Chapter 2

Ecology of the Ocean SAMP Region

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Section 200. Introduction

The term “ecology,” translated from its Greek origins, literally means “the study of home.” From this, ecology can be thought of as a description, based on information gleaned and gathered during various studies, of the place where something resides. Ecology incorporates study not just of living things—the biota—but also non-living elements—the abiotic resources—because they profoundly influence where and how the living organisms exist. Ecology attempts to understand and describe the interactions between various living organisms with each other, between living organisms and the non-living resources existing in the local environment, and between the various abiotic components of the ecosystem.

While ecological study can be performed at various scales in the environment, this chapter will generally attempt to provide description at an ecosystem scale, though that description may be based on a subset of smaller patches of environment with the ecosystem. An ecosystem is defined as the collection of the various ecological communities, which are comprised of the populations of different species living in the area, and the non-living resources upon which they depend. For the purposes of this chapter, the ecosystem being described is that of the Ocean Special Area Management Plan (SAMP) region, the boundaries of which are shown in Figure 2.1.

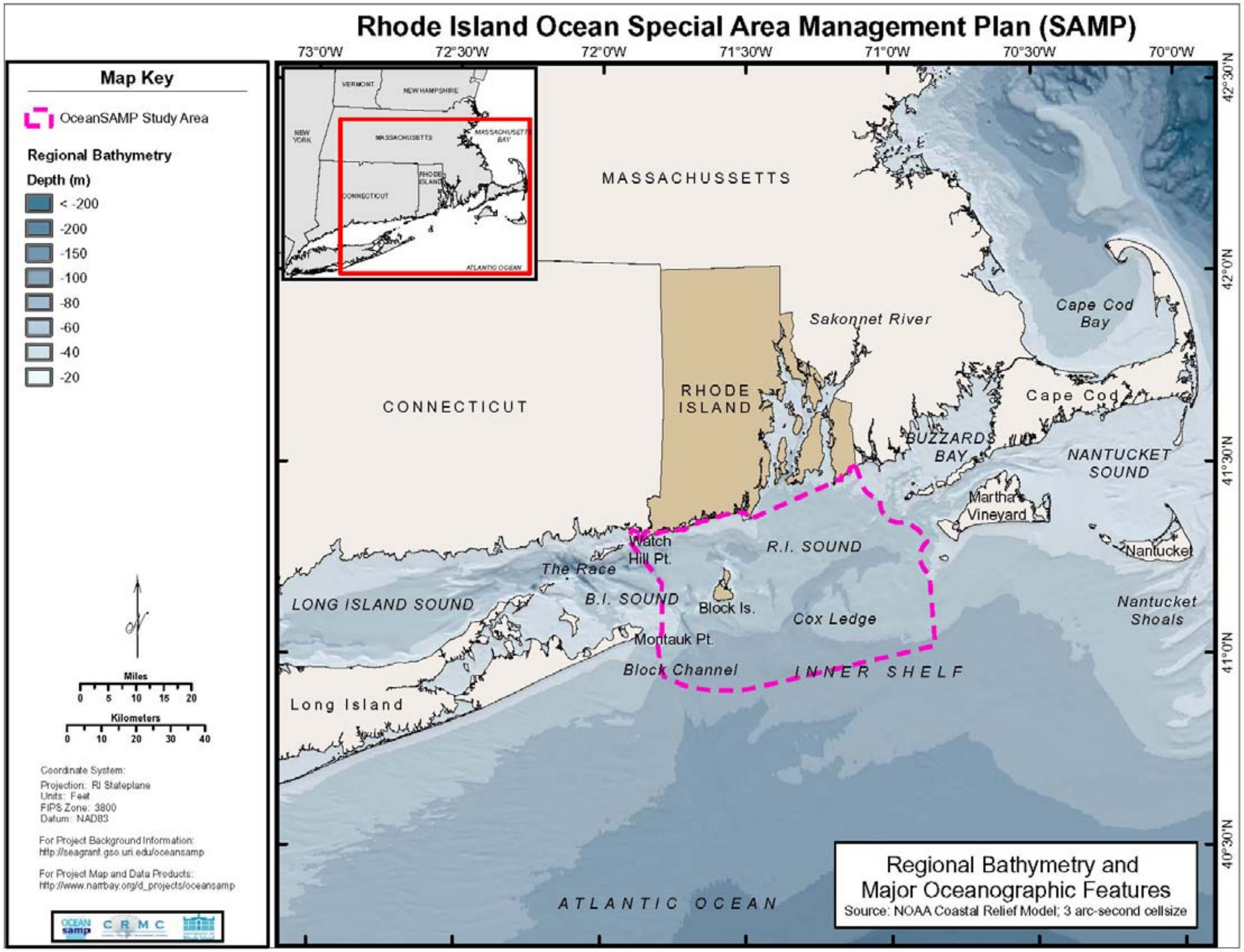


Figure 2.1. General geographic layout, basic bathymetry, and major features of the Ocean SAMP area as discussed in this chapter.

The Ocean SAMP region is a busy maritime entryway to Narragansett Bay, Long Island Sound, Buzzards Bay and the Cape Cod Canal. It could be anticipated that much would be known about the ecology, biology and ecological functioning of this important region. To date, mainly small-scale areas of the sea floor and water column have been intensively studied in Rhode Island Sound, Block Island Sound or the Offshore Ocean SAMP area (the region immediately south of Rhode Island Sound and Block Island Sound, roughly that area south of Block Island to the Continental Shelf Slope, is considered here to be the Offshore Ocean SAMP area, and will be referred to as such throughout this chapter). Therefore understanding of the overall ecology of this ecosystem is somewhat fragmented.

The Ocean SAMP area is an ecologically unique region—the Rhode Island Sound and Block Island Sound ecosystems are located at the boundary of two intermingling biogeographic provinces, the Acadian to the north (Cape Cod to the Gulf of Maine) and the Virginian to the south (Cape Cod to Cape Hatteras). Because of this, the Ocean SAMP area contains an interesting biodiversity that is a mix of northern, cold water species and more southern, warm water species.

Unfortunately, there is no baseline of information for the area that pre-dates human disturbances such as trawl fishing, so scientists have been and are investigating a changed ecosystem. New studies, however, are underway by a variety of researchers sponsored by various agencies and institutions. This chapter takes the patchwork of available information and attempts to stitch it together into a coherent fabric that describes the basic ecology of the overall Ocean SAMP area. The chapter should be updated from time to time to reflect the findings of new research.

The Ocean SAMP area includes Rhode Island Sound and the central and eastern portions of Block Island Sound, both of which are shallow, nearshore continental shelf waters lying between Martha's Vineyard/Elizabeth Islands, and Long Island. The area is dynamically connected to Narragansett Bay, Buzzards Bay, Long Island Sound, and the Atlantic Ocean via the Continental Shelf. Long Island Sound is a significant influence on the physical oceanography of the area due to the input of low salinity water from several major rivers (e.g., Connecticut River). A shallow sill extends from Montauk Point to Block Island at a depth of 15–25 meters, and partially isolates Block Island Sound from the Continental Shelf acting to some degree as a buffer to wave impacts. A canyon—Block Channel—extends several tens of kilometers from the deepest point of the sill, forming a deep connection between Block Island Sound and the Offshore Ocean SAMP area region of the Atlantic Ocean. The area of Rhode Island Sound and Block Island Sound overlapping the Ocean SAMP area is approximately 3,800 km^2.

Located in a temperate climate, the waters of the Ocean SAMP area are highly seasonal. Winter water temperatures, at both surface and bottom, range from 3–6°C and from 10–21°C during summer. During winter, bottom waters are often warmer, by several degrees, than surface waters, while in summer this trend is reversed with bottom water often 10°C colder than surface water. The disparity between surface and bottom water temperatures are important to the physical structure of the water column—summer conditions tend to promote stratification while winter conditions have a destabilizing effect that breaks down stratification. Water column stratification, a naturally occurring event in Ocean SAMP area waters, reduces interaction between surface waters and the rest of the water column. Stratification often sets up physical conditions that concentrates food items and draws in marine life, becoming a "hot spot" of biological activity. In warm, shallow areas, stratification can sometimes lead to reduced oxygen concentrations in bottom waters, creating stressful conditions. Anoxia or hypoxia (no or little dissolved oxygen) are not reported for waters in the Ocean SAMP area.

With a direct, open connection to the Atlantic Ocean, salinity in the Ocean SAMP area has varying, small ranges, with lowest values in spring and summer as influenced by spring rains and melting snow pack. While these ranges are small, they can be important in driving circulation, assisting in the development and stability of stratification, and influencing the marine life inhabiting the region. The dynamic physical oceanography of the area sets up zones where sharp differences in temperature and/or salinity between inshore and shelf water create discontinuities, called fronts. These fronts, which occur mainly during summer along the Offshore Ocean SAMP area, and in a region just south of Block Island, provide unique biological and/or physical characteristics that cause them to be major fish attraction areas.

The Ocean SAMP area is a biologically productive area, comparable to though slightly less so than nearby waters, such as Long Island Sound and Nantucket Sound. The growth of phytoplankton is seasonal, with spring and fall generally being the most productive times of year. Species composition of phytoplankton in the Ocean SAMP area reflects its interactions with Narragansett Bay, Long Island Sound and the Continental Shelf regions. Like Narragansett Bay, the annual winter–spring bloom of phytoplankton in Rhode Island Sound appears to be becoming less consistent in its regularity. Zooplankton populations are also seasonal, generally following the trends of phytoplankton abundance. Species composition and seasonality of zooplankton abundances does not appear to have changed much over the past 50 or so years for dominant species. Shifts towards smaller species of copepods in Continental Shelf waters has been documented, but it is not clear if this trend is being mimicked in Ocean SAMP waters.

Juvenile fish and eggs (e.g., ichthyoplankton) in the Ocean SAMP area are rich and varied, and show strong seasonality for many species, which is most often linked to reproduction. The seasonality of some ichthyoplankton appear to be changing over time, but the data are too sparse to say this with any degree of surety. For adult fishes however, the pattern is clearer. The fish community of Ocean SAMP waters is dynamic and diverse, but has undergone major change over the recent past. Demersal, or bottom dwelling fishes such as winter flounder, once were the dominant fish types of the area. Since the mid-1970s there has been a shift towards pelagic fish species dominance, with a corresponding increase in bottom invertebrates such as crabs and lobster. Dominant fish species are now bluefish, butterfish, and sea robins, at the expense of winder flounder and hake, for example. Squid, a large pelagic invertebrate, has also increased in abundance as this shift from demersal fish species ensued. Similar change is being noted throughout the broader North Atlantic region, and appears to be correlated to warming water temperatures resulting from changing climate.

The organisms living in the sediments make up an important food source for demersal fishes, and play a critical role in the cycling of organic material. The benthic communities in the Ocean SAMP area are dominated by various species of amphipods, with tube dwelling species (e.g., ampeliscids) being the most dominant throughout the area. Bivalves, marine worms, and small shrimps make up the bulk of the remaining dominant benthic species. There appears to be correlation between the types of sediments making up the bottom and the species that occur in them, but there is not enough information at hand to map this in any meaningful way, or to make species–bottom type correlations with any degree of surety.

Marine mammals—whales, dolphins, porpoise and seals—utilize the Ocean SAMP area, but sparsely and generally on a seasonal basis. While whales will often venture into Ocean SAMP waters, they are not resident and generally are passing through; most whale sightings occur in deeper waters out over the Continental Shelf. Harbor seals do utilize Ocean SAMP waters during winter months, and a growing North Atlantic population of this species makes them a regular sight from late fall to early spring before the seals move north to breed. Gray seals are less common to the area, though increasing populations of this species is resulting in increased visitation as well. Sea turtles too are often sighted in Ocean SAMP waters, but most are traveling through the area and as such are considered occasional visitors.

Bird life throughout the Ocean SAMP area is varied, with waterbirds being the most abundant. Passerines utilize Ocean SAMP air space during migration periods, and Block Island is an important stop over and resting spot for many species. Use of Ocean SAMP waters by waterbirds is heaviest during winter months, with a peak from early March through mid-April. Water of less than 20 m in depth is important feeding habitat for diving ducks, and nearshore shallow waters are important feeding habitat for terns nesting onshore during summer months.

A major issue of concern for the overall ecology of the Ocean SAMP area is changing climate. Changes to fish communities are evident, and findings from adjacent waters suggest changes in phytoplankton and zooplankton communities as well; the benthos has not been studied robustly enough to determine if major shifts might be occurring, and is an area ripe for further study. Existing data however, suggest relative stability of the Ocean SAMP zooplankton community over the past several decades, which does not agree with trends reported for the larger North Atlantic area. Altered ecosystem conditions are allowing for various native species to increase in abundance, sometimes to nuisance proportions, and non-native (invasive) species are gaining a toe-hold as they expand their ranges, often out competing and excluding native species in the process. While less is known about marine microbial communities and disease organisms in Ocean SAMP waters, lobster shell disease is increasing in abundance in the area and is being tied to changing climatic conditions. The northerly spread of shellfish diseases such as Dermo and MSX are also being documented, and again appear to be related to warming waters throughout the area.

In summary, the Ocean SAMP region is a dynamic, biologically productive, unique marine habitat area that is similar to nearby waters. It also is different in that it abuts two major eco-regions, and is therefore an expression of both. The Ocean SAMP region, like nearby areas, appears to be undergoing change as a result of changing climatic conditions. Our knowledge-base for the Ocean SAMP area however, is patchy, and much of it outdated. This makes it an even further challenge to understand its complex ecology.

Section 210. Geological Oceanography

1. The basic geological characteristics of the Ocean SAMP area create the foundation for its ecology. Large scale features, such as glacial moraines and boulder fields, are largely stable over long spans of time. Smaller scale features however, influence the physical forces of waves, tides and currents that move and sort the sediments which form the basic benthic habitat types available for colonization by organisms. Some of these habitats are fairly stable (e.g., boulders) while others are quite transitory (e.g., sand waves). Each habitat type supports different communities of organisms that make up the mosaic of benthic life in the Ocean SAMP area.

2. The geology of a region determines the basic characteristics upon which physical, chemical and biological elements of the ecosystem build. The geology is generally a static or slowly changing element of the landscape, though cataclysmic alteration (e.g., an earthquake or volcanic eruption) can occur and bring rapid, dramatic change. Block Island Sound, Rhode Island Sound, and the Offshore Ocean SAMP area, derive their basic topography and geology from Pleistocene glaciation activity, in particular the Wisconsinan Laurentide ice sheet that reached its maximum extent about 24,000 years ago (Stone and Borns 1986; Boothroyd and Sirkin 2002). The maximum southern extent of the ice sheet falls within the Ocean SAMP area, and its retreat created a unique patchwork landscape of boulders, sand, gravel, and moraine features that make up the ecological foundation of Rhode Island Sound, Block Island Sound and the Offshore Ocean SAMP area region.

3. Marine waters are estimated to have entered Block Island Sound and Rhode Island Sound about 9,500 years ago when sea level was 35 m lower than at present. Prior to that time, ancient glacial lakes were in existence, and drainage from the lakes helped create some of the major submarine features (e.g., canyons) on the Continental Shelf (Figure 2.2). Sea level rose at an estimated rate of 2 m per century, filling the ancient lakes with seawater, then slowing to a rate of 30 cm per century (3 mm yr^{-1}) about 5,000 years ago (Boothroyd in prep). Current sea level rise rate at Montauk, New York is 2.78 mm yr^{-1} (± 0.32 mm yr^{-1}; tidesandcurrents.noaa.gov/geo.shtml?location=851056); the tidal station at Newport, Rhode Island, is experiencing a sea level rate of rise of 2.58 mm yr^{-1} (± 0.19 mm; tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8452660%20Newport,%20RI), the station in New London, Connecticut a rate of rise of 2.25 mm yr^{-1} (± 0.25 mm; co-ops.nos.noaa.gov/sltrends/sltrends_station.shtml?stnid=8461490%20New%20London,%20CT) and the station on Nantucket Island, Massachusetts a sea level rise rate of 2.95 mm yr^{-1} (± 0.46 mm yr^{-1}; tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8449130%20Nantucket%20Island,%20MA) . It is expected that the Ocean SAMP area would currently experience a rate of sea level rise somewhere within the bounds of the Montauk, New London, Newport, Nantucket tide stations (2.25–2.95 mm yr^{-1}). The overall impact of rising sea level on the ecology of the area, with its subsequent loss as well as creation of new habitat, is not known (see Chapter 3. Climate Change, for further discussion of sea level rise in the Ocean SAMP area).

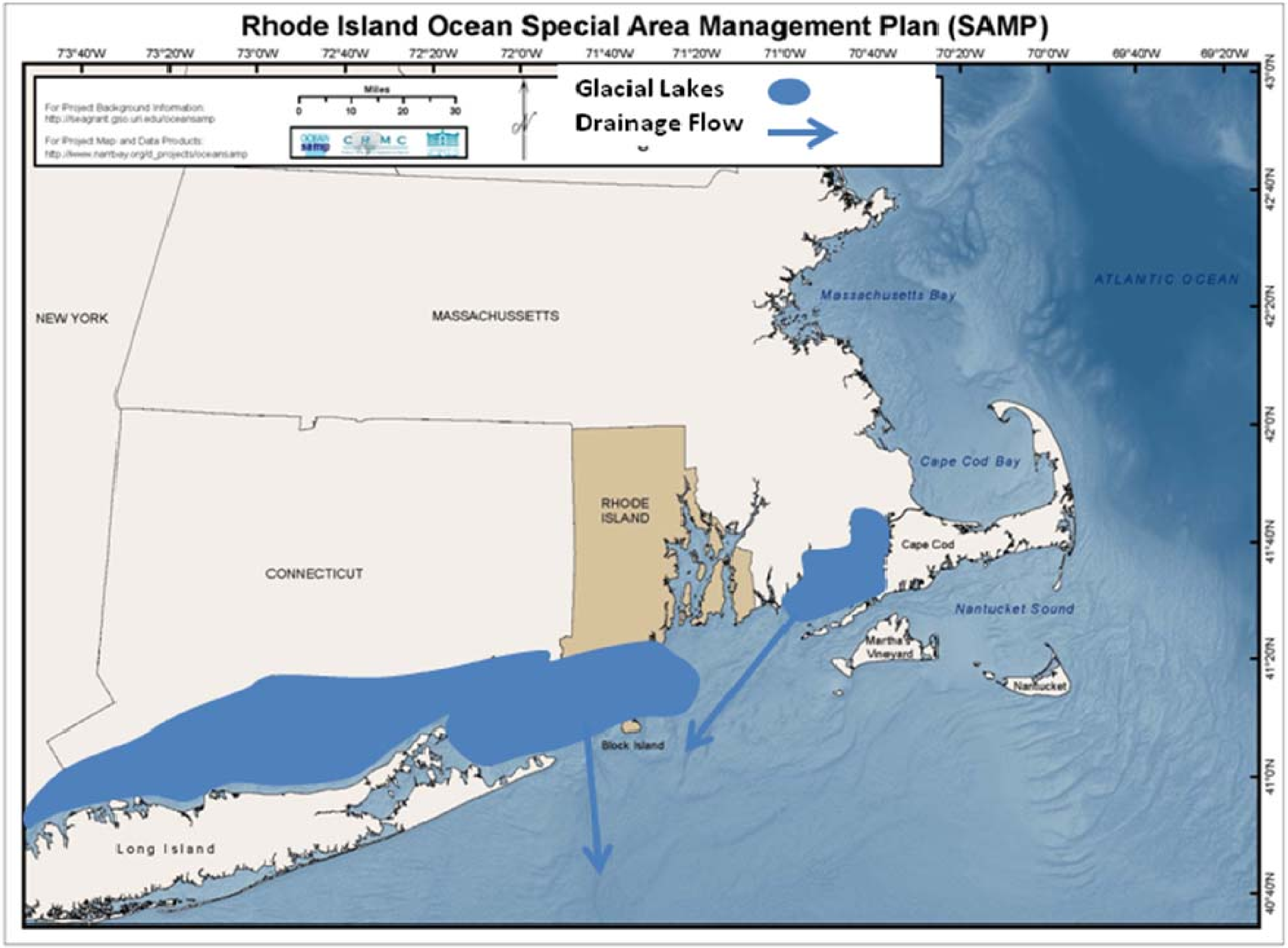


Figure 2.2. Schematic of approximate location of major glacial lakes and direction of drainage flows approximately 19,000 years ago, and which helped create current seabed topography. Adapted from Uchupi et al. (2001).

