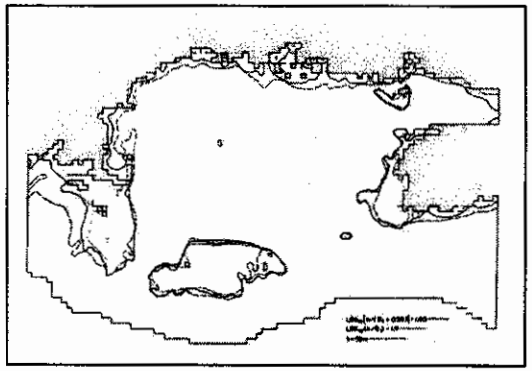


Figure 21. Predicted frontal positions for tidal and summertime wind mixing, using tidal dissipation rates calculated from Greenberg's (1983) model. The positions of the log (h/Dt) = 1.9 contour (...) and the 50 m isobath (---_ are also shown. Figure from Loder and Greenberg (1986). Brooks (1992).

In the Gulf of Maine, current speeds in upper surface currents in areas away from the banks are typically 30 to 50 centimeters per second, but in narrow channels and over sills, deep current speeds can be several times greater.

The Gulf is also known for its tidal resonance, which means that the tides are reinforced or amplified due to the basin's configuration and orientation (long axis running from northeast to southwest) relative to the moon's orbit about the earth (apparent east to west motion). Tidal heights increase eastward, exceeding 15 meters in the Bay of Fundy. Tidal currents resulting from the amplified tides can reach velocities of more than 1 meter per second in the upper Bay of Fundy, shallower areas and inner edge of Georges Bank, and the western end of the Scotian Shelf, while in the southwestern gulf the tidal currents are typically a few tens of centimeters per second (Brooks, 1992).

6.3. Tidal Mixing Fronts

Tidal fronts are formed when tidally well-mixed water meets less well-mixed water. Due to the large tidal variation and rapid tidal currents, there is vigorous tidal mixing of the waters of Georges Bank, the western Nova Scotia shelf, and most of the Bay of Fundy and small areas along the coast of Maine. Where these tidally well-mixed waters meet the stratified fresher water along the coast or the upper warmer water layer during the summer, tidal fronts form. Wind-mixing also causes water to overturn, or convect. An example of wind-mixing is blowing across the top of a cup of coffee with a layer of cream added; the cream disperses downward because the "wind" creates friction along the liquid's surface, which causes the liquid to move, which displaces liquid, leading to convection.

Mixing throughout the vertical water column is thorough during the winters, due to wind-driven mixing and the convection brought about by cold surface water sinking to the bottom. When wind-mixing is added to tidal mixing, the resulting tidal fronts are shown in Figure 21 (Brooks, 1992). Tidal fronts occur in the above-mentioned areas, and also in some eastern Maine coastal bays, over the cap of Browns Bank, near Grand Manan Island, and Nantucket Shoals. A tidal mixing front was observed along the eastern edge of Nantucket Shoals during the SCOPEX oceanographic cruises, indicating tidally mixed waters inside the area of Nantucket shoals (Chen et al., 1994a, b).

Physical Oceanographers recovering a water sampling apparatus.
photo: WOAA library

Thorough mixing of ocean layers is important for stimulating productivity of phytoplankton and zooplankton and the ensuing food chain. As Brooks (1992) says, *"One of the important consequences of the tidal stirring is to bring deep dissolved nutrients upward into the surface layers, where the enhanced light can result in higher biological productivity, so that the areas near and inside the tidal fronts shown in Figure 6* (Figure 21 in this review) *also tend to support high primary and secondary production. For example, the tidally-stirred waters of the eastern gulf and Georges and Browns Banks support one of the world's richest fisheries (Yentsch and Garfield, 1981)."* (Brooks, 1992). Note that the area inside the tidal front boundary in Figure 19 includes the Nantucket Shelf Region (e.g., Nantucket Shoals, Nantucket Sound, Vineyard Sound), and Buzzards Bay.

Physical oceanography, therefore, suggests that the Nantucket Shelf Region should be a biologically productive area, due to thorough mixing of the water column by strong tidal currents. Vigorous mixing promotes high oxygen levels in the water column, and in general, well-mixed, well-aerated water bodies can support greater numbers and more diversity of organisms than water with low or no oxygen. The prediction concerning enhanced productivity due to high mixing rates is borne out by remote sensing observations of primary productivity (chlorophyll concentrations) in the Nantucket Shelf Region, discussed in a later section in this review. Biodiversity is discussed in a later section as well.

6.4. Shelf-Slope Currents

In the Nantucket Shelf Region, water depths are generally too shallow to allow intrusion of deeper slope water, such as the slope water intrusion that occurs at the north end of the Gulf of Maine, over the Northeast Channel sill (Brooks, 1992). But the reverse - flow of water from the shallow Nantucket Shelf Region to deeper water - is conceivable, perhaps by analogy with the Gulf of Maine situation where winter chilling creates a dense layer that sinks to form the cold Maine Intermediate Water layer.

USGS studies of the outer continental shelf south and southwest of Martha's Vineyard indicate that so-called "cross-shelf currents" flow down off the edge of the continental shelf towards the continental slope, particularly in areas where there are preexisting submarine canyons cut into the edge of the continental shelf (Butman, 1988; Butman, 1987; Bumpus, 1973). Tidal forces appear to be responsible for causing the currents, which are found in water depths of 200 to 300 meters. In a 1972 study, a shelf-slope current was measured at 950 meters depth on the continental slope (Wunsch and Hendry, 1972). The Nantucket Shoals Flux Experiment also documented a net downslope current at 200 meters depth (Beardsley et al., 1985). Although such currents are typically weak, with speeds of 1 to 5 centimeters per second, they carry continental shelf materials (sediments, nutrients, organisms, organic detritus) towards the deeper slope environment. Such off-shelf currents that transport water and suspended sediments into the upper continental slope environment appear widespread off the New England shelf (Butman, 1988; Ross, 1968).

Turbidity currents, which are underwater flows of sediment-laden water from underwater landslides and river deltas, can travel hundreds of miles, depositing sediments far over the abyssal ocean plain. Underwater submarine fans on the continental slope, continental rise, and abyssal plain represent the accumulation of sediment deposited by many such turbidity events. In many cases, large submarine fans such as the Hudson Canyon fan, represent the seaward end of the deposits carried by rivers. Turbidity flows originating from the Gulf of Maine have deposited sediments far out over the Atlantic slope, rise and abyssal plain (Horn et al., 1971, in Leeder, 1982).

6.5. Issues and Data Gaps

Physical oceanographic studies of Nantucket Sound / Vineyard Sound water mixing, water residence time, seasonal changes, and transport to other ocean areas, such as the Great South Channel and outer continental shelf and slope, are lacking. Such studies would be invaluable for evaluating current and past productivity of the region, and for predicting how productivity will change over time. There are no studies, for example, of how much nutrient loading Nantucket Sound and Vineyard Sound can withstand before showing impacts; up to now, we have assumed that the rapid tidal currents will flush pollutants out of the sounds. Also, adjacent areas may eventually be impacted eventually.

Although tidal currents flow between Nantucket Sound and the southern Gulf of Maine and the Great South Channel, the interactions between Nantucket Sound and the other two bodies of water have not really been investigated. This is a significant information gap, particularly given coastal nutrient inputs into Nantucket and Vineyard Sounds and high primary productivity in the Nantucket Sound-Vineyard Sound area, based on remote sensing of ocean color. The proximity of Nantucket Sound to the Great South Channel, where high nutrient and chlorophyll concentrations support copepod blooms, which in turn support high densities of right whales (Kenney et al., 1995; Kenney and Wishner, 1994; Durbin et al., 1994a and 1994b;

Wishner et al., 1994; Macaulay et al., 1994; Winn et al., 1994; Kenney and Winn, 1986; Kenney et al., 1986), suggests an important ecological connection between the three bodies of water. But this remains to be investigated.

The relationship between currents and sedimentary bedforms, such as sand waves, ripples, depressions, and sediment grain size needs to be investigated because these are key features of benthic habitat for important fish and invertebrate species. There are no studies of this type for Vineyard or Nantucket Sounds.

Studies show that there is considerable transport of continental materials into the deep sea in general. There is no information concerning whether such transport occurs from the Nantucket Sound shallow shelf into adjacent deeper waters. The possible linkage between productivity in shallow continental shelf areas and deeper outer shelf and continental slope areas needs to be investigated further, since there are currents that can transport sediments and other materials to deeper areas of the ocean. Is there a possible linkage between shelf nutrients and slope ecosystems? This is an important topic for oceanographic research into the biogeochemical cycling of nutrients between major regions of the ocean, and certainly bears on deep-sea fisheries on the upper continental slope.

The high degree of mixing in the Nantucket Shelf Region, combined with the high primary productivity in this region, nutrient loading into coastal estuaries of Cape Cod and the Islands, the regional productivity in terms of fisheries, the highly productive Great South Channel attracts endangered Right Whales, suggest that a larger ecoregional approach is needed. A better understanding is needed about how the physical oceanography of Nantucket and Vineyard Sounds dovetails with the regional oceanographic processes of Nantucket Shoals, the Gulf of Maine, Georges Bank, the Great South Channel and the outer continental shelf and slope.

7. CHEMICAL OCEANOGRAPHY

Chemical oceanography is the study of the chemical composition of the sea and, more importantly, the many chemical, biological and physical processes that cause the ocean to differ in composition from area to area. Chemical oceanographers want to find out how much of a particular substance exists in the ocean, how it got there, how long it will take to disappear or be consumed, what affects the composition, and what composition tells us about these other shadowy processes.

Biogeochemical cycling is one particular interest of chemical oceanographers. This refers to the transfer of an element, say, between water, sediments, air and living organisms (acting as "reservoirs" to store and hold an element), and the many physical, chemical and biological processes that carry the element between these reservoirs. Elements such as carbon, nitrogen, sulfur, and certain trace elements, which are the building blocks of living organisms, are of great interest for those who study biogeochemical cycling and chemical oceanography.

The biogeochemical cycling of carbon between the ocean, continental shelf, land plants and organisms, and the atmosphere, is of great interest now, because of the role of carbon dioxide in trapping heat in the earth's atmosphere (global warming). Nitrogen cycling is important in the ocean because of eutrophication – an excess of nutrients, particularly nitrogen, brought about by man's activities.

Oceanographer collecting water samples for analysis, photo NOAA library

7.1. Older Studies

Chemical oceanographic studies that include the Nantucket Sound region are rare, older and largescale in scope (Kester and Courant, 1973), compared to chemical oceanographic studies of nutrients and organic matter cycling in the Gulf of Maine (Townsend, 1997; Kelly, 1997; Christensen, 1989), nutrients, metals and organic pollutants in Georges Bank (Walsh et al., 1987; Bothner et al., 1987; Farrington and Boehm, 1987), and nutrients in the Great South Channel (Durbin et al., 1995 a and 1995b). Massachusetts Bay and Boston Harbor have been extensively studied in terms of their sediment chemistry and pollutants, because of the monitoring required for the Boston Harbor sewage outfall and the Massachusetts Bay Disposal Site.

The older study by Kester and Courant describes dissolved oxygen concentrations, which are in the range of 5 to 6 milliliters per liter off the Massachusetts coast. Nutrient loading studies of Cape Cod embayments are even more numerous, due to concerns about coastal nutrient loading and eutrophication and thanks to the Massachusetts Department of Environmental Protection (DEP) Estuaries Project and the Cape Cod Coastal Embayment Project (see Cape Cod Commission, 1998). However, none of the coastal embayment studies will examine long-term nutrient loading of Vineyard and Nantucket Sounds.

A good example of a chemical oceanographic process study is that by Christensen (1989), who examined transport of carbon from the continental shelf of the Gulf of Maine into the adjacent continental slope. His approach used measurements of sulfate reduction and carbon oxidation rates in sediments, which store organic matter. Sulfate reduction is a bacterial process that turns organic matter into carbon dioxide and hydrogen sulfide under low-oxygen, reducing conditions in sediments. Christensen's measurements showed that the amount of carbon falling to bottom sediments (the flux, or the carbon received in sediments) was 47 grams of carbon per meter squared per year, and that sediment processes that used carbon and oxygen, including denitrification and carbon burial, totaled 52.1 grams of carbon per meter squared per year – that is, carbon received roughly equaled carbon spent or permanently buried.

Christensen's study suggested that, for the semi-enclosed Gulf of Maine located on a wide shelf, little export of organic carbon to the deep slope might be expected. In contrast, on a narrow shelf like that off the state of Washington, about 22 to 50 percent of the primary production may be exported from the shelf to the slope (Christen, 1989). This type of study looking at nutrient transport is needed for the Nantucket Shelf Region, particularly given concerns about coastal nutrient loading and our untested assumption that strong tidal currents in the sounds will flush all coastal pollutants away.

7.2. Issues and Data Gaps

There is much that could be done to understand the chemical oceanography of Nantucket Sound, Vineyard Sound, and Nantucket Shoals. Chemical oceanographic studies in these areas are non-existent and constitute a significant data gap that should be addressed by ocean managers. We need to know: 1) basic distributions and concentrations of natural compounds, nutrients, and pollutants, and 2) Chemical oceanographic processes that change, distribute or create these materials. The lack of such basic information will hinder any resource management efforts to, say, restore fisheries or other natural resource values.

8. BIOLOGICAL PRODUCTIVITY

8.1. Importance of Productivity Studies in Ecology

Ecology is the study of relationships between living organisms, their activities, and their environment. Ecologists study biological functions and processes such as photosynthesis, respiration, the transfer of energy from primary producers (plants) to herbivores to predators, the rates at which such processes occur, the physical and chemical environments where these processes take place, and the kinds of organisms which are responsible for specific processes. Measuring and understanding biological productivity of different types of organisms is important for judging the success or impacts on a species, for measuring biodiversity, energy transfer between trophic levels, and ecosystem functioning. It is also critical information for resource managers.

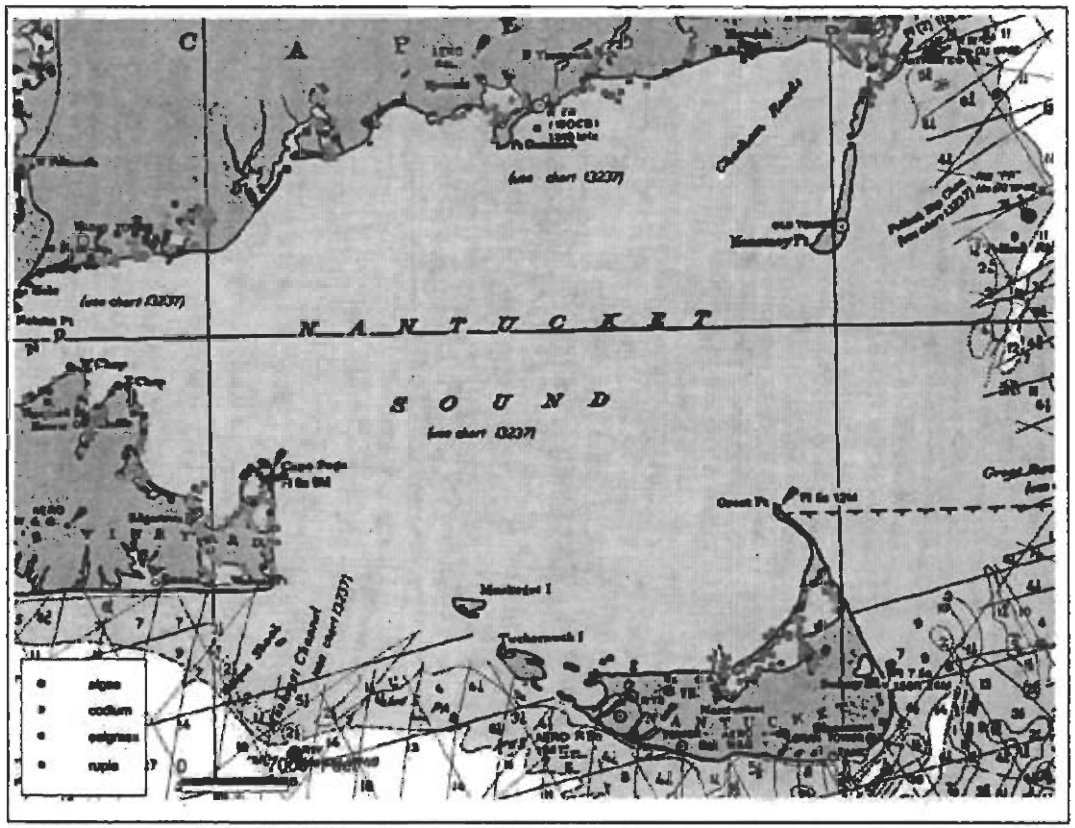


Figure 22. Seagrass and Algae Distributions. Data from MASSGIS, map by Horsley Witten Group.

Ecology also requires sound taxonomy, which is the science of correctly identifying and understanding the ancestral relationships between species of organisms and their evolution. Incorrect identification of a species can lead to incorrect assessments of its role in ecological processes and its place in the evolutionary tree. The science of biological taxonomy has languished in recent decades as ecological studies have gained in prominence and as sophisticated tools for conducting ecological studies have improved and proliferated.

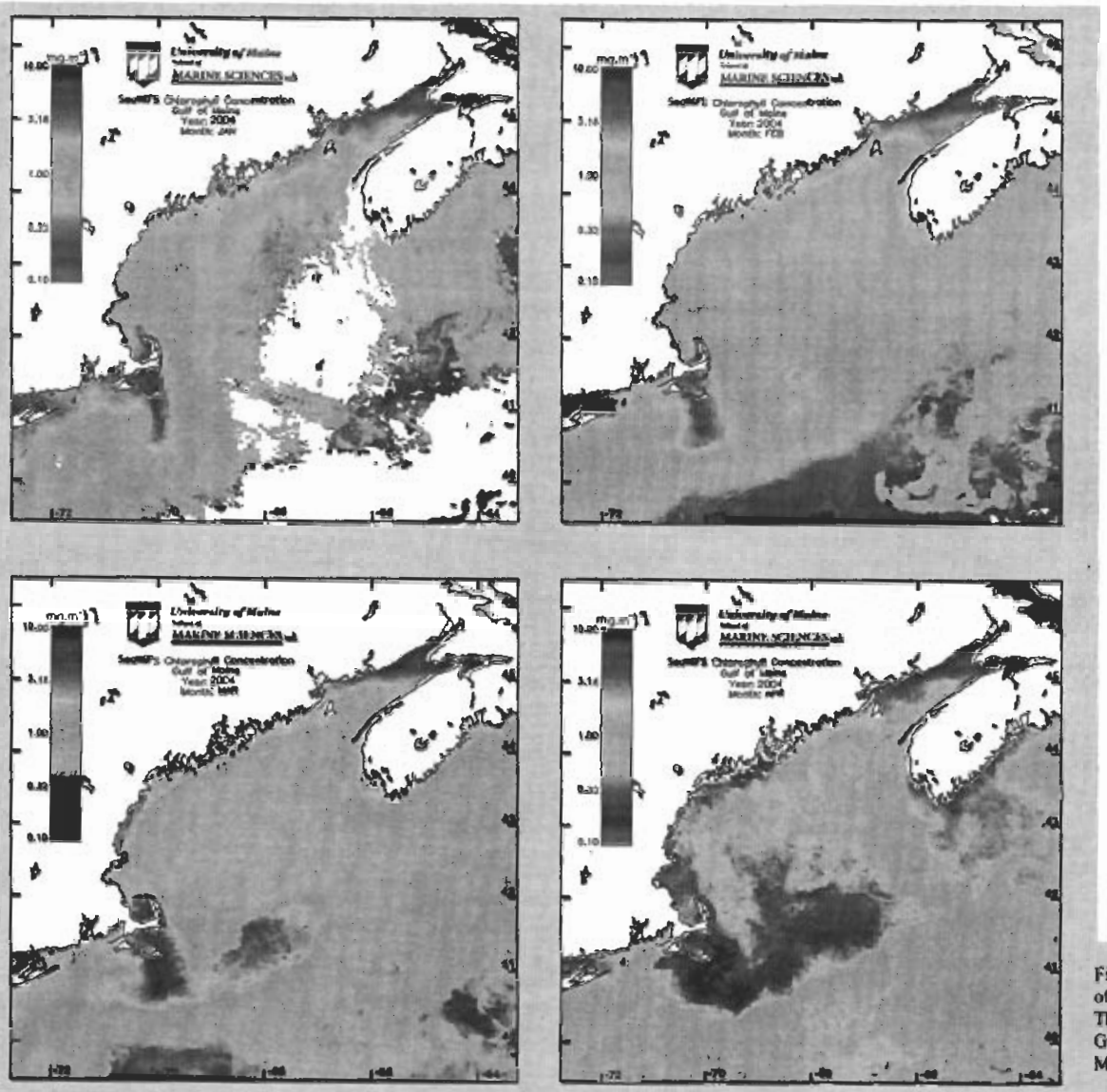
In the open waters of the Nantucket Shelf Region, and particularly in Nantucket Sound, Vineyard Sound, and Nantucket Shoals, marine ecological studies, biological productivity studies and marine invertebrate taxonomic scientific studies are scarce. Studies of birds, marine mammals, and fish are more common. Still, there is no comprehensive study of this area as a regional ecosystem.

8.2. Nutrients and Primary Production

Primary production is the organic matter created through photosynthesis by organisms such as plants, algae and phytoplankton. Primary production forms the basis of the food chain.

Seagrasses, which are vascular plants, provide one important source of primary production, particularly in shallow coastal ecosystems. Eelgrass (*Zostera marina*) is the principal seagrass on the Massachusetts coast, while widgeon grass (*Ruppia maritima*) is present in areas of lower salinity along the Cape Cod and Buzzards Bay coast. Seagrasses provide food and habitat for a wide variety of commercially important fish and shellfish species and for many other plants and animals. Seagrasses require clear water that allows light transmission in order to photosynthesize, although the leaves filter and trap suspended particles, and therefore their growth is limited to the depth where light penetration is adequate to support photosynthesis. In the clearer waters of Nantucket Sound, the depth limit for growth of eelgrass is more than 6 meters below mean lower low water (MLLW), while in the more turbid waters of portions of Buzzards Bay and Cape Cod, the depth limit is less than 3 meters below MLLW.