4. The geological features of Rhode Island and Block Island Sounds have strong influence on the physical oceanographic characteristics of those water bodies, which in turn has significant influence upon biological and ecological processes. Glacial moraines for instance, span the Ocean SAMP area, creating unique bottom topography which influences the patterns of currents, and creates a mosaic of habitats (e.g., sediment types) which diversifies the overall ecological fabric of the area (Figure 2.3). The moraine features, in general, are composed of coarse materials such as boulders and large rock. These materials provide vertical relief on the seafloor, which influences currents and provides greater surface area for colonization by attached organisms. In this way the moraines provide for habitat complexity. While other elements of the ecosystem may change dramatically and rapidly in response to changing climate, storms, and other perturbations, the basic geological foundation will remain as a solid influence in the face of all but the most catastrophic of events (e.g., volcanic activity). The basic resiliency of the benthic environment in the region has allowed the development of what appears to be a realtively stable benthic ecological community (see Section 250.2 for further details).

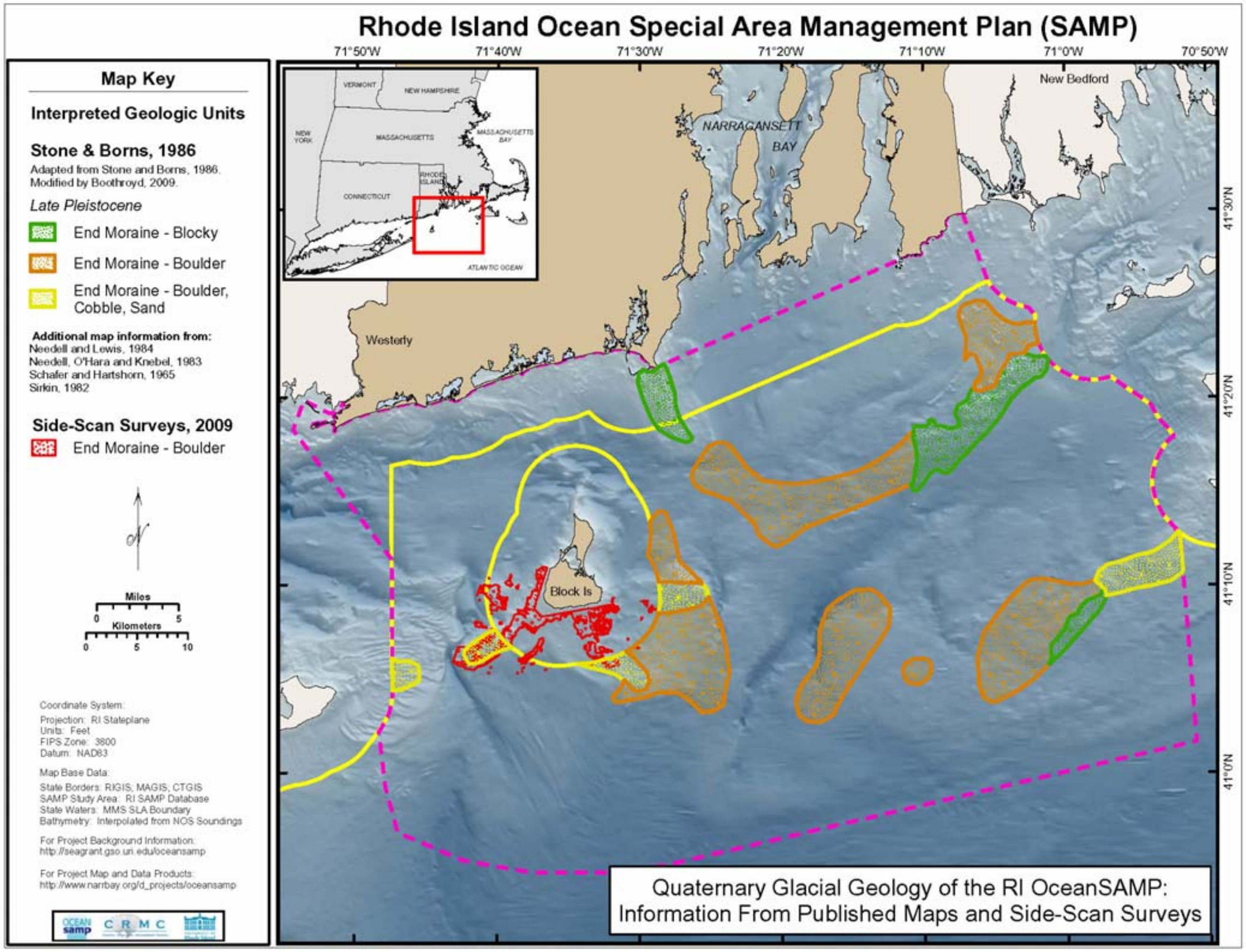


Figure 2.3. Location of glacial moraines in the Ocean SAMP area. The map is a composite of the moraines as defined by several researchers, shown according to compositional materials to emphasize the largest possible extent of the more substantial bottom materials such as boulders. These features help shape physical oceanographic forces such as currents, as well as benthic ecological habitats.

5. The glacially derived bottom topography and composition determines the benthic characteristics that will create the ecological habitats of Rhode Island and Block Island Sounds. Boothroyd (in prep) finds that the seafloor bottom in the Ocean SAMP area is characterized by four (4) major depositional environments, presented below in order of increasing grain size:

    a. A shore-parallel feature, called a depositional platform sand sheet, comprised of medium sand containing small ripples. This feature serves an important function as a short-term sand storage area for supplying alongshore transport of sand to the east, or onshore transport to shoreline environments. These features provide habitats that regularly undergo significant change;

    b. Features that are slightly lower than the cobble–gravel surrounding them, called cross-shore swaths, are composed of medium to coarse sand with small dunes. These features serve as a conduit for sand transport during storm events (Griscom 1978; Hequette and Hill 1993), providing habitat that undergoes regular, but less frequent, alteration;

    c. Cobble gravel that is in equilibrium (e.g., no loss or accretion), but often rearranged after and during storm events, called depositional gravel pavement. These features provide habitat that is relatively stable, yet subject to occasional disturbance;

    d. Concentrations of boulders and gravel inherited from the moraine, referred to as glacial outcrops, and which are more or less fixed in place, providing long-term habitats.

    These features, containing sand, coarse sand, cobble–gravel, and boulders, describe the composition of the major benthic environments found in the Ocean SAMP area. These features are characteristic, though not definitive, of the seafloor composition which shows gradation from and between one to another of these features.

6. While the basic overall geology of the Ocean SAMP area can be considered to be static, the actual local, physical, benthic environment found on the bottom is not. Sediments and bottom features are continually subjected to physical forces that alter their characteristics, and their location on the seafloor. Upwelling and downwelling currents, the orbital motion of waves, and unidirectional lateral flows all act upon and alter bottom features. Likewise channels, bottom topographic high points, and other bathometric features will influence as well as create these flows and currents. The flows and currents promote the transport of sand-sized materials and the migration of large bedforms such as dunes, sand ripples and sand waves, across the bottom. The sorting, movement, and placement of seafloor sediments that occurs during these processes creates a patchwork of habitats ranging from fine silts to gravelly areas to boulder fields (Figure 2.4; and see Figures 2.25 and 2.26). The diversity of physical habitats is a powerful influence on benthic ecological make up, determining what species will reside in what habitats in the bottom community; most often, the greater the structural physical diversity of an environment, the greater the biotic diversity of that ecosystem (Eriksson et al. 2006). Since these ecological "shaping" processes are ongoing, the bottom

community of the Ocean SAMP area is in a constant state of flux as habitat patches are altered or destroyed, moved or recreated along the bottom. The benthic community of the Ocean SAMP area is therefore expected to be composed of organisms that can withstand, and perhaps even thrive in an ever changing physical benthic environment.

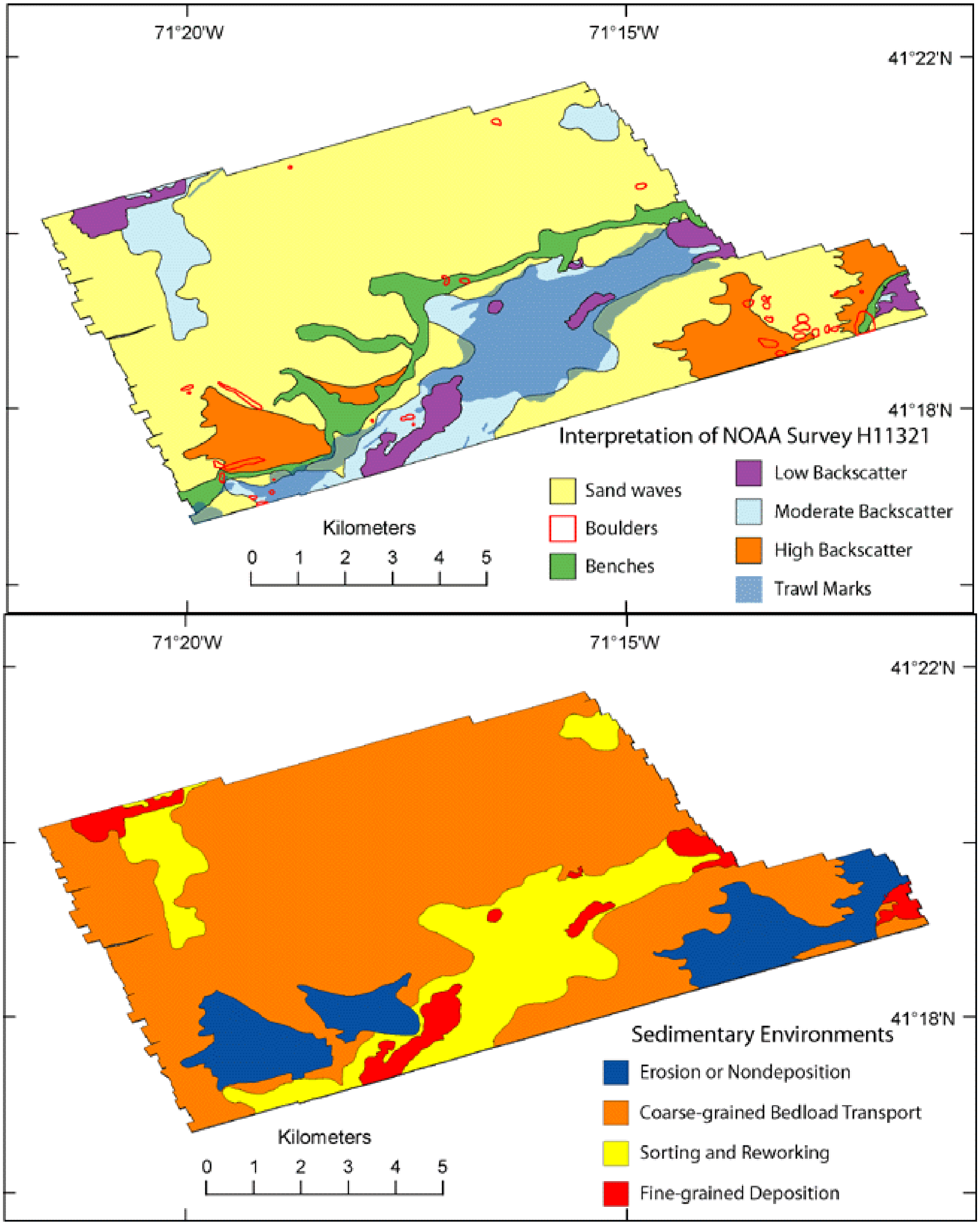


Figure 2.4. Bottom characteristics in a section of Rhode Island Sound as interpreted from sidescan sonar images (McMullen et al. 2008; their Figure 14 (upper) and Figure 10 (lower)). Note the large expanses of sandy area punctuated by scattered boulders in the upper panel. Yellow area in the lower panel shows more stable habitat areas, with orange (sand areas in the upper panel) areas being more transitory.

7. In recent side scan sonar surveys of portions of Rhode Island Sound (Figure 2.4), McMullen et al. (2008) found a mosaic of sedimentary environments that are the result of erosion and sediment transport, deposition and sorting, and reworking, with large areas comprised of transitory coarse-grained materials. Boulders were found scattered throughout the study area, though there were areas where concentrations of boulders existed, and which create areas of increased habitat complexity which would promote higher species diversity. Depositional areas where sediments were sorted and reworked tended to be found along channels and bathymetric high points. A preponderance of commercial fish trawl marks in depositional areas suggests a preference for this environment by commercially important demersal fish species. This in turn suggests a highly productive benthic community which is providing a rich food source. McMullen et al. (2008) found sand waves to be a predominant feature, and infer they are a result of coarse-grained bedload transport as was noted previously in this section. These features highlight the glacial origins of the area, and the stability of various features, for example glacial till, but also the transitory nature of other features, such as sand waves. Both bottom types—transitory and stable—are important characteristics in defining benthic habitat, and the types of organisms that will thrive there.

8. In an earlier survey conducted in Block Island Sound, Savard (1966) described the east–central portion as a smooth plain with an average depth of 34 m, with the rest of the section being dissected by holes, ledges and submerged valleys and ridges. In the area north of Block Island, the Savard (1966) found a northerly running ridge flanked by deep holes, and submerged hills and valleys. The deepest hole in Block Island Sound is an area 100 m deep located 6.4 km south of East Point on Fishers Island. This description notes similar features in Block Island Sound as are seen in Rhode Island Sound, and reinforces the existence of a mosiac of common bottom habitats through the Ocean SAMP area.

Section 220. Meteorology

1. Wind, waves, and storms are important forces shaping marine ecosystems. They influence water column mixing, current patterns and the transport of waterborne particles and planktonic organisms, as well as drive transport and sorting of bottom sediment. Water column mixing is enhanced by the turbulence created by winds and waves, thereby increasing oxygenation, and replenishing nutrients to the water column where they fuel plant production. Storms, although episodic, can create severe wind and wave stress, rapidly and completely breaking down stratification, altering seasonal productivity, and shaping both benthic and pelagic community composition. All these forces and their resulting influence on the area play a role in shaping the overall ecological makeup of the Ocean SAMP area.

2. A unique feature of Block Island Sound is that the impacts of large storm systems may be naturally mitigated, to some degree, by the submerged portion of the glacial moraine that extends from the eastern tip of Long Island to Block Island, and then continues northward toward Point Judith (see Figure 2.3). The moraine acts as a submerged jetty at the mouth of Block Island Sound, dissipating storm wave energy (Driscoll 1996). The degree of storm buffering provided, and its effect on Ocean SAMP area ecological and physical oceanographic functions, is not well understood. Though not cited as a cause-and-effect relationship, Spaulding (30 Nov 2007—www.crmc.ri.gov/samp_ocean/Wind_Energy_RI_EBC.pdf; accessed 11 February 2010) reports that wave heights within Block Island Sound are 40–60% smaller than those propagated offshore.

220.1. Wind

1. While winds are a highly variable phenomenon, there are seasonal, and daily, patterns that occur and that influence various physical attributes of the water column and sea surface. By exterting this influence, wind no doubt plays a role in shaping the ecology of the Ocean SAMP area, though specific study of this is lacking.

2. Winds in the Ocean SAMP region contain a seasonal, diurnal (e.g., late morning through late afternoon/early eveing), summer sea breeze component blowing from the southwest, with winter winds generally blowing from the northwest, and stronger than during summer (Loder et al. 1998). Winter northwesterlies often generate rough seas in Block Island Sound (Williams 1967), with east and southeast winds producing the biggest waves, up to 7 m reported. Wind velocities during winter months tend to be, on average, twice the speed of summer winds (Figure 2.5; O'Donnell and Houk in prep). Maximum wind speeds also show seasonality, but with a distinct decrease during May and June followed by a sharp increase during July and the early part of August (Figure 2.5). Increased maximal wind speeds during late summer assists in the breakdown of water column stratification. For instance, Shonting and Cook (1970) found wind stress to be an important element in the breakdown of the seasonal thermocline (e.g., stratification due to differences in temperature between surface and bottom water) in Rhode Island Sound.

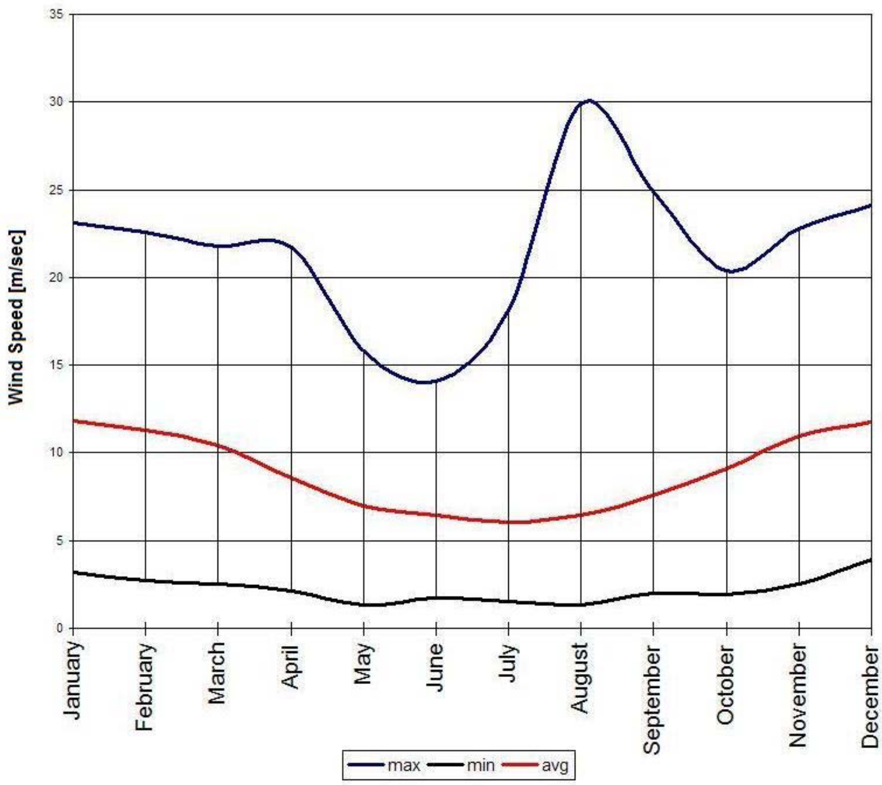


Figure 2.5. Average annual, average maximum, and average minimum wind speeds over the Ocean SAMP area. (www.crmc.ri.gov/samp_ocean/Wind_Energy_RI_EBC.pdf).

3. Winds have not been shown to play a major role in driving the long-term circulation patterns observed in Rhode Island Sound or Block Island Sound, though on a seasonal and shorter time frame basis wind can be a significant factor. Summer south westerly winds (e.g., sea breeze), while only half as strong as winter winds, drives upwelling along the coast which appears to help drive the flow of Long Island Sound water towards the shelf and offshore (O'Donnell and Houk in prep). Westerly summer winds also tend to increase the exchange of water between Block Island Sound and Rhode Island Sound, while winter winds, predominantly from the northwest, promote increased water column mixing rather than increased horizontal exchange (Gay et al. 2004). This mixing may help bring nutrients into the water column for uptake by phytoplankton, perhaps contributing to spring blooms when they occur.

4. Pilson (2008) reports long-term changes occurring in the winds experienced over Narragansett Bay; a nearly 4.0 km per hour (1.11 m sec^{-1}) decrease in annual average wind speed has occurred since 1950, with westerly winds (e.g., blowing to the east) showing this trend more markedly than winds in other directions. Whether these patterns are applicable to the broader Ocean SAMP area is not known, but trends towards decreasing wind speeds, suggested to be related to climatic warming, may have the potential to impact water column stratification events, upwelling of nutrients, and perhaps the overall ecology of the area as well.

220.2. Storms

1. The Ocean SAMP area is not an area regularly frequented by hurricanes—there has not been a single hurricane strike (to Rhode Island) since 2000 despite that decade being labeled one of the most active hurricane periods on record (http://csc-s-maps-q.csc.noaa.gov/hurricanes/viewer.html). Figure 2.6 shows the historical record of hurricane activity in the Ocean SAMP area (e.g., those hurricanes where the eye crossed into Rhode Island). The historical record shows 17 hurricanes making landfall in Rhode Island; 7–Category 1, 8–Category 2 and 2–Category 3 rated storms. The most recent Category 3 hurricane was Esther during 1961, and the most recent named hurricane was Bob, a Category 2 hurricane, during 1991. Hurricanes and intense storms systems however, can have significant impact on marine ecosystems. For instance, Smayda (1957) found a 16 to 27-fold increase in phytoplankton standing crop at the mouth of Narragansett Bay following the passage of major hurricanes. Storms, particularly hurricanes because of their intense winds, have the ability to significantly impact marine aquatic ecosystems since the depth to which wave generated orbital motion will be deep, and can impact the bottom (e.g., First 1972), particularly transitory bottom types as described in Section 210. How such a disturbance event might influence the ecology of the Ocean SAMP area is not known, but it could be presumed that benthic habitat would be disturbed, and that some impact, positive or negative, would be imparted.

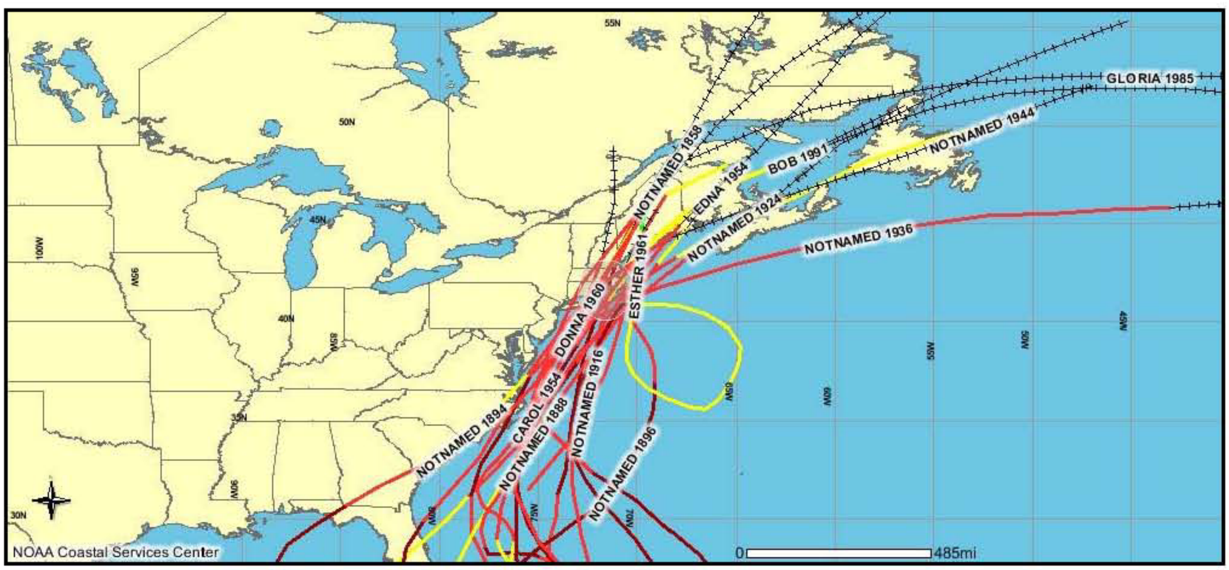


Figure 2.6. Hurricane tracks where the eye moved over Rhode Island, intersecting the Ocean SAMP area (http://csc-s-maps-q.csc.noaa.gov/hurricanes/viewer.html).

2. While hurricane frequency in the Ocean SAMP area has generally been low, there is strong evidence that the power dissipation index (PDI, a measure of destructive potential) has markedly increased since 1980 (e.g., Emanuel 2005; Webster et al. 2005). This increase correlates well with variations in tropical Atlantic sea surface temperature (Mann and Emanuel 2006; Holland and Webster 2007), which have been shown by numerous studies and reports to be on the increase, and has been linked to increased warming due to climate

change (IPCC 2007). While currently not considered a major ecological driver, the potential impacts of more frequent intense hurricanes on Rhode Island Sound and Block Island Sound ecology, circulation dynamics, and sediment transport, has not been well considered, but could be significant, and would be dependent both on the frequency and intensity of the disturbance events.

3. Southern New England coastal waters experience frequent intensive wintertime storms referred to as Nor'easters that generate strong alongshore currents and cross-shelf pressure gradients that can be felt from Cape Cod to Cape Hatteras (Beardsley et al. 1976). These storms are largely responsible for the episodic events that drive destructive waves and currents, and ultimately sediment transport along the coastlines resulting in beach erosion and sediment re-suspension offshore. While impacts of Nor'easters are well known for Rhode Island shorelines, their impact, if any, on the ecology of the Ocean SAMP area is not. Nearshore benthic habitats would certainly be impacted as sand was moved across depositional environments (see Section 210). Boicourt and Hacker (1976) however, note that winds associated with Nor'Easters can move waterborne particles, similar in size to common zooplankton and larval fishes, 40 to 80 km over the course of the several days that these storms hold together and create strong winds over an area. Such movement could have considerable short-term impacts upon planktonic organisms, particularly settlement patterns and juvenile survival rates for a variety of vertebrate and invertebrate species. While such events, because they occur infrequently, would tend to have short term impact upon the ecology (e.g., poor juvenile survival in a given year class), increasing frequency of such events due to climate change increases the probability that ecological impact could occur.

4. All storms facilitate a "storm surge," which is a wave of water created by strong winds blowing in a given direction for extended periods of time. The size of the storm surge is dependent largely upon the wind speed, though bottom bathymetry, water depth, and duration of high wind speed are all important contributors. For the Ocean SAMP area, probable storm surge over given time frames are: 10 year–2.52 m; 50 year–3.51 m; 100 year–3.58 m; SPH (Simulated Particle Hydrodynamics)–4.85 m (www.crmc.ri.gov/samp_ocean/Wind_Energy_RI_EBC.pdf). Asher et al. (2009) modeled slightly higher storm surges: 50 year–4.376 m; 100 year–4.446 m. The impact of storm surge on the ecology and/or physical oceanography of the Ocean SAMP area is not well known, though coastline areas would be suspected to receive the greatest impact from such events.

5. It has been noted that major storm tracks have been moving northward as a result of changing climate (Yin 2005). Major storms have the capacity to drive ocean circulation via wind stress, and can have significant impacts on vertical mixing of the water column (Hays et al. 2005), and hence upon water column stratification. If increased frequency and/or increased strength of storms alter circulation patterns in the Ocean SAMP area, plankton and larval fish distribution, and regeneration of nutrients into the water column, could be altered. Such change could alter the ecology of the Rhode Island Sound and Block Island Sound ecosystems, though in what ways and by what mechanisms is not known.

Section 230. Physical Oceanography

1. Rhode Island Sound, located in the eastern section of the Ocean SAMP area (Figure 2.1), encompasses approximately 1,530 km^2 (Shonting and Cook 1970), is bounded to the west by the eastern side of Block Island, to the north by the Rhode Island coast, and to the east by Martha's Vineyard and Nantucket Shoals. Rhode Island Sound is open to the Atlantic Ocean to the south, and has an average depth of 31 m and reaches depths of about 60 m, with a calculated volume of 4.74×10^{10} m^3 (surface area x average depth; McMullen et al. 2007; Shonting and Cook 1970). Rhode Island Sound exchanges water with Narragansett Bay through the East and West Passages, with the Sakonnet River, Buzzards Bay, Vineyard Sound and Block Island Sound, and with the Offshore Ocean SAMP area region of the Atlantic Ocean.

2. Block Island Sound, located in the western section of the Ocean SAMP area (Figure 2.1), encompasses approximately 1,350 km^2 (Staker and Bruno 1977), is bounded to the east by the western shore of Block Island, to the north by the Rhode Island coast, and to the west by Long Island, Fishers Island, and Long Island Sound. Block Island Sound is open to the Atlantic Ocean to its south, has an average depth of 40 m, reaching depths of 100 m, and has a calculated volume of 5.4×10^{10} m^3 (surface area x average depth; Staker and Bruno 1977). Block Island Sound exchanges water water with Long Island Sound through The Race and via a smaller opening between the east end of Fishers Island and Napatree Point, and the Offshore Ocean SAMP area to the south. A shallow sill (part of the moraine; see Figure 2.3) extends from Montauk Point to Block Island at a depth of 15–25 m, and partially isolates Block Island Sound from the Continental Shelf (Edwards et al. 2004). A canyon—Block Channel—extends several tens of kilometers from the deepest point of the sill, forming a deep connection between Block Island Sound and the Offshore Ocean SAMP area region of the Atlantic Ocean (Edwards et al. 2004).

3. The region immediately south of Rhode Island Sound and Block Island Sound, roughly that area south of Block Island to the Continental Shelf Slope (Figure 2.1), is considered here to be the Inner Continental Shelf, and will be referred to as the Offshore Ocean SAMP area throughout this chapter. The Offshore Ocean SAMP area region shows a strong overall current flow to the west (Cowles et al. 2008). Winds over the Offshore Ocean SAMP area are highly variable and seasonal, tending to be light in summer with infrequent strong wind events in both fall and spring; intermediate to strong wind events occur more frequently during winter (Cowles et al. 2008). Waters of the Offshore Ocean SAMP area become strongly stratified on an annual cycle, being generally well mixed throughout the winter and strongly stratified in summer due to a combination of heating, freshwater influence and reduced wind strength (Cowles et al. 2008). The breakdown of stratification on the Offshore Ocean SAMP area results mainly from the impact of wind from the west. Cowles et al. (2008) report a front that separates fresher, nearshore shelf water from salty continental slope water, to be a prominent hydrographic feature located between 70 and 100 m isobaths (see Section 230.4.1 for further details). Cowles et al. (2008) also report that warm core rings, calved from the Gulf Stream, occasionally enter the area and may have significant but short-term impact on circulation over the Offshore Ocean SAMP area region. Another perturbation

in the form of low salinity water from the Long Island Sound system is seen during years of very high river flow (Cowles et al. 2008).

4. The physical oceanographic components of marine systems, such as tides, water temperature and circulation, have broad, and often strong influence over chemical and biological processes. Freshwater input for instance, mainly from Long Island Sound in this case, sets up and strongly influences water circulation in Block Island Sound. Rhode Island Sound is influenced by the circulation patterns of Block Island Sound, and by water moving in across the Offshore Ocean SAMP area and from the east across Nantucket Shoals. The mixing and mingling of these different masses of water, particularly with regard to vertical mixing which is a critical parameter for nutrient recycling and the breakdown of water column stratification, creates a dynamic environment over both space and time.

5. Beardsley et al. (1985) referred to the general area encompassed by the Ocean SAMP as a “mixing basin” because of the diversity of water types and species that were observed. At the scale of the North Atlantic Ocean, the Gulf Stream moves warm water northward, with a return flow of cold water moving southward from the Gulf of Maine. Warm water from the Gulf Stream interacts with the water on the Offshore Ocean SAMP area (Beardsley et al. 1985), and provides opportunities for southern species to access the Ocean SAMP area. Figure 2.7 depicts the large scale general flow of water in the Ocean SAMP region. A large, meandering lobe of warm water can be seen extending northward towards the Ocean SAMP area. Sometimes these lobes break free and are referred to as “warm core rings,” that bring distinctive pockets of tropical water, including the biota entrained in it, onto the Continental Shelf where interaction with the Ocean SAMP area is possible. There are also distinct current flows that move from north to south, originating in the Gulf of Maine, moving around Cape Cod and then into and influencing the Offshore Ocean SAMP area region (Figure 2.7; Loder et al. 1998). In this fashion the Ocean SAMP area has contact with the larger Northeast US Large Marine Ecosystem, the cold northern water and the species that travel with it, as well as warm southern waters and the biota it carries. It should be noted however, that in the Ocean SAMP area there is a general flow to the southwest, exiting the Ocean SAMP area, and a commensurate inflow into the area from the northeast. Because of this, the Ocean SAMP area has a higher probability of coldwater species from the north entering the area. This also accentuates this importance of unusual events, such as storms from the south or Gulf Stream warm core rings, fostering the entry of more southerly species.

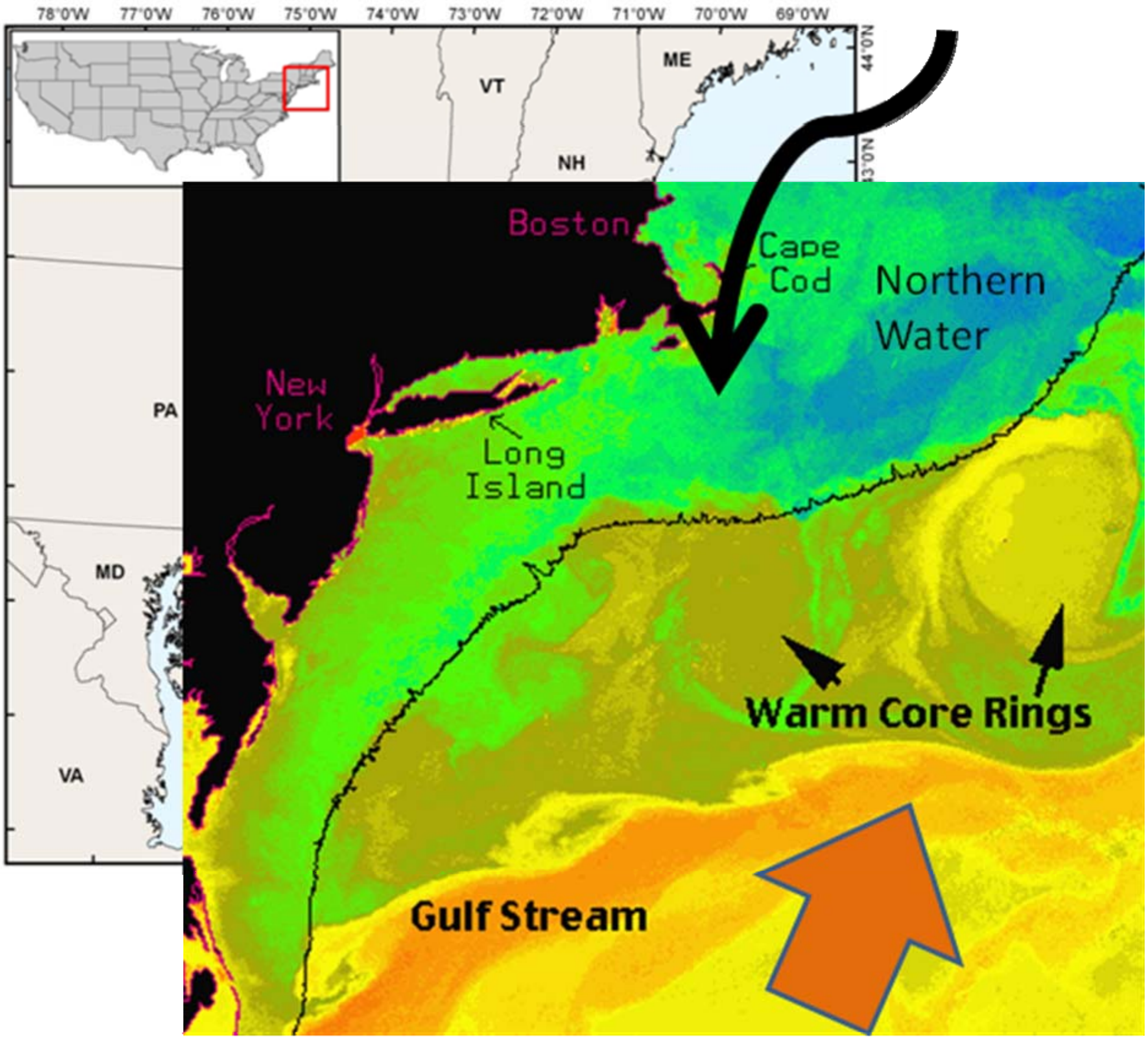


Figure 2.7. Schematic representation of northern cold water currents, southern warm water currents, and Gulf Stream warm core rings entering the Ocean SAMP area, making it a very dynamic ecosystem. Warm core rings graphic from: Coastal Carolina University ; http://kingfish.coastal.edu/gulfstream/p6.htm.

6. While there have been studies of the physical oceanographic characteristics of the Ocean SAMP area, many of them are geographically limited in their scope and do not portray a picture of how the area functions as a connected, dynamic system. A practical way to proceed at a systems-level scale is through modeling. The physical oceanography of the Ocean SAMP area however is complicated due to complex topography, which makes modeling attempts more challenging. Furthermore, a major challenge will be linking biological/ecological functions to physio-chemical processes to gain an ecosystem-based view of the region as a functional whole. Dr. Changshen Chen (University of Massachusetts Dartmouth; fvcom.smast.umassd.edu/research_projects/NECOFS/index.html) and collaborators have developed the U.S. Northeast Coastal Ocean Forecast System (NECOFS), which contains detailed geometry for Rhode Island Sound and Block Island Sound. Future

application of this model to the Ocean SAMP area would assist in better understanding circulation dynamics, and the ecology because biological components can be incorporated into the model to develop an ecosystem-level understanding. Codiga and Ullman (2010) report on many of the physical oceanographic aspects of the Ocean SAMP area that would be of importance to the NECOFS model application.

230.1. Waves

1. Wave analysis performed by Spaulding (2007) found that nearly 53% of the waves in the Ocean SAMP area come from three dominant directions: 22% from the south, 19% from the south southwest, and 12% from the south southeast, with average annual wave heights for each direction: 1.09 m (SSE), 1.15 m (S) and 1.29 m (SSW). Asher et al. (2009) are in agreement that the greatest frequency of waves, regardless of size, come from a southerly direction, with a mean wave height of 1.2 m and an extreme height of 8.4 m. Spaulding (2007) estimated probable wave height extremes for 10 year: 6.5–7.0 m; 25 year: 7.5–7.75 m; 50 year: 8.2–8.35 m; 100 year: 8.8–9.0 m frequencies. Asher et al. (2009) also estimated 9.0 m extreme wave height at a 100 year frequency, but noted that the probability of such a wave was not applicable to all Ocean SAMP areas. They found that geography influenced wave height, with waves from the south and the southeast having the greatest potential for larger size, with 10+ m extreme waves possible. Asher et al. (2009) found that the moraine stretching between Block Island and Montauk provided a wave damping action, with a net result that extreme wave heights would be 2–3 m less to the west of Block Island (versus to the south or southeast). This may be important ecologically as it tends to create an environment less influenced by disturbance events.

2. Average wave heights in the Ocean SAMP area tend to be 1–3 m, and overall, would be expected to have little impact on bottom waters, though surface waters would tend to stay well mixed. Larger waves, generated by winds associated with storms, will have a greater potential to impact the water column, particularly water column stratification. First (1972) found that statistically modeled wave induced bottom velocity should be strong enough, given 97 km hr^{-1} (60 mph) winds, to impact bottom sediments at a depth of about 60 m (e.g., Cox Ledge). From their modeling efforts, First (1972) further determined that wave induced bottom impact in water depths of 60 m should occur 1.5–4.9% of the time between September and November. This suggests that high intensity winds have the potential to mobilize sediment at the surface of the seafloor throughout much of the Ocean SAMP area, reworking sediments and sorting them as described previously (see Section 210). The impact of wave disturbance on the benthic environment of the Ocean SAMP area is not well known.

230.2. Tides and Tidal Processes

1. Tides are a constant physical attribute of marine ecosystems in the New England area. Their impact along the shoreline in shaping intertidal ecology is apparent, though in deeper, offshore waters the influence of the tides may be less obvious. Tides are of major importance in that they set up currents that alternate in direction every flood and ebb tide, moving water and waterborne constituents from place to place. Due to its geomorphology, tides in the Ocean SAMP area are major forces that shape circulation in the region, and tidal interaction with Long Island Sound is a defining feature of tidal circulation dynamics.

2. The Ocean SAMP area experiences a dominantly semi-diurnal tide (e.g., nearly twice daily) with a mean tidal range of about 1.0 m (Shonting and Cook 1970). The most extreme tide measured at the Newport gauge station was 2.96 m high on 19 August 1991 with the passage of Hurricane Bob, though this was due to storm surge plus the high tide, not just tidal influence (http://tidesandcurrents.noaa.gov/data_menu.shtml?extremetype=maxmin&bdate=19900211&edate=19950212&unit=0&format=Apply+Change&stn=8452660+Newport%2C+RI&type=Extremes). The diurnal tides move water from the Offshore Ocean SAMP area towards the sounds and then in an opposite direction on the following change of tide. The intensity of tidal interchange is much stronger in Block Island Sound than in Rhode Island Sound due to stronger tidal velocities, though how this influences ecological differences between the two sounds, if any, is not known. The tides also interact with connected bodies of water such as Nantucket Shoals, Buzzards Bay, Narragansett Bay and Long Island Sound, moving water throughout the various ecosystems.

3. Long Island Sound, because of the large volume of freshwater it receives, and the narrowness of the connection to Block Island Sound (e.g., The Race), is a significant influence upon the physical oceanographic and chemical characteristics of Block Island Sound. Current velocities in The Race, which are tidally driven, are strong (e.g., > 5 knots; Figure 2.8), and water moving out of Long Island Sound moves a considerable distance into Block Island Sound, and even into Rhode Island Sound. Freshwater, nutrients, pollutants and biota are mixed, mingled and exchanged between these water masses during each tidal cycle, particularly in the Block Island Sound ecosystem. The intense current flow at The Race, and at Montauk Point, create ideal feeding conditions for predatory fishes and these spots are noted regionally as prime fish concentration areas.