The Massachusetts Department of Environmental Protection (DEP) Wetlands Conservancy program has completed a project to map the state's submerged aquatic vegetation, working with assistance from NOAA's Coastal Change Analysis Program (C-CAP) and NOAA's Coastal Services Center. The project was conducted from 1994 through 1997, and used aerial photography and fieldwork to map coastal submerged aquatic vegetation (see http://www.state.ma.us/mgis/eelgrass.htm). A MassGIS map showing distribution of eelgrass around Nantucket Sound is shown in Figure 22. Note that the mapping project does not cover areas further offshore because vascular plants do not grow in deeper water (see comment above concerning depth limitation).



Eelgrass was formerly more widespread along the Cape Cod shoreline. Some causes for loss are: 1) Poor water quality, caused by both nutrient loading and the resulting eutrophication and boating activity causing resuspension of sediments, results in reduced sunlight reaching plants; 2) Physical damage to plants from boating and propeller turbulence; and 3) other environmental impacts.

In deeper offshore waters, the most important primary producers are phytoplankton, microscopic aerobic algae of various species, which grow suspended in the water column. Phytoplankton will grow and multiply as long as there are enough nutrients, oxygen and sunlight, and they are not limited in the area which they can cover because they are not rooted. Their growth is limited to the photic zone, the upper 10 meters or so of the water column where enough light of the preferred wavelength can penetrate to allow photosynthesis to occur. Phytoplankton, together with bacteria and other microorganisms, form the all-important base of the food chain in marine ecosystems.

One primary ecological question for any ecosystem is, how much primary production is occurring? Primary production can be measured in many ways, including biomass, growth rates, respiration rates, rate of nutrient uptake, and pigment content. Phytoplankton contain characteristic photosynthetic pigments, of which chlorophyll is the best-known, most abundant and most widely measured. Chlorophyll is frequently used as an indicator of primary productivity in the oceans, although it is not the only pigment that is biologically important.

Chlorophyll in water can be measured using chemical analysis or through remote sensing of ocean color, using satellites. Remote sensing of ocean color, measuring wavelengths that specifically include the color of chlorophyll, can be used to rapidly map large areas of the ocean, in contrast to shipboard water sampling and chemical analysis of chlorophyll. This method, utilizing coastal zone color scanning (CZCS) imagery for chlorophyll, has been used since the late 1970's to remotely map chlorophyll and hence primary production, and to track seasonal and other changes in production (Yoder et al., 2001). For example, Yoder's study focused on a large area of the outer continental shelf off the U.S. east coast, including portions of Georges Bank, the area south and southwest of Martha's Vineyard, and south to Cape Hatteras. This study did not include the Gulf of Maine or Nantucket Sound or the eastern portion of Nantucket Shoals.

Figure 23. Remote sensing satellite data on ocean color (chlorophyll) in the Gulf of Maine and Nantucket Shelf region for January, February, March and April, 2004. These data were downloaded from the Regional Association for Research on the Gulf of Maine (RARGOM) website at http://zeus.mbl.edu/rargom and the Gulf of Maine Ocean Observing System (GoMOOS) website.

Scientists studying primary productivity in the Gulf of Maine have identified several areas where primary production by phytoplankton occurs year-round: Georges Bank, Nantucket Shoals, Browns Bank, and nearshore coastal areas (Thomas et al., 2003). Primary production is affected by bathymetry, temperature, salinity, nutrient concentrations, and tidal mixing of the water column. In deeper parts of the ocean, primary production is limited to the spring and fall. The year-round primary production on Georges Bank is significant because of the important fisheries located here and the stresses on this fishery. The year-round primary production in Nantucket Shoals was noted, but was not a focus of Thomas's study.

SeaWIFS

The SeaWIFS satellite has been used by scientists to map chlorophyll in the Gulf of Maine for several years (see Figure 23 and Thomas et al., 2003). These data, (available online through the Regional Association for Research on the Gulf of Maine (RARGOM) website at http://zeus.mbl.edu/rargom and the Gulf of Maine Ocean Observing System (GoMOOS) website), were collected in early 2004; older data from previous years are available from the website. These maps show that, beginning in January 2004, primary production was already occurring in the shallow Nantucket Shoals and Nantucket Sound area, and on Georges Bank. By April, primary production had expanded to include more of the Massachusetts coast, Georges Bank, and the Gulf of Maine.

This time-series sequence shows that the Nantucket Shelf Region has intense primary production beginning in winter and continuing through the spring and summer. Primary productivity appears to expand outward from this area. Is this apparent expansion real, and why does it occur? The Nantucket Shelf Region also has high primary production compared to other coastal areas. This is significant for fish, shellfish and other marine organisms, and particularly important for commercial and recreational fisheries and for the animals that feed upon these.

8.3. Issues and Data Gaps

So far, there have not been any studies focusing on the primary production within Nantucket Sound, Vineyard Sound or on Nantucket Shoals. It would be important to learn more about such primary production, and how such primary production supports other organisms. If fisheries were to be restored in Nantucket Sound and Vineyard Sound, for example, it would be important to know to what extent the fisheries could be supported by the primary production that occurs here.

The potential effects of coastal nutrient pollution on primary production in Vineyard Sound, Nantucket Sound, or the Nantucket Shelf also have not been addressed through any scientific studies. Coastal nutrient pollution occurs through stormwater runoff, groundwater leachate from septic systems and sewage treatment facilities, boating discharges, agricultural discharges, and other point and nonpoint sources that enter the coastal environment (Natural Resources Council, 2000). Typically, studies of coastal nutrient loading have focused on coastal embayments and nearshore areas, with the exception of monitoring studies of wastewater discharges from ocean outfalls such as the Boston Harbor sewage outfall. Although Nantucket and Vineyard Sounds are swept twice-daily by vigorous tidal currents, the long-term cumulative effects of nutrient inputs on these coastal ecosystems should be investigated. A long-term Ocean Observatory would be suitable for performing such long-term monitoring.

9. BENTHIC FAUNA

9.1. Background

Benthic fauna include invertebrates and certain fish species which live on or in bottom sediments. Benthic fauna include many trophic types: those which graze on algae (grazers), those which strain seawater to get the plankton (filter-feeders), those which feed on plankton and organic matter (suspension-feeders, detritivores), predators, and scavengers. Benthic fauna are an important food source for fish, marine mammals and birds.

Studies of benthic fauna in the Nantucket Shelf Region, focusing on Georges Bank, are summarized by Theroux and Grosslein (1987). In 1871, the U.S. Fish Commission was established to determine the causes of decline in certain fisheries, including investigating benthic fauna; prior to this, benthic faunal studies were primarily done by academic researchers and private scientific societies. After World War II, the Commission's work was expanded, with an emphasis on quantitative population estimates. The Bureau of Commercial Fisheries and the present National Marine Fisheries Service, the successors to the U.S. Fish Commission, continued to investigate benthic fauna due to interest in fisheries, oil drilling, marine mining, and ocean dumping in the Georges Bank-Cape Cod area (Theroux and Grosslein, 1987).

More recent programs investigating the benthic environment of the New England shelf include NOAA's Northeast Monitoring Program (NEMP), the National Marine Fisheries Service' Marine Mapping Assessment and Prediction Program (MARMAP), the Ocean Pulse Program (OP) of the Northeast Fisheries Center (NEFC), and the Woods Hole Oceanographic Institution's Georges Bank Study Group. Benthic sampling for benthic fauna studies has been done at several hundred stations in Nantucket Sound, Nantucket Shoals, the southern New England shelf, Georges Bank, and the Gulf of Maine (reviewed in Theroux and Grosslein, 1987; Pratt, 1973).

A clamshell type grab sampler. NOAA Photo Library

Seafloor image southeast of Nantucket Island, NOAA Photo Library

These studies show that on Georges Bank and the New England region, among 39 groups of benthic macroinvertebrates, four are typically predominant: annelids, crustaceans, mollusks, and echinoderms. However, depending on a number of other factors, such as sediment grain size, water temperature, bathymetry, and whether biomass or numerical densities are used, the relative percentages of these groups varies from area to area (Theroux and Grosslein, 1987).

9.2. Effect of Sediment Type

Sediment type is one of the most important determinants of the distribution and type of bottom-dwelling invertebrates, although water depth, water temperature and other physical and biological factors are important as well. On Georges Bank, for example, coarse to fine sands support the highest biomasses of macroinvertebrates; the coarser the sand, the higher the biomass supported (e.g., coarse sand supports a benthic biomass of 371 grams per meter squared (g/m^2), while fine sand sustains a mean biomass of over 220 g/m^2). Silt and clay support a moderately high biomass of about 200 g/m^2. Mean densities of individuals are highest in the coarsest sands (exceeding 2,000 individuals per meter squared) and decrease as grain size decreases (e.g., clay supports 775 individuals per meter squared) (Theroux and Grosslein, 1987).

Sand fauna are benthic faunal species which are found on clean sand in water depths shallow enough to allow sediment transport to occur at least intermittently (Pratt, 1973). Such habitat is found from sandy beaches offshore to depths of several meters of 30 to 50 meters offshore, depending on exposure. Nantucket Shoals and much of Nantucket Sound and Vineyard Sound and the area south of the Elizabeth Islands provide such sand habitat. Other areas include the shelf areas connecting Cape Cod, Block Island and Long Island.

Sand movement is characteristic of these areas, as evidenced by ripple marks and sand waves, and sediment and water movement is significant. Animals that live in such areas must be adapted to such changing dynamic conditions where burial or undermining of the organism may occur frequently. The benefits of living in such a dynamic environment include high oxygen levels in the water column and in sediments, and abundance of suspended food particles (Pratt, 1973).

Surf Clams. NOAA Photo Library

Important sand fauna species from Nantucket Shoals, Georges Bank and other areas of the sandy shelf region extending from Cape Cod down to Long Island Sound are listed below (from Wigley, 1958, as summarized by Pratt, 1973):

1) Polychaete worms: *Scoloplos fragilis, Nephtys bucera, Nephtys picta, Nereis arenaceodonta, Sthenelais limicola, Spiophanes bombyx, Ophelia, Goniadella, Clymenella* sp., *Aricidea* sp., and *Magelona* sp. (deposit feeders);
2) Bivalves: *Spisula solidissima* (surf clam); *Astarte castanea; Ensis directus* (razor clams; suspension feeders), *Tellina agilis* (deposit feeder).
3) Gastropoda: *Polinices duplicatus* and *Lunatia heros* (predators of bivalves).
4) Amphipods: haustorids (suspension feeders), phoxocephalids and lysianassids (deposit feeders and scavengers).
5) Decapods: *Crangon septemspinosus* (shrimp) and *Cancer irroratus* (crab) (omnivores and scavengers).
6) Echinoderm: *Echinarachnius parma* (Sand dollar, deposit feeder).
7) Ascidians: *Amaroucium* (sea pork) and *Mogula arenata* (sea squirt or tunicate) (suspension feeders).
8) Anthozoa: *Paranthus rapiformis* (anemone) (suspension feeder) in southern area (Mid-Atlantic region).

Silty sand is sand that contains up to 25% silt. The occurrence of a significant amount of fine-grained silts generally indicates that the wave and current energy regime is less than in an area where sand or gravel predominate. The energy regime in an area of silty sand is typically less than the energy regime found in sandy areas. However, sandy areas that are located in deeper water may have moderate energy regimes like the energy regimes found in silty sands or sandy silts closer to shore. In such cases, a quiet deep sandy area may have fauna similar to the fauna found in silty sand habitats (Pratt, 1973).

Benthic macroinvertebrates that are found in silty sand include suspension feeders and deposit feeders living in tubes and burrows. There is often vertical structure within the infaunal community. The types of benthic organisms found in silty sands off southern New England in water depths of 40 to 58 meters includes polychaetes (deposit feeders), bivalves (suspension feeders), including the ocean quahog (Arctica islandica), amphipod crustaceans (deposit feeders, suspension feeders), anemones (suspension feeders), and sea cucumbers (deposit feeders) (Wigley and McIntyre, 1964). Silty sands provide important habitat for the benthic organisms that provide food for fish. Northern groundfish (e.g., cod, haddock, hake, yellowtail flounder, lobsters and crabs) feed on benthic organisms found on silty sands during the winter (Pratt, 1973).

Silt-clay sediments are not common or extensive in offshore waters, being rather characteristic of estuarine sediments and deeper shelf and slope sediments. However, there is an area with a high silt-clay content 40 miles onto the shelf in Southern New England (i.e., the Mud Patch). Silt-clay sediments in deeper shelf and slope areas are not necessarily comparable with silt-clay sediments in shallower estuaries and nearshore environments, because the deeper shelf and slope sediments may represent deposits laid down during lower sea level during a glacial period (summarized in Pratt, 1973; McMaster and Garrison, 1966; McKinney and Friedman, 1970).

Sea Stars. NOAA Photo Library

Characteristic silt-clay benthic fauna include deposit-feeding echinoderms (heart urchin, *Brissaster fragilis*), brittle stars *(Ophiura sarsi, O. robusta,* and *Amphiura otteri)*, sea star (*Clenodiscus crispatus*), deposit-feeding polychaetes and bivalves. Wigley and MacIntyre sampled this fauna off southern New England at 69 to 99 meters water depth, and found high densities of mollusks, mostly bivalves (200 to 500 per square meter), abundant polychaetes, and abundant brittle stars (100 to 700 per square meter). Another study of this area reported 5,314 benthic organisms per square meter, comprising 41% polychaetes, 23% ophiuroids, 19% bivalves, 5.5% coelentera, and 3.4% crustaceans (Sanders, Hessler and Hampson, 1965). The silt-clay fauna is thus important for supporting populations of groundfish as well as migrating continental shelf edge lobsters (Pratt, 1973).

9.3. Biomass

Benthic productivity is important in maintaining the food chain of the ocean. In fact, the term "fish-food biomass" means the organic biomass in sediments available for fish to feed upon. The higher this number, the more food is available for bottom-feeding fish (Pratt, 1973). Benthic productivity is measured by biomass per unit area (grams of organism tissue per meter squared) and by the numbers of individuals per unit area. In the New England shelf area, biomass and population density both tend to decrease as water depth increases. For example, on Georges Bank, benthic biomass is greatest in depths between 25 and 150 meters, while population density tends to be greatest at midshelf depths (50 to 99 meters depth). (Theroux and Grosslein, 1987).

Often a thin layer of fine-grained flocculent organic matter covers the sediment surface, derived from the settling remains of plankton, fecal pellets, animals and plants living in the water column above. This results in a sediment that typically has more organic matter (2%) than sand (1% or less), and hence has greater food value. For example, Wigley and McIntyre (1964) sampled the benthic fauna off southern New England at depths of 40 to 58 meters, and reported an average dry weight concentration of amphipods in sediment of 2-6 g/m^2 dry weight (reported in Pratt, 1973). Closer to shore, Lee (1944) measured dry weight of all benthic organisms at 4.6 g/ m^2, and the concentration of fish food organisms (excluding large bivalves and echinoderms) was 2.3 g/m^2.

Lee (1944) described a quantitative survey of fishing areas in Menemsha Bight off Martha's Vineyard and reported that sandy areas had lower fish-food biomass than silty-sand areas, less than 1 g/m^2 dry weight. However, Wigley (1965) shows a dry weight biomass of greater than 10 g/m^2 in stable sand areas surrounding Nantucket Shoals (Pratt, 1973). Butterfish, scup and summer flounder remain in areas of sandy bottom in the Mid-Atlantic Bight through much of the year (Pratt, 1973).

9.4. Biogeography

In terms of biogeography, the science of the geography of organisms, the offshore region between Cape Hatteras and Georges Bank, from 35 degrees N to about 42 degrees N, is complex and consists of a mixture of warm-water and cold-water species, as well as a number of species endemic to the area. Historically this region has been placed in any one of three benthic faunal provinces, described by Hazel (1970) and reviewed in Theroux and Grosslein (1987):

- A separate province, often called the Virginian Province, with a mild-temperate fauna, lying between a cold-temperate province to the north of Cape Cod (Nova Scotian or Boreal province), and a warm-temperate province (Carolinian) south of Cape Hatteras;
- An area of overlap or transition with a mixture of cold-temperate and warm-temperate fauna, not unique to the region, lying between the Nova Scotian and Carolinian provinces,
- A cold-temperate Boreal Province extending all the way from Cape Cod and Georges Bank to Cape Hatteras (south of which is the warm-temperate Carolinian province).

Different studies support one or another of these zoogeographic provinces, and are summarized in Theroux and Grosslein (1987) and below.

1) Separate province (Virginian province) lying between warmer southern and colder northern provinces

Hall (1964) studied mollusk distributions relative to temperatures required for successful reproduction, and concluded that the Cape Cod/Cape Hatteras region belonged in a separate Virginian province. Hazel (1970) studying ostracodes also concluded that this region was distinct, noting that the warm summer/fall temperatures off Cape Cod, the depth of the Northeast Channel and the high summer temperatures on Georges Bank were all barriers to the southward extension of many cold-water northern species, and similarly that a number of warm-water species reached their northern limit on eastern Georges Bank or off Cape Cod. Briggs (1974) felt that the entire region from Cape Hatteras to the Strait of Belle Isle should be a separate province, the Western Atlantic Boreal Zoogeographic region, based on the criteria of 10% endemism for province status. Watling (1979) showed that 18% of amphipods found from Cape Hatteras to Georges Bank were endemic, thus supporting the Virginian province (reviewed in Theroux and Grosslein, 1987).

2) An area of overlap, mixing, or transition between southern and northern fauna

Stephenson and Stephenson (1954) studied intertidal biota from Cape Cod to Cape Hatteras and concluded that the fauna represented a mixture of cold-temperate animals found north of Cape Cod and warm-temperate animals found south of Cape Hatteras. Kinner (1978) suggested that polychaetes in the Georges Bank-Cape Hatteras region fell into an overlap zone containing both northern and southern species. Bowen et al. (1979) studying benthic crustaceans in the Middle Atlantic Bight also came to this conclusion, finding that Cape Cod formed the northern range limit for numerous warm-water species of crustacea, although Cape Hatteras formed a more effective barrier for some species.

3) Southernmost limit of a cold-temperate Boreal province

Coomans (1962) studying mollusk distributions, decided that this region was mainly Boreal, since only about 10% of the species were endemic and most of the rest were of boreal (cold-water northern) origin. Most of the seastars and starfish in Georges Bank and the Gulf of Maine are related to boreal/subarctic groups, but some species reached their southern range limits along strong bottom-temperature gradients along the margins of Georges Bank and Nantucket Shoals (Franz, Worley and Merrill, 1981).

Theroux and Grosslein (1987) conclude that the benthic zoogeography of Georges Bank has yet to be definitively studied, that while most species are associated with cold-water fauna, there are significant southern associations, and that Georges Bank and nearby areas are clearly within a zone of rapid transition.

Scientists deploy a Bongo-net on Georges Bank. NOAA Photo Library

9.5. Issues and Data Gaps

Because of the importance of benthic fauna in maintaining ocean productivity, and because of concerns about the state of the offshore fisheries in the Nantucket Shelf Region, the study of benthic fauna productivity, ecology, and taxonomy remains important. As climate changes, the physical factors that affect distributions and biomass of benthic fauna, such as water temperature, currents that affect sediment distributions, and primary productivity may change, thus affecting benthic fauna. Monitoring changes in benthic ecology and benthic fauna will continue to be important for understanding the overall ecology and living resources of the Nantucket Shelf Region.

Scientists recover a Chain-dredge on Georges Bank. NOAA Photo Library

Detailed mapping of benthic sediment characteristics and essential fish habitat should be done throughout the Nantucket Shelf Region, building on earlier studies of benthic fauna. Such information would provide a basis for better management of commercial and recreational fisheries in the region. The USGS has recently mapped sediment grain size off the northeast coast, including Nantucket Sound, Nantucket Shoals and the areas offshore of Cape Cod (Poppe and Polloni, 2000). This map provides a regional map of the sediment distribution in this area, and it provides an extremely useful tool for estimating where essential fish habitat may be located, based on extrapolation from other studies of Georges Bank and Stellwagen Bank. However, this mapping effort does not match the degree of detail achieved in high-resolution benthic mapping of Stellwagen Bank, for example.

The comprehensive approach used by USGS-NMFS, utilizing multisensor (sidescan and multibeam sonar, video photography, still photography, sediment sampling) to map and analyze benthic habitats should be applied to mapping Nantucket and Vineyard Sounds, Nantucket Shoals, the Great South Channel, and Georges Bank. The detailed information gained from such a comprehensive approach would provide resource managers with information needed to manage essential fish habitat and other important habitat.

10. FISH, FISHERIES AND SHELLFISH

Cape Cod forms a geographic boundary between the warm waters of the Mid-Atlantic Bight (Virginian zoogeographic province) and the colder waters of the Gulf of Maine (Acadian zoogeographic province), creating a transitional zone in Nantucket Sound and the adjacent shelf areas where warm and cold currents mix, and migratory species reach the extremes of their respective ranges (Ayvazian et al., 1992). This highly productive, dynamic environment sustains a diverse array of marine fish and invertebrate species that support commercial and recreational fisheries, contributing significantly to the economy of the region.

Since 1978, the Massachusetts Division of Marine Fisheries has conducted annual research cruises in spring and fall, utilizing a standardized otter trawl to assess population trends of demersal species. The database provides the most complete assessment of numbers and relative abundance of demersal species in Nantucket Sound during spring and fall. Although some fast-swimming pelagic species are not susceptible to the trawl gear, and a few species may be absent during the survey periods, it is the best long-term database available for Massachusetts Territorial Waters. During this period, over 100 species of fish and invertebrates have been captured, weighed and measured in Nantucket Sound.

Spring survey tows (Table 1) are characterized by adult fish, which migrate into Nantucket Sound for feeding and/or spawning purposes. Historically, the most numerous have been northern searobin (*Prionotus carolinus*), longfin squid* (*Loligo pealeii*), scup (*Stenotomus chrysops*), windowpane flounder (*Scophthalmus aquosus*), winter flounder (*Pseudopleuronectes americanus*), Atlantic herring (*Clupea harengus*) juveniles, little skate (*Leucoraja erinacea*), butterfish (*Peprilus triacanthus*), winter skate (*Leucoraja ocellata*) and Atlantic cod (*Gadus morhua*) juveniles).

Fall survey tows (Table 2) include a larger number of species, characterized by many juvenile fish for which Nantucket Sound is a nursery area where temperature and available food promote rapid growth. Most numerous have been scup, longfin squid*, butterfish, black sea bass (*Centropristis striata*), bay anchovy (*Anchoa mitchilli*), striped anchovy (*Anchoa hepsetus*), northern searobin, little skate, smooth dogfish (*Mustelus canis*) and winter skate.