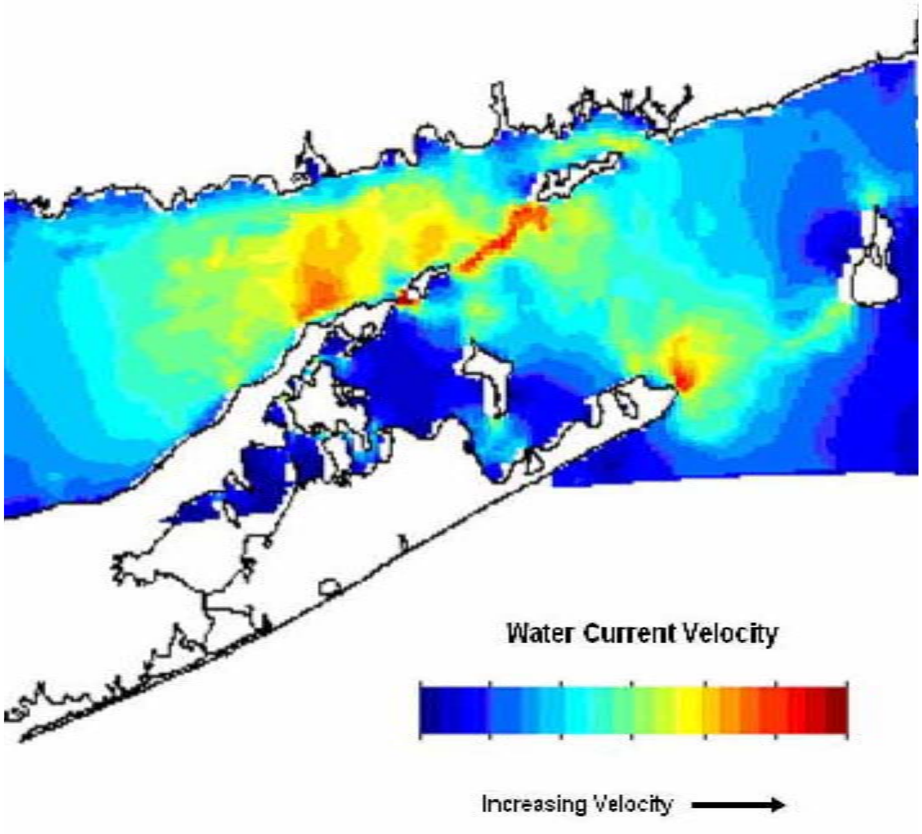


Figure 2.8. Water current velocities in Block Island Sound, particularly at The Race, showing the intense current speed in that area. ([www.crmc.ri.gov/samp_ocean/Ocean SAMP_Renewable_Energy.pdf](www.crmc.ri.gov/samp_ocean/OceanSAMP_Renewable_Energy.pdf)).

4. Riley (1952) described the tides in Block Island Sound as a progressive wave, with low water occurring 1½ hours earlier at Block Island than at The Race (the entrance to Long Island Sound). Riley found the topography of Block Island Sound to be a major force on tidal flows due to the variety of slopes and troughs found as bottom features. Such features create drag and turbulence, as well as upwelling and perhaps even downwelling currents, all of which influence sediment transport and sorting, and the overall ecological character of the benthos and water column.

5. Shonting and Cook (1970) found that tidal currents in Rhode Island Sound tended to have a northwest to southeast flow, but that this was quite variable due to the influence of wind stress and turbulent flow around shoals and islands (e.g., complex bottom topography). The major tidal flow in the Ocean SAMP area is via bottom water moving through Block Island Sound from offshore and into Long Island Sound via The Race (Edwards et al. 2004), and out again on the opposing tide.

6. Tidal flow from Long Island Sound interacts considerably less with Rhode Island Sound than it does with Block Island Sound. On the ebb flow from Long Island Sound, water runs east to the north of Block Island and interacts with the western edge of Rhode Island Sound. The majority of the ebb flow however moves out and around Montauk Point, creating high

current velocities (Figure 2.8), and then to the southwest parallel to the coast of Long Island and into the Mid-Atlantic Bight region (Edwards et al. 2004). Various studies (Koppelman et al. 1976; Kenefik 1985; Codiga and Rear 2004) suggest that more than 50% of the tidal transport entering Block Island Sound from Long Island Sound exits to the south between Montauk Point and Block Island. In all cases, the flow from Long Island Sound tends to be lower salinity water than that originating in the sounds, which has implications for mixing, stratification, circulation, and the ecology.

230.3. Hydrography

230.3.1. Temperature

1. Water temperature is a key criterion in determining the distribution of organisms, most all of which are limited to some degree geographically by physiological thermal tolerance that sets northern and southern (and often depth) limits to their range. Temperature is also an important factor that defines the density of water, which sets up circulation patterns at both vertical and horizontal scales, and plays an important role in water column stratification. In the Ocean SAMP area, temperature is highly seasonal, and therefore ecological change is highly seasonal as well. As a major element in defining the “comfort zone” of many marine organisms, temperature is a critical ecological variable.

2. Codiga and Ullman (2010) found during summer months that the warmest waters (11–21°C), at both surface and bottom of the Ocean SAMP area tended to reside in central Rhode Island Sound, and that Block Island Sound and the eastern portions of Rhode Island Sound were typically 1–2°C cooler. This is largely because stronger vertical mixing in Block Island Sound tends, as a result of its interaction with Long Island Sound, to keep the water column better mixed and temperatures therefore slightly cooler. It is unclear if this difference in summer temperatures plays any ecological role.

3. During winter, warmest waters occur offshore in the area around Cox Ledge, with lowest temperatures found along the periphery of the sounds abutting the landmass of the coast. During summer, the warmest waters are seen in northern and central Rhode Island Sound, while Block Island Sound, the area around Block Island and the eastern portion of Rhode Island Sound are cooler, because of the influence of Long Island Sound. A distinct thermal front (where two water masses that differ in their physical and/or chemical attributes collide) is noted south of Block Island at the periphery of cooler waters, and this front is coincident with a salinity front derived from the input of lower salinity water from Long Island Sound (see Section 230.4.1). During autumn, central Rhode Island Sound remains slightly warmer than adjacent waters.

4. Temperature data (Taylor et al. 2009) have been collected by the Northeast Fisheries Center as part of its Marine Resources Monitoring, Assessment and Prediction Program (MARMAP) conducted within the Northeast Continental Shelf ecosystem, with data collected at a suite of stations located within Ocean SAMP boundaries. Figure 2.9 shows the seasonality of water temperature, at both surface and bottom, showing a clear

difference in temperature (6–7°C) between surface and bottom from early spring through late fall, confirming that this is the time most probable for the water column to stratify.

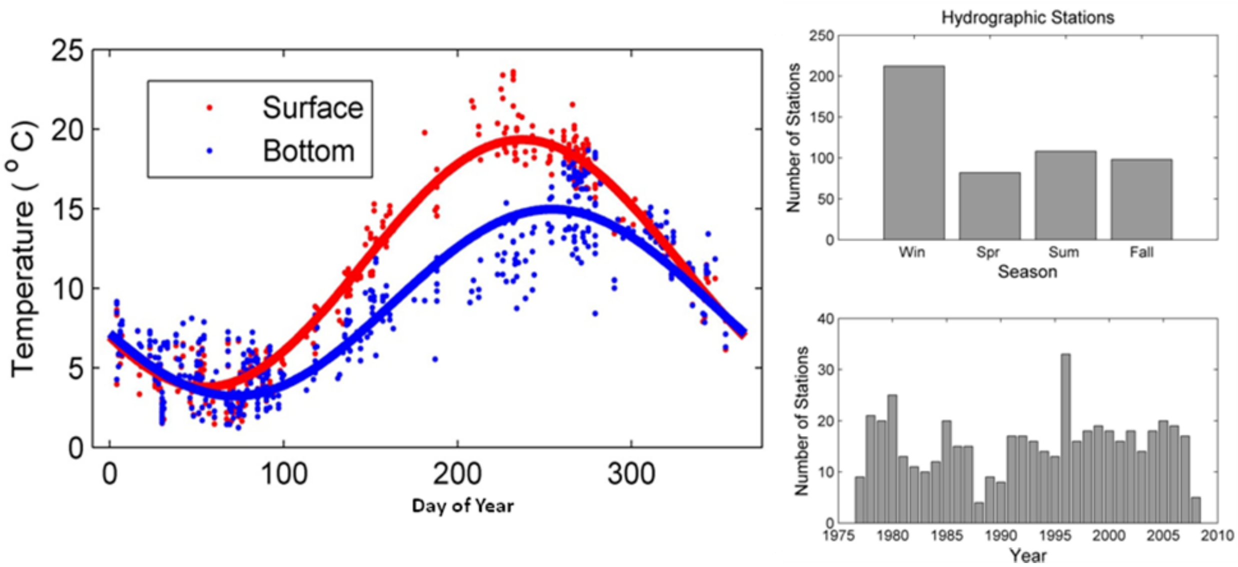


Figure 2.9. MARMAP water temperature data for all stations located within the Ocean SAMP area, and for all years of sampling (Taylor et al. 2009). Seasonality of collected data, as well as level of sampling effort over time, are shown in the stacked graphs to the right.

5. Figure 2.10 shows water temperatures within the Ocean SAMP area on a seasonal basis, and at various depths. It is important to note that during winter, bottom waters are considerably warmer than at surface or at mid-depth. Fish will often spend winter months near bottom where this thermal refuge exists (Sanders 1952; see Section 250.3). During summer months, bottom waters are cooler than at surface or at mid-depth, and fish will congregate near bottom as a refuge from warm surface waters that may be near the upper limit of their thermal tolerance. Strong storms that mix the water column could influence the occurrence of thermal refuges, though this has not been documented.

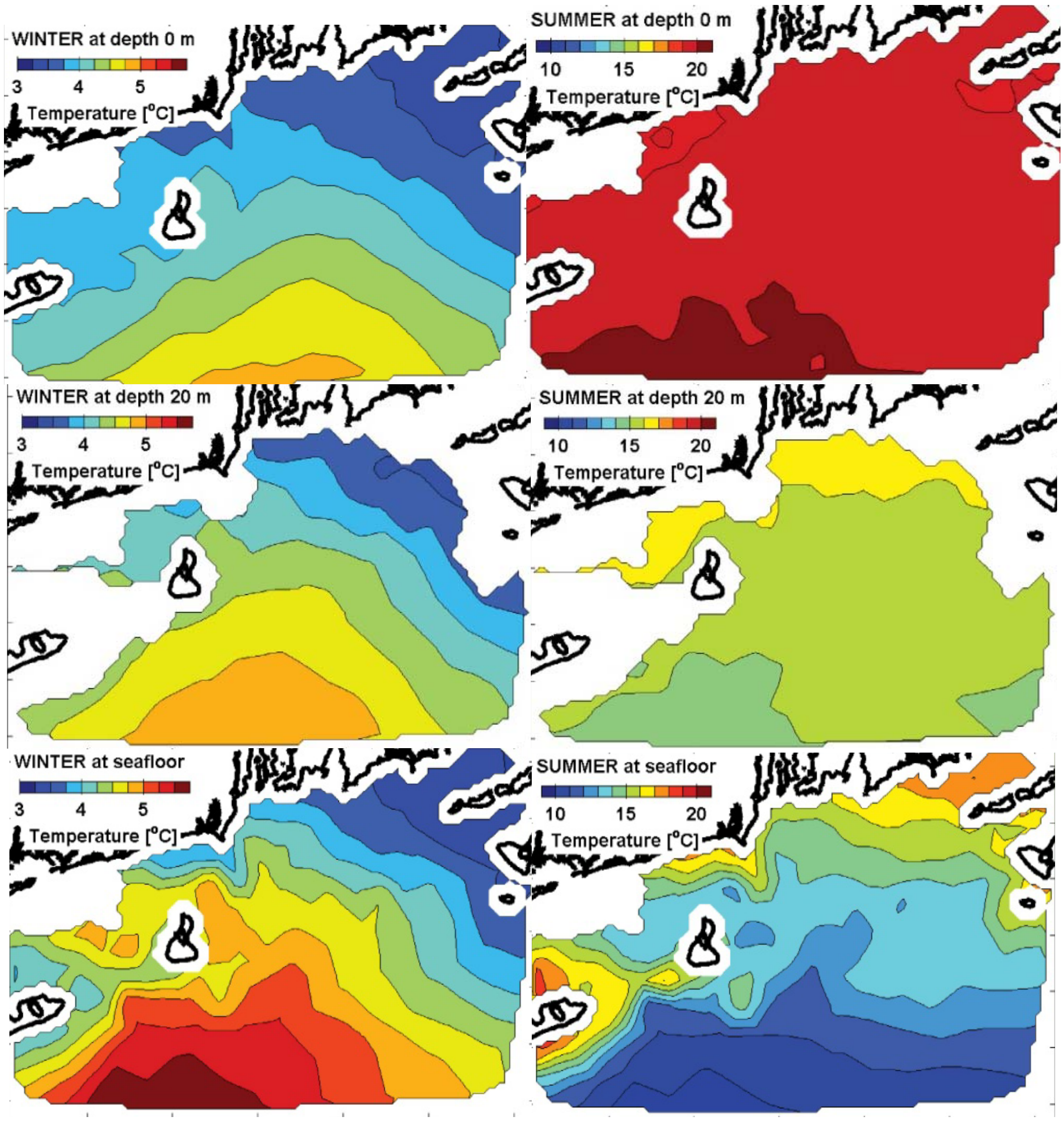


Figure 2.10. Seasonal water temperatures at sea surface, 20 m depth, and seafloor in the Ocean SAMP area, based on archived CTD data collected between 1980 and 2007 (from Codiga and Ullman 2010).

6. O'Donnell and Houk (in prep) note a strong seasonal signal in temperature at both surface and bottom at a station located northwest of Block Island, and about ¾ of the distance to The Race. Figure 2.11 shows the seasonal peak in water temperature consistently occurs in later summer/early fall (Aug/Sep), with the seasonal low occurring in late winter/early spring (Feb/Mar). During those years where surface and bottom temperatures are nearly identical (e.g., 1996), the water column is most likely well mixed. Conversely, in those years where surface and bottom temperatures are considerably divergent (e.g., 1998), the water column appears not to be well mixed and water column stratification is likely.

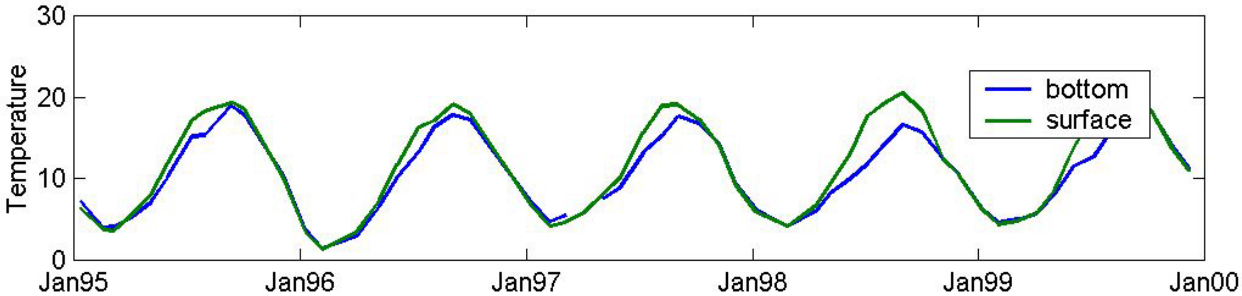


Figure 2.11. Average annual surface and bottom temperatures at a station in Block Island Sound (CTDEP No. N3; between NW of BI, ¾ of the way to The Race; from O'Donnell and Houk in prep).

230.3.2. Salinity

1. The seasonal input of freshwater is important to the ecology of the Ocean SAMP area—it brings an influx of terrestrial-based nutrients to fuel plant growth. The freshwater influx also promotes exchange with offshore bottom waters by fostering a return flow that offsets surface water outflow to offshore areas. It also brings the potential to promote water column stratification, particularly later in the season when overall wind speeds over the area decrease, and water temperatures increase. All of these factors shape the ecological composition of the Ocean SAMP area.

2. Long Island Sound estuarine circulation, driven primarily by the freshwater input of the Connecticut and Thames Rivers, is the major freshwater influence on Block Island Sound and the overall Ocean SAMP area (see Section 230.4). No large rivers or streams flow directly into Block Island Sound because of the terrestrial-based Charlestown Moraine which diverts all surface water flow either to the east to Narragansett Bay, or more generally to the west and into the Pawcatuck River system (Savard 1966).

3. Narragansett Bay is not considered to be a major source of fresh water to the Rhode Island Sound ecosystem, and does not appear to be a significant factor in circulation dynamics (Codiga and Ullman 2010). Shonting and Cook (1970) suggest that freshwater from Narragansett Bay influences Rhode Island Sound, but with a 2 to 3 month lag time; they found the mean salinity of Rhode Island Sound to be inversely related to freshwater runoff into Narragansett Bay. Further study is needed to verify or deny these suggested interactions.

4. Codiga and Ullman (2010) show salinity, which is strongly influenced by freshwater input, in the Ocean SAMP area by season, and at various depths (Figure 2.12). During winter, salinity is higher at bottom than at surface, with higher salinity water occurring with distance moved offshore (Figure 2.12). Salinity decreases during spring, particularly at surface and mid-depth as would be expected due to spring rains and snowmelt runoff into river systems. Summer salinities are very similar to those seen during spring throughout the water column. Fall sees a shift towards increased salinity, particularly at surface and mid-depth, as would be expected during dry late summer and early fall months. Spring and summer see the strongest salinity

differences at horizontal and vertical scales, which corresponds to the occurrence of the seasonal "front" to the south of Block Island (see Section 230.4.1).

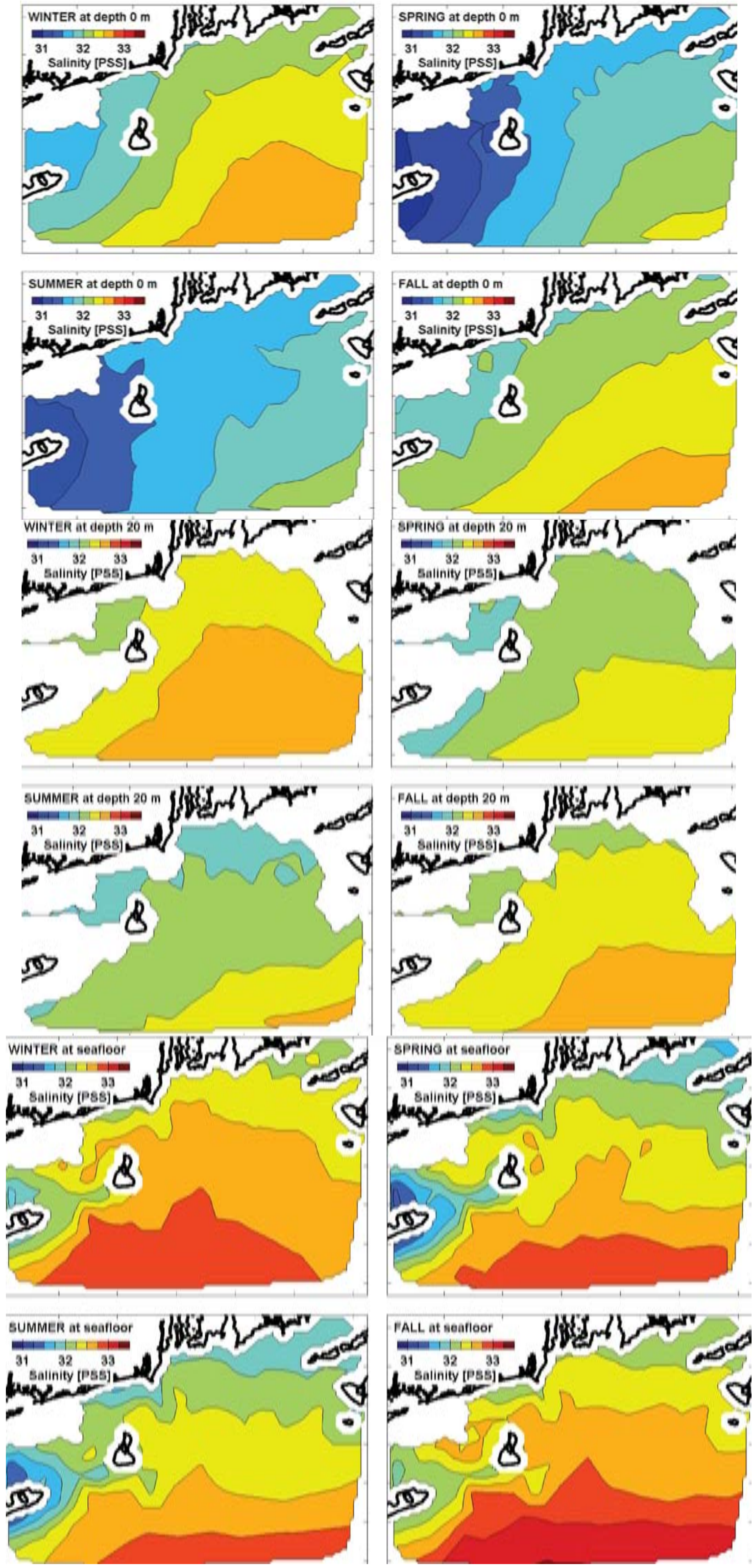


Figure 2.12. Seasonal water salinities at various depths in the Ocean SAMP area based on archived CTD data collected between 1980 and 2007 (from Codiga and Ullman 2010).

5. The Atlantic Multidecadal Oscillation (AMO) is a 65–80 year oscillation in sea surface temperatures in the North Atlantic. There has been a distinct warming trend since 1990, and Enfield et al. (2001) suggest that the AMO is entering a warm phase during which less than normal rainfall is seen. How such a trend may impact freshwater input to Long Island Sound, and hence buoyancy driven circulation between Block Island Sound and the Offshore Ocean SAMP area, is not known. For instance, Merriman and Sclar (1952) found that dominant year classes of butterfish, weakfish and cunner were produced in June and July of 1944, and that the reproductive success of all three species was correlated to high salinity water in Block Island Sound, which was the result of lower than normal freshwater input to Long Island Sound. Further research is needed to better describe the role of freshwater input and seasonal salinity patterns on the ecology of the Ocean SAMP area, and possible impacts to the ecology from changing precipitation patterns as a result of climate change.See Chapter 3, Climate Change, for further discussion of changing precipitation patterns in the Ocean SAMP area.

230.3.3. Stratification

1. While winds, tides, and circulation all promote the transport and mixing of water and the constituents contained in it, water column stratification—because of differing water density regimes at surface and at depth—plays an opposing role by setting up the physical conditions that can limit or preclude vertical mixing. A stratified water column is vertically stable, and promotes an accumulation of phytoplankton, which can then grow to bloom proportions (Mann and Lazier 2006). Decomposition of plant matter in the bloom consumes oxygen, and since stratification prevents vertical mixing, hypoxic or anoxic conditions can ensue, to the detriment of marine life. Water column stratification—sometimes strong stratification—sets up in both Rhode Island Sound and Block Island Sound, and over the Offshore Ocean SAMP area as well; stratification appears to be highly seasonal. It has been suggested that Block Island Sound, due to its more vigorous circulation and mixing regimes, is less prone to stratification than Rhode Island Sound. However, observations suggest that strong stratification can occur in either sound. The onset of stronger winds during the fall tends to break down stratification of the water column in all areas. Further work is needed on this topic to clarify the onset and persistence of stratification events, and to then begin exploration of impacts, if any, to the ecology of these ecosystems. There are however, no reports of water column anoxia or hypoxia for Ocean SAMP waters.

2. Beardsley et al. (1985) report that the outer shelf and continental slope waters are stratified on a seasonal basis—strong (e.g., stable and resistant to breakdown) stratification sets up during summer months, but breaks down in the fall, with the water column remaining well mixed throughout the winter. They found mixing of the water column to 200 m below surface. Codiga and Ullman (2010) also find strong stratification of the water column during the spring and summer, with stratification either weak (e.g., unstable and easily dispersed) or absent during fall and winter, in both Rhode Island and Block Island Sounds. Based on this, it can be noted that stratification appears to be a common, seasonal phenomenon throughout the Ocean SAMP area.

3. Shonting and Cook (1970) found a distinct thermocline in Rhode Island Sound during a survey in July of 1963; surface temperatures were 20°C and bottom temperatures less than

10°C; this is a significant difference and suggests strong stratification of the water column. Shonting and Cook (1970) found the thermocline to be most pronounced on the southern side of Rhode Island Sound, and much less pronounced near shore to the north. They further suggest this might be a function of the tidal currents in areas near the mouth of Narragansett Bay which would mix the water column. The thermocline was virtually eliminated by decreasing temperatures and increasing winds during the fall. Codiga and Ullman (2010) found stratification in the western region of Rhode Island Sound during spring months, and again during most of the summer months as well. Water column sampling at four stations in Rhode Island Sound (December 2002, between Block Island and Brenton Reef) found weak stratification with a fairly homogenous water column with regard to temperature, salinity and dissolved oxygen (U.S. Army Corps 2002). Dissolved oxygen concentrations in both surface and bottom waters however, remained well above the criteria established for highest quality marine waters, suggesting that hypoxia/anoxia may not be a condition typically associated with stratification in the Ocean SAMP area.

4. Freshwater input from Long Island Sound sets up water column stratification just south of Block Island. The area of stratified water expands northward during times of high river discharge, but is seasonal in its nature and breaks down during summer months and/or times of reduced precipitation/river flow. Williams (1969) found the water column to be well-mixed during the winter, with temperatures 1–3°C. During summer months, a strong thermocline developed, with surface water at 20°C and bottom water as low as 10°C. O'Donnell and Houk (in prep) note a seasonal cycle to salinity in Block Island Sound, but with greater variability than that observed for water temperature. Figure 2.13 shows seasonal averages for surface and bottom salinity in northwestern Block Island Sound. Times where surface and bottom water salinity are near equal suggest intense mixing events, perhaps from storms, that breakdown and eliminate water column stratification. Wide differences between surface and bottom water salinity, particularly in those times where surface water salinity decreases rapidly, suggest influxes of freshwater from Long Island Sound, with intensified water column stratification a high probability (Figure 2.14). Codiga and Ullman (2010) found winter stratification to be stronger in Block Island Sound than in Rhode Island Sound, largely due to the freshwater influence of Long Island Sound outflow. They also found stratification to be enhanced in eastern Block Island Sound during spring months, again because of the influence of Long Island Sound outflow. In general terms, Codiga and Ullman (2010) found stratification to be consistently the strongest in the western Ocean SAMP area, particularly south of Block Island.

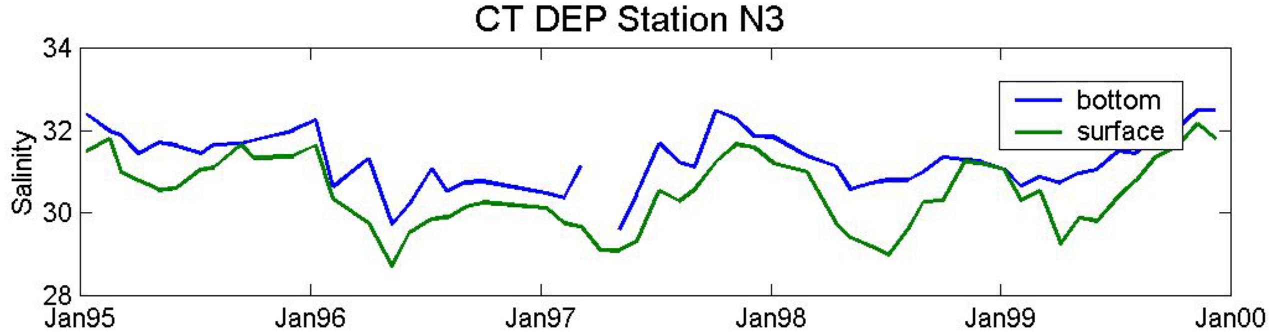


Figure 2.13. Average annual surface and bottom salinity at a station in Block Island Sound (CTDEP No. N3; between NW of BI, ¾ of the way to The Race; from O'Donnell and Houk in prep). Periods where surface and bottom salinities are nearly equal suggest mixing events, while rapid declines in salinity of surface waters suggests increased freshwater input associated with increased runoff in rivers feeding Long Island Sound.

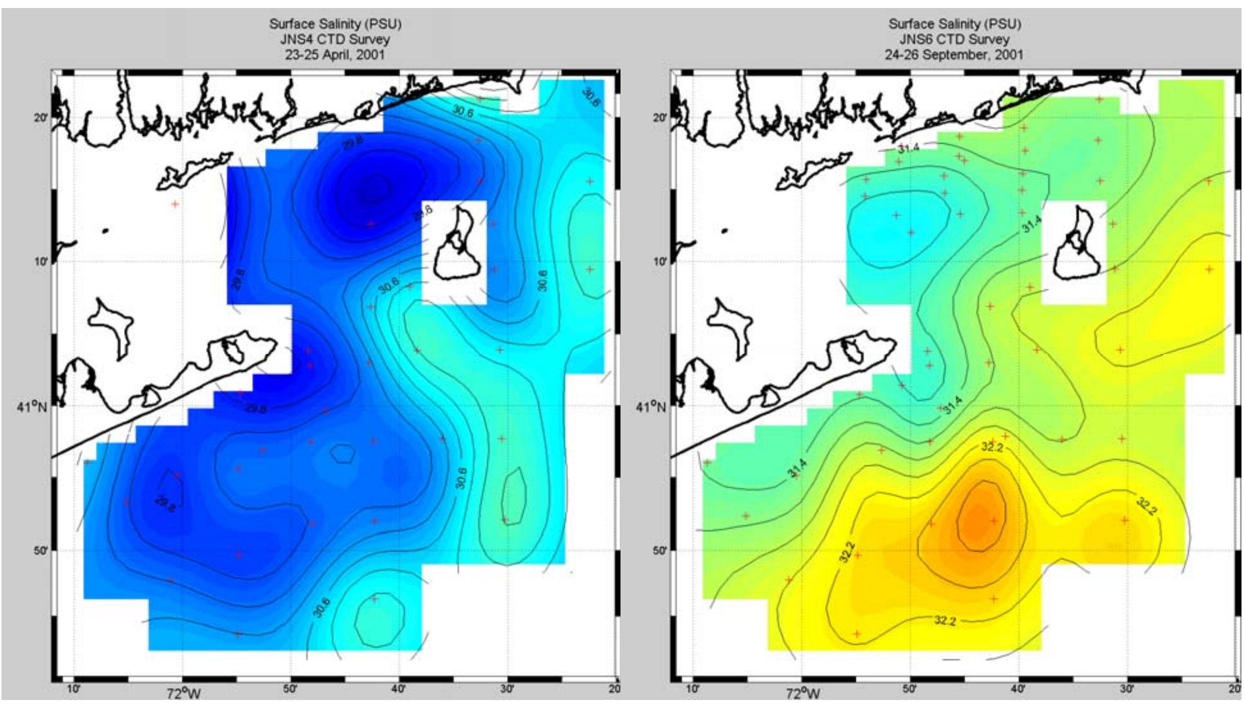


Figure 2.14. Surface water salinity during times of high freshwater discharge (left panel) and low discharge (right panel; from O'Donnell and Houk in prep).

5. During times of low freshwater discharge into Long Island Sound, O'Donnell and Houk (in prep) observed high salinity water intruding into Block Island Sound from the Offshore Ocean SAMP area region at mid-depth in the water column (not shown in Figure 2.14). Intrusions of high salinity water from the shelf such as noted by O'Donnell and Houk, have not been reported previously and are little understood with regard to the frequency of

occurrence, and how they relate to other physical forcing factors such as winds and tides. The impact of mid-depth, high salinity intrusion events on the ecology of the area has not been studied.

230.4. Circulation

1. Circulation is a major force shaping the ecology of the Ocean SAMP area, being responsible for the distribution of much of the flora and fauna found in Rhode Island Sound and Block Island Sound. Planktonic organisms and planktonic life-cycle phases (e.g., fish eggs and larval crustaceans) are at the mercy of circulation patterns for dispersal and to take them to suitable settlement sites. Circulation determines areas of food concentration, which in turn largely determines where predators will congregate to feed.

2. Circulation patterns in Rhode Island and Block Island Sound are influenced by temperature and salinity differences in the water column, tidal ebb and flood, and wind shear. Buoyancy driven circulation—circulation that occurs based on the relationship between water temperature and salinity, which together define the density of water, and the differences in water density both vertically and laterally—makes an important contribution to the mean circulation on seasonal and longer timescales (Codiga and Ullman 2010). Tidal ebb and flood is considered to play an important role in creating turbulence and in mixing the water column, while wind-driven currents play a significant role on timescales of a day to several days, particularly during winter in association with storms, but also in summer due to the diurnal sea breeze. For instance, westerly winds during summer increase the exchange of water between Block Island Sound and Rhode Island Sound in the area between Block Island and the Rhode Island coastline. Winter winds on the other hand, which are predominantly from the northwest and stronger than summer winds, promote water column mixing rather than increased water exchange (Gay et al. 2004).

3. Observed tidal circulation patterns vary considerably between Rhode Island Sound and Block Island Sound. Rhode Island Sound appears to behave as an appendage of the Offshore Ocean SAMP area region, while Block Island Sound behaves, to a large degree, more as an arm of Long Island Sound. Because of significant dynamic interaction with Long Island Sound, it is generally considered that Block Island Sound has a more intensive mixing and circulation regime than Rhode Island Sound (Codiga and Ullman 2010). Codiga and Aurin (2007), through direct observations, found that exchange flow between Long Island Sound and Block Island Sound is strongest during summer months. Figure 2.15 (Mau et al. 2007; He and Wilkin 2006) shows graphical results of two separate circulation studies, one in Block Island Sound and the other in Rhode Island Sound. The panels are joined to provide a view of the general current patterns of the Ocean SAMP area, though scales differ and actual velocities are not directly comparable; they do however show the relative vigor of the circulation in both systems. Current velocity is seen to be vigorous throughout most of Block Island Sound, particularly in the west where influence of The Race is strong, while the majority of the area of Rhode Island Sound is under the influence of relatively mild current speeds, except to the east where it interacts with Vineyard Sound and Nantucket Shoals. Impacts of this major difference between the sounds regarding their ecology is not known. While significant differences exist between Rhode Island Sound and Block Island Sound, these water bodies

are connected and do interact with each other, and with the Offshore Ocean SAMP area region.

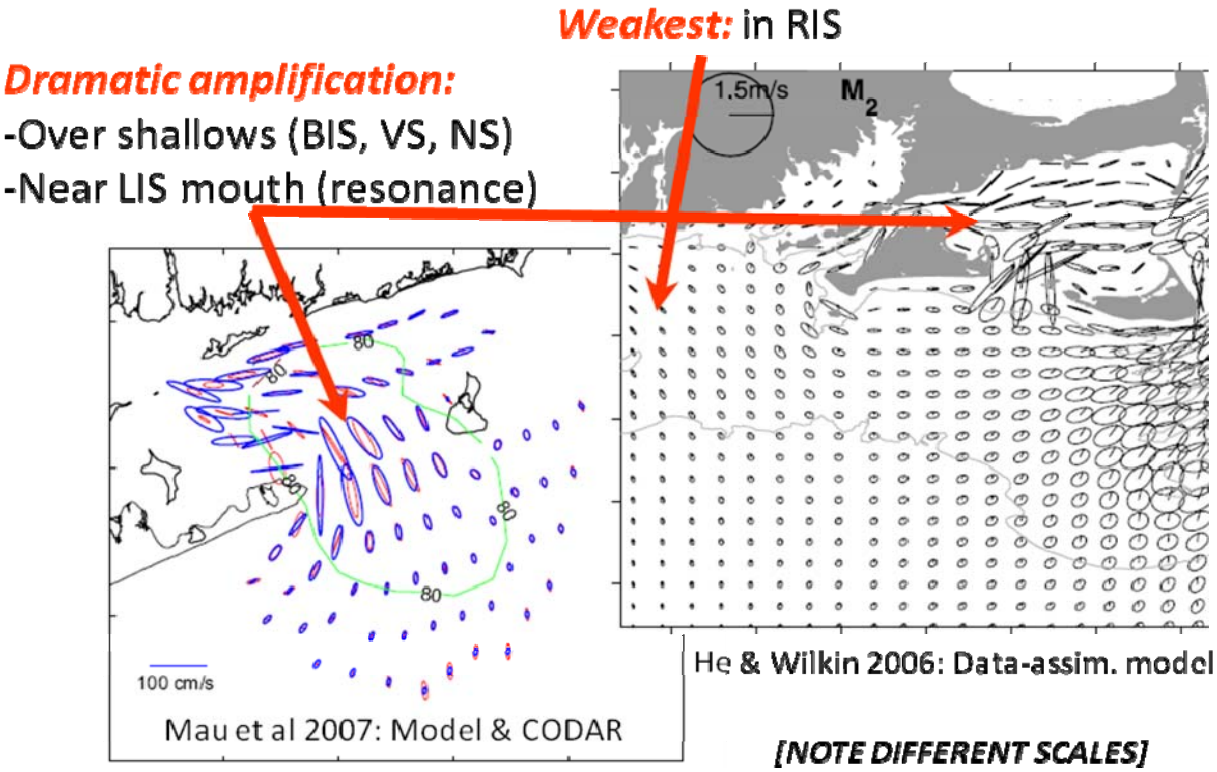


Figure 2.15. Differences in circulation velocities between Rhode Island Sound (RIS) and Block Island Sound (BIS), showing Block Island Sound to be more vigorous and dynamic than Rhode Island Sound. Velocity is greatest over shallow areas and at constricted areas. Note different scales; this does not allow direct comparison between the two diagrams. [VS=Vineyard Sound; NS=Nantucket Shoals]

4. Available data suggests that there is a deep flow into Block Island Sound from the east, running between Point Judith and Block Island, and that a cold current of water flows into the eastern portion of Rhode Island Sound from Nantucket Shoals (Codiga and Ullman 2010). The deep portion of the flow entering from Nantucket Shoals moves largely westward into Block Island Sound while its surface component flows largely southward, joining Long Island Sound flow to form a major coastal current that moves to the southwest, away from the region, over the Offshore Ocean SAMP area and into the Mid-Atlantic Bight (Codiga and Ullman 2010; Beardsley and Boicourt 1981). Kincaid et al. (2003) and Riley (1952) found a generally tending westward flow between Block Island and the Rhode Island coastline that moved into Block Island Sound and could perhaps interact with Long Island Sound water.

5. Based upon findings presented previously, and upon results of their own modeling and research, Codiga and Ullman (2010) have developed a schematic that shows circulation transport pathways in Rhode Island Sound and Block Island Sound (Figure 2.16). They find minor interaction between Rhode Island Sound and Narragansett Bay, Buzzards Bay and

Vineyard Sound both at surface and at depth. Deep flow from Point Judith, moving westward along the Rhode Island shore and into Block Island Sound is moderate, as are return flows at surface from Block Island Sound into Rhode Island Sound around the north side of Block Island. Moderate flow at the surface (into Block Island Sound) and strong flow at the bottom (into Long Island Sound) is seen through The Race. Moderate flows are seen at depth coming off the Offshore Ocean SAMP area into both Rhode Island Sound and Block Island Sound, with strongest cross-shelf deep flow occurring into Rhode Island Sound along its eastern portion; Codiga and Ullman (2010) concede that there is limited information for this section of Rhode Island Sound, and that further study is needed. Strong surface flows are observed moving water out of both sounds, generally in a southwestward direction parallel to the south shore of Long Island. Surface water transport out of both sounds and south following the coast of Long Island is a major pathway for water in the Ocean SAMP area to move into the Mid-Atlantic Bight ecosystem.