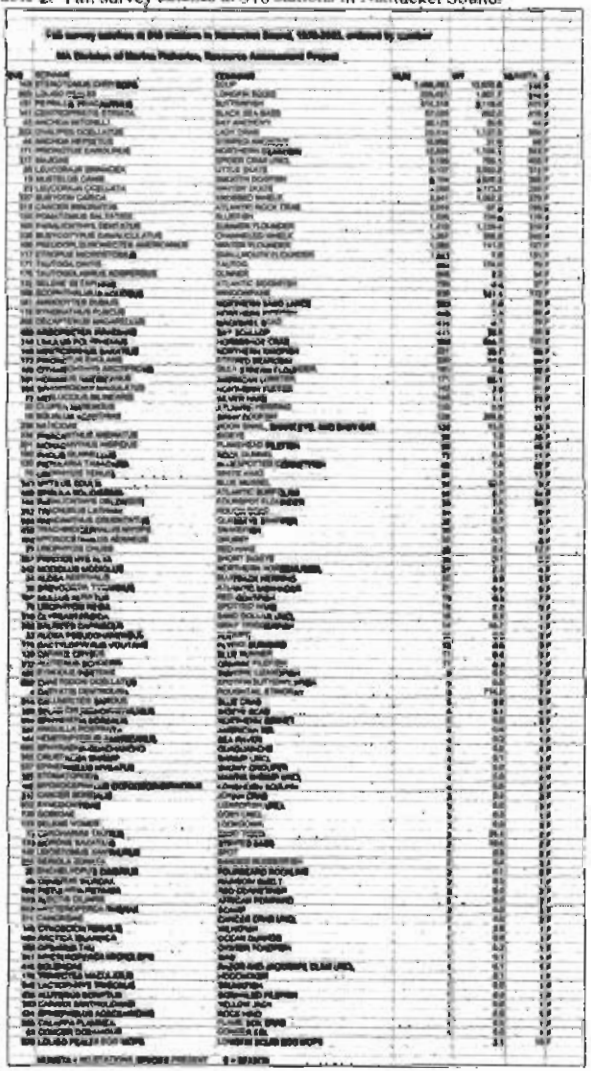
In addition to longfin squid, which is included with the finfish because of its similar life history characteristics, ecological importance and abundance, there are a number of invertebrate species that are susceptible to the survey gear, have been captured in great abundance, and are included here because of their importance in the demersal ecology. These include spider crabs (*Majidae* sp.), lady crab (*Ovalipes ocellatus*), Atlantic rock crab (*Cancer irroratus*), knobbed whelk (*Busycon carica*), and channeled whelk (*Busycotypus canaliculatis*).

A close examination of these data yields insights on the inter-specific relationships that make Nantucket Sound a productive marine ecosystem and important habitat for many species. By examining both weights and numbers of fish captured, the importance of the area as a nursery ground for a number of valuable commercial and recreational species is revealed (J. King, personal communication). The large number of juveniles, both those that are produced in the sound, like squid, and those that are produced outside the sound and migrate or drift in, like cod, thrive on benthic invertebrates and zooplankton in this productive environment, and grow to provide critical recruitment to these migratory populations. Some of the most numerous species, like anchovies, and the large numbers of juveniles of other species, like squid and scup,

Table 1. Spring catch at 522 Nantucket Sound stations.

Spring Catch at 522 Nantucket Sound Stations MA Division of Marine Fisheries 1978 - 2003					
SVS	SCIENTIFIC	COMMON	NUM	WEIGHT	NUMSTA
171	PRIONOTUS CAROLINUS	NORTHERN SEAROBIN	126,955	23,854.5	387
23	LEUCORAJA OCELLATA	WINTER SKATE	5,800	7,575.5	389
108	SCOPHTHALMUS AQUOSUS	WINDOWPANE	21,301	6,242.4	425
143	STENOTOMUS CHRYSOPS	SCUP	30,848	5,310.2	352
317	MAJIDAE	SPIDER CRAB UNCL	47,363	5,148.9	461
106	PSEUDOPLEURONECTES AMERICANUS	WINTER FLOUNDER	14,790	4,555.5	405
28	LEUCORAJA ERINACEA	LITTLE SKATE	7,351	4,445.5	454
903	LOLIGO PEALEI	LONGFIN SQUID	52,299	3,913.6	473
177	TAUTOGA ONITIS	TAUTOG	1,054	1,794.4	147
13	MUSTELUS CANIS	SMOOTH DOGFISH	429	1,602.8	84
15	SQUALUS ACANTHIAS	SPINY DOGFISH	365	1,380.0	46
105	PARALICHTHYS DENTATUS	SUMMER FLOUNDER	879	760.0	200
315	CANCER IRRORATUS	ATLANTIC ROCK CRAB	7,119	703.6	359
141	CENTROPRISTIS STRIATA	BLACK SEA BASS	978	511.8	180
307	BUSYCON CARICA	KNOBBED WHELK	1,777	496.3	136
131	PEPRILUS TRIACANTHUS	BUTTERFISH	8,613	348.8	126
183	MYOXOCEPHALUS OCTODECEMSPINOSUS	LONGHORN SCULPIN	1,044	323.8	159
309	BUSYCOTYPUS CANALICULATUS	CHANNELED WHELK	1,360	320.8	291
316	LIMULUS POLYPHEMUS	HORSESHOE CRAB	227	287.2	112
322	OVALIPES OCELLATUS	LADY CRAB	2,799	230.9	353
139	MORONE SAXATILIS	STRIPED BASS	300	224.8	58
31	ALOSA PSEUDOHARENGUS	ALEWIFE	1,696	127.1	87
530	LOLIGO PEALEI EGG MOPS	LONGFIN SQUID EGG MOPS		90.1	21
301	HOMARUS AMERICANUS	AMERICAN LOBSTER	376	87.6	138
335	NATICIDAE	MOON SNAIL, SHARK EYE, AND BABY-EAR	1,030	80.2	119
172	PRIONOTUS EVOLANS	STRIPED SEAROBIN	532	46.6	36
154	HEMITRIPTERUS AMERICANUS	SEA RAVEN	94	42.6	56
104	PARALICHTHYS OBLONGUS	FOURSPOT FLOUNDER	160	39.0	79
121	SCOMBER SCOMBRUS	ATLANTIC MACKEREL	71	32.9	18
340	MYTILUS EDULIS	BLUE MUSSEL	795	23.3	11
197	LOPHIUS AMERICANUS	GOOSEFISH	3	23.1	1
72	MERLUCCIUS BILINEARIS	SILVER HAKE	887	22.7	82
32	CLUPEA HARENGUS	ATLANTIC HERRING	63,834	19.4	40
77	UROPHYCIS CHUSS	RED HAKE	169	13.6	61
135	POMATOMUS SALTATRIX	BLUEFISH	7	13.2	5
181	AMMODYTES DUBIUS	NORTHERN SAND LANCE	3,156	12.6	36
193	MACROZOARCES AMERICANUS	OCEAN POUT	9	12.7	4
73	GADUS MORHUA	ATLANTIC COD	4,754	9.9	262
402	ARGOPECTEN IRRADIANS	BAY SCALLOP	214	8.5	29
105	LIMANDA FERRUGINEA	YELLOWTAIL FLOUNDER	29	3.7	15
75	POLLACHIUS VIRENS	POLLOCK	1,842	3.4	72
34	ALOSA AESTIVALIS	BLUEBACK HERRING	70	3.3	5
36	BREVOORTIA TYRANNUS	ATLANTIC MENHADEN	5	2.6	2
33	ALOSA SAPIDISSIMA	AMERICAN SHAD	30	2.5	10
28	AMBLYRAJA RADIATA	THORNY SKATE	4	2.0	3
170	TAUTOGOLABRUS ADSPERSUS	CUNNER	852	1.8	84
403	MODIOLUS MODIOLUS	ATLANTIC BUNFOLAM	11	1.8	11
312	CANCER BOREALIS	JONAH CRAB	12	1.6	2
146	EUPRIPA HEROS	NORTHERN MOONSNAIL	13	1.5	9
78	UROPHYCIS TENUIS	WHITE HAKE	113	1.4	63
401	PLACOPECTEN MAGELLANICUS	SEA SCALLOP	14	0.8	3
400	ARCTICA ISLANDICA	OCEAN QUAHOG	2	0.8	2
76	UROPHYCIS REGIA	SPOTTED HAKE	33	0.7	21
186	PHOLIS GUNNELLUS	ROCK GUNNEL	98	0.7	42
314	CALLINECTES SAPIDUS	BLUE CRAB	4	0.7	4
199	OPSANUS TAU	OYSTER TOADFISH	1	0.6	1
413	MERCENARIA MERCENARIA	NORTHERN QUAHOG	1	0.6	1
119	SYNGNATHUS FUSCUS	NORTHERN PIPEFISH	28	0.6	26
148	MENTICIRRHUS SAXATILIS	NORTHERN KINGFISH	2	0.4	2
326	PAGURIDEA	HERMIT CRAB UNCL	6	0.3	2
264	ANGUILLA ROSTRATA	AMERICAN EEL	1	0.3	1
117	ETROPUS MICROSTOMUS	SMALLMOUTH FLOUNDER	34	0.3	26
482	MICROGADUS TOMCOD	ATLANTIC TOMCOD	1	0.3	1
198	CYCLOPTERUS LUMPUS	LUMPFISH	4	0.3	4
83	ENCHELYOPUS CIMBRIUS	FOURBEARD ROCKLING	1	0.1	1
109	CITHARICHTHYS ARCTIFRONS	GULF STREAM FLOUNDER	13	0.1	12
330	CLYPEASTEROIDA	SAND DOLLAR UNCL	10	0.1	1
331	ECHINOIDEA	SEA URCHIN AND SAND DOLLAR UNCL	3	0.1	1
321	STOMATOPODA	MANTIS SHRIMP UNCL	6	0.1	3
188	MYOXOCEPHALUS AENAEUS	GRUBBY	36	0.1	17
3	PETROMYZON MARINUS	SEA LAMPREY	1	0.0	1
170	LIPARIS ATLANTICUS	ATLANTIC SEASNAIL	1	0.0	1
180	ILEX ILLECEBROSUS	NORTHERN SHORTFIN SQUID	11	0.0	4
306	CARCINUS MAENAS	GREEN CRAB	1	0.0	1
182	LUMPENUS LUMPRETAEFORMIS	SNAKEBLENNY	1	0.0	1
43	ANCHOA MITCHILLI	BAY ANCHOVY	5	0.0	2
160	ASTROPHORODES MONOPTERYGIUS	ALLIGATORFISH	2	0.0	1
113	MENIDIA MENIDIA	ATLANTIC SILVERSIDE	5	0.0	3
74	MELANOGRAMMUS AEGLEFINUS	HADDOCK	6	0.0	2

Table 2. Fall survey catches at 516 stations in Nantucket Sound.



are forage for migratory predators that seasonally enter the sound to feed when conditions are favorable. These species, including striped bass, summer flounder, bluefish, Spanish mackerel, bonito and false albacore depend on the concentration of abundant prey species on shoals and sand waves as a critical part of their life histories, sustaining seasonal growth and increasing reproductive potential. The role of Nantucket Sound as a spawning/nursery area and seasonal feeding area qualifies it as essential fish habitat for most of the species listed above. The concentration of predators and prey on shoal areas and other bottom features creates fishing opportunities for commercial and recreational fishermen.

The estuaries along the south shore of Cape Cod represent a different habitat for a similar suite of species. Curley et al. (1971) and (1975) listed a total of 40 finfish species in Waquoit Bay, and 43 species in Bass River (Tables 3 and 4, respectively). The important role of these estuaries in providing nursery areas and primary productivity, contributing to the ecology of Nantucket Sound, cannot be overemphasized.

Table 3. *Relative Abundance of All Species Taken at Seven Finfish Sampling Stations in Waquoit Bay, 1987–1988.*

Species	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.* [1]	Feb.* [1]	Mar.	Apr.	May	Total
Tidewater silverside	597	187	674	671	1,561	2,290	107			812	18	944	7,852
Mummichog	1,273	1,057	817	2,250	1,147	9	16			8	47	524	7,148
Atlantic silverside	656	60	1,320	724	198	33	134			30	95	240	3,490
Striped killifish	43	16	227	201	353	96	10			10	9	58	1,023
Fourspine stickleback	420	131	79	47	30	30	14			38	37	14	840
Winter flounder	27	76	52	78	40	15	7			10	43	49	399
Northern pipefish	146	31	73	15	16	11	2			1	6	7	308
Gunner	18	18	44	36	32	8				2	6	35	199
Sheepshead minnow	4		32	53	64	9	7						169
Threespine stickleback	15	4	30		16	6	8			8	30	14	131
Rainwater killifish	12	47	22	22	19	5	L						128
Atlantic menhaden				116	3	1							120
Tautog	9	21	39	24	10	1				1		5	110
American eel	25	50	8	2		4					2	9	100
Alewife			71	2	8	1						1	83
Atlantic tomcod	23	26	12	1	1		1				5	9	76
Northern puffer			47	2									49
Scup			23	5	13								41
Grubby	11	1	3		2	3	9			1	8	2	40
White hake	15	6	9	4	2								36
Oyster toadfish	5	2	5	3	1						5	13	36
Pollock	1										15	2	18
American sand lance	3	2			3	2					1	1	10
Rainbow smelt			3	1	1					1	1	2	9
Atlantic needlefish		1	3	1									5
Blueback herring			4										4
Northern searobin			1	3									4
Rock gunnel	3	1											4
Summer flounder		2	2										4
Atlantic cod	2												2
Bluefish				2									2
Ninespine stickleback			1									1	2
Black seabass					1								1
Golden shiner			1										1
Longhorn sculpin						1							1
Lumpfish							1						1
Striped bass					1								1
Striped mullet					1								1
Striped searobin			1										1
Blackspotted stickleback											1		1

[1] No sampling was conducted in January due to ice.
[2] Only Station 4 (East Flat) was sampled in February.

Table 4.

Numerical Rank of Finfish Species Taken in Bass River During Monthly Beach Seine Sampling, 1970-1971

	1970			1971										
	10/5	11/3	12/3	1/12	3/16	4/6	4/21	5/5	6/7	7/1	7/21	8/2	8/18	9/16	Total
Atlantic silverside	907	403	357		398	57	1246	348	70	4110	3125	2069	3499	3283	19,872
tidewater silverside	3432	4087	596		15	11	2	55	186	1443		350		1	10,176
mummichog	507	962	315		17	9	8	44	561	854	755	3558	1979	6	9,575
striped killifish	527	265	275			1	1	3	105	618	1120	1991	1464	39	6,409
fourspine stickleback	160	384	54		34	9	1	124	95	23	1	184	10	7	1,086
Atlantic menhaden												600			600
American sand lance			5		493	5		1							505
Atlantic herring							160								160
northern puffer											4	116	21	1	142
Atlantic needlefish	4									14	10	27	44	36	135
northern pipefish	36	1				1			6	10	4	35	3	1	97
striped mullet									1			8	21	56	86
crevalle jack												2	19	58	79
winter flounder	6	6	9		1		3		1	13	2	8	2	8	57
sheepshead minnow	18	3	1									1	18		41
scup														36	36
alewife			6							14	4	2		7	33
American eel	2				1			1	1	13		11	1	2	32
striped searobin										1	7	12	5	1	26
threespine stickleback		1				1	1	14	6						23
black sea bass	16														16
oyster toadfish	1											3		3	7
rainwater killifish	2	1												1	4
blue runner												3			3
bluefish	2											1			3
Atlantic tomcod															2
blueback herring	1							2			1				2
northern kingfish												1			1
tautog												1			1

	1970			1971									
	10/13	11/10	12/15	2/23	3/9	4/8	5/11	6/8	7/6	8/6	8/18	8/18*	9/23	Total
fourspine stickleback			4		17	18	2	60	6		35	6	59	207
winter flounder	1			1	3	9	20	6	3	1	8	10	1	63
black sea bass											31	11	11	53
oyster toadfish							12	5	6	1	7	3	2	37
tautog							1			1	1	2	32	36
American eel							1	15	12	3	3		2	36
scup												17	18	35
mummichog											4	20	3	27
northern pipefish								2		3	4	4	2	15
Atlantic tomcod					1		2	6	1			1	2	13
Atlantic menhaden										1		7		8
tidewater silverside			6								2			8
common searobin									3		2	2		7
cunner											1	1	3	5
alewife						2							1	3
hogchoker								1	1			1		3
Atlantic silverside										1			1	2
orange filefish												1	1	2
smooth dogfish												2		2
lookdown										1				1
northern puffer													1	1
planehead filefish												1		1
striped bass												1		1
striped searobin											1			1
threespine stickleback						1								1

*Supplementary night sampling

10.1. Commercial Fisheries

Cod fishermen early 1900s. photo: NOAA library

Nantucket Sound has historically supported a variety of important commercial fisheries for finfish and invertebrate species that have contributed to the local character and economy since the colonial era. Traditional methods, which in some cases predate the earliest European settlement, are commonly used in the area.

Fish weirs, which consist of netting hung on wooden poles driven into the bottom, with a long leader guiding fish into a heart-shaped trap, are one of the oldest forms of passive fishing, still practiced on the shoals west of Monomoy Island, in the eastern end of the sound and along the south shore of Cape Cod. Schooling fish typically encounter the leader as they follow the shoreline, and swim into the trap. Landings in recent years have included Atlantic, king, and Spanish mackerel, squid, scup, butterfish, and bluefish, and have exceeded a million pounds in recent years (Division of Marine Fisheries).

Hooks on baited longlines, rod and reel, or handlines are used by a large fleet of small dayboats fishing from Chatham, Harwich, and other Cape and Islands Towns. Cod are targeted during early spring and late fall on Nantucket Shoals and the Great South Channel and east of Cape Cod, and some boats travel farther offshore to fish for haddock. Some of these boats switch to bluefin tuna and striped bass during the summer and early fall to take advantage of the migrations of these high-value species. Other species commonly landed by hook and line include pollock, bluefish, summer flounder, scup and black sea bass. Harpoons are also used to take bluefin tuna east of Cape Cod. Gillnets, although not allowed in Nantucket Sound or in state waters to the south, are fished by a number of Chatham vessels east of Cape Cod.

Fishing on the Bank. photo: NOAA library

A variety of baited pots and traps hauled to the surface are used to fish for lobster, black sea bass, scup, and conchs. Although few lobster pots are fished inside the sound, lobster vessels from Cape and Islands ports fish at the extreme eastern and western ends, in Vineyard Sound and south of the Islands. Black sea bass and conch are potted throughout the sound. A total of 35 vessels fished black sea bass pots in 2000, and landed a reported 625,902 pounds. In the same year, 39 conch potters reported landings of 1,078,956 pounds (Division of Marine Fisheries).

Larger vessels towing otter trawls fish seasonally in the sound as quotas and regulations allow. They fish mainly for squid, flounders (summer flounder, winter flounder, and windowpane), scup, conchs and horseshoe crabs. Landings by trawlers in 2000 included 637,522 pounds of squid and 508,785 pounds of summer flounder, most from Nantucket and Vineyard Sounds (Division of Marine Fisheries). South and east of Cape Cod these vessels also pursue groundfish, including cod, haddock, and yellowtail flounder.

Commercial fishing for migratory species found south of Cape Cod is subject to fisheries management plans developed outside Massachusetts, either by the Atlantic States Marine Fisheries Commission or the Mid-Atlantic Fisheries Management Council, and most species are subject to strict quotas. Although the center of Nantucket Sound beyond three miles from shore is Federal water (Exclusive Economic Zone), it falls under the fisheries management authority of the Commonwealth, and is subject to regulations of the Division of Marine Fisheries. Commercial landings from lower Cape Cod ports (Provincetown – Chatham) totaled 15.4 million pounds worth 15.2 million dollars. (NOAA Fisheries). A large percentage of these landings are from the Nantucket Shelf and the Great South Channel.

10.2. Recreational Fisheries

Although it is difficult to separate the number of Nantucket Sound anglers from the rest of the Massachusetts coastline, they surely number in the hundreds of thousands. Statewide, about 800,000 marine anglers generate nearly a billion dollars in annual economic activity, and Nantucket Sound is one of the most popular fishing areas. From early spring to late fall a succession of migratory species are available to local anglers and tourists. In early spring, winter flounder and white perch are found in the estuaries. Spring brings tautog, scup and black sea bass, along with the premier sport fish, striped bass. Late spring brings bluefish and summer flounder.

More exotic species like bonito, false albacore and Spanish mackerel arrive in mid-summer and stay through early fall when the warmest water temperatures occur. South of the Islands, at the edge of the shelf, offshore sportfishing vessels fish for large oceanic pelagic species, such as blue marlin, white marlin, swordfish, bluefin tuna, yellowfin tuna, blue shark and mako shark. Fishing occurs from shore and from large numbers of private vessels. Approximately 150 charter and party vessels are available for hire, making it easy for visitors to access productive fishing areas. The close association with tourism makes recreational fishing one of the most important activities contributing to the economy of Cape Cod and the Islands.

10.3. Anadromous Fish

Most of the rivers and large streams entering Nantucket Sound from Cape Cod and the Islands provide spawning habitat or access to freshwater ponds for spawning by river herring. Blueback herring spawn in the rivers, while alewives ascend the rivers to freshwater ponds to spawn. River herring are an important component of the forage base, providing food for striped bass and other large predators during the spawning run and when spent fish return to the Sound. During fall, large schools of juvenile herring migrating from fresh to salt water are preyed upon by a wide variety of fish and avian predators, forming an important component of the forage base. Figure 24 shows the location of anadromous fish runs and fish passage facilities bordering Nantucket Sound.

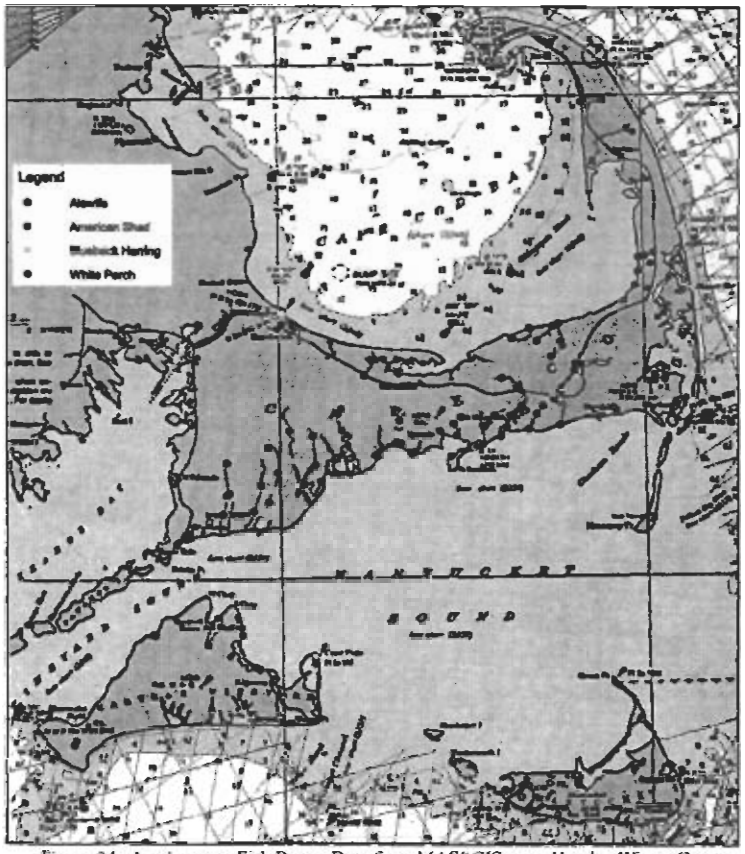


Figure 24. Anadromous Fish Runs. Data from MASSGIS, map Horsley Witten Group.