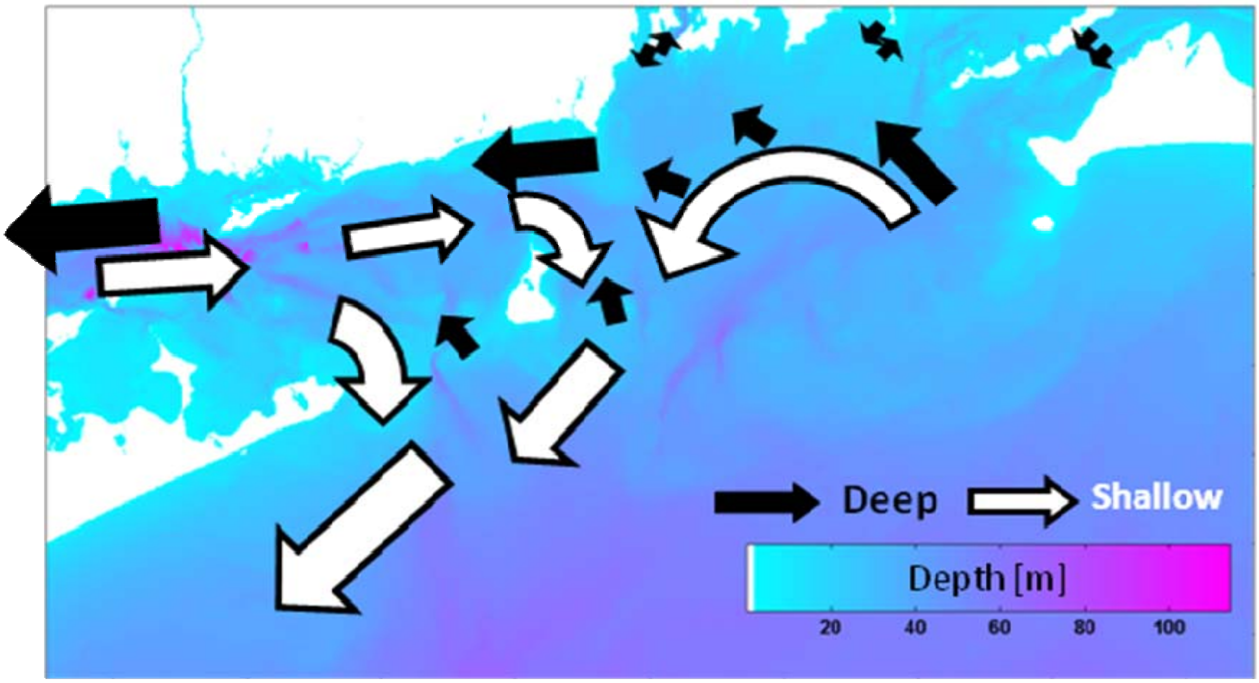


Figure 2.16. Modeled water flow, temperature, salinity and density (sigma-t) at surface and at depth in the Ocean SAMP area (from Codiga and Ullman 2010).

6. While Figure 2.16 shows overall patterns of circulation, Figure 2.17 shows modeled surface and bottom flows on a seasonal basis. Fall and winter show dominant offshore flow out of Rhode Island Sound, with a reversal during spring and summer months; this reversal could promote inshore transport of larval forms produced during winter/spring spawning events. Block Island Sound shows continuous interchange with all adjacent waterbodies, though the interchange is most vigorous in spring and summer when Long Island Sound influence is the greatest. Interaction between Block Island Sound and Rhode Island Sound in year round, but most intense in spring and summer when freshwater input from Long Island Sound intensifies overall circulation in the Ocean SAMP area.

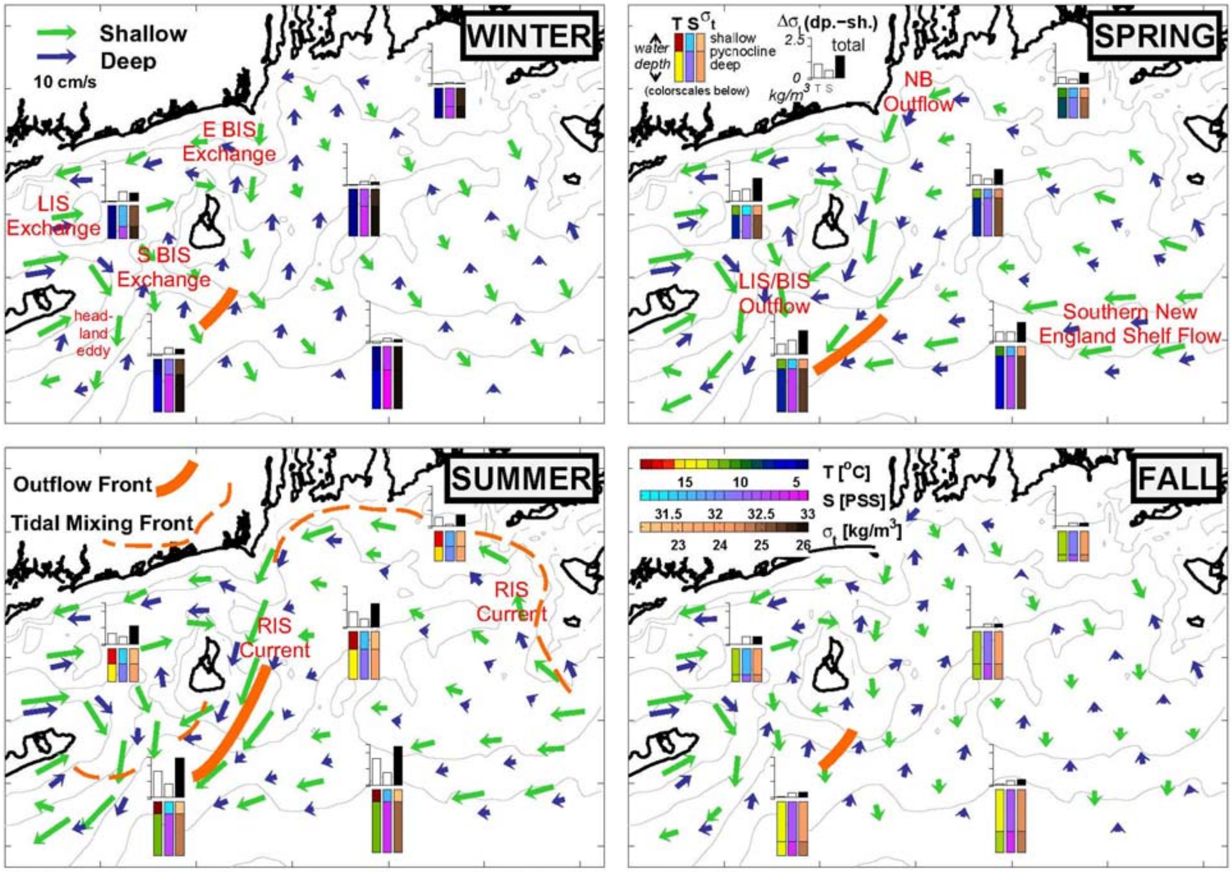


Figure 2.17. Hypothesized annual water flow volumes at both surface and at depth in the Ocean SAMP area; size of arrow indicates magnitude of the flow (from Codiga and Ullman 2010). Histogram inserts show detail of temperature, salinity and density at various sites.

230.4.1. Block Island Sound

1. Circulation in Block Island Sound is largely influenced by interaction with Long Island Sound and the volume of freshwater being received by its major rivers, the Connecticut and Thames, which provide 80% of the freshwater inflow (Gay et al. 2004). The main portal for exchange between Block Island Sound and Long Island Sound is a narrow, deep channel called The Race, which approaches depths of 100 m (Edwards et al. 2004; Gay et al. 2004). Because of the narrowness of the opening, water velocities can exceed 2.68 m sec^{-1} (5.2 knots) on the ebb tide and 2.06 m sec^{-1} (4.0 knots) on the flood (Savard 1966). The Race is an important feature as it allows for the exchange of warmer, nutrient rich, low salinity water from Long Island Sound with colder, saltier water from the Continental Shelf. Codiga and Aurin (2007) suggests that the approximate mean annual volume transport between Long Island Sound and Block Island Sound through The Race is 24,000 m^3 sec^{-1} (Figure 2.18). The transport is also seasonal in nature, responding to increased freshwater inflow during spring and early summer months. Because of the intense interaction with Long Island Sound, the western portion of Block Island Sound can be considered well-mixed as far as 5–10 km out

onto the Offshore Ocean SAMP area region, and to a depth between 20 and 40 m (Edwards et al. 2004). There is a second point of interaction between Block Island Sound and Long Island Sound through an opening between Napatree Point (RI) and the eastern tip of Fishers Island (NY; Figure 2.1) though water depth and current velocities are considerably less than those observed in The Race.

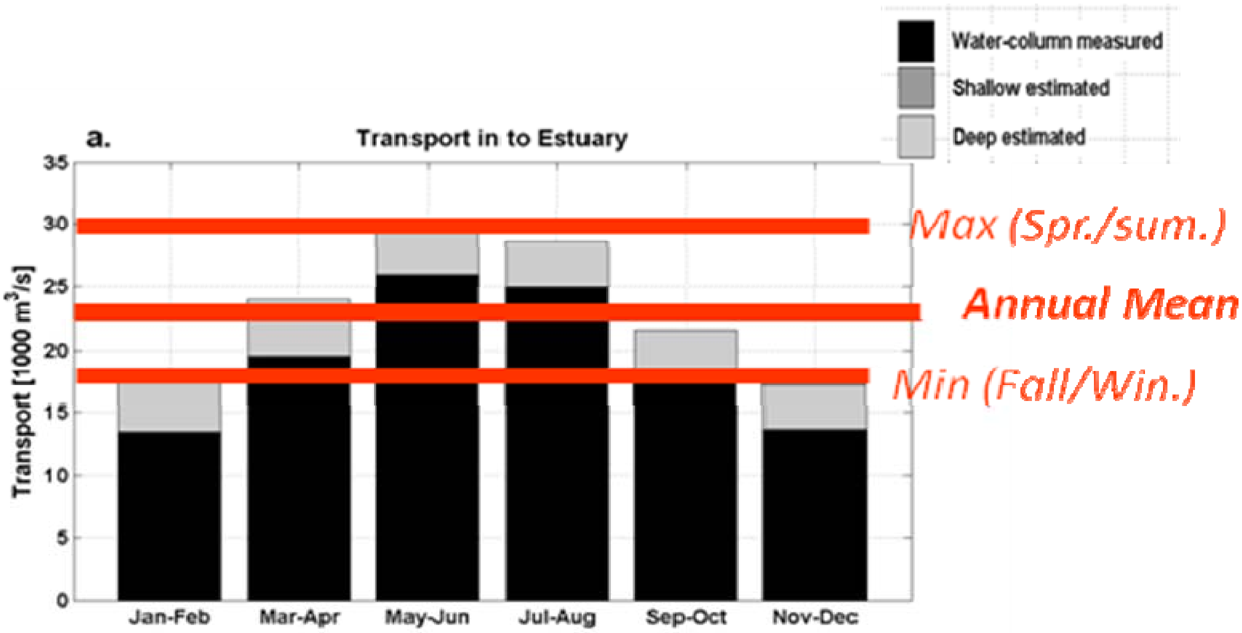


Figure 2.18. Seasonal volume transport from Block Island Sound into Long Island Sound (from Codiga and Aurin 2007).

2. Upon leaving The Race, shallow flow tends southwestward towards the opening to Block Island Sound between Montauk Point and Block Island, with a peak flow of 10–25 cm s^{-1} (Figures 2.15 and 2.16; Ullman and Codiga 2004). This flow is deflected westward along the south shore of Long Island by the Coriolis force, where it moves southward to mingle with southern waters of the Mid-Atlantic Bight ecosystem. This flow is seasonally stratified; strongly so during late spring and early summer due to estuarine flow driven by freshwater input to Long Island Sound. During the spring freshet (e.g., snow melt plus spring rains) this flow is significant, and is referred to as a "jet" which can be detected 5 km south of Montauk Point (Ullman and Codiga 2004). Codiga (in prep) reports an annual mean volume flow out of Block Island Sound at surface of 24,000 m^3 sec^{-1} onto the Offshore Ocean SAMP area, with a bottom water return from the Shelf into Block Island Sound of 10,000 m^3 sec^{-1}.

3. A sharply delineated boundary, or sharp gradient (e.g., a front), is observed south of Block Island where lower salinity estuarine waters meet saltier continental shelf waters (Edwards et al. 2004; Ullman and Cornillon 2001). The front may represent the outer boundary of estuarine influence from Long Island Sound on the Offshore Ocean SAMP area (Ullman and Codiga 2004; Ullman and Cornillon 2001). The front is readily noted by a temperature discontinuity, and is seasonal in its nature. Figure 2.17 shows the seasonality of the front; offshore in winter then moving north and intensifying in spring with a strong presence off

Block Island during summer months. During summer, the front is strongly set and is often observed to extend from the region northeast of Block Island southwestward, 15–20 km southeast of Montauk Point (Figure 2.19; Edwards et al. 2004). The influence of this front on the ecology of the sounds is not well known. However, fronts are areas of high biological activity due to nutrient mixing across water masses, which stimulates increased primary production (Mann and Lazier 2006); increased primary production often leads to increased secondary production (Munk et al. 1995). Commercial and recreational fishermen actively seek out the location of the front to help locate specific species and/or areas of greater fish abundance, suggesting the front either acts as an area of food concentration, or as an area of thermal refuge, or both. Roff and Evans (2002) note that distinct, special oceanographic processes that occur at local scales (e.g., a front) create distinctive habitat that is attractive to fish. Worm et al. (2005) correlated sea surface temperature gradients to increased tuna and billfish diversity. Further description of the ecological importance of oceanic fronts can be found in Mann and Lazier (1996).

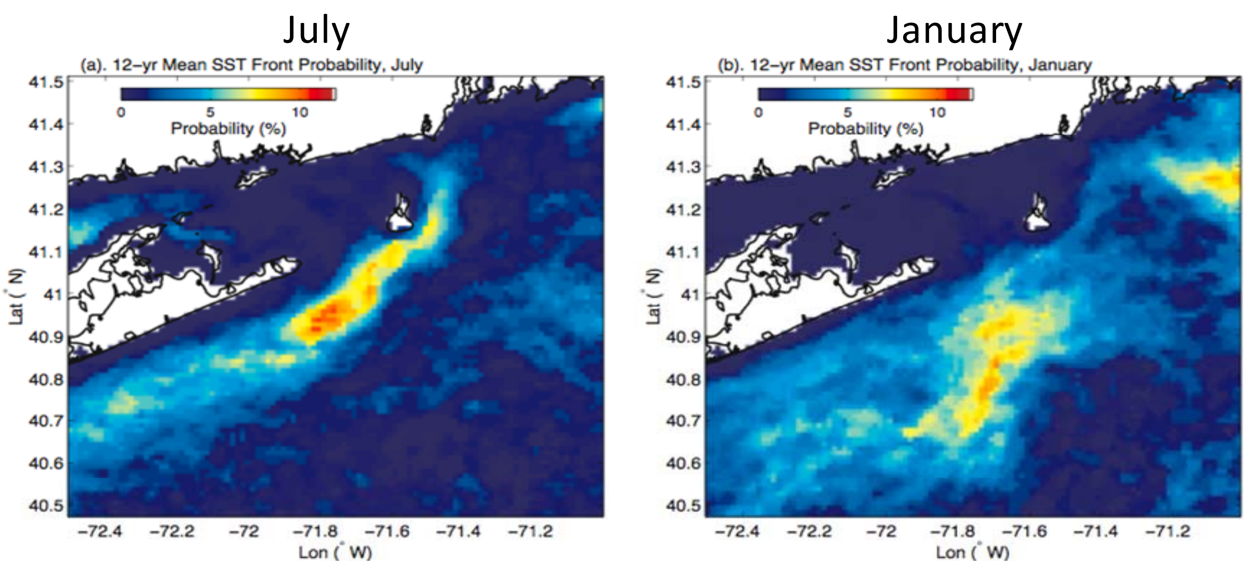


Figure 2.19. Probability of sea surface temperatures occurring along the "front". Averaged 1985-1996. The front is narrow, stable in summer; diffuse, unstable in winter (Ullman in prep).

4. Tidal exchange rates for Block Island Sound and the Offshore Ocean SAMP area have been estimated at a rate of 2.9 x 10^5 m^3 s^{-1} (Codiga and Rear 2004), 3.5 x 10^5 m^3 s^{-1} (Kopplman et al. 1976 using a tidal prism approach) and 6.3 x 10^5 m^3 s^{-1} (Kenefik 1985 using a numerical modeling approach). Williams (1969), at a station located 40 miles south of Fishers Island, measured average tidal flows of 0.75 m s^{-1} on the flood tide (1.46 knots), and 0.55 m sec^{-1} on the ebb tide (1.07 knots), with a maximum recorded flow of 1.08 m s^{-1} (2.1 knots; tidal phase not stated). The volume of water exchange with the Offshore Ocean SAMP area is therefore significant, though velocity of exchange is considerably less than experienced near shore. The exchange promotes the influx of offshore and southern species into the Ocean SAMP area, as well as promotes dispersal of Block Island Sound species (e.g., planktonic organisms) into offshore waters.

230.4.2. Rhode Island Sound

1. Circulation in Rhode Island Sound is influenced by interaction with Narragansett Bay through the East and West Passages, Buzzards Bay and Vineyard Sound, Nantucket Shoals, Block Island Sound and the Offshore Ocean SAMP area. The East Passage, which has an average depth of 18 m and a maximum depth of 40 m, is the deeper of the two connections to Narragansett Bay and experiences current flows of 20,000 m^3 sec^{-1} on the flood tide and 30,000 m^3 sec^{-1} on the ebb (Kincaid et al. 2003). The West Passage sees current speeds about 60% less than those for the East Passage, on either tide.

2. Shonting (1969) observed bottom currents in Rhode Island Sound flowing at rates of 8–12 cm sec^{-1} and showing little overall variability. Surface currents were found to flow at rates of 15–35 cm sec^{-1}, with an average speed of 22 cm sec^{-1} and with great variability. Surface flows tended towards the west-southwest at speeds of 12–14 cm sec^{-1}, while bottom flows showed a rotary motion in anti-cyclonic swirls that provided little net transport. The rotary motion suggests that bottom water does not effectively aid in benthic transport. However, Shonting (1969) notes that there was no expression of the typical summer sea breeze during the time frame of their survey, and they suggest this may have been an influencing factor which may not be typical of the season. Kincaid et al. (2003) and Hyde (in prep), both reported cyclonic flow in Rhode Island Sound, and that it was seasonal in nature. Such a circulation pattern could have significant influence on the ecology of that area of Rhode Island Sound, though further study to verify and describe this phenomenon in greater detail would be needed.

3. First (1972) measured bottom currents at a station located on Cox Ledge in Rhode Island Sound, in 54 m water depth, and found that current flows were generally to the northeast or to the southwest, and that the bottom currents tended to flow according to bottom topography. First (1972) measured a maximum velocity of 20 cm sec^{-1} and an average velocity of 5 cm sec^{-1} along the bottom in that area, and found these flows to be considerably less that those measured at a station just off Point Judith (average velocity of 21 cm sec^{-1} at 15 m water depth).

4. Cook (1966) notes that during the spring there is a non-tidal surface drift to the east and the northwest in Rhode Island Sound, with a northwesterly tending bottom non-tidal drift. Cook (1966) also found a strong westerly flow running between Block Island and Point Judith (see Figure 2.16). During summer, Cook (1966) found a north tending non-tidal drift at the surface, and a northwest bottom drift. During autumn there was southerly drift at surface, but to the north on bottom. Annual average drift rates at the surface were observed to be 2–16 cm sec^{-1}, while on bottom they tended between 0.1 and 3 km day^{-1} (0.1–3.0 cm sec^{-1}).

5. Kincaid et al. (2003) hypothesized upwelling of Rhode Island Sound water in the area of Brenton Reef, and that this water was then advected (movement in a horizontal direction) into the East Passage of Narragansett Bay. Such an exchange could be an important source of nutrients to lower Narragansett Bay, but needs to be further quantified to determine if and how it influences the ecology of Narragansett Bay.

6. Kincaid et al. (2003) also found a distinct, significant flow during summer time in the eastern portion of Rhode Island Sound that moved to the west, and then southwest, following the coast of Rhode Island (Figure 2.20). Riley (1952) noted a similar westward flow into Block Island Sound between Point Judith and Block Island, as have Codiga and Ullman (2010). During winter months this flow continued, but at a much diminished rate. Kincaid et al. (2003) suggest that a seasonal cyclonic gyre exists in Rhode Island Sound, and that this gyre has significant influence upon dynamic exchange with Narragansett Bay. However, Codiga and Ullman (2010) point out that reports of a gyre in Rhode Island Sound are consistent with reports of flow around the periphery of the sound, but that there is no evidence that the flow is closed to form a distinct gyre as originally noted by Cook (1966). This is an area where further research is needed to improve understanding of circulation in Rhode Island Sound.