10.4. Catadromous Fish

Most of the rivers and streams in the area are inhabited by American eels. The entire population of this species spawns in the Sargasso Sea area of the South Atlantic. Larvae drift north in the Gulf Stream and eventually reach the shoreline. Since they have no control over where they reach landfall, they are assumed to ascend the nearest freshwater stream and morph into elvers, then juvenile eels. They may live for many years in fresh water before making the return journey to spawn, while some stay in the brackish estuaries. The adults are trapped commercially and are valued as food by certain ethnic groups, while the juveniles are prized as bait for striped bass.

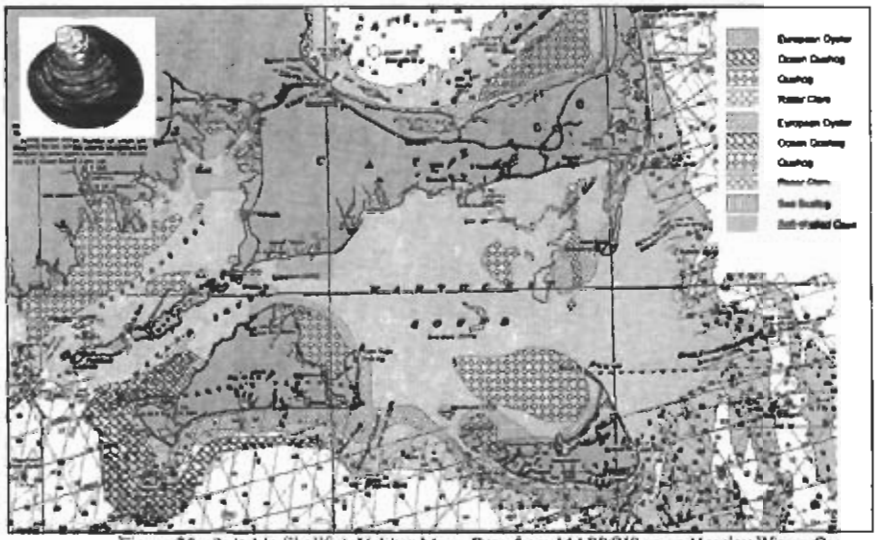


Figure 25. Suitable Shellfish Habitat Map. Data from MASSGIS, map Horsley Witten Group.

10.5. Shellfish

In Massachusetts, coastal towns have primary management authority over shellfish resources within their boundaries. Each of the towns bordering the sound has a variety of shellfish species that provide a source of employment and recreation. These include the hard clam or quahog, soft-shelled clam, blue mussel, American oyster, and bay scallop. Also under town control with state oversight are a number of private aquaculture operations raising shellfish in controlled culture. A total of 31 sites in the estuaries bordering the sound are licensed to aquaculturists raising quahogs and oysters (Moles, 2002). Offshore, there are state-managed species such as surf clam and ocean quahog, which are harvested by large dredge vessels around and south of the Islands. There are also offshore populations of bay quahog in the eastern end of the sound and on the shoals that are harvested by dredge boats. Just outside state waters on the shelf east of Chatham and Nantucket there are vessels dredging for sea scallop and blue mussel. Figure 25 shows the mapped areas of known shellfish habitat in nearshore areas of the Nantucket Shelf area (from MassGIS).

10.6. Issues and Data Gaps

Rapid development of the coastal zone of the Cape and Islands has created challenges for shellfish managers, including greatly increased numbers of recreational and commercial harvesters and increased non-point contamination of growing waters. From 1990 to 2002, Cape Cod's population grew 21% to nearly 250,000 year-round residents (Cape Cod Times, 7/27/04). Thanks to aggressive local, regional and state programs to abate non-point pollution, most areas are still suitable for shellfishing, at least on a seasonal basis, and DMF programs to monitor bacterial contamination and paralytic shellfish poison ensure that the public can continue to safely enjoy the benefits of safe shellfish resources.

Given the rich and abundant fisheries and fishing activities that exist in Vineyard and Nantucket Sounds, it is surprising that no systematic in-depth benthic habitat surveys, like those conducted by the USGS and NMFS for Stellwagen Bank and Georges Bank, have ever been conducted in these areas, for the purpose of assessing the condition of the benthic habitat and informing coastal fisheries managers. The lack of such studies is a serious and significant information gap that should be addressed by coastal managers seeking to restore essential fish habitat.

The importance of nursery habitat needs to be understood thoroughly. In a recent review of the science of nursery habitats in marine and coastal ecosystems, a panel of scientists concluded that, although the concept of nursery habitat has been used by resource managers, nursery habitat has not been clearly defined and therefore identification of valuable nursery habitat has been hindered (Beck et al., 2003). The best measure of nursery habitat value may be tracking the number of individuals that move from juvenile to adult habitats, while the best single measure of the value of juvenile habitats is the total biomass of individuals added to adult populations.

Shellfisherman, photo NOAA archive

11. MARINE MAMMALS

11.1. Marine Mammal Occurrences

In the Nantucket Shelf region, the Great South Channel, Stellwagen Bank and Georges Bank are the premier areas for congregation, feeding and passage of marine mammals, including seals,right whales, humpback whales, fin whales, and Atlantic white-sided dolphins (Figures 26, 27). Sharks and pelagic and demersal fish and seabirds also are attracted to this area because of the copepod blooms that occur in spring.

Few whales enter Nantucket or Vineyard Sound, although some have been observed over the years (Pilson and Goldstein, 1973). Smaller marine mammals such as seals and dolphins do enter the Sounds.

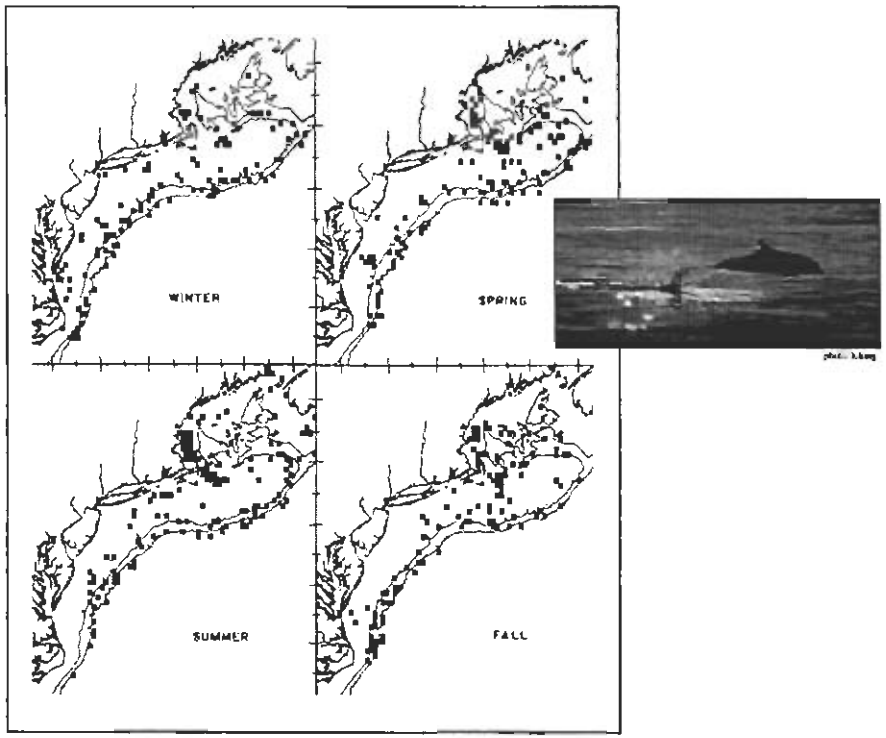


Figure 26. Seasonal patterns of the top 10% of total cetacean biomass per unit effort values. Kenney and Winn (1986).

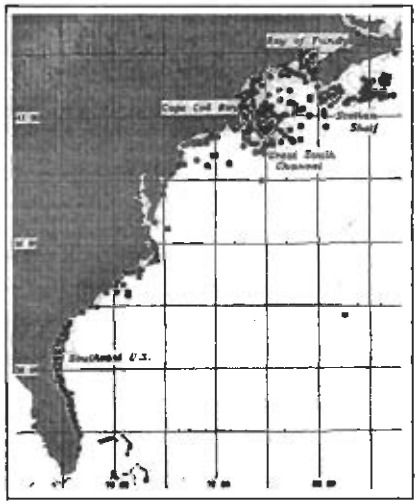


Figure 27. Distribution of sightings of right whales (*Eubalaena glacialis*) in the western North Atlantic, identifying the five primary habitats which are currently known. Kenney et al. (1995).

In the area between Cape Cod and Cape Hatteras, the following marine mammals are found (Pilson and Goldstein, 1973) (Table 5). Food preferences are noted.

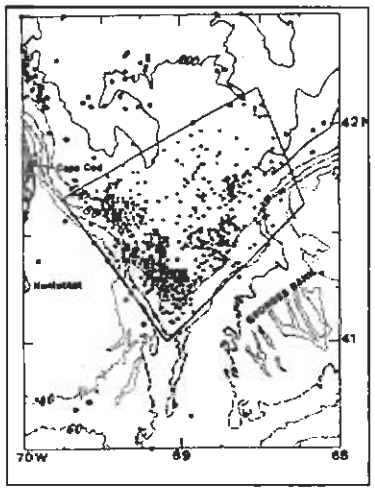
Table 5. Marine Mammals Occurring Between Cape Cod and Cape Hatteras (Pilson and Goldstein, 1973).

Family	Genus and Species	Common name	Food
Odobenidae	*Odobenus rosmarus*	Walrus	Clams
Phocidae	*Phoca vitulina*	Common (Harbor) seal	Fish
	Halichoerus grypus	Gray seal	Fish, squid
	Pagophilus groenlandicus	Harp seal	
	Cystophora cristata	Hooded seal	Fish, squid, shrimp, mussels, starfish
Balaenidae	*Balaena glacialis*	Right whale - Endangered	Planktonic crustaceans (e.g., copepods, others)
Balaenopteridae	*Balaenoptera acutorostrata*	Minke whale	Fish (esp. herring)
	Balaenoptera borealis	Sei whale - Endangered	Plankton (e.g., copepods)
	Balaenoptera physalus	Fin whale - Endangered	Pelagic crustaceans (e.g., euphausiids), capelin, and herring
	Balaenoptera musculus	Blue whale (Gulf of Maine) - Endangered	Plankton and krill
	Megaptera novaeangliae	Humpback whale - Endangered	Krill, capelin, sand lance, and herring-sized fish

(Table 5. continued) Marine Mammals Occurring Between Cape Cod and Cape Hatteras
(Pilson and Goldstein, 1973).

Delphinidae	*Tursiops truncatus*	Bottle-nosed dolphin	Fish, birds, sea lettuce (*Ulva*), other
	Grampus griseus	Grampus or Risso's dolphin	Squid
	Lagenorhynchus albirostris	White-beaked dolphin	Whiting, whelk, capelin, cod, squid, hermit crabs, other crustaceans
	Lagenorhynchus acutus	White-sided dolphin	Herring and squid
	Stenella dubia	Spotted dolphin	Fish and cephalopods (e.g., squid, octopus)
	Delphinus delphis	Common dolphin	Fish
	Pseudorca crassidens	False killer whale	Squid, octopus, fish
	Globicephela melaena	Pilot whale	Squid, cod
	Globicephala macrorhyncha	Short-finned pilot whale	Squid, cod
	Orcinus orca	Killer whale	Seals, porpoises, sea otters, birds, fish, squid, octopus, leatherback turtles
	Phocoena phocoena	Harbor porpoise	Pilchard, herring, mackerel, whiting, hake, pollock
Monodontidae	*Delphinapterus leucas*	Beluga or white whale	Anadromous fish, squid, bottom-living fish, invertebrates
Physeteridae	*Physeter catodon*	Sperm whale	Squid, octopus, halibut, bottom fish, sharks
	Kogia breviceps	Pygmy sperm whale	Squid, crabs, shrimp
	Kogia simus	Dwarf sperm whale	Squid, crabs, shrimp?
Ziphiidae	*Mesoplodon bidens*	North Sea beaked whale	Squid?
	Mesoplodon mirus	True's beaked whale	Squid, octopus, occasionally fish
	Mesoplodon densirostris	Dense-beaked whale	No information
	Ziphius cavirostris	Goose-beaked whale	Cuttlefish and squid?
	Hyperoodon ampullatus	North Atlantic bottle-nosed whale	Squid, occasionally herring and other fish

From this list, it is apparent that the marine mammals found in this region are either carnivorous or planktivorous; that is, none feed upon vegetation solely. This is probably related to their caloric needs to sustain their large body masses. For example, a Right Whale needs a food density of 7.57 to 2,395 kilocalories per cubic meter (1 kilocalorie = 1 dietary calorie for humans) in order to maintain itself (Kenney et al., 1986). This energy requirement is believed to drive the Right Whale to seek out areas of the ocean where their favorite food is highly concentrated, much as humans seek out supermarkets.
This concentration of food required is about 1 to 3 orders of magnitude greater than the highest concentrations of calories found in the Great South Channel, an area where the spring bloom of a particular species of copepod, *Calanus finmarchicus*, provides such a nutritional boost, attracting Right Whales to congregate here in high densities (Kenney and Wishner, 1994; Kenney et al., 1994; Kenney et al., 1986). Figure 28 shows all right whale sightings in the Great South Channel between 1975 and 1989 (National Marine Fisheries, 1991).



Right Whale flukes.

Figure 28. All right whale sightings in and near the proposed Great South Channel critical habitat between 1975 and 1989. Sightings within the proposed critical habitat are shown by + symbols; sightings outside by "o". bathymetry shown in meters. N = 942 sightings.
From National Marine Fisheries Service (1991).

Right whales must therefore have to be efficient in collecting their food, given that the optimum food concentration occurs only occasionally. The Right whale is also unusual in that it is an apex predator, yet feeds low on the food chain, on copepods, in particular *Calanus finmarchicus* (Kenney and Wishner, 1995). Only several hundred Right whales exist in the western North Atlantic population, and together with the Southern hemisphere population, they are the most endangered large whale species in the world. Aside from hunting, the lack of dense food sources in the ocean may account for their failure to recover as a species (Kenney et al., 1995).

The nutrient processes that sustain the growth of phytoplankton that *Calanus* feeds upon are not well understood. In a program to study the physical oceanography, biology, and chemistry of the Great South Channel, called the South Channel Ocean Productivity Experiment (SCOPEX), Kenney and Wishner (1995) cited three possible mechanisms for the high concentrations of *Calanus* and other zooplankton in the Great South Channel:

> Hypothesis 1: The *in situ* productivity hypothesis. There is an increase in primary productivity because of added nutrients from upwelling and/or mixing in the Great South Channel, and a transfer of energy up the food chain, resulting in increased zooplankton abundance.
>
> Hypothesis 2: The advection hypothesis. There is a continuous advection of zooplankton from source regions outside the Great South Channel into the Great South Channel, where the hydrographic features (e.g., circulation patterns, tides, basin geometry, ec.) result in a concentration of zooplankton. The concentration mechanisms may involve an interaction between the oriented swimming behavior of the zooplankton and the regional hydrography.
>
> Hypothesis 3: The behavior hypothesis. There is a behavioral (possibly ontogenetic) tendency to form dense patches ("swarming"). This would not necessarily require any overall increase in average water column abundances in zooplankton.

The SCOPEX studies did not provide evidence for localized upwelling that would bring nutrient-rich water to the surface to enhance primary productivity, and Kenney and Wishner concluded that the *in situ* productivity hypothesis could be ruled out. Copepods do appear to be carried into the area in a southward-flowing low salinity plume on the western side of the Great South Channel. This suggests that the advection hypothesis may be true. The behavior hypothesis was partially addressed during the SCOPEX experiments (Durbin et al., 1995), although this study focused on vertical rather than lateral migration.

Even less understood is the role of the Nantucket Shelf region, and in particular Nantucket Sound and Nantucket Shoals, in nutrient cycling and dynamics. The Nantucket Sound and Nantucket Shoals regions are very well mixed due to the strong tides, currents and winds in this area. In fact, there is a distinct boundary between the well-mixed Nantucket Shoals water and the water flowing through the Great South Channel. This boundary, or "mixing front", is located approximately 10 km east of Nantucket Shoals (Chen et al., 1994a, 1994b). This mixing front located east of Nantucket Shoals is significant for ecosystem dynamics because it represents a place where the well-mixed water of the Sound and Shoals, carrying nutrients, salt, and any pollutants from human activities on land, feeds into the more stratified or layered waters of the Great South Channel.

11.2. Issues and Data Gaps

Little or no information is available concerning nutrients in Vineyard Sound, Nantucket Sound and Nantucket Shoals, and how such nutrients may affect offshore shelf ecosystems. Available data concerning nutrient loading come from studies of coastal embayments along Cape Cod. These data indicate that developed coastal embayments are generally suffering from nutrient loading. Once nutrients and other pollutants enter Nantucket Sound or Vineyard Sound, however, they are generally assumed to be diluted by rapid mixing. One major question is how much nutrient loading Nantucket Sound or Nantucket Shoals could accommodate before beginning to show signs of ecological stress. This question has not been addressed for Nantucket Sound or Nantucket Shoals. The impact upon marine mammals has yet to be studied.

It is clear that marine mammals depend upon fish, shellfish and other invertebrates for their food, and that the collapse of marine fisheries and damage to benthic habitats must therefore affect marine mammal populations. There are no studies of benthic habitat, prey densities and marine mammal ecology for Nantucket or Vineyard Sounds or Nantucket Shoals. Such studies have been conducted on Georges Bank and in the Gulf of Maine for humpback whales and fin whales and one of their important prey species, sand lance (*Ammodytes americanus*) (Payne et al., 1985; Meyer et al., 1979). In order to help restore these populations, which include endangered species, a holistic ecosystem restoration must take place which includes restoration of benthic habitat for invertebrates and restoration of fish populations.

If the Nantucket Shelf region serves an important role in fisheries and benthic habitat (as is indicated by the fisheries activities), then we may hypothesize a "spillover effect" of prey populations that spread into adjacent shelf regions via the rapid currents; this remains to be tested, however. This hypothesis is like the "advection hypothesis" posed by Kenney and Wishner (1995) to explain why copepods are abundant in the Great South Channel; they appear to be carried in, or advected into, the Great South Channel, where they proceed to mature.

12. BIRDS

12.1. Coastal and Marine Species

photo: NOAA library

The shores of Cape Cod and the islands provide important migratory, resting, breeding and nesting areas for a large number of migratory coastal and marine birds. In particular, pelagic birds and waterbirds have formed colonies in various coastal areas (Figure 29 and Table 6, Veit and Petersen, 1993). Several of the largest tern colonies in New England are located within 20 miles of Horseshoe Shoals. Approximately 50 percent of the North American population of federally endangered Roseate Terns breeds in Buzzards Bay (U.S. Fish and Wildlife Service, 1998) and in 2003, approximately 10,000 pairs of Common Terns nested at Monomoy (Carolyn Mostello, personal communication to Perkins et al., 2003). In late summer during the fall migration, the Roseate Terns that stage in Chatham may represent nearly the entire North American population of Roseate Terns (Trull et al., 1999).

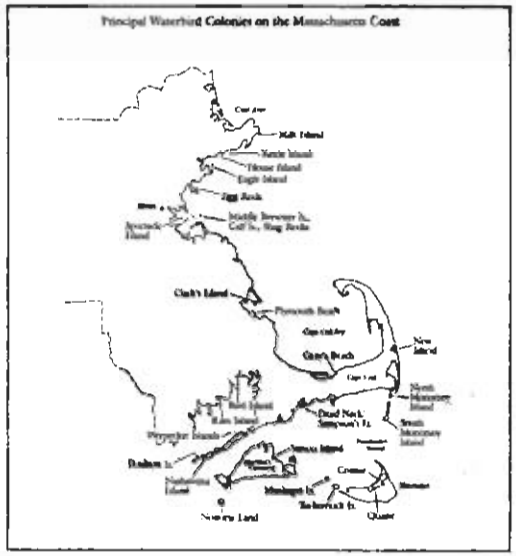


Figure 29. Principal Waterbird Colonies on the Massachusetts Coast. From Veit and Petersen (1993).

Table 6. Principal areas in Massachusetts where waterbirds form colonies (Veit and Petersen, 1993).

Colony Name	Double-crested Cormorant	Great Egret	Snowy Egret	Little Blue Heron	Cattle Egret	Black-crowned Night-Heron	Glossy Ibis	Laughing Gull	Herring Gull	Great Black-backed Gull	Roseate Tern	Common Tern	Arctic Tern	Least Tern
Milk Island	717								1330	700				
Kettle Island			33	4		18	11		437	46				
House Island									280	75				
Eagle Island			2		2	42			375	50				
Egg Rock	304								135	62				
Spectacle Island		1	40			60	10		920	36				
Middle Brewster Island	92		124			270			1400	116				
Calf Island			25			50	1		810	149				
Shag Rocks	886								17	3				
Clark's Island		2	127	1		285			1813	156				
Plymouth Beach											6	1114	6	17

Colony Name	Double-crested	Great Egret	Snowy Egret	Little Blue Heron	Cattle Egret	Black-crowned Night-Heron	Glossy Ibis	Laughing Gull	Herring Gull	Great Black-backed Gull	Roseate Tern	Common Tern	Arctic Tern	Least Tern
Gray's Beach											64	856		
Dead Neck/ Sampson's Island			1			20			300	90	53	164		15
New Island								254			40	1540	6	
North Monomoy Island								800	570	63	2	1200	3	2
South Monomoy Island			65			82			13,951	4933				35
Bird Island											1656	810		
Ram Island									500	90				
Warpecken Islands	1135								658	130				
Nashawena Island			30			20			930	200	2	145		68
Penikese Island									383	8				
Bergen Island			3						175	5		250		

(Table 6. continued)

Colony Name	Double-crested Cormorant	Great Egret	Snowy Egret	Little Blue Heron	Cattle Egret	Black-crowned Night-Heron	Glossy Ibis	Laughing Gull	Herring Gull	Great Black-backed Gull	Roseate Tern	Common Tern	Arctic Tern	Least Tern
Nomans Island			13			60			1200	200	3	150		3
Muskeget Island									250	750				
Tuckernuck Island									800	400				250
Coatue		1	11			42			970	679				
Quaise		1	45			8								

Shaded rows represent areas bordering Nantucket and Vineyard Sounds.

Although land observations and banding studies of birds are abundant due to public interest in birdwatching, these types of studies provide data only at points where humans catch or observe the birds, which are generally on land or occasionally at sea. The detailed migration paths and patterns of birds through the Nantucket Shelf area has generally not been studied, with one exception: a study by the Massachusetts Audubon Society, conducted in 2003, to study tern activity within Nantucket Sound during the 2003 breeding season, and in particular activity of the endangered Roseate Tern (Perkins et al., 2004). This study is important because it used rigorous methods for observing and documenting avian use of airspace over the water.

Perkins' team used aerial flights and boat surveys across a portion of Nantucket Sound (Horseshoe Shoals) and collected data on abundance, distribution, behavior, flight heights, and temporal changes in behavior of Common Terns and the federally endangered Roseate Tern (Figures 30 and 31, Perkins et al., 2004). Their results showed that:

1) The greatest numbers of birds of both species were documented early in the survey period (May through the first half of June); numbers decreased thereafter, with one peak in late July.
2) Most of the birds observed on Horseshoe Shoals were traveling rather than fishing or sitting on the water ("rafting").
3) Slightly greater numbers of birds were recorded on the southern part of Horseshoe Shoals, possibly in response to stronger currents that create stronger upwelling, bringing plankton and baitfish near the surface for terns to feed upon;
4) The Monomoy colony contained about 63 percent of all the breeding Common Terns in Massachusetts (approximately 10,000 pairs).
5) The altitude range of all traveling terns was between 5 and 250 feet, with an average height of 29 feet (median height of 25 feet).
6) Horseshoe Shoals may be more important as a migratory stopover point or "refueling" area than as a feeding area for locally nesting resident terns.

Other state-listed endangered or threatened birds that utilize the shores of the Cape and islands include the Piping Plover (*Charadrius melodus*) and potentially the Bald Eagle (*Haliaeetus leucocephalus*) (Massachusetts Natural Heritage and Endangered Species Program).

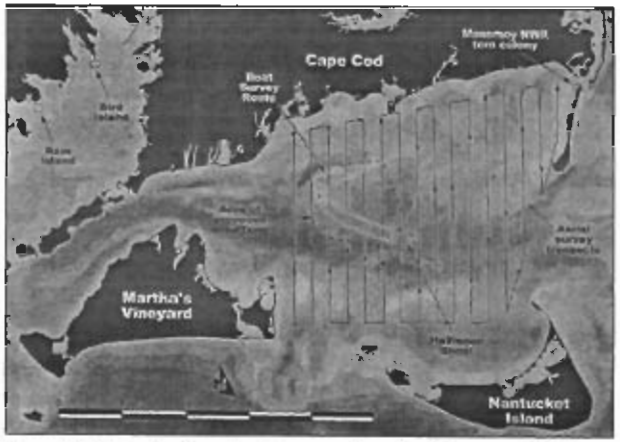


Figure 30. Nantucket Sound study area and associated features, including aerial and boat transect routes, and the area of proposed wind farm, major tern colonies. Figure 1 from Perkins et al. (2004).

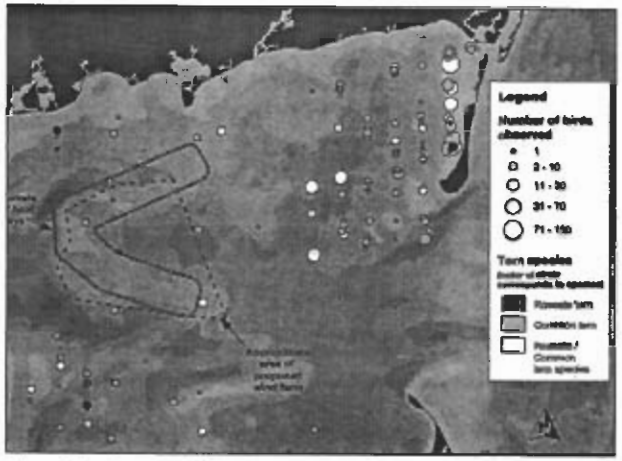


Figure 31. Summary distribution map of terns by species observed during 2003 breeding season aerial surveys of Nantucket Sound. Number of terns seen at any one location represents the combined total of three aerial surveys and the magnitude indicated by the diameter of the circle. Perkins et al. (2004).

In all, a total of 190 species of marine and coastal birds have been observed along the entire Atlantic coast from Florida to Maine (Table 7). Of these, which approximately 131 species have been observed along the Massachusetts coast along the Atlantic Flyway, in the nearshore area or far offshore (Hoopes et al., 1994, 4 volumes). These species are listed below (note that many of these sightings would be rare, occasional, observed only far offshore, or accidental):

Table 7. Marine and Coastal Birds observed along the Atlantic Coast. From Hoopes et al. 1994.

Red-Necked Grebe	Black Tern	Harlequin Duck	Sanderling
Horned Grebe	Black Skimmer	Common Eider	Bar-Tailed Godwit
Pied-Billed Grebe	Black-Browed Albatross	King Eider	Willet
Common Loon	Northern Fulmar	Black Scoter	Ruff
Arctic Loon	Cory's Shearwater	White-Winged Scoter	Buff-Breasted Sandpiper
Red-Throated Loon	Greater Shearwater	Surf Scoter	Eurasian Curlew
Atlantic Puffin	Manx Shearwater	Ruddy Duck	Whimbrel
Black Guillemot	Audubon's Shearwater	Canada Goose	Black-bellied Plover
Common Murre	Black-Capped Petrel	Brant	Killdeer
Thick-Billed Murre	Leach's Storm-Petrel	Barnacle Goose	Piping Plover
Razorbill	Wilson's Storm-Petrel	Mute Swan	Ruddy turnstone
Dovekie	White-Faced Storm-Petrel	Wood Stork	American Oystercatcher
Great Skua	White-Tailed Tropicbird	American Bittern	Northern Harrier
South Polar Skua	Brown Booby	Least Bittern	Bald Eagle
Pomarine Jaeger	Northern Gannet	Great Blue Heron	Peregrine Falcon
Parasitic Jaeger	Great Cormorant	Great Egret	Osprey
Long-Tailed Jaeger	Double-Crested Cormorant	Snowy Egret	Belted Kingfisher
Ivory Gull	Common Merganser	Tricolored Heron	
Black-Legged Kittiwake	Red-Breasted Merganser	Little Blue Heron	
Glaucous Gull	Hooded Merganser	Cattle Egret	
Iceland Gull	Mallard	Green-Backed Heron	
Great Black-Backed Gull	American Black Duck	Black-Crowned Night Heron	
Lesser Black-Backed Gull	Gadwall	Yellow-Crowned Night Heron	
Herring Gull	Eurasian Wigeon	King Rail	
Ring-Billed Gull	American Wigeon	Virginia Rail	
Common Black-Headed Gull	Green-Winged Teal	Sora	
Laughing Gull	Blue-Winged Teal	Yellow Rail	
Franklin's Gull	Northern Pintail	Red Phalarope (oceanic)	
Bonaparte's Gull	Wood Duck	Black-Necked Stilt	
Little Gull	Redhead	Long-Billed Dowitcher	
Ross's Gull	Canvasback	Stilt Sandpiper	
Sabine's Gull	Greater Scaup	Red Knot	
Forster's Tern	Lesser Scaup	Purple Sandpiper	
Common Tern	Ring-Necked Duck	Pectoral Sandpiper	
Arctic Tern	Common Goldeneye	White-Rumped Sandpiper	
Roseate Tern	Barrow's Goldeneye	Dunlin	
Least Tern	Bufflehead	Semipalmated Sandpiper	
Bridled Tern	Oldsquaw	Western Sandpiper	

12.2. Issues and Data Gaps

It would be useful to develop a three-dimensional map of the airspace above the Massachusetts coastline and the Nantucket Shelf Region, showing observations of marine and coastal birds, migration routes and activities. Using modern computerized methods and Geographic Information System (GIS) mapping, this could eventually be done. The resulting database and map would be useful for resource managers looking for comprehensive information in order to manage many species, rather than managing for one or two species.

The role of healthy fisheries and benthic habitats in sustaining many coastal and marine birds should be quantified. The relationship between oceanic productivity and coastal and marine bird activity should also be quantified, as many of these species are endangered or threatened or otherwise rare.

13. SEA TURTLES

13.1. Sea Turtles In Massachusetts

Sea turtles are turtles which live their entire lives at sea, with the exception of coming ashore to lay their eggs on tropical beaches. Five species of sea turtles can occur in Massachusetts offshore waters, and all four are state-listed and/or federally listed as endangered or threatened. They include:

- Hawksbill sea turtle (*Eretmochelys imbricata*) – Endangered
- Kemp's Ridley sea turtle (*Lepidochelys kempii*) – Endangered
- Leatherback sea turtle (*Dermochelys coriacea*) – Endangered
- Loggerhead sea turtle (*Caretta caretta*) – Threatened
- Green turtles (*Chelonia mydas*) - Endangered

Sea turtles generally spend more time in the warm waters of the Caribbean, mid-Atlantic or Gulf of Mexico, but some travel to cooler temperate waters. Three species commonly use Stellwagen Bank for foraging: the leatherback, the loggerhead, and Kemp's Ridley.

The Leatherback has been known to travel as far north as Labrador. Loggerheads are the most numerous of the sea turtles found along the New England coast, but they cannot tolerate cold water and are not found north of Stellwagen Bank. Kemp's Ridley is particularly susceptible to cold and they frequently die of exposure; studies indicate that the waters south of Cape Cod may be the northern limit of their range (reviewed in Ward, 1995).

Threats to sea turtles in the marine environment include:

- Entanglement at sea in longlines, fish trap warps, buoy anchor lines, and other ropes and cables
- Ingestion of marine debris
- Commercial fisheries
- Boat collisions
- Oil and gas exploration, development transportation and storage
- Pollution

Sea turtles are in extreme jeopardy worldwide. Because they nest on tropical or subtropical beaches, many of which are outside the U.S., impacts include destruction of their nesting habitat by coastal development, beach nourishment, dredging, and other nearshore or onshore activities (National Marine Fisheries Service and U.S. Fish and Wildlife Service, 1991; 1992; 1993).

13.2. Issues and Data Gaps

The effect of commercial fisheries on sea turtle populations in the Nantucket Shelf area, both through direct impacts (entanglement) or indirect effects (damaging benthic habitat and causing prey food, such as invertebrates and shellfish, to become scarce), needs to be better understood. A comprehensive benthic habitat monitoring program using multisensor methods, like those conducted by the USGS and NMFS, should be conducted to evaluate habitat impacts.

Similarly, the effects of coastal pollution on sea turtles needs to be evaluated, particularly as coastal development increases along the southeastern Massachusetts coast.

Methods to help stranded or cold-stunned sea turtles need to be improved. A National Marine Life Center has been built in Buzzards Bay to provide such care for stranded or cold-stunned or injured sea turtles and smaller marine mammals.

Global climate change may result in changing largescale ocean circulation. Sea turtles prefer warm water, so if ocean circulation off the mid-Atlantic and New England coast changes, it may affect the routes and distribution of sea turtles.

14. DISCUSSION

Vineyard Sound, Nantucket Sound, Nantucket Shoals, the shelf south of Martha's Vineyard, and the Great South Channel all form part of a large shallow coastal shelf ecosystem that is characterized by a common geological origin, highly dynamic sedimentary environment, shallow clear water that is vigorously mixed and well-aerated by fast tidal currents, and high phytoplankton productivity. Because of these shared features, this area should be treated as one marine ecological unit, the Nantucket Shelf region. Other nearby areas which share a similar geological origin and physical characteristics include Georges Bank and Stellwagen Bank.

The Nantucket Shelf ecosystem can be summed up in the following ways:

- Highly dynamic water flow and circulation, creating well-oxygenated and well-flushed system;
- Highly dynamic sediment system is probable, based on current speeds and sediment grain size, but more information is needed to map benthic habitats. It is probable that sedimentary bedforms (e.g., sand waves, sand ripples, other features) exist that would provide essential fish habitat;
- High primary productivity year-round, and may serve as a source of nutrients and plankton for adjacent offshore areas through advection and transport by rapid tidal currents out of Nantucket and Vineyard Sounds, but this should be confirmed through scientific studies;
- Transition zone between southern and northern biogeographic provinces;
- Located in an important bird migration corridor, the Atlantic Flyway (birds, sea turtles, fish, whales);
- Islands and shorelines provide important nesting, breeding, and feeding habitat for coastal birds and seals, including some state-listed and federally-listed endangered species;

- Coastal areas contain suitable shellfish habitat, which could be improved by improving water quality;
- Nantucket Shelf region and its estuaries are rich in fish, although the fishery was probably more extensive in the past, and the area doubtless serves as a nursery habitat for Anadromous and Catadromous fish. Nursery habitat ecology deserves more scientific study.
- Contains rich whale feeding grounds in the Great South Channel, fed by blooms of copepods that may be advected from elsewhere. This area should be protected due to the importance of the area for the endangered right whale;
- Extensive area of shallow shelf sands may absorb storm wave energy and lessen coastal erosion; and
- Data gaps are significant and include: lack of information on sedimentary environments and benthic habitats, impacts on benthic habitats, benthic ecology and taxonomy, physical oceanography, residence times, water quality, water and nutrient advection into and out of the area and implications for the area serving as a "feeder" zone to nearby marine waters, longterm effects of coastal water quality on nearby coastal areas, nursery areas for fish and other species based on tagging studies, effects of declining fisheries and other living resources on predators (birds, marine mammals) and marine ecology in general.

Remote-sensing of ocean color for chlorophyll mapping indicates that the Nantucket Shelf Region, like Georges Bank, Stellwagen Bank and other shallow shelf areas, has high primary productivity year-round. This remarkable fact suggests that the Nantucket Shelf Region should be as productive a fishery as Georges Bank once was.

The year-round primary productivity, combined with the tidal currents that race across Vineyard and Nantucket Sounds and Nantucket Shoals, also suggest that nutrients and plankton may be carried into adjacent areas, such as the Great South Channel. The Great South Channel is remarkable for its copepod blooms which attract the endangered right whale and other marine mammals and fish. Although our hypothesis that the Nantucket Shelf Region acts as a source of nutrients to adjacent areas is only conjecture, the one single lesson of ecology is that all ecosystems are ultimately connected through physical, chemical and biological processes. This is especially true for ecosystems located next to each other.

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Collecting trip to Martha's Vineyard conducted by H.M. Smith, 1923.
right to left: Chilchester, Galtsoff, Smith, unknown, Bigalow.
Photographer: Galtsoff, Paul - historic collection - NOAA Photo Library

Part II.
Management Options For Resource Protection and Sustainable Uses

1. INTRODUCTION

The Nantucket Shelf Region is one of the most heavily used ocean areas in the Northeast, due to its bountiful natural resources, proximity to major population centers, and rich fishing grounds. A wide range of coastal management issues, human activities and cultural values characterize this area. The region's natural resources and beauty are threatened by increasing coastal development, associated water quality problems, conflicting uses, and increasing intensity of use. There is no comprehensive regional coastal and ocean management plan for this important ocean sector.

Part II of this report explores possible options for comprehensive protection and management of the Nantucket Shelf Region. The goal of this analysis is to identify and recommend measures that will protect the key environmental, ecological, and human values of this region while allowing and promoting sustainable human activities.

Part II begins with a discussion of recent calls for ocean protection and the timeliness of ocean protection. Section 2 describes the ocean-based human uses and socioeconomic values of the Nantucket Shelf Region. Existing coastal management issues facing the region are described in Section 3. Section 4 describes existing ocean management approaches that have been used in the region or considered for other ocean areas. Key principles for sound ocean management are described in Section 5. Section 6 discusses ecological and socioeconomic criteria for siting Marine Protected Areas. Section 7 evaluates possible ocean management approaches that could be applied to the Nantucket Shelf Region.

The management and protection of the Nantucket Shelf Region is currently provided through a myriad of local, state, regional and federal laws and agencies that are disjointed, sometimes conflicting, and occasionally lacking the appropriate authority to manage. Regional ecosystem-based management may be the solution to disjoint and incomplete ocean management. This is a conclusion reached by a number of state and federal commissions and agencies which have recommended that the U.S. should provide better protection of its coastal and ocean waters. These include the following:

- The U.S. Commission on Ocean Policy has recommended increasing protection of our oceans, applying Marine Protected Areas as a protection approach, increasing scientific research on the oceans, using ecosystem-based management, and providing more outreach concerning the importance of the oceans (U.S. Commission on Ocean Policy, 2004).

- The Pew Ocean Commissions Report (2003) identified 9 major challenges for America's oceans, including nonpoint and point source pollution, invasive species, aquaculture wastes, climate change, bycatch, habitat alteration, overfishing, and coastal development.

Whale Watch out of Hyannis

- Executive Order 13158, May 26, 2000, calls for the establishment of Marine Protected Areas to "help protect significant natural and cultural resources within the marine environment for the benefit of present and future generations." (Federal Register, Volume 65, No. 105, May 31, 2000, Presidential Documents).

- In 2003, the Governor established the Massachusetts Ocean Management Initiative, whose goals are to proactively manage ocean resources within the 3-mile state jurisdictional limit, work with federal agencies to improve ecosystem-based management of ocean resources in federal waters, and improve management and protection of environmental, planning and public trust issues in both state and federal waters (see http://www.mass.gov/czm/oceanmgtinitiative.htm).

- The science of managing ocean reserves is at the leading edge of natural resource management policy because of rapid and radical degradation of the world's oceans (U.S. Commission on Ocean Policy, 2004; Lubchenco et al., 2003; Cicin-Sain and Knecht, 1998).

- At the international level, the use of Marine Protected Area (MPA) designation is being utilized in many countries and is strongly supported by many international ocean programs. International agencies like USAID and the World Bank are funding MPAs and regional ocean protection initiatives (NOAA Coastal Services Center, March 2002; U.S. Commission on Ocean Policy, 2004).

The need for regional ocean protection is a worldwide need, because the oceans represent a common heritage for all of mankind.

2. HUMAN USES AND SOCIOECONOMIC VALUES

The Cape and Islands have a long tradition of maritime activities and environmental protection. These human uses and cultural values were described in the 1980 Nomination Letter for a National Marine Sanctuary in Nantucket Sound, but they also apply to the larger Nantucket Shelf Region discussed here (Massachusetts Coastal Zone Management, Department of Environmental Management, Division of Marine Fisheries, 1980). The region contains regionally and nationally significant historic, recreational, scientific, socioeconomic and aesthetic resources that are ocean-based. These are described in more detail below.

Maritime Tradition

The sea has shaped the history, life and culture of the Nantucket Shelf Region. In the 16th century, fishermen from Portugal and other European countries discovered the rich fishing grounds of Georges Bank and Cape Cod. The Pilgrims and other English colonists arrived and began settling Cape Cod, Martha's Vineyard and Nantucket in the early 17th century. During the 18th and 19th centuries, colonists and settlers cleared and sold timber to shipyards, set up a salt industry to evaporate seawater to obtain the salt, and provided ship-building and maintenance services. Tourism became important in the second half of the 19th century and has continued to be an important industry ever since.

The New England fishing and whaling trade reached its peak during the early 19th century. At its peak, the Nantucket whaling fleet of 88 vessels sailed far afield in search of whales, even into the remote South Pacific, returning to Nantucket to offload their precious cargo. Nantucket was the leading whaling port in the world then, and was also the third largest city in Massachusetts, after Boston and Salem (Nantucket Chamber of Commerce website at http://www.nantucketchamber.org/visitor/trivia.html). In recognition of its important role in national and international maritime history, the entire island of Nantucket was included in the U.S. National Register of Historic Landmarks in 1975 (Massachusetts Coastal Zone Management, Department of Environmental Management, Division of Marine Fisheries, 1980).

Today, the Cape and Islands continue to provide a variety of maritime uses and maritime industries. These include commercial and recreational boating, fishing and shellfishing; shellfish aquaculture; working boatyards and marinas; oceanographic and coastal research and education; and coastal tourism. A number of military facilities exist in the area, including a Coast Guard facility in Woods Hole, Pave Paws radar facility in Bourne, the Massachusetts Military Reservation, and an facility at the Cape Cod National Seashore. Commercial and private aviation facilities are busy, due to the popularity of the Cape and Islands as a tourist destination and the need for regular commuting services, and the Barnstable Municipal Airport is the third busiest airport in the Commonwealth of Massachusetts.

Human Uses and Activities

photo: NOAA photo library

Cape Cod, Martha's Vineyard and Nantucket and its surrounding waters have long been one of the most popular tourist destinations along the East Coast. The popularity of this region is due to its natural scenery, proximity to major urban centers, agreeable summer climate, and easy access. Each year, hundreds of thousands of people visit the beaches, while others participate in recreational boating and fishing, swimming, and other water sports. The low topographic relief encourages bicycling, walking and family activities. In the well-mixed, productive waters of Nantucket and Vineyard Sounds and beyond, water quality is good and promotes recreational shellfishing, fishing and boating.

Boating is an important recreational activity in the Nantucket Shelf Region. The proximity of the islands to the mainland of Massachusetts promotes traffic to and from the islands and Cape Cod and the mainland. The narrow channels and fast currents of Vineyard Sound and Nantucket Sound provide challenging sailing within close proximity to Boston, Providence, and other growing communities in Southeastern Massachusetts. Ferry service exists between Provincetown and Boston, Cape Cod and the Islands, and New Bedford and the islands. The shallow shoals surrounding Nantucket and Vineyard Sounds excludes large commercial vessels, thus making the region attractive for recreational boaters.