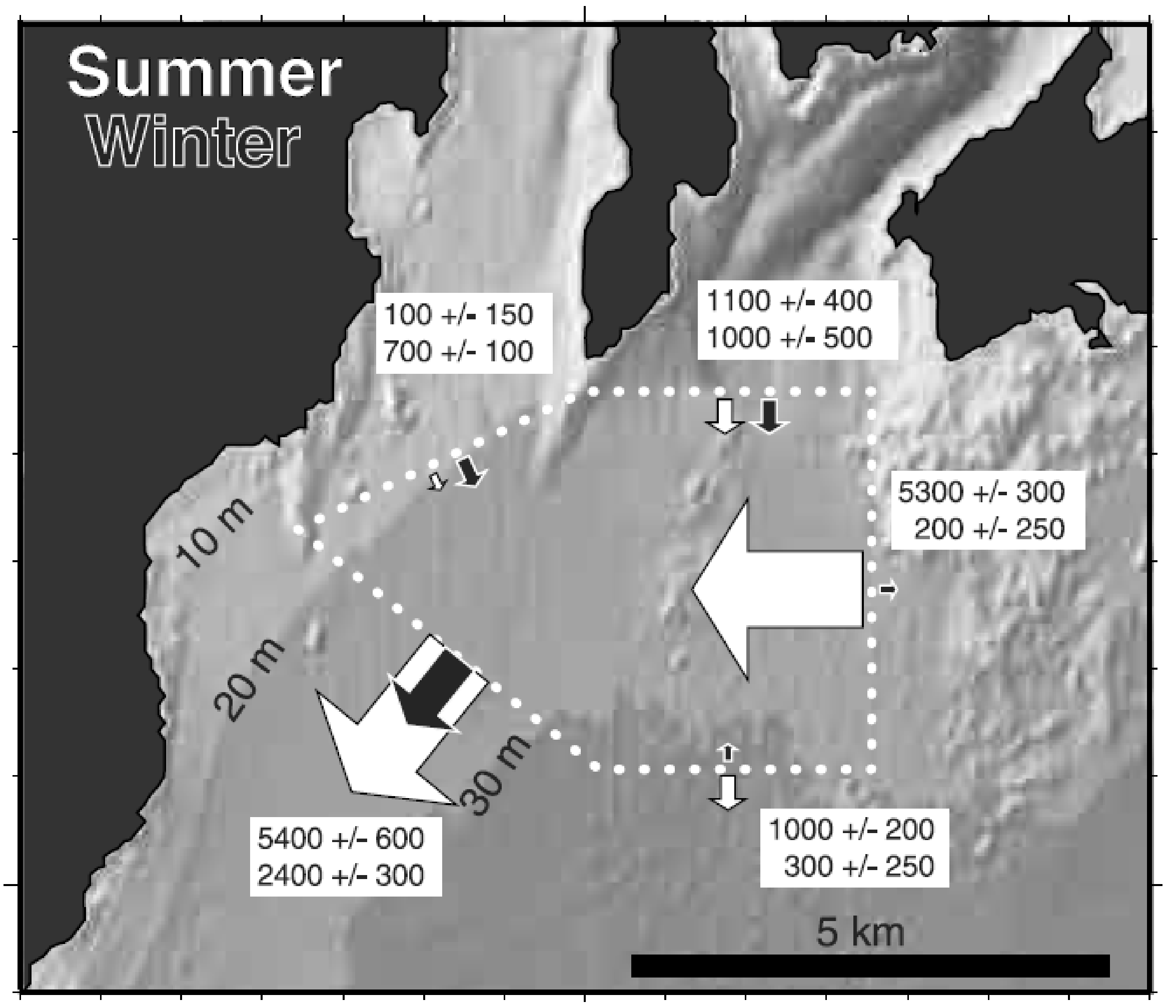


Figure 2.20. Seasonal, tidally averaged volume transport between Narragansett Bay and Rhode Island Sound (from Kincaid et al. 2003) White arrows are for summer flows and black for winter; size of arrow is relative to volume of flow; units are $m^3\ sec^{-1}$.

7. While Signell (1987) found modeled interaction between Rhode Island Sound and Buzzards Bay to be weak, there is intermixing with offshore water in the Cape Cod region. Hicks and Campbell (1952) noted a net flow of water from Buzzards Bay into Rhode Island Sound; in

winter the tongue of water was colder than offshore waters. They found a surface water salinity minima of 29.5‰ at the mouth of the West Passage, and a maxima of 32.9‰ on the Offshore Ocean SAMP area region; bottom waters ranged from 31.2–33.0‰. A coastal current flows south of Block Island Sound, entering from the northeastern region of Rhode Island Sound (Figure 2.16; Kincaid et al. 2003). This current flow is at least partially due to water coming around the arm of Cape Cod, moving through Nantucket Shoal and into Rhode Island Sound (Figure 2.7 and Figure 2.16; Shcherbina and Gawarkiewicz 2008). Furthermore, work by He and Wilkin (2006) show current flows moving around the south side of Martha's Vineyard and then into Rhode Island Sound, providing a clear path for water from the north into Rhode Island Sound and the Ocean SAMP area.

Section 240. Chemical Oceanography

1. Over the course of the millennia of its existence, planet Earth has come to a form of equilibrium with the “chemical soup” contained in its soils, waters, oceans, atmosphere, and biota. Nearly all the elements that can be found in “the soup” are essential to sustaining life, though generally in modest quantities and often only in trace amounts and all are continuously recycled through biological, chemical, physical, and geological processes.

2. Toxins are important limiting factors to productivity. In trace amounts, toxins are generally not problematic, but at higher concentrations can lead to chronic or acute symptoms that reduce quality of life for effected organisms, and/or create more serious impacts, such as increased mortality or alteration of reproductive potential.

3. Existing studies do not suggest that toxins are problematic in the benthic sediments of impacted sites in Rhode Island Sound; there are no reported impacted sites (e.g., dredged materials disposal) for Block Island Sound. Since all sources of toxins are anthropogenic and are of external origin (e.g., accidental spill, purposeful placement), it would not be anticipated that the sediments in either ecosystem pose toxic threats to biota or to the ecosystem at large.

240.1. Nutrients

1. Nutrients are critical to the growth of plants, and in the marine environment nitrogen is generally the most critical nutrient as it is often to be found in limiting quantities and thus sets limits to growth. Nutrients, critical elements for sustaining life, are recycled within the ecosystem. Nutrient dynamics are often complicated by biological uptake, as well as interaction with the benthos both biologically and physically, and can be difficult to comprehend even in well-studied ecosystems. Overall, there has been little work completed on nutrient dynamics in either Block Island Sound or Rhode Island Sound, and what has been done has often been conducted close to shore and/or several decades ago. This is an area where further research work is needed since nutrient dynamics set limits to primary production, which in turn strongly influences ecosystem make up and function.

2. Ramp et al. (1988) report a net transport of shelf water from Nantucket Shoals to the west, eventually flowing to the Mid-Atlantic Bight as described previously. Ramp et al. (1988) suggest that 39–53% of the nitrogen reaching the Mid-Atlantic Bight moves in this flow. Given that there is interaction between the waters flowing south along the shelf (Loder et al. 1998; Figure 2.7 and Figure 2.16) and the waters of the Ocean SAMP area, particularly Block Island Sound, this may be an important source of nitrogen to Rhode Island Sound and Block Island Sound, though further study is needed.

3. While often more limiting in freshwater systems, phosphorus is a required nutrient for growth of plants in marine systems. Riley (1952) found phosphate concentrations at a maximum in mid-winter in Block Island Sound, with a rapid decline during the time of the spring phytoplankton bloom; it was suggested that phosphate was not a limiting nutrient in Block Island Sound waters. Similar work has not been published for Rhode Island Sound.

4. Staker and Bruno (1977) sampled nutrients in Block Island Sound (Table 2.1). The stations were relatively close to shore (south side of Long Island and near Gardners Island) and in shallow water (15 m and 6.5 m, respectively), so it is unclear how representative these measurements might be for more central areas, such as between Block Island and Montauk Point. These researchers conclude that overall, nutrient concentrations were highest in the autumn and near zero/undetectable in late spring and early summer. Phosphate was found not to be a limiting nutrient to growth in the Block Island Sound ecosystem and in agreement with Riley (1952); nitrate and nitrite may become limiting seasonally, mainly during the time period of late May to early July.

Table 2.1. Nutrient concentrations measured in Block Island Sound (Staker and Bruno 1977).

Nitrate (NO_3)	*Concentration*	*Time*
	10 µM	Nov to Jan
	3–4 µM	March and April
Nitrite (NO_2)		
	6 µM	October
	0 µM	Summer
	4–5 µM	September
Orthophosphate (PO_4)		
	1.8 µM	November
	1–2 µM	July

5. Oviatt and Pastore (1980) sampled the concentration of various nutrients in Rhode Island Sound (Sta.16 at the mouth of Narragansett Bay; Sta.17 just outside the mouth) on a seasonal basis (Table 2.2). Unfortunately not all measures can be readily compared to those for Block Island Sound because of timing differences, but orthophosphate (PO_4) concentrations appear to be similar for the one area of overlap for samples taken in November (Table 2.1), and are in general agreement with one another.

Table 2.2. Nutrient concentrations measured in Rhode Island Sound by Oviatt and Pastore (1980; estimated from graphs in original report–highest concentration within a time span is given).

	Concentration (µM)		
Ammonia (NH_3)	*Sta. 16*	*Sta. 17*	*Time*
		0	Jan–May
	1	1.5–2	Jun–Aug
	3–4	2–2.5	Nov–Dec
Nitrite + Nitrate (NO_2 + NO_3)			
	6	6	Jan
	1–2	5	Feb
	0.5	0.5	Mar
	5	4	Apr
	0	1–2	May–Aug
	6	6	Nov
	12	10	Dec
Orthophosphate (PO_4)			
	1–2	1–1.5	Jan–Aug
	1.5	1.5–2	Nov–Dec
Silicate (SiO_4)			
	1.5	1.5	Feb–Mar
	7	4	Apr
	4	5	May–Jun
	16	18	Jul
	6–7	10–11	Aug
	7	8	Nov
	20	18	Dec

6. The nutrient data are too meager to draw any firm conclusions regarding the trophic status (e.g., eutrophic, oligotrophic) of the Ocean SAMP area. This is an area where further work is needed. However, slightly lower primary production measures (see Section 250.1.1) than is seen for adjacent waters suggests that perhaps nutrient availability may be limiting.

240.2. Toxins

1. The Ocean SAMP area is not industrially developed, does not receive direct discharges of municipal or industrial wastes, and is not the regular recipient of refuse or other disposed materials. As such, toxins in the environment would be expected to non-problematic in the Ocean SAMP area. However, Rhode Island Sound has received dredged materials from Narragansett Bay on several occasions, and was the site of an oil spill in the 1990s. Dredged materials often contain various contaminants that in general, will be limited in their realm of impact to the containment site once the disturbance from placement has diminished. Furthermore, contaminants would mainly be restricted to the sediments and impacts would tend to be restricted to the benthos. If benthic sediments are disturbed however, whether through natural (e.g., turbulent mixing due to storm activity) or human induced means (e.g., seafloor disturbance), then contaminants could be put into suspension in the water column where they could directly impact the pelagic ecosystem, or be disbursed and settle in other areas, possibly impacting the benthic ecosystem. Dredge materials disposal sites in Rhode

Island Sound are at a depth where bottom sediment could be mobilized during hurricane events (e.g., see Section 230.1; First 1972). It is also possible that sediment reworking by infaunal invertebrates (e.g., living in the sediments) could mobilize toxins into the food web where bioaccumulation could become problematic. However, based upon toxicity testing at both dredged materials disposal sites and oil spill impacted areas, it appears that environmental toxins are not a significant threat to the Ocean SAMP ecosystem.

2. The Rhode Island Sound Disposal Site (RISDS), designated in December 2004 and located in Rhode Island Sound, has been used for the disposal of dredged materials. The 3.24 km^2 site, with water depths from 36 to 39 m, is located at 41° 13.850' N, 71° 22.817' W (NAD 83; Figure 2.21). The site lies approximately 21 km south of the entrance to Narragansett Bay and is within the Separation Zone for Narragansett Bay Inbound and Outbound Traffic Lanes. Approximately 3.4 million m^3 of sediment from the Providence River (primarily from the Federal Navigation Project) were disposed of at this site.

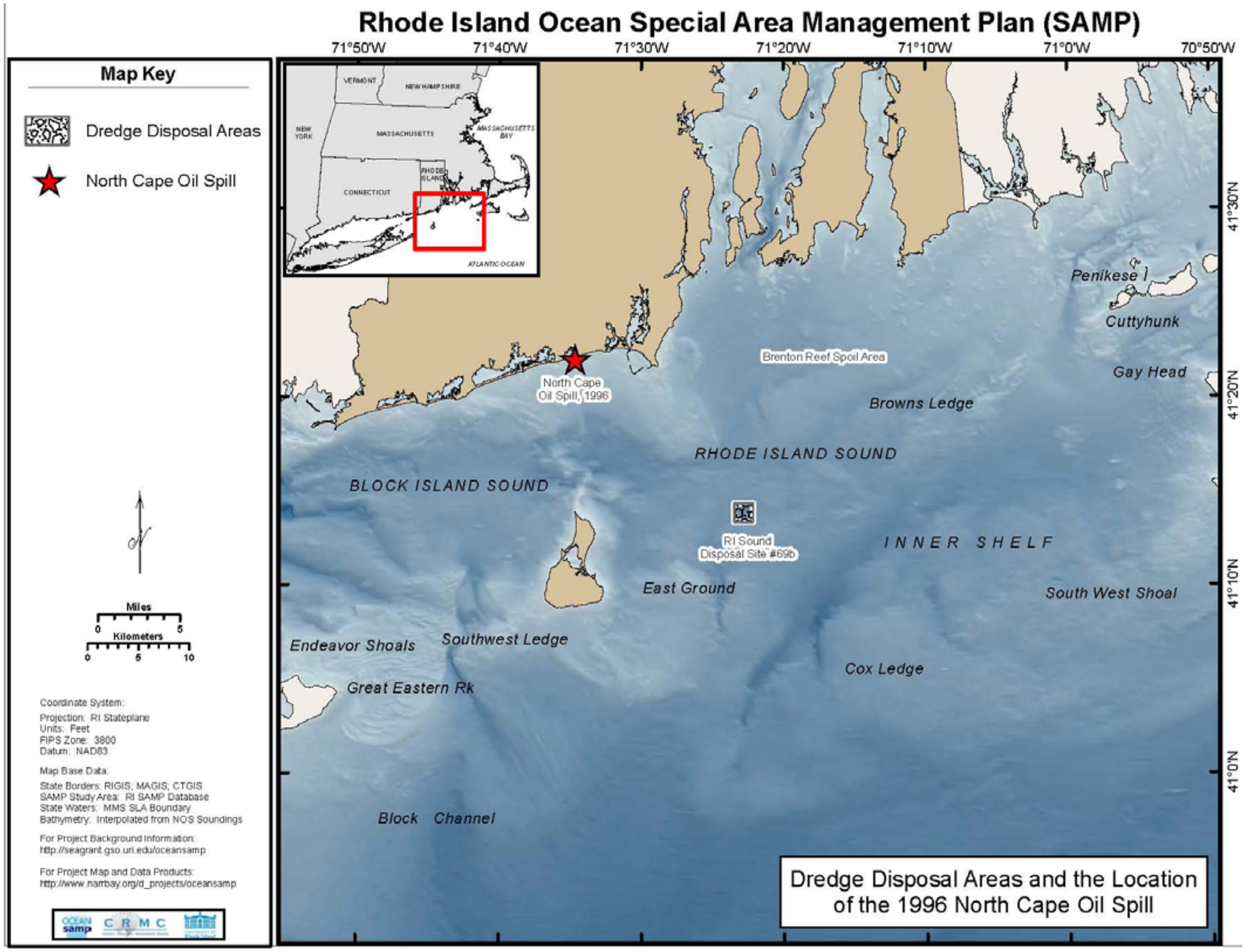


Figure 2.21. Dredged materials disposal sites, and location of the *North Cape* oil spill.

3. The Brenton Reef Disposal Site (Figure 2.21) has been extensively used for the disposal of dredged materials from Rhode Island waters, mainly from the dredged navigation channel in Narragansett Bay, with the last dumping at the site occurring in the 1970s. Battelle (2002a) conducted a study to test toxicity levels at the Brenton Reef and Rhode Island Sound disposal sites, and 2 stations between the two sites, and found that species composition among the various sites, both inside and outside of the dredged materials disposal areas, were not significantly different from one another, suggesting that benthic community recovery from the disturbance event has occurred.

4. Measurement of metals concentrations (Ag, As, Cd, Cr. Cu, Ni, Pb, Se, Zn) in the water column at four sample stations (same stations as those for Battelle 2002a) in Rhode Island Sound found detectable levels, but at concentrations that were well below ambient Rhode Island Department of Environmental Management water quality criteria for toxic pollutants (U.S. Army Corps 2002). Similar results were found for organic and inorganic contaminants (PCBs, Pesticides, Hg) at the four sample sites.

5. On January 19, 1996, the barge *North Cape* spilled more than three million liters of No. 2 fuel oil, a relatively light, readily aerosolized petrochemical, into Rhode Island Sound off Matunuck (Figure 2.21). The plume of oil moved to the east with the greatest impact being seen in the area around Point Judith. Studies by Ho (1999) showed that toxicity in the sediments at a heavily impacted site were small (3% ± 6% mortality for the amphipod *Ampelisca abdita*) after nine months. It is not clear if hydrocarbon concentrations occur at levels of concern in the sediments at this point in time, though it seems unlikely that toxicity levels would be of concern given the time that has elapsed since the spill occurred.

Section 250. Biological Oceanography

1. The unique geological, physical, and geographic characteristics of the Ocean SAMP area provide conditions for making it suitable to a suite of organisms spanning all trophic levels. Living phytoplankton and other photosynthetic organisms are limited to the light-penetrated upper layers of the water column where they convert sunlight into organic matter. Zooplankton convert phytoplankton into animal matter (e.g., protein) which fuels upper levels of marine ecosystem food webs from bait fishes to apex predators. Microbes are responsible for much of the decomposition of dead organisms, recycling nutrients and making them once again available for uptake by plants and animals both in the water column and the benthos.

2. Primary production takes place in the presence of light, and therefore plants are limited to the sunlit layer of the water column (e.g., the photic zone). Depth to which light can penetrate the water column is therefore an important factor in production. Ayers (1950) took water clarity readings in Block Island Sound using Secchi disks; measures of 4.3 m were found near Mount Prospect on Fishers Island and 6.1 m near Great Salt Pond during winter months. During summer, Secchi depths at the same stations were 2.4 m near Fishers Island and 4.6 m off Great Salt Pond. Secchi disk readings were taken in Rhode Island Sound during the months of February and March by Hicks and Campbell (1952); average readings were 6 m with a maximum of 10 m. In all cases transparency decreased with closeness to shore. Decreased transparency in shallow waters close to shore may be due to increased particulates, nutrients and/or primary production in the water column. This suggests a photic zone of 10 m or less, with light penetration decreasing seasonally during summer months.

3. Richardson and Schoeman (2004), based on trends observed in the Northeast Atlantic Ocean, note that warming waters have tended to increase phytoplankton standing stock in cold waters, but decreased it in warmer waters. It is not clear, given that the Ocean SAMP area overlaps two distinct bio-regions, how warming waters due to climate change will impact phytoplankton populations, and if any impact would be in a positive or negative direction.

250.1. Plankton

1. There appear to be correlations between phytoplankton species composition in Narragansett Bay and Rhode Island Sound, though more work is needed to prove and clarify that correlation, as well as to research trends for species shifts over time. Primary production is seasonal in the Ocean SAMP area, and production values are generally similar to though slightly lower than those of adjacent areas. As is noted for Narragansett Bay, Rhode Island Sound appears to be experiencing a less consistent winter–spring phytoplankton bloom, though again more research is needed to verify and clarify this observation, and define its importance to the overall ecology of the area. Zooplankton species composition was found to be seasonal, and heavily influenced by change in salinity and/or temperature in the water column; distinct species changes were noted in warm vs. cool years, dry vs. wet years. Influx of the ctenophore *M. leidyi* had significant impact on the zooplankton community of Narragansett Bay, though similar study has not been conducted in Rhode Island Sound so it is unclear if similar interaction is occurring. Differences between Rhode Island Sound and

Block Island Sound regarding zooplankton control of phytoplankton stocks was suggested, but has not been studied in a comparative sense, nor is it known if ctenophore outbreaks have influenced zooplankton–phytoplankton interactions in Rhode Island or Block Island Sound. Very preliminary comparison (Deevey 1952a,b; Kane 2007) suggests zooplankton dominant species have not changed over the past 50 to 60 years, nor has the seasonality of at least some dominant species. Rigorous analysis however, needs to be undertaken before this can be stated with any degree of surety.

2. Plankton is the collection of organisms that live in the water column and are subject to oceanic currents for their distribution. The organisms making up the plankton range from microscopic plants and animals to larger organisms with limited mobility, such as jellyfishes. The plankton makes up a crucial source of food for marine ecosystems, and in general, forms the foundation of marine food webs.

3. Since the distribution of plankton is determined by the movement of oceanic water masses via current flows, tidal movement and wind-induced flow, understanding plankton distribution can be simulated through circulation models and/or observed circulation patterns (see Section 230.4). The generalized schematic of circulation in the Ocean SAMP area (Figure 2.16) may provide a reasonable first-order estimate for probable plankton transport pathways. Other forces, wind in particular, will play a role in transport at smaller/local scales within the larger Ocean SAMP area.