Coastal tourism is a vital part of the year-round economy of the Cape and Islands. For year-round residents who work in service industries (restaurants, rental accommodations, transportation, retail shops and markets, etc.), tourism is essential for maintaining adequate annual incomes. Economic data collected by the Cape Cod Commission indicates that in 2003, nearly one-third of all Cape Cod jobs were related to travel (travel is defined by the Massachusetts Office of Travel and Tourism as including 16 categories of public and auto transportation, travel arrangement, retail, food, accommodations, entertainment and recreation industries). In 2001, annual travel-related jobs on Cape Cod alone averaged 29,506, or 32.9% of the 89,761 public and private-sector jobs in Barnstable County. At their peak in July, travel-related jobs accounted for 39.3% of all 102,131 Cape jobs. Jobs in eating and drinking establishments led all industries, averaging 12.1% of all Cape jobs (10,845 jobs). At their peak in July of 2001, jobs in this sector were 15.7% (16,072 jobs) of the total number of jobs (Cape Cod Commission, August 14, 2003).

Martha's Vineyard businesses are even more dependent on seasonal tourism. The Martha's Vineyard Commission reports that in a recent survey of business owners, 77.8% of businesses relied upon seasonal tourism, and at least one-third of all businesses said that more than 75% of their businesses were dependent on tourism (http://almanac.vineyardconservationsociety.org/mvc/mvc-mainpage.shtml).

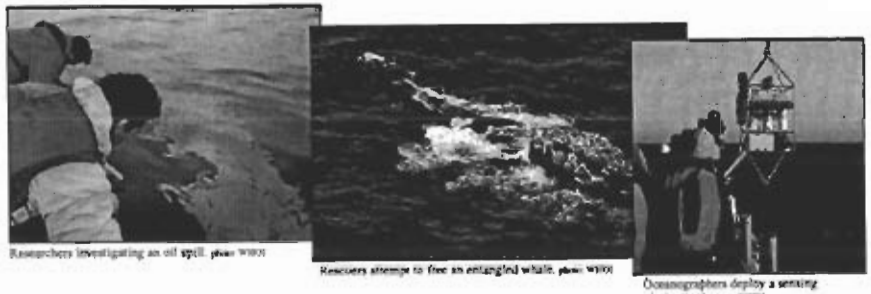
As another indicator of the importance of coastal tourism, Cape Cod's state room tax revenues (state 5.7% room occupancy tax) reached $12.5 million in 2003. This figure represents 15% of the total statewide ($83.1 million) collection of room tax revenues (Cape Cod Commission, August 14, 2003). In economic terms, therefore, the tourism industry is important for Cape Cod and the Islands and provides a significant portion of the state's economy.

Coastal and Marine Science, Technology and Education

Coastal and marine science, technology and education figure prominently in the history, culture and economics of the Nantucket Shelf Region. The unusual concentration of educational and scientific institutions, museums, reserves, and parks devoted to marine science, technology and education is unique in the Northeast. High-tech small businesses and industries based upon oceanographic instrumentation and marine products and technology have sprung up as an outgrowth of science and technology institutions in the area.

Marine Biological Laboratory scientists. photo: NOAA Archive

Scientific research in marine biology and oceanography became established in the late 19th century, beginning with the Marine Biological Laboratory, followed by the Woods Hole Oceanographic Institution in the early 20th century. There are research facilities for the NOAA National Marine Fisheries Service and U.S. Geological Survey in Woods Hole, while a number of non-profit scientific research organizations are also located in the region (e.g., Woods Hole Research Center, Nantucket Field Station, Center for Coastal Studies).



Researchers investigating an oil spill. photo: WHOI

Rescuers attempt to free an entangled whale. photo: WHOI

Oceanographers deploy a sensing instrument. photo: WHOI

Marine educational institutions include SEA (Sea Education Association), the Waquoit Bay National Estuarine Research Reserve (WBNERR), and a network of marine educators coordinated through the Woods Hole Science and Technology Education Partnership (WHSTEP).

WBNERR also serves as a hub of coastal environmental education and management activities that involve the Department of Environmental Management, NOAA, and the Massachusetts Office of Coastal Zone Management. Marine animal research and rescue operations include the National Marine Life Center and the Cape Cod Stranding Network in Bourne, Massachusetts Audubon Sanctuary in Wellfleet, NOAA National Marine Fisheries Service, and the Center for Provincetown Coastal Studies. The Massachusetts Maritime Academy in Bourne provides marine and military training in marine engineering, navigation, coastal issues, and practical seamanship.

A number of non-profit and government agency-operated museums and natural history centers are located in the Nantucket Shelf Region (e.g., Cape Cod Museum of Natural History, Cape Cod National Seashore, respectively). Technical assistance for addressing a variety of coastal and environmental issues is available from a number of agencies, including the Buzzards Bay Project, the Cape Cod Commission, the Martha's Vineyard Commission, Barnstable County Extension, regional Coastal Zone Management for the Cape and Islands, and Wampanoag Tribal natural resource departments.

To recap, the open waters of the Nantucket Shelf Region are the wellspring of the history, economy, culture, science, and natural beauty of the region. Tourism and recreational activities in the Cape and Islands literally depend upon the attractive, open, undeveloped character of the coastal and ocean waters of the region. Coastal and marine science, technology and education are particularly active in the region and are an important economic and cultural force.

photo: NOAA photo library

Aesthetic Value

In the 21st century, although maritime industries such as marinas and fishing continue, the principal outstanding value of the entire region may lie in its natural beauty. The natural beauty of the Nantucket Shelf Region is based upon open, undeveloped coastal and ocean vistas. The coastal scenery of the Cape and Islands encompasses dunes, beaches, low hills, coastal plains, salt marshes, islands and scenic water vistas. The extensive beaches, quiet estuaries, the proximity to important whale feeding grounds off Provincetown, the rich bird life, and other natural features, are highly attractive to those who enjoy nature.

Protecting the natural scenery of the Cape, Martha's Vineyard and Nantucket is a high priority for the residents of the region. Local voters have approved land protection and management measures such as regional development agencies (Cape Cod Commission, Martha's Vineyard Commission, Nantucket Regional Planning Council), regional growth management planning, Cape Cod Land Bank, active volunteerism, and the passage of local ordinances protecting natural resources.

Thus, despite the rapid pace of coastal development, many coastal land areas are protected or managed through local zoning or regional planning, or through designation as a national park, wildlife refuge, National Estuary, or other means of protection. Coastal waters within the 3-mile state jurisdiction are protected from development activities under the Massachusetts Ocean Sanctuaries Act, which designated three state ocean sanctuaries in southeastern Massachusetts: Cape and Islands Ocean Sanctuary, Cape Cod Bay Ocean Sanctuary, and Cape Cod Ocean Sanctuary. However, significant areas of coastal waters outside the 3-mile state limit remain unprotected.

Coastal erosion, photo WHOI/[illegible]

3. COASTAL MANAGEMENT ISSUES

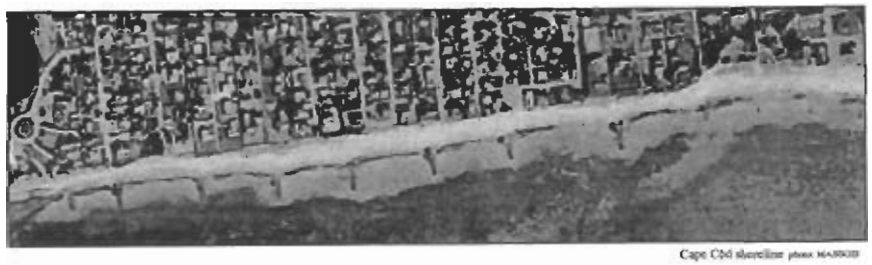
There are many coastal management issues in the Nantucket Shelf Region, owing to its popularity as a tourist destination, coastal development, and the many recreational and commercial activities that are ongoing or possible. Some of these activities have already caused environmental impacts. Some of the most significant coastal management issues are listed below:

- Coastal development and population growth;
- Water quality impacts (contaminated groundwater plumes, coastal nutrient loading, nonpoint source pollution, atmospheric deposition of pollutants, floatables, pathogens);
- Fishery activities;
- Boating;
- Offshore mining of sand, gravel, oil and gas;
- Other potential uses requiring infrastructure and/or disturbance of natural resources (e.g., proposed wind farm, potential future desalinization for water supply, outfall pipes, etc.);
- Offshore utilities;
- Poor air quality during the summer;
- Sea level rise and climate change;
- Coastal erosion and flooding;
- Habitat loss resulting from all of the above;
- Significant information gaps concerning offshore resources;
- Environmental contamination and security issues related to the presence of military installations (e.g., Massachusetts Military Reservation, Pave Paws radar installation) and energy facilities (e.g., Canalside power plant, Plymouth nuclear power plant); and
- The incomplete patchwork of different coastal protection and management measures in Southeastern Massachusetts.

Some important ocean management issues are described in more detail below.

Coastal Development

Coastal population growth and development pose some of the biggest environmental challenges for coastal managers (U.S. Commission on Ocean Policy, 2004). Coastal development poses one of the most significant impacts on coastal and marine ecosystems, because it has such wide-ranging effects. Coastal development and increasing human use of the coastal zone generally impacts water quality, decreases habitat, lessens



Cape Cod shoreline photo MASSGIS

quality of life, increases coastal hazards related to sea level rise, and increases need for energy, water and public infrastructure for the expanding population. Increased nonpoint and point source discharges of nutrients, pathogens, and other contaminants are inevitable. As the population grows, so too will the cumulative impacts on the marine ecosystem increase.

Cape Cod, Nantucket and Martha's Vineyard experienced some of the most rapid population growth in Massachusetts, based on the 2000 U.S. census. While the statewide population growth rate between 1990 and 2000 was 1.3%, Barnstable County, Nantucket County and Duke's County year-round populations increased by 3.3%, 12.6%, and 4.1%, respectively. Cape Cod alone was estimated to rank fifth in the state in terms of overall population growth by July 2003 (Cape Cod Commission, August 5, 2004, http://www.capecodcommission.org). In the 2000 census, Cape Cod's year-round population was 222,220, and the summer population reportedly swells to more than three times this number (http://www.barnstablecounty.org/). The year-round populations of Nantucket County and Duke's County (Martha's Vineyard) in the 2000 U.S. census were 9,520 and 14,987, respectively.

Cape Cod, Martha's Vineyard and Nantucket have regional development commissions which regulate larger development projects and provide guidance for smaller development projects. These are the Cape Cod Commission, the Martha's Vineyard Commission, and the Nantucket Planning and Economic Development Commission, respectively.

The long-term cumulative effects of coastal pollutant loading on the Nantucket Shelf Region have not been studied with the goal of developing a detailed model of how coastal pollutants behave in the Nantucket Shelf region. Studies of coastal pollutant loading typically focus on coastal embayments on Cape Cod and the Islands and assume that once pollutants reach marine waters, they will be flushed away by the rapid currents. But the larger questions of the long-term effect or whether the Nantucket Shelf thereby acts as a source of pollutants to nearby areas of the shelf have not been posed.

Similarly, the long-term cumulative effects of a number of human activities and natural processes on the entire Nantucket Shelf Region have not been studied.

Water and Wastewater

Wastewater treatment plant, photo source

Water quality and water quantity can both deteriorate as coastal communities expand. Although freshwater rivers and streams on the Cape and Islands are small in terms of flow, they serve as conduits for watershed pollutants to enter the sea. Increased withdrawal of groundwater and surface water for drinking water supplies will tend to deplete the groundwater aquifer and cause streams to become less of a factor in estuarine inputs. Although groundwater recharge could increase as a result of more septic systems that would be needed to handle the wastewater of a growing population, this may occur at slower rates than stream flow rates. One potential consequence is decreased freshwater flow into Vineyard and Nantucket Sounds. If this were to happen, salt water intrusion may also occur.

Salt water intrusion may also occur as a result of sea level rise. The best expert estimate of the rate of sea level rise over the next century is 19 inches (IPCC, 2002). Cape Cod, Nantucket and Martha's Vineyard each have sole-source aquifers that would be subject to saltwater intrusion as sea level rises. Managing water supply at a time when the demand will be growing and the supply will be shrinking will be problematic.

Contamination from wastewater treatment facilities and septic systems already poses significant threats to coastal embayments on Cape Cod and the Islands. The DEP Estuaries Project is focusing on nitrogen loading to coastal embayments on Cape Cod. The potential long-term impact of wastewater on water quality in the Nantucket Shelf Region has not been evaluated, partly because it is always assumed that the vigorous tidal action will disperse and dilute any discharged treated wastewater. However, the efficacy of the reversing tidal currents in dispersing pollutants should be evaluated for the Sounds, as well as the long-term effect of nutrient loading.

Fisheries Impacts

Although most fishing gear, especially mobile gear, has unintended effects on substrates and benthic communities, damage has been minimized through effective regulation by state, regional and federal agencies. A series of area and seasonal fisheries closures have protected spawning and nursery areas at appropriate times. Similarly, the mesh size of towed nets is regulated to control the bycatch of juvenile and non-target species. Gillnets have been banned in state waters south of Cape Cod to prevent bycatch of non-target species and in the Great South Channel Critical Habitat to protect right whales. Other sectors have increased, including hook and fishpot fisheries. These gears produce less bycatch of juvenile and non-target species, but must be limited in scope to prevent overfishing, and regulated to prevent or minimize entanglements of mammals, birds and turtles.

Since many of the species that spawn and feed seasonally in Nantucket Sound are migratory species, subject to fisheries in other states and the EEZ, they have presented a challenge to regulators, since conservation efforts in one jurisdiction may not be supported in others. Regional fishery management plans, backed by state regulations to control effort in these fisheries, are necessary to achieve coordinated management. The Mid-Atlantic Fisheries Management Council and the Atlantic States Marine Fisheries Commission have instituted hard quotas on migratory species such as squid, scup, summer flounder, black sea bass, and striped bass. In addition to management by gear restrictions and size limits, quotas are an efficient way to control harvest and allocate fishing effort among the states. Modern management plans are designed to allow recovery of depleted species by preventing overfishing throughout the range of each species, at all life stages.

The importance of the Nantucket Shelf Region as a spawning / nursery area for many species, providing important recruitment to populations outside the area, is well - recognized. Similarly, juvenile protection in this area would not be effective unless complemented by protection from small mesh fisheries in the wintering areas to the south and east, and allocated effort on migrating adults.

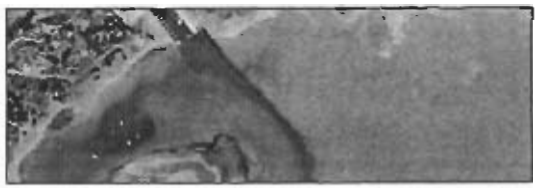
Boating and Navigation Impacts

Recreational boating activities are popular in Vineyard and Nantucket Sounds. Yet the environmental impacts of such activities are seldom considered. Impacts of boating include proliferation of docks, sediment resuspension due to water turbulence, noise, marine animal strikes, and water quality impacts.

Although scientific research is limited, available studies indicate that small-boat navigation can cause resuspension of sediments in the water column through propeller-driven turbulence (reviewed in Barr, 1993; Crawford et al. (Eds.) and various articles, 1998). In a number of studies, Yousef (1974) and Yousef et al. (1978, 1980) found that a 50 horsepower outboard motor had an effective mixing depth of 4.6 meters and bottom sediments were readily resuspended by the same outboard motor in water depths of 1.5 meters or less in a period of 5 minutes of boating activity. The resulting decrease in water clarity and increase in turbidity can cause decreases in seagrass productivity, affect fish, increase concentration of nutrients in the water column, and generally impact water quality (Short et al., 1991; Sherk et al., 1975; Servizi and Martin, 1992; Rhoads et al., 1975; Orth and Moore, 1983; Short et al., 1989).

Boating activity also generates wakes, which can increase bank erosion (Mason and Bryant, 1975; Moss, 1977; Liddle and Scorgie, 1980; Hilton and Phillips, 1982; Garrad and Hey,1988a, 1988b, 1989)

Navigational channels in coastal areas generally require maintenance dredging in order to keep them open. Dredging is often done to help improve water quality in coastal ponds. There can be temporary adverse effects on water quality due to sediment and nutrient resuspension during dredging. Shoreline alteration and habitat alteration can also occur as a result of dredging.



Sea-Level Rise and Climate Change

As a result of global warming due to both natural and manmade causes, sea level has been rising quickly and is expected to continue to rise (IPCC, 2002). Best scientific estimates of the rate of sea level rise over the next century is that sea level will rise on average by 19 inches (IPCC, 2002). The U.S. Geological Survey has been evaluating coastal vulnerability to sea level rise along the nation's coasts, including the Atlantic Coast and the Cape Cod National Seashore, through the National Coastal Vulnerability Study (Thieler et al., 2002; Thieler et al., 2001; Thieler and Hammar-Klose, 1999). Based on such studies, much of the shoreline along the Outer Cape, from Monomoy Island to Provincetown, already lies within a high-hazard area due to the probability of increased flooding and storm wave damage as sea level continues to rise. These studies highlight the seriousness of global warming and sea-level rise on these coastal areas.

Global warming also may result in changes in currents and storm frequency and intensity. As the atmosphere warms, hurricanes and storms may become more intense and coastal erosion would increase as a result. The patterns of ocean circulation may change. Southern species will move north. Such largescale changes in the environment need to be taken into account when planning for protection and management of a region.

The sandy shoals of the Nantucket Shelf Region may potentially play a role in absorbing storm wave energy and lessening storm damage due to waves and currents. The potential role of offshore shoals in lessening storm damage in the Nantucket Shelf Region needs to be better understood. The Nantucket Shelf Region is one of the few areas along the Massachusetts coast where significant sand deposits lie offshore. Paradoxically, the Massachusetts coastline is experiencing net erosion due to sand loss from coastal sand systems, partly due to rising sea level and partly due to coastal armoring which has blocked sand transport and sand sources (Thieler et al., 2001).

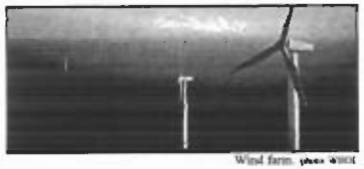
Oil and Gas Exploration, Mining and Development

Oil rig, photo: NOAA archive

In 1980, the Massachusetts Coastal Zone Management identified oil and gas exploration and development on Georges Bank as a potential concern for Nantucket Sound, due to the potential for environmental, ecological and aesthetic impacts from oil transportation, oil spills, pipelines, and associated infrastructure and maintenance activities. Nantucket Sound itself was not identified as a potential oil *and* gas field. Shifting sediment bedforms leading to instability of oil mining platforms, leading to oil spills and impacts on water quality, fish habitat, waterfowl, marine mammals, and sea turtles were also cited as concerns. Navigation was cited as a concern. An oil spill occurring during the nesting season for endangered bird species (Roseate tern) would endanger a major portion of the entire North American population of this species and could impact many other species. An oil spill could have disastrous consequences on the tourist-driven economy if it occurred during the warmer months. The 2003 Bouchard oil spill in Buzzards Bay, involving approximately 98,000 gallons of thick No. 6 oil, resulted in the oiling of approximately 93 miles of coastline, hundreds of birds killed, and long-term impacts on coastal habitat and aesthetic values that are still being evaluated.

Other Proposed Uses

A proposed wind farm involving the placement of 130 wind turbines on the sea floor of Nantucket Sound has generated much concern due to potential impacts on environmental and human values. Concerns range from impacts on recreational boating, bird strikes by the turbine blades, impacts on aesthetic and visual values, and use of a public resource for profit.



Wind farm, photo: MMS

Another example of potential use of the outer continental shelf is mining of sand and gravel for shoreline beach nourishment. This concept was being discussed in the late 1990's by a number of state and federal agencies and coastal stakeholders. Due to concerns regarding impacts on essential benthic fish habitat, however, the concept has been abandoned for now (R. Haney, Coastal Zone Management, personal communication). Yet the demand for beach nourishment will grow as sea level rises, and offshore sources may provide an economical solution when the cost is compared with buying sand from upland sources (which involves environmental alteration).

Habitat Loss

Habitat loss can occur in airspace, in the water, on the ground and in submerged sediments through a variety of human activities. Habitat loss in coastal areas can occur through coastal development, shoreline alteration, human activities and presence, and habitat degradation. Impacts on benthic habitat can occur through the use of mobile fishing gear and through boating activities that cause sediment resuspension and turbulence. Habitat loss in the water column generally occurs through degraded water quality as a result of pollutants and resuspended sediments, which in turn can cause nuisance or harmful algal blooms. Loss of avian habitat in airspace is probably one of the least well-studied aspects of ecology. Structures that intrude into airspace, such as tall buildings, microwave towers, cellphone towers, utility lines and poles, etc., can pose considerable hazards and cause significant mortalities among birds. In general, avian habitat loss in the Nantucket Shelf Region will be greatest in coastal and nearshore areas, and least in the areas which are less accessible to humans or their activities.

Information Gaps

Despite the region's significant resources, heavy recreational and commercial uses, significant environmental issues, and its strategic position in terms of economy, coastal population and national security, there are some surprising and significant data gaps concerning important natural resources. These data gaps are surprising because they occur in areas that are close to major population centers and in areas where coastal environmental issues have received much attention. Aside from coastal studies along the shore and in coastal embayments, the detailed ecology, physical oceanography, benthic habitat, sedimentology, marine biology, and water quality of the offshore areas in Nantucket Sound and Vineyard Sound are not well-studied. Georges Bank and the Gulf of Maine are better studied, scientifically speaking, than Nantucket Sound, Vineyard Sound, Nantucket Shoals, or the large area of continental shelf south of Martha's Vineyard (Wallace and Brausch, 1996; Wiggin and Mooers, 1992; Backus, 1987).

Incomplete Patchwork of Ocean Protection

Massachusetts coastal waters are protected by a patchwork of different federal and state ocean management jurisdictions. These jurisdictions do not necessarily overlap, nor are they necessarily contiguous. The resulting patchwork has a number of holes in it, in areas where preliminary (and sometimes old) scientific information suggests that the natural resources must be the same as in nearby protected areas. The absence of a single coordinating framework for ocean protection in the Nantucket Shelf Region results in coastal and ocean protection which is patchy and inconsistent.

4. EXISTING OCEAN MANAGEMENT AND PROTECTION

Existing ocean and coastal protection measures include designation of Massachusetts Ocean Sanctuaries for ocean areas within the 3-mile state jurisdictional limit, designation of Buzzards Bay as a National Estuary, designation of the Gerry E. Studds National Marine Sanctuary in Stellwagen Bank, Cape Cod National Seashore (a national park), and Monomoy National Wildlife Refuge and Wilderness Area. Farther offshore, areas of Georges Bank and the Great South Channel are managed for fisheries.

Despite this extensive patchwork of near-shore protection measures, the central area of Nantucket Sound, the area of Nantucket Shoals, large areas of the shelf south of Martha's Vineyard, and Georges Bank are not protected from development. The 1980 nomination of Nantucket Sound as a National Marine Sanctuary by the Massachusetts Office of Coastal Zone Management (CZM) recognized the many values of Nantucket Sound.

Protection or management options can provide various benefits, depending on the option selected. In all cases, protection and management options help to conserve or restore species, habitats, and ecological processes, while providing for appropriate and sustainable economic uses of the resources. The benefits conferred depend on the area's size, location, and permanence, as well as the level and extent of protection provided (Recchia et al., 2001). The degree of limitation on human activities varies greatly, and depends upon the ultimate goals for nominating a protection or management area.

Historically, ocean management areas have included harbors and ports, navigation channels, fisheries closure areas, oil and gas drilling leases, dredged material disposal areas, marine disposal sites, buffer zones around ocean outfalls, munitions testing areas, and sensitive habitats such as coral reefs, seagrass beds, rare species habitat, and others. Typically such ocean management areas are managed for a narrowly defined interest and are generally limited in area.

Designation of marine protected areas in oceanic habitats, as opposed to coastal and onshore habitats, is a more recent phenomenon (Courtney and Wiggin, 2003). Marine protected areas, or MPAs, includes a wide variety of coastal and ocean areas managed according to specific regulations. The term is used in a general sense, although the definition of an MPA used by The World Conservation Union (IUCN) forms the basis for most definitions: "Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment." (Courtney and Wiggin, 2003). For comparison, the U.S. Government, in Executive Order 13158, defines an MPA as: "any area of the marine environment that has been reserved by Federal, State, territorial, tribal or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein." (Executive Order 13158, 2000).

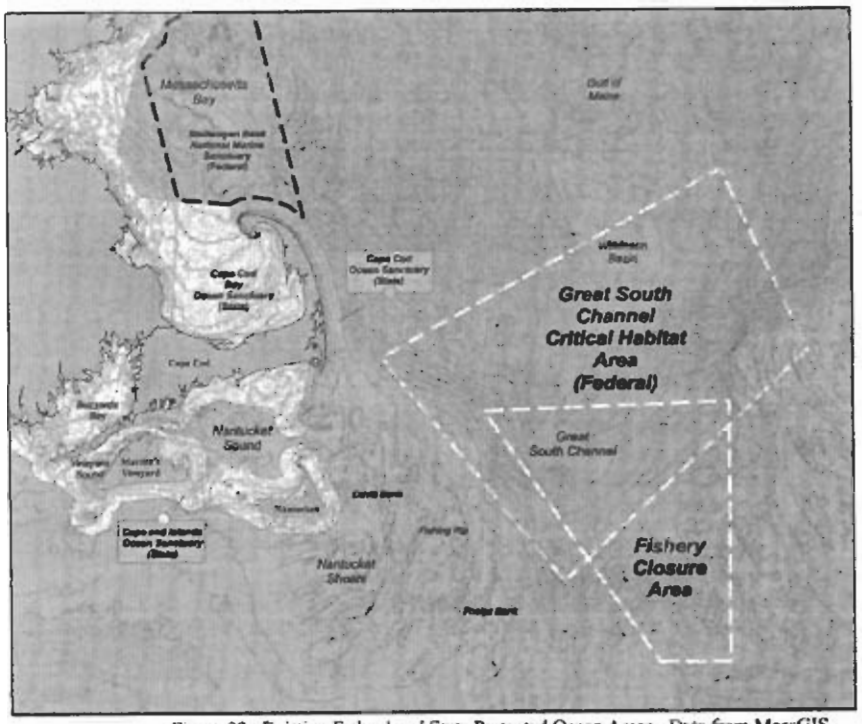


Figure 32. Existing Federal and State Protected Ocean Areas. Data from MassGIS.

Marine protected areas primarily protect and conserve biological diversity, habitat and natural resources, but the range of human uses that may be accommodated, the level of protection, size of area, and type of MPA vary widely. Within an MPA, different areas may be designated for differing uses, depending on the resources present, their value and sensitivity, and human uses. The U.S. Commission on Ocean Policy, in its April 2004 preliminary report, recommended that marine protected areas be used as one management tool to protect and manage important areas of the ocean (U.S. Commission on Ocean Policy, 2004).

The Gulf of Maine provides some examples of local, state and federal approaches to managing coastal and marine areas. The Ocean Conservancy has published a useful and succinct review of "Marine and Coastal Protected Areas in the United States Gulf of Maine Region" (Recchia et al., 2001). Other information on regional values and existing protected coastal and marine areas was obtained from a 2003 white paper by the Provincetown Center for Coastal Studies (Center for Coastal Studies, 2003).

4.1. Federal Ocean Protection

Federal jurisdiction over the nation's ocean and coastal waters extends out to the 200-mile limit, and therefore provides the greatest jurisdiction. At the federal level, there are a number of existing management and/or protection options for coastal and marine areas in the Gulf of Maine and Nantucket Shelf region (Recchia et al., 2001). These are listed below.

- National Marine Sanctuaries
- National Estuary Program
- National Estuarine Research Reserves
- National Wildlife Refuges
- Critical Habitat Areas
- Federal fishery closure areas

The key features of each of these options are briefly described below.

National Marine Sanctuary System (NMS System)

The U.S. National Marine Sanctuaries Act of 1972 allows designation of marine areas to protect critical marine and cultural resources and allow sustainable use. Overall management authority is granted through specific legislation, which may provide coordination and/or supercede other authorities. Canada and Australia have adopted similar legislation to protect marine areas (Canadian Conservation Areas Act, 2002; Great Barrier Reef Marine Park Act, 1975) (Courtney and Wiggen, 2003).

National Marine Sanctuaries (NMSs) are designated to provide comprehensive protection for their marine resources. NOAA administers the National Marine Sanctuary system. They are established to identify, manage, and conserve marine areas that are nationally significant to "*conservation, recreational, ecological, historical, scientific, educational, cultural, archeological or esthetic qualities*" (Recchia et al., 2001). Generally, National Marine Sanctuary designation prohibits development of non-renewable resources and limits marine discharging, dumping and marine construction. Few NMSs directly regulate fishing or extraction of other living resources.

Stellwagen Bank National Marine Sanctuary is the only NMS in the Gulf of Maine and southeastern Massachusetts. Stellwagen Bank was designated as an Sanctuary in 1992 due to concerns about the potential impacts of proposed and current activities, including oil and gas mining, and because it is prime feeding habitat for many whale species.

National Estuary Program (NEP)

The National Estuary Program (NEP) was established under the federal Clean Water Act to identify, restore, and protect nationally significant estuaries that are threatened by pollution, development or overuse. The NEP focuses on watershed and estuarine protection, particularly water quality protection and related issues. Designation as an NEP does not provide automatic protection nor regulatory protection, but provides a mechanism for various local, state and federal agencies to develop a "Comprehensive Conservation and Management Plan" (CCMP) to protect the site using existing agencies. At each estuary site, a local committee comprising stakeholders, citizens, agencies, scientific and academic institutions, industry, and estuary users develop the CCMP and implement it.

In the Gulf of Maine and southeastern Massachusetts, there are four NEP sites: Massachusetts Bays Program (including Cape Cod and Boston Harbor), the New Hampshire Estuaries Project, the Casco Bay Estuary Project, and the Buzzards Bay Estuary Program (Recchia et al., 2001).

National Estuarine Research Reserves (NERRs)

Under the federal Coastal Zone Management Act, estuarine sites may be designated as a National Estuarine Research Reserve (NERR), forming part of a network of nationwide NERRs. NERRs are chosen to represent habitat types within specific ecoregions and are set up to conduct scientific research over a long term, including long-term monitoring. Other NERR goals are to protect rare species, provide public access, and provide public outreach concerning the marine environment. NERR designation does not automatically confer regulatory protection. Like an NEP site, an NERR is managed locally by local, state and federal agencies using federally-approved management plans that apply state law to coastal and territorial waters. Within an NERR, habitat alteration and coastal development are prohibited, and habitat restoration is frequently a goal. NERRs generally have not restricted fishing or hunting. NERRs are managed by state agencies. NOAA's Estuarine Reserve Division manages the NERR system (Recchia et al., 2001). There is one existing NERR within the Nantucket Shelf region, on Vineyard Sound: this is the Waquoit Bay National Estuarine Research Reserve (WBNERR).

National Wildlife Refuges

National Wildlife Refuge sites are designated to "*conserve, manage and restore wildlife and their associated habitats for the benefit of present and future generations*." Coastal sites may include islands and nearshore areas to protect migratory birds, seabirds, or anadromous fish (e.g., Atlantic salmon). Terrestrial portions of Refuge sites are owned by the federal government and are protected from development. However, marine resources and habitats are generally not protected. Activities such as cable-laying, marine discharges, dredging, dumping, fishing, hunting, development of non-renewable resources, shoreline alterations, coastal development, and coastal habitat alteration are forbidden. NWRs are managed by the U.S. Fish and Wildlife Service in the Department of the Interior (Recchia et al., 2001).

The Mashpee National Wildlife Refuge and the Monomoy National Wildlife Refuge are the only NWRs in the Nantucket Shelf region. Monomoy National Wildlife Refuge also contains a federally-designated Wilderness Area, which is managed under the 1986 Wilderness Act. In 1970, 94% of the Refuge area was designated as a Wilderness Area, under the 1964 Wilderness Act, which prohibits any development, alteration or disturbance. Monomoy is the only Wilderness Area in southern Massachusetts (http://www.capecodconnection.com/monomoy/monomoy.htm).

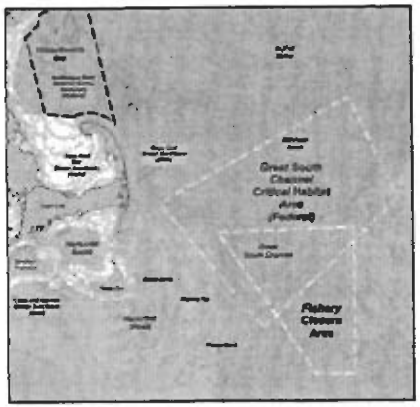
Critical Habitat Areas

Under the federal Endangered Species Act, Critical Habitat Areas in specific geographic areas can be designated to conserve, protect and restore threatened or endangered species that may require special protection or management in order to survive. Further development is not necessarily prohibited or restricted. Only activities that are likely to destroy or adversely affect the area or the species or their habitat, or activities that require a federal permit or license or receive federal funding, are affected. Either the U.S. Fish and Wildlife Service or the National Marine Fisheries Service or both may oversee a Critical Habitat Area, depending upon whether the species involved is found on land or in the ocean, respectively.

Two Critical Habitat Areas have been designated in the Gulf of Maine, both to protect the endangered northern Right Whale. Cape Cod Bay and the Great South Channel both are Critical Habitat Areas. Some protection applies year-round, but is strongest when whales are present. Restrictions on fishing apply. Other regulated or limited activities include marine discharging and dumping, non-renewable resource extraction, dredging, and cable-laying (Recchia et al., 2001).

Federal Fishery Closure Areas

Closure of areas to fishing has been shown to be an effective means of restoring depleted fisheries. Fishery closures are areas which are closed to some or all forms of fishing in order to restore depleted species. Typically they are designated to serve a specific fishery objective, such as rebuilding a depleted stock or protecting spawning or nursery areas, rather than conservation. However, other marine species can benefit from fishery closures, depending on the type, duration, and extent of closures. Closures can provide more effective protection to marine ecosystems than more conventional marine protected areas. Fishery closures are designated under the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act), for "*zones where, and periods when, fishing shall be limited, or shall not be permitted, or shall be permitted only by specific types of fishing vessels or with specified types and quantities of fishing gear.*"



The National Marine Fisheries Services (NMFS) has implemented some fishery closures in the Gulf of Maine, including year-round comprehensive protection for marine species and habitats: the Western Gulf of Maine Closed Area (partly overlaps with Stellwagen Bank National Marine Sanctuary); Closed Area I (partly overlaps Great South Channel Northern Right Whale Critical Habitat Area); and Closed Area II (northeastern Georges Bank). These areas were established to support rebuilding overfished groundfish stocks (cod, haddock, flounder) and are closed year-round to many types of fishing, including bottom trawling. Additional areas are closed seasonally or to some types of fishing activities (Recchia et al., 2001).

Of the several federal options described above, only National Marine Sanctuaries, Federal Fishery Closure Areas, and Critical Habitat Areas can be applied to open ocean areas. NEPs and NERRs are restricted to nearshore estuaries, although Nantucket and Vineyard Sounds can be considered estuaries. Federal Wilderness Areas and National Parks have not been applied to open ocean areas, although the recently-designated Boston Harbor Islands National Park incorporates coastal waters.

4.2. State Ocean Protection

State protection of coastal waters is limited to state waters, which extend only out to the 3 mile-limit from Mean High Water. Existing state managed/protected areas in the Gulf of Maine (Figure 32, Recchia et al., 2001).

- Massachusetts Ocean Sanctuaries
- State fishery closure areas
- State Essential Habitat for Endangered Species

The key features of these state marine protection areas are described below.

Massachusetts Ocean Sanctuaries

State ocean sanctuaries in Massachusetts protect the ecology and the appearance of the ocean and the seabed from exploitation, development, or other activity that would alter or endanger these resources. State ocean sanctuaries extend from Mean Low Water to the 3-mile state limit. Designation does not regulate fisheries or extraction of other living marine resources, but does limit discharges, dumping, extraction of non-renewable resources, marine construction, and shoreline alteration. The program is administered by the Massachusetts Coastal Zone Management Office and Department of Environmental Management (Recchia et al., 2001).

There are three existing Ocean Sanctuaries in southern Massachusetts: Cape Cod Bay Ocean Sanctuary, Cape Cod Ocean Sanctuary (along the Outer Cape), and the Cape and Islands Ocean Sanctuary. There are two additional Ocean Sanctuaries in northern Massachusetts (South Essex Ocean Sanctuary and North Shore Ocean Sanctuary) (Figure 32, from MassGIS data). The three Ocean Sanctuaries in southern Massachusetts exclude significant areas of Nantucket Sound, Nantucket Shoals, and nearby ecologically similar areas.

Massachusetts State Fishery Closure Areas

Like the fisheries closures implemented under the federal Magnuson-Stevens Act in federal waters, the Massachusetts Division of Marine Fisheries implements fishery closures in Massachusetts state waters. Similar to the federal closures, most closures are seasonal. There are no areas closed to all fishing. State estuaries and harbors are designated as Inshore Net Areas, within which fishing nets and mobile gear (i.e., bottom trawls and scallop dredges) are generally prohibited year-round, but scallop dredges are allowed pursuant to town regulations. (Recchia et al., 2001)

State Habitat for Rare Species

The Massachusetts Division of Fisheries and Wildlife oversees protection of rare and endangered species, vernal pools, and critical or endangered habitats, through its Natural Heritage and Endangered Species Program (NHESP). Critical habitat for rare species is identified and mapped, and provides the basis for reviewing and commenting upon proposed projects in or near rare species habitat. The Massachusetts Endangered Species Act (MESA) and portions of other resource regulations (e.g., state Wetlands Protection Act regulations, etc.) protect rare species and prohibit or limit disturbance or development of habitat which has been documented to contain state-listed species. All federally listed species occurring in Massachusetts are also state-listed to avoid discrepancies. State habitat for rare species is generally very limited in area and is delineated based on documented observations of state-listed species and information on their habitat needs.

4.3. Other Approaches - Marine Protected Areas and Ocean Zoning

Marine protected areas for ocean protection provide one approach for comprehensive ocean management and protection. This is a tool that has become available in the last several years since a Presidential Executive Order was issued in 2000 calling for increased designation of Marine Protected Areas (MPAs) to protect ocean resources (Executive Order 13158, 2000). The U.S. Commission on Ocean Policy, in its 2004 report, recommended that marine protected areas be used as one management tool to protect and manage important areas of the ocean (U.S. Commission on Ocean Policy, 2004).

Executive Order 13158 on Marine Protected Areas defines a Marine Protected Area (MPA) as: "any area of the marine environment that has been reserved by Federal, State, territorial, tribal or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein." (Executive Order 13158, 2000). For comparison, the World Conservation Union (IUCN) defines a Marine Protected Area as: "Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment." (Courtney and Wiggin, 2003).

Marine protected areas include a wide variety of coastal and ocean areas managed according to specific regulations. Marine protected areas are intended to protect and conserve biological diversity, habitat, natural resources, sustainable uses, and cultural heritage for future generations. The range of human uses that may be accommodated, the level of protection, size of area, and type of MPA vary widely. Within an MPA, different areas may be zoned for differing uses and degrees of activity, depending on the resources present, their value and sensitivity, and sustainable human uses (see NOAA and Department of the Interior website on Marine Protected Areas at http://www.map.gov/what_is_an_mpa/sup_terminology.html).

Designation, establishment or recommendation of a Marine Protection Area, based on Executive Order 13158, is undertaken by the Department of Commerce (NOAA) and the Department of the Interior, with input from other Federal agencies (e.g., Department of the Interior, Environmental Protection Agency, USAID, Department of State, Department of Transportation, the National Science Foundation, Department of Defense, and others). Recommendation and establishment of an MPA requires science-based identification and prioritization of natural and cultural resources for protection, assessment of ecological linkages, assessment of areas needing special protection of natural and cultural resources, identification of threats and gaps in protection, identification of emerging threats and user conflicts, identification of equitable management solutions to reduce threats and conflicts, assessment of the economic effects of such management, and identification of linkages with international marine protected area programs ((Executive Order 13158, 2000).

Ocean zoning is a regulatory plan to implement planning and protection. Ocean zoning consists of the division of a marine area into districts and within these districts regulating uses to achieve specific goals. The uses may differ between districts, depending on the goals of each district. Certain uses may be prohibited in some zones, due to the sensitive nature of the zone, but may be allowed in other zones where sensitivity is less or non-existent. Ocean zoning requires development of a map that outlines the boundaries of the districts, followed by development and implementation of a set of regulations for each district or zone created.

The advantages of ocean zoning include:

- Reduction of user conflicts by separating incompatible uses;
- Distributing uses according to an area's suitability for that use;
- Providing a flexible approach to management and protection on a site-specific basis;
- Adding predictability to the management and regulatory system; and
- Providing a way to coordinate management of a region (Courtney and Wiggin, 2003).

Ocean zoning faces some challenges. These are:

- Multi-dimensional nature of the ocean (physically and legally);
- Lack of consistent spatial data;
- Lack of accurate, up-to-date information on the resources;
- Importance of a scientific objective in setting up boundaries;
- Accessibility to agencies, users and stakeholders; and
- Movement of living and non-living resources across zoning boundaries.

Some examples of marine zoning already exist. These include the Town of Edgartown Surface Water District on Martha's Vineyard, including all waters seaward of Mean High Water (MHW) in the town's harbors and coves; Town of Orleans Watersheet Zoning for Pleasant Bay ACEC; New Jersey Marine Conservation Zoning to protect critical coastal habitat from Mean High Water out to 300 feet in the area of the Sedge Islands; National Marine Sanctuaries; and Marine Parks.

Courtney and Wiggen (2003) proposed ocean zoning for the Gulf of Maine, following an Ocean Zoning Forum held in 2002 by the Gulf of Maine Council on the Marine Environment. The goal of the Council was to promote marine sustainability in the Gulf of Maine; that is, manage uses, protect habitat and conserve biodiversity in the marine environment.

WHOI scientist investigating an oil spill, photo WHOI

5. KEY PRINCIPLES OF OCEAN MANAGEMENT

Given the ecological and human values of the Nantucket Shelf region, existing and potential management issues, increasing population pressures, and the Ocean Commission's recommendations regarding the need for ocean protection, it is time to consider nominating the Nantucket Shelf region for marine protection. What are the key principles of sound ocean management?

5.1. Ecosystem-Based Management

Ecosystem-based management and protection of resources should be one of the most important goals of marine protection (U.S. Ocean Commission on Ocean Policy, 2004). Ecosystem-based management is based on the principle that the best resource management and protection is firmly grounded in a sound understanding of the ecosystems being managed. Ecosystem-based resource management takes account of the complex relationships between all living organisms, including humans, and the environment in which they live. Complex issues that cross traditional jurisdictional boundaries and disciplines can be addressed (U.S. Commission on Ocean Policy, 2004).

Ecosystem-based management also incorporates change. Ecosystem-based decisions acknowledge that the environment can change, even in the absence of anthropogenic influences. Adaptive management also allows for new and improved scientific information and management tools to be used as they become available (Busch et al., 2003).

Ecosystem-based management is an alternative to traditional management of marine resources (e.g., single-species or single-resource management) because it is multidisciplinary and interdisciplinary. The U.S. Commission on Ocean Policy has recommended that ecosystem-based management approaches be used for protection and management of marine resources because of the complexity of marine ecosystems (U.S. Commission on Ocean Policy, 2004).

Ecosystem-based decisionmaking includes addressing the following:

1) Consideration of the health and vitality of ecosystems into the indefinite future;
2) The larger landscape and connections among other landscapes, and
3) Stakeholders' perspectives and human goals.

Ecosystem-based management requires attention to ecosystem integrity, interagency cooperation, specific management measures for specific areas, and time-series data for multiple species and habitats.

The benefits of utilizing ecosystem-based management include the following:

- Avoiding costly mistakes. Ecologically-based decisionmaking ensures that costly ecological mistakes in resource management are avoided;
- Well-coordinated, comprehensive management that takes account of natural processes. Entire ecological processes (feeding relationships, nutrient cycling, production, etc.) and ecological units (e.g., colonies, species, breeding populations, age-classes, etc.) are protected and managed in a comprehensive manner rather than managing for one or two species or a single process. This helps to avoid a piecemeal, uncoordinated approach to resource management.
- Boundaries are based on natural features. Resource areas are delineated along natural ecological boundaries rather than artificial political boundaries, allowing for efficient management of an ecological resource or function;
- Stakeholder issues are taken into account. Stakeholder concerns and human issues are considered;
- Adaptive management allows for improvements and change as information and knowledge improve. Resource management takes account of change in the environment and changes and improvements in knowledge and management tools. Adaptive management is described in more detail below.

Recently, ecosystem-based resource management in the marine realm has been proposed by several organizations. The U.S. Commission on Ocean Policy recommended that ocean and coastal managers use ecosystem-based management.

5.2. Integrated Coastal and Ocean Management

Integrated coastal and ocean management is a resource management principle that is applicable to managing and protecting a large and diverse region such as the Nantucket Shelf. Integrated coastal and ocean management can be defined as "*a continuous and dynamic process by which decisions are made for the sustainable use, development, and protection of coastal and marine areas and resources. First and foremost, the process is designed to overcome the fragmentation inherent in both the sectoral management approach and the splits in jurisdiction among levels of government at the land-water interface. This is done by ensuring that the decisions of all sectors (e.g., fisheries, oil and gas production, water quality) and all levels of government are harmonized and consistent with the coastal policies of the nation in question. A key part of ICM is the design of institutional processes to accomplish this harmonization in a politically acceptable manner.*" (Cicin-Sain and Knecht, 1998). The goals of integrated coastal and ocean management are:

- To achieve sustainable development of coastal and marine areas;
- To reduce vulnerability of coastal areas and their inhabitants to natural hazards;
- To maintain essential ecological processes, life support systems, and biological diversity in coastal and marine areas;

In addition, the processes involved in integrated coastal and ocean management are characterized by the following:

- Multi-purpose goals, planning and activities
- Analyzes implications of development, conflicting uses and interrelationships among physical processes and human activities, and
- Promotes linkages and harmonization between sectored coastal and ocean activities.

Integrated coastal and ocean management provides a flexible, protective, science-based approach that incorporates stakeholder and public interests, in a manner that is consistent with adaptive management principles (Cicin-Sain and Knecht, 1998).

5.3. Adaptive Management

Adaptive management is a third goal of resource protection and management. Adaptive management involves developing resource management plans and policy based on up-to-date scientific information concerning resources, monitoring the effects of these plans and policies on resources, modifying plans and policies as needed to achieve overall resource goals, and using science and policy to formulate and modify plans and policies. Future planning is done in a flexible manner to accommodate unforeseen events (Walter et al., 2000; Allison et al., 2003; Walters, 1997).

Although large areas of the Nantucket Shelf Region remain largely unexplored, there is sufficient information to indicate that the entire Nantucket Shelf Region provides significant ecological and recreational values. The U.S. Commission on Ocean Policy (2004) recommends that marine protection and management be based on sound science, but where such science is incomplete, protection and management actions should nevertheless proceed and build the capacity for collecting relevant scientific information. An adaptive management approach is recommended for the Nantucket Shelf Region, in addition to ecosystem-based management and integrated management.

6. CRITERIA FOR DESIGNATING MARINE PROTECTED AREAS

Criteria are measures of value, and the designation of marine protected areas begins with identifying criteria for judging the need for and type of protection and management. The identification of suitable criteria for designating protection is a necessary step in identifying an area to be protected, whether it is on land or in the ocean.

Possible criteria for designating a marine protected area fall into two categories: ecological criteria and socioeconomic criteria. The science and social science of resource protection in the U.S. has matured in the last century and a half since the first national parks were designated in the late 1800's. Resource managers today are keenly aware of the need to take account of socioeconomic factors as well as ecological factors in designing, managing and protecting natural resources. This is especially true for marine resources, which span a wide geographic area.

Examples of possible ecological and socioeconomic criteria for designation of a marine protected area are described below.

6.1. Ecological Criteria for Marine Reserve Design

A good example of ecological criteria for a marine reserve is provided by a study of the design of a network of marine reserves for conservation and fisheries management in the Channel Islands off the California coast (Airame et al., 2003). The Channel Islands are managed under a variety of state and federal jurisdictions, including the Channel Islands National Park, Area of Special Biological Significance, Channel Islands Biosphere Reserve, Channel Islands National Marine Sanctuary, and Santa Barbara Channel Ecological Preserve. The need to evaluate and improve resource management was driven by a steady deterioration of marine resources despite the state and federal management overlays.

Agencies, organizations, fishermen, environmentalists, and others first developed a set of goals. These goals are listed below (from Airame et al., 2003):

Table 8. Goals for Siting of a Marine Reserve Network in the Channel Islands, California. (Airame et al., 2003).

Goal Categories	Goals for Marine Reserves
Ecosystem biodiversity	To protect representative and unique marine habitats, ecological processes, and populations of interest in the Channel Islands National Marine Sanctuary
Sustainable fisheries	To achieve sustainable fisheries by integrating marine reserves into fisheries management
Economic variability	To maintain long-term socioeconomic viability while minimizing short-term socioeconomic losses to all users and dependent parties
Natural and cultural heritage	To maintain areas of visitor, spiritual, and recreational opportunities which include cultural and ecological features and their associated values
Education	To foster stewardship of the marine environment by providing educational opportunities to increase awareness and encourage responsible use of reserves

Table 8 provides a succinct yet comprehensive set of goals for a marine protection area. Based on these goals, the stakeholders then developed a set of regional ecological criteria, or set of ecological values, to help identify areas and suites of potential reserves. The concept of suites of reserves includes networks of reserves that provide organized management of ecological features throughout several areas or overlapping jurisdictions in order to achieve goals. Thus the ecological criteria are intended to overcome several criticisms of conventional resource protection: 1) Protection of a single resource without consideration of other resources can cause overall ecosystem damage; 2) A single resource that is distributed throughout several jurisdictions may not be managed adequately throughout all of the jurisdictions because of inconsistent goals; and 3) Existing types of individual reserves may not be adequate to manage an entire ecosystem.

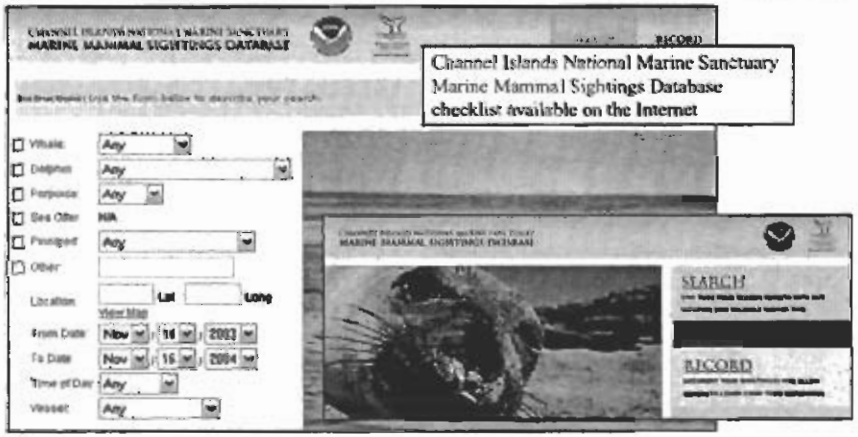
The regional ecological criteria developed by the Channel Islands stakeholders are given in Table 9.

Table 9. Application of ecological criteria for marine reserve design in the Channel Islands, Southern California. (Airame et al., 2003).

Ecological Criteria	Application to the Channel Islands	Limitations
Biogeographical representation	Three major biogeographical regions were identified using data on biota and substrate type.	Boundaries of biogeographical regions are not fixed.
Habitat representation	Representative and unique marine habitats in each biogeographical region were classified using depth, exposure, substrate type, dominant plant assemblages, and a variety of additional features.	Data on the distributions of habitat types may be limited.
Habitat heterogeneity	This was not incorporated as a specific criterion, but the analysis required representation of 30-50% of all habitats within the smallest area possible, this selecting areas of high habitat heterogeneity.	Data on the distributions of habitat types may be limited.
Vulnerable habitats	To ensure adequate representation, vulnerable habitats were considered as unique habitat types.	Data on the distributions of vulnerable habitats may be limited.
Species of special concern and critical life history stages	Island coastlines and emergent rocks were weighted according to the distributions of sea haul-outs and seabird colonies. The algorithm selected areas of high sea and bird diversity. Other species were not weighted due to insufficient data on their distributions.	Data on distributions and life-history characteristics of species of special concern may be limited.
Exploitable species	Habitats likely to support exploitable species, especially rockfishes (e.g., emergent rocks and submerged rocky features) were included for specific representation.	Data on distributions and life-history characteristics of exploitable species may be limited.

(Table 9. continued)

Ecosystem functioning and linkages	Not used.	Determining the extent to which ecosystem linkages constrains reserve design may be difficult.
Ecosystem services	Locations of Channel Islands National Park kelp forest monitoring sites were not included as a formal criterion, but borders of potential reserves will be adjusted, if needed, to include some of those sites.	Sufficient information on ecosystem services may not be available.
Human threats and natural catastrophes	The reserve size needed to meet reserve goals in a stable environment was multiplied by a factor that accounts for the frequency of severe disturbances.	Data on the frequency of severe disturbances may be limited.
Size and connectivity	At least one, and no more than four, reserves should be placed in each of the three biogeographical regions. For one region (650 square nautical miles), two to three reserves was recommended.	Optimal number of reserves will generally depend on the size of each biogeographical region. Reserve placement will depend on plant and animal dispersal among sites.



Channel Islands National Marine Sanctuary Marine Mammal Sightings Database checklist available on the Internet

These ecological criteria provide a good example of the way in which ecological factors are incorporated into resource management and protection, resulting in ecosystem-based management. Although the criteria were developed for the Channel Islands, they are applicable in their general sense to the Nantucket Shelf region as well. Specific details of each ecological criterion would have to be developed for the Nantucket Shelf Region.

6.2. Combined Socioeconomic and Ecological Criteria for Siting of a Marine Protection Area

In addition to ecological criteria, socioeconomic criteria are important in designing and siting a marine protection area. An example of socioeconomic criteria for selecting marine protection areas was summarized by Roberts et al. (2003), based on information from the Swedish Environmental Protection Agency and others. This example is reproduced in Table 10.

Table 10. Social and economic criteria used to select the locations of marine protected areas. (Roberts et al., 2003).

Value	Criteria
Economic	Number of fishermen dependent on the area. Value for tourism. Potential contribution of protection to enhancing or maintaining economic value.
Social	Ease of access. Maintenance of traditional fishing methods. Presence of cultural artifacts/wrecks. Heritage value. Recreational value. Educational value. Aesthetic appeal.
Scientific	Amount of previous scientific work undertaken. Regularity of survey or monitoring work done. Presence of current research projects. Educational value.
Feasibility / practicality	Social/political acceptability. Accessibility for education/tourism. Compatibility with existing uses. Ease of management. Enforceability.

(Information for Table 10 was summarized by Roberts et al. (2003) from the Swedish Environmental Protection Agency (Naturvårdsverket, 1995; Kelleher and Kenchington, 1992; Nordic Council of Ministers (Nordiska Ministerrådet 1995); Salm and Price, 1995; Hockey and Branch, 1997; Agardy, 1997; and Nilsson, 1998).

The relative importance of socioeconomic vs. ecological criteria, however, can differ, depending on the area, or depending on timing. For example, in the early stages of considering marine protection for an area, information on ecological and/or socioeconomic resources may not be complete. Typically, a marine protected area such as an estuarine research reserve might first be identified by its ecological values, followed by a growing appreciation of its socioeconomic values. Given that the appreciation of socioeconomic vs. ecological values may differ in time and according to the particular area, how can socioeconomic and ecological criteria be incorporated into a single system of criteria?

The answer lies in developing marine reserve networks that can maintain ecological values, such as biodiversity and ecosystem functioning at large scales, and where the values of ecosystem goods and services for people depend upon meeting the ecological goals, as described in Roberts et al. (2003).

This approach is applicable to the Nantucket Shelf Region, where socioeconomic values (appreciation of natural beauty, tourism, recreation, marine education) revolve about the ecological and natural values of the region. The Nantucket Shelf Region may be an example of an area where the socioeconomic values are important and well-defined in the public's mind, while appreciation of ecological values may be lagging due to gaps in scientific understanding.

7. EVALUATION OF POSSIBLE MARINE PROTECTION AND MANAGEMENT APPROACHES FOR THE NANTUCKET SHELF REGION

In this section, possible management and protection models are evaluated in terms of their potential usefulness for protecting and managing the values of the Nantucket Shelf Region. Different types of marine protected areas afford differing degrees of protection.

Of the many kinds of MPAs considered, most are suitable for managing or protecting watershed or coastal areas, and their marine jurisdiction ends at either a nearshore boundary (e.g., Mean High Water), a specified coastal boundary or at most to the limit of jurisdiction of the agency that oversees their management.

Currently, seven types of MPAs address or could address strictly marine or marine estuarine areas:

- National Estuary Program sites;
- National Estuarine Research Reserves;
- National Marine Sanctuaries;
- Critical Habitat Areas for marine organisms;
- Fishery Closed Areas or other federally-managed fisheries areas;
- Massachusetts Ocean Sanctuaries; and
- Ocean zoning.

Of these strictly marine or estuarine MPAs, only Fishery Closed Areas and Critical Habitat Areas strictly limit or temporarily prohibit fishing activities. Most of these allow or limit other activities, while National Marine Sanctuaries and the Cape Cod National Seashore prohibit development of nonrenewable resources.

Of these MPAs, federal jurisdiction is the greatest, up to 200 miles from shore. Thus National Marine Sanctuaries, federal Critical Habitat Areas, and federal Fishery Closure Areas provide the most jurisdiction. Extensive jurisdiction is important for an area so large as the Nantucket Shelf, portions of which lie outside of the 3-mile state jurisdictional limit.

The degree of protection afforded by MPAs also differs greatly. Most MPAs allow a variety of activities. Some limit or restrict activities. Only National Marine Sanctuaries prohibit specific activities (development of non-renewable resources).

National Marine Protected Area

State jurisdiction is generally limited to the 3-mile limit, and could not be used to protect the resources of the outer Nantucket Shoals, or the central portion of Nantucket Sound, or the shelf south of Martha's Vineyard, much less the Great South Channel. The most extensive jurisdiction is federal. For an area as large as the Nantucket Shelf region and its ecosystems, federal jurisdiction would provide the best coverage. This narrows the options to National Marine Sanctuary, Federal Fishery Closure Areas, Critical Habitat Area, or other Federal option.

While fisheries management within the area of Nantucket Shelf is highly desirable, the prohibition of fishing is not. Human uses of the area include recreational fishing and shellfishing, and these are important to the local economy. Too, the important functions of the Shelf region are nursery habitat and migration habitat. These functions can be protected through careful management for sustainable fisheries rather than prohibition of fishing. Protection of the area solely for fisheries also would overlook many of the other important natural and human values of the Nantucket Shelf.

The areas used by endangered species for breeding and nesting should be protected as Critical Habitat Areas. In particular, nearly the entire North American population of Roseate terns passes through the Cape and Islands region and stops in Monomoy to nest and feed. Terns also fly to Buzzards Bay, which is a National Estuary. Existing Critical Habitat Areas, such as the Great South Channel, which may be ecologically linked, should be incorporated as well. But designation of the entire Nantucket Shelf as a Critical Habitat Area is probably not warranted.

Outreach and scientific research are important activities that should be provided. Scientific research in particular needs to be ramped up in order to understand a coastal area that is just at our doorstep, so to speak. Designation as a National Estuary or National Estuarine Research Reserve (NERR) would provide these important activities of outreach and research but would not provide much regulatory protection. NEPs or NERRs can be overlaid on another type of MPA in order to provide protection, outreach and research.

A National Marine Protected Area (MPA), managed by NOAA, would provide the most comprehensive, flexible, and yet protective form of protection and management, particularly if it incorporates ocean zoning. Ocean zoning can be done within the context of one or more of these MPAs, and provides a flexible tool for managing large areas, subject to the shortcomings described above. For example, a Marine Protected Area may be divided into management and use zones depending on the need to protect sensitive resources, uses, and appropriate ecosystem-based management tools. Ocean zoning provides a highly flexible and effective tool. Ocean zoning areas would need to be designated, but could be developed around the major ecoregions and values already identified.

The Nantucket Shelf Region could be designated as a new federal Marine Protected Area, zoned into different ocean zones according to the relative importance of ecological and socioeconomic factors within each of the zones.

Example of Possible Ocean Zones Within the Nantucket Shelf Region: (see Figure 33)

Ocean Zone 1: National Marine Sanctuary designation for Nantucket Sound, Vineyard Sound, and Buzzards Bay. The designation would provide the highest degree of protection for both ecological and socioeconomic values, and would acknowledge the high degree of socioeconomic value placed upon the open ocean. This area is characterized by aesthetic and cultural values, active recreational boating and fishing, marine science and education, increasing coastal development, a coastal economy that is heavily dependent on the natural scenery, many management issues, and a network of several existing coastal protected or managed areas (Cape Cod National Seashore, Monomoy National Wildlife Refuge and Wilderness Area, Waquoit Bay NERR, Buzzards Bay National Estuary Program, Mashpee National Wildlife Refuge, and Massachusetts Ocean Sanctuaries). Other features in common include their marine estuarine nature; highly dynamic sediment and water processes; important fisheries and nursery functions; important avian habitat including nesting, breeding and airspace habitat. This zone is characterized by well-defined socioeconomic values that revolve about the undeveloped ocean, and less well-defined ecological values, particularly marine ecological values, that should be the subject of further study. Hazards include rising sea level and moderate to high coastal erosion, resulting in high coastal vulnerability. The area represents a moderate to high risk for shipping due to its shallow depth, variable shoals, and rapid currents.

Ocean Zone 2: Nantucket Shoals and Georges Bank. These two areas share many ecological and socioeconomic features: shallow sandy benthic habitat; high-energy environment (wind, waves and currents); important fisheries habitat; distance from land; ecological transition area between Great South Channel and the two Sounds; moderate recreational use; high cultural value; and a hazard to shipping. Georges Bank is actively managed for fisheries and fishery closures are in effect in some areas.

Ocean Zone 3: Great South Channel. This area is important for both ecological reasons (feeding grounds for endangered Right whales, fish and other marine animals, high productivity) and socioeconomic reasons (commercial shipping). The area contains a federal Critical Habitat for the Right whale and the fishery is seasonally closed.

Ocean Zone 4: Outer Continental Shelf. This area includes the large area of continental shelf south of Martha's Vineyard, Nantucket Shoals, and the Great South Channel, out to the edge of the continental shelf. The area is characterized by its open ocean character highly dynamic water processes, high rate of coastal erosion, moderate recreational value, fisheries habitat, high aesthetic value, and low to moderate risk for shipping. Relatively little is known about the ecological values of this area.

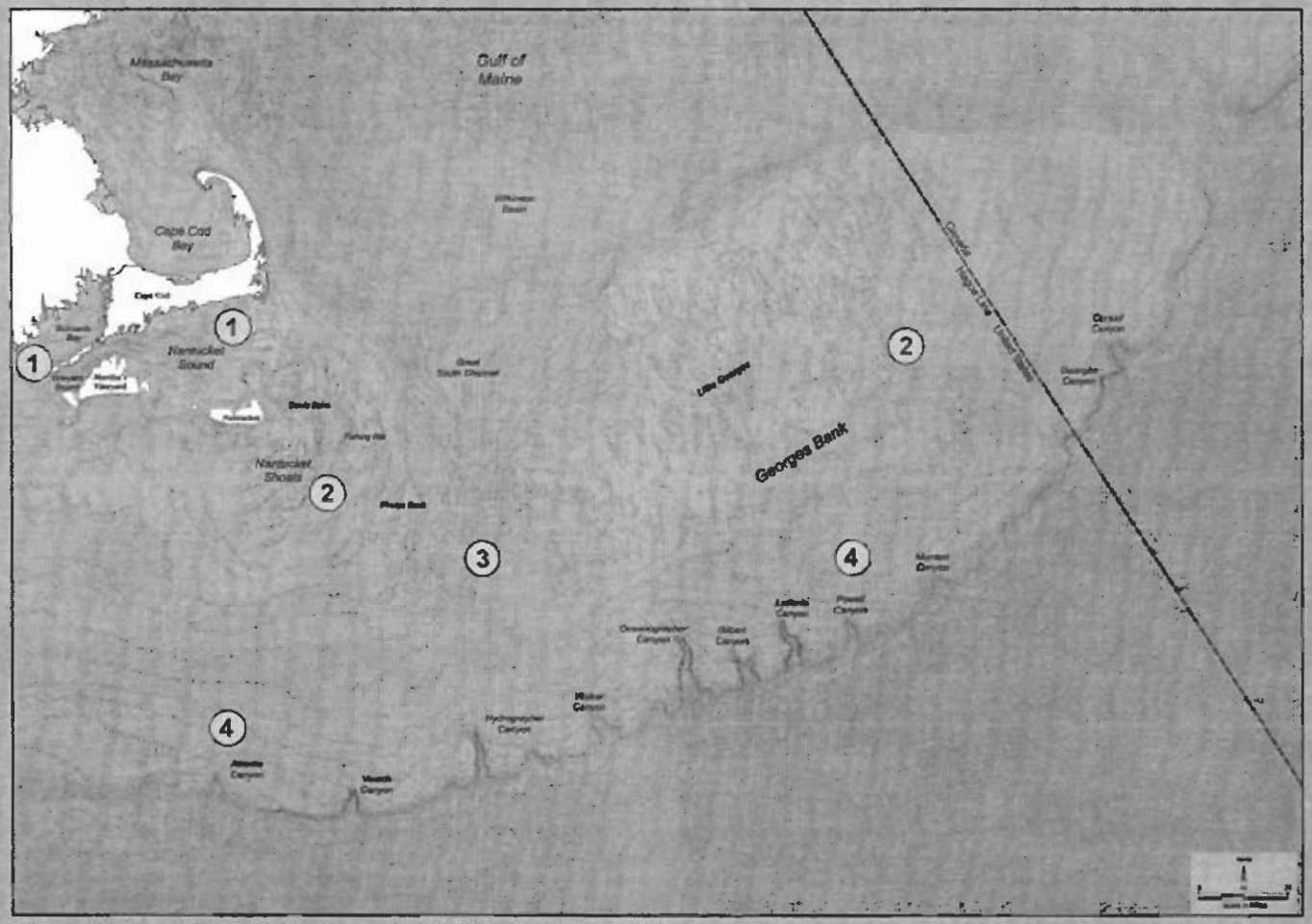


Figure 33. Ocean Zones Within a Nantucket Shelf Marine Protected Area:

1. **Ocean Zone 1:** National Marine Sanctuary designation for Nantucket Sound, Vineyard Sound, and Buzzards Bay.
2. **Ocean Zone 2:** Nantucket Shoals and Georges Bank.
3. **Ocean Zone 3:** Great South Channel.
4. **Ocean Zone 4:** Outer Continental Shelf.

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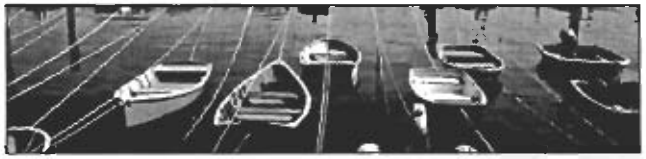

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