4. Seventy-five species were recorded during a 1954-1955 survey of phytoplankton (Smayda 1957); nine diatoms and four flagellates were found to account for 94% of the total phytoplankton abundance in Narragansett Bay. Riley (1952) found nine genera constituted 98% of the total number of phytoplankton cells in Block Island Sound in 1949. While it is not well known how closely species composition for phytoplankton matches between Narragansett Bay and Rhode Island Sound, both studies show that in both locations the majority of the overall "crop" consists of a relatively few species. However, recent changes in the plankton dynamics of Narragansett Bay are related to climatic warming (Sullivan et al. 2008). Given the lack of recent data on phytoplankton species composition in the Ocean SAMP area, it is not clear if change similar to that seen in Narragansett Bay is underway. Changes in zooplankton composition (see Section 250.1.3) suggest a need for research in this area.

250.1.1. Phytoplankton Productivity

1. Plants have the all-important function of trapping sunlight, a very abundant yet dilute form of energy, and converting it into organic matter (in the form of plants) that is a more concentrated (though less abundant) form of energy that then becomes the foundation for most food webs. Measurement of plant production, referred to as primary production, provides an indication of how fertile, or how much food is being produced, in a given area and perhaps over a given unit of time. Primary production is often reported in units of mg m^{-3} (milligrams per cubic meter), which indicates the amount of organic plant matter produced (dried to remove the weight of water, which is substantial) in a given area or volume of water. Primary production is also often reported in units of g C m^{-2} day^{-1} (grams of carbon

per meter square per day), which is the mass of carbon (the basic building block of organic matter) produced in a given area and over a given time span.

2. The New York Ocean Science Laboratory initiated a general survey of the physical and chemical characteristics of Block Island Sound and adjacent waters with the intention of creating a baseline data bank (Hollman 1976; Staker and Bruno 1977). Staker and Bruno found chlorophyll *a* (the green pigment contained in primary producers) concentrations that were highly seasonal, and varied from near zero to 9.94 µg l^{-1}. The species *Thalassiosira nordenskioldii* was numerically dominant in the samples, but *Skeletonema costatum* and *Ceratium tripos* presented a larger biomass in the community. Of interest is that Staker and Bruno (1977) found *Ceratium tripos* (a dinoflagellate) to be very abundant in the phytoplankton community during their survey, while Riley and Conover (1967) only found this species in 2 samples during their previous surveys. No causality for the difference was stated. Staker and Bruno (1977) also found that *Thalassiosira nordenskioldii* was more abundant than reported in previous surveys. It cannot be deduced from these limited data if a change in the ecosystem occurred, or if the variability is due to small sample size, though it does point to a need for new research and better knowledge in this area.

3. Riley (1952) found that phytoplankton abundance generally increased with depth to a maximum at 10–20 m. Riley also noted a spatial trend towards reduced phytoplankton concentrations with distance south; concentrations were half as much near Block Island than they were near Watch Hill, and there was no indication of a bloom at the site south of Block Island. Riley further noted that phytoplankton concentrations in Block Island Sound were higher than those found to the east in Rhode Island Sound, or to the south in the Offshore Ocean SAMP area. It is likely that the dynamic interaction with Long Island Sound promotes higher primary production in this area, perhaps bringing additional nutrients from land-based sources in Connecticut, though this has not been quantified.

4. Smayda (1973) reported net primary production of 300 g C m^{-2} yr^{-1} for Block Island Sound, which he found comparable to Long Island Sound and Narragansett Bay, though less than that found for continental shelf waters. Smayda (1957) noted that *Skeletonema costatum* comprised 81.2% of the total phytoplankton population in lower Narragansett Bay, which is on par with Riley's (1952) estimate of 83.5% for this species. Outside of this pairing, there was not good matching between the less abundant phytoplankton species in lower Narragansett Bay and outside waters. Smayda (1957) suggested that Narragansett Bay might be a source of phytoplankton for outside waters via the westward current flow from the mouth of the bay towards Long Island Sound. If this is so, broad overlap of species would be expected between Narragansett Bay and Rhode Island Sound, but this comparative research has not been conducted. Given similarities between various former studies (e.g., Smayda 1957 and Riley 1952), and divergence or change in later studies (e.g., Smayda 1973), this is an area where further research would be useful for improved understanding of relationships between Narragansett Bay and Rhode Island Sound, as well as within the overall, larger Ocean SAMP area phytoplankton community.

5. Hyde (in prep), using ocean color remote sensing data, estimated phytoplankton average annual biomass and productivity for the past 10 years for the Rhode Island Sound and Block Island Sound area as 1.07 mg m^{-3}. Primary production estimates for the Ocean SAMP area

ranged from 143 to 204 g C m^{-2} d^{-1} and were comparable to, though slightly lower than, primary production measurements for nearby regions (Table 2.3). Sampling at four stations in Rhode Island Sound found chlorophyll *a* concentrations of 6 to 9 µg l^{-1} (U.S. Army Corps 2002), which is comparable to those noted by Staker and Bruno (1977) for Block Island Sound. They are also consistent with oceanic systems and slightly lower than an average estimate of phytoplankton production on continental shelves (Mann 2000), and are consistent with Hydes' assessment. Figure 2.22 shows annual phytoplankton growth (via chlorophyll *a*) in the Ocean SAMP area over a decadal span of time. While there is year-to-year variability, a general trend of increased production closer to shore is apparent. Nearshore waters will be shallower, better mixed, closer to nutrient sources, and warmer than offshore waters, all factors which promote increased productivity. No trend over time is visibly apparent from this time series data set, though statistical analyses are lacking to make any further judgment.

Table 2.3. Comparison of the range of primary production (g C m^{-2} d^{-1}) in Ocean SAMP waters with nearby ecosystems (adapted from Hyde in prep); production in the Ocean SAMP area is comparable to, though slightly lower than, nearby coastal systems.

Ecosystem	**Production**	**Reference**
Ocean SAMP	143–204	Hyde (in prep)
Narragansett Bay	160–619	Oviatt et al. (2002)
Massachusetts Bay	160–570	Keller et al. (2001); Oviatt et al. (2007); Hyde et al. (2008)
Cape Cod Bay	231–358	Hyde et al. (2008)
Boston Harbor	211–1087	Keller et al. (2001); Oviatt et al. (2007)
New York Bight	370–480	Malone and Chervin (1979)
Mid-Atlantic Bight	260–505	O'Reilley et al. (1987); Mouw and Yoder (2005)
Georges Bank	265–455	O'Reilley et al. (1987)
Gulf of Maine	260–270	O'Reilley et al. (1987)

6. The diatom *Skeletonema costatum* was found to be abundant in Long Island Sound, comprising nearly 72% of the total population, but being almost nonexistent in Vineyard Sound, suggesting a possible west-east gradient in abundance across the Ocean SAMP area (Lilick 1937; Riley 1952). Riley (1952) found *Skeletonema costatum*, *Thalassionema mitzachioides* and *Rhizosolenia setigera* to be dominant species, and that nine genera made up 98% of the phytoplankton counted.

7. Staker and Bruno (1977) found 125 species of phytoplankton over the course of their 13-month study; *Bacillariophyta* and *Pyrrophyta* were the most abundant groups, with *Chrysophyta*, *Chlorophyta*, *Cyanophyta* and *Euglenophyta* well represented. *Skeletonema costatum* was found to be the numerically dominant phytoplankton species, while *Thalassiosira nordenskioldii* and *Ceratium tripos* were dominant regarding biomass. These findings are consistent with those of earlier surveys noted above; there is however, little contemporary comparable species data for the Ocean SAMP area, so current species dominance is not known.

250.1.2. Phytoplankton Seasonality

1. Riley (1952) conducted 12 surveys during 1949 that counted phytoplankton cells and analyzed plant pigments in surface waters. A phytoplankton minimum was seen in mid-winter and mid-spring, with a bloom in February and smaller blooms during mid-summer. Deevey (1952a) suggested that phytoplankton seasonality was driven by physical oceanographic processes rather than by zooplankton grazing. The characteristics of phytoplankton seasonal cycles in Block Island Sound appear to be common in neritic temperate waters; a midwinter minimum, a small and early spring bloom, and a moderate abundance during late summer (Riley 1952). Riley also found 80% of the phytoplankton species to be either littoral or neritic species (see Section 250.1.3. for definitions).

2. Contemporary measures of primary production and chlorophyll *a* concentrations in the Ocean SAMP area show fairly consistent peaks during late summer and early fall, and a distinct and significant fall bloom (Figure 2.22). However, no clear, consistent winter-spring bloom is seen (Hyde in prep), which is a deviation from historical observations. Rhode Island Sound seems to be mimicking Narragansett Bay in its loss of a consistent annual winter-spring diatom bloom; causes for this are not clear, but suggests that large-scale forces (e.g., changing climate) may be at work. Chlorophyll *a* concentrations and primary production show a fairly consistent minimum during summer months, which is in general agreement with nutrient availability patterns noted previously (Section 240.1).

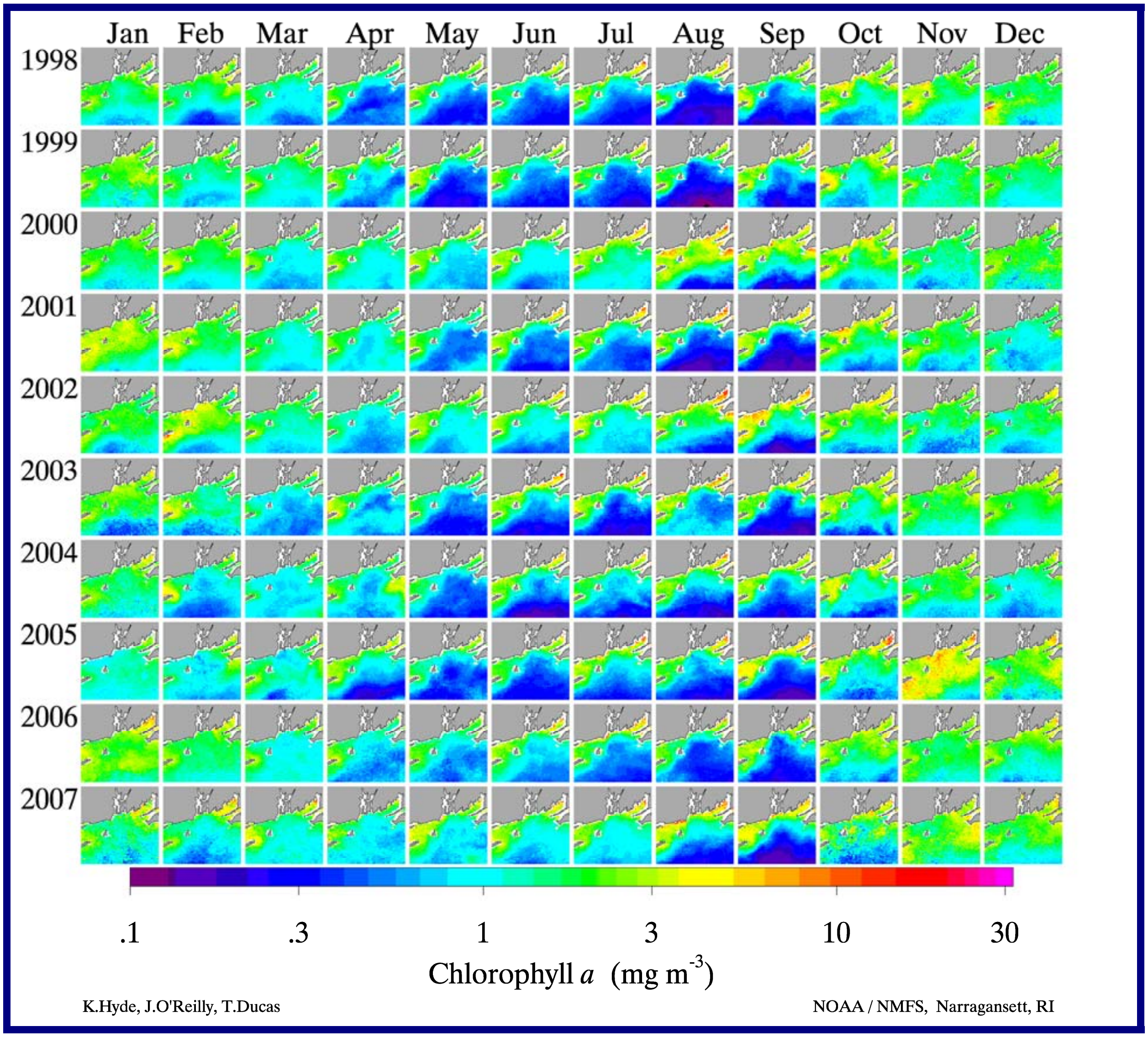


Figure 2.22. Monthly averaged chlorophyll *a* concentrations, 1998 through 2007, in the Ocean SAMP area (from Hyde in prep). There is distinct seasonality, as well as greater phytoplankton growth nearshore where shallower water, increased nutrient availability, and warmer waters all combine to improve growing conditions.

250.1.3. Zooplankton

1. Zooplankton are important components of marine ecosystems as they convert plant matter (phytoplankton) into protein that then fuels higher trophic levels of the food web. Long-term change in the zooplankton community of the Ocean SAMP area is not readily apparent based on existing data, suggesting stability in this food web component.

2. Deevey (1952a) found that the zooplankton community of Block Island Sound was a mix of oceanic (from beyond the continental shelf), neritic (from the continental shelf area), littoral (from sheltered waters and bays) and estuarine species (from areas were salinity varies widely over short periods of time). In essence, Deevey (1952a) considered the area to act as

an intermediary, or "mixing basin," for various adjacent environments. It is possible that this unique mixture of species may facilitate species interactions (predator-prey relationships, competition, etc.) and alternative food-web structures that may not occur in other environments, though this has not been studied.

3. This unique zooplankton community changes seasonally. Deevey (1952a,b) furthermore found that there was a distinct zooplankton maxima that occurred in mid-winter, with seasonal lows in early spring and again in late autumn. There was a seasonal progression where native species (e.g., littoral species and larval forms of bottom invertebrates) dominated the zooplankton community from January through July; then from August through December the number of species doubled due to an influx of Atlantic Ocean water containing myriad warm water, non-native species from farther south. Given current trends of warming waters, such a phenomenon as this could be important in promoting an influx of southern, warm water species to the Ocean SAMP area.

4. Species composition of the zooplankton changed with salinity (Deevey 1952a). For instance, the copepod *Centropages typicus* was dominant in surface waters, but then its abundance declined as salinity levels declined. During the 1945 and 1946 surveys, Deevey (1952a) reported no midsummer zooplankton maximum (e.g., a population increase between spring and fall minima) as a result of reduced salinity in Block Island Sound, which was noted at both surface and at depth and was suggested to be a result of an increase in freshwater input to Long Island Sound during that time. Increased water column stratification was also observed over the same time frame as was the observed shift in composition of the zooplankton community, though no causality was implied. The zooplankton community is dynamic and changes with temperature and salinity changes, which in turn may influence the presence and abundance of upper trophic level species in the area, though this has not been studied.

5. Important types of zooplankton in Block Island Sound (in 1949) included copepods, cladocerans, pelagic tunicates, larval forms of bottom invertebrates, and ctenophores (Deevey 1952b). In another report, Deevey (1952a) describes some of the important zooplankton assemblages and community members:

    a. Copepods—*Centropages typicus*, a neritic species, was found year round in Block Island Sound but responded negatively to declining salinity, with an apparent threshold at 30‰. This species was a dominant community member throughout the survey period. *Centropages hamatus*, a littoral/neritic species at the southern edge of its range, was important over the course of the survey period. *Acartia tonsa*, a littoral species very common in Narragansett Bay, became more abundant in Block Island Sound waters during late summer as numbers of *C. typicus* declined. It is not known if warming temperatures due to changing climate have altered the abundance of this species in Block Island Sound.

    b. Cladocerans—*Podon leuckarti* was found during late spring and comprised about 20% of sample tows during that time. *Podon intermedius* was found during summer and fall in varying numbers. *Evadne normanni* was found only in the later part of the study and not in large numbers. However, this species appeared to favor lowered salinities and could be an important community member under reduced salinity conditions.

c. Other—Larval forms of *Balanus balanoides* (common barnacle) were common during the winter and spring. Early larval forms of a *Lysiosquilla* stomatopod that appears to be common but not well known for Block Island Sound, probably living a reclusive life style in deep burrows, was common during late summer/early fall. Pelagic tunicates were common during later summer, with various jellyfish developmental stages abundant spring through summer. Various southern species that had traveled north on the Gulf Stream, as well as northern species, were found in the tows but only as stragglers and were considered unimportant in the zooplankton community overall.

6. Zooplankton can be voracious grazers on phytoplankton and are capable of limiting production available for consumption by other species (as in Narragansett Bay; Riley 1952, Martin 1965). Riley (1952) did not see any correlation between zooplankton grazing and phytoplankton abundance, and therefore concluded that zooplankton grazing did not control the size of the phytoplankton population at any time in Block Island Sound. Riley's conclusion however, was based on Deevey's findings (1952a,b) for Block Island Sound, and those may not apply to adjacent waters. Further research in this area could alleviated confusion, and perhaps better define the role of zooplankton grazing on phytoplankton stocks in the Ocean SAMP area.

7. There has not been much work published on the zooplankton of Rhode Island Sound, so a sample station located at the mouth of Narragansett Bay is considered as a proxy for at least that area where it meets Rhode Island Sound. Zooplankton abundance peaked in February, April and July during surveys conducted 1959-1962 (Martin 1965). Later studies showed that zooplankton abundance declined to almost zero in late summer and fall as seen in surveys conducted 1972-1973 (Hulsizer 1976), though Martin (1970) found that *Skeletonema* abundance declined coincident with an increase in the abundance of the ctenophore *Mnemioposis leidyi*. Ctenophores can be voracious consumers of *Skeletonema* and other zooplankton. Martin (1970) noted the importance of this ctenophore in controlling zooplankton abundance, though this species was not noted to increase during Martin's earlier study (1965). *Acartia tonsa, A. clausi* and *Pseudoclanus minutus* were the major species of zooplankton present in later surveys (Hulsizer 1976). Ctenophores have a strong, but apparently inconsistent, influence on zooplankton abundance and composition in the Ocean SAMP area.

8. Marine Resources Monitoring, Assessment and Prediction Program (MARMAP; Kane 2007) zooplankton data collected at a suite of stations in Rhode Island Sound and Block Island Sound between 1978 and 2007 provide a contemporary look, and show a seasonal progression of dominant species (Table 2.4). The most abundant zooplankton types throughout the year are copepods, which make up 82% of the total number of zooplankton sampled in winter, 76% in spring, 63% in summer and 70% in fall. Species abundances reported here are in general agreement with those of Deevey (1952a,b), suggesting no long-term shift in dominant zooplankton species during the previous 50 to 60 years. Seasonal shifts noted by Deevey (1952a; e.g., *Acartia tonsa*) also appear to have remained stable over that same 50 to 60 year time frame.

Table 2.4. MARMAP Ocean SAMP area zooplankton data collected since 1978 (Kane 2007). The number of stations sampled has decreased from a high of 28 stations since the mid-1980s.

		Percent of Total Number			
Taxa	**Common name**	**Winter Jan-Mar**	**Spring Apr-Jun**	**Summer Jul-Sep**	**Fall Oct-Dec**
Centropages typicus	copepod	32.6	7.0	27.2	49.7
Pseudocalanus spp.	copepod	33.4	28.7	11.6	1.7
Temora longicornis	copepod	5.1	19.3	5.3	1.7
Appendicularia	free swimming tunicates	8.5	11.8	2.4	3.3
Calanus finmarchicus	copepod	2.1	10.5	7.9	1.2
Penilia avirostris	cladoceran	0.0	0.0	13.9	12.3
Acartia spp.	copepod	1.1	1.7	5.0	8.1
Echinodermata	larvae of sea stars, urchins, etc.	2.0	0.1	8.1	4.7
Centropages hamatus	copepod	1.6	5.5	3.1	1.3
Paracalanus parvus	copepod	6.1	0.2	1.5	6.5
Salpa	tunicates	0.0	0.0	5.6	6.1
Gastropoda	larvae of snails, etc.	3.1	1.0	3.7	0.7
Evadne spp.	cladoceran	0.2	4.2	1.2	0.2
Acartia longiremis	copepod	0.3	2.7	1.6	0.2
Chaetognatha	arrow worms	0.9	1.6	1.5	1.9
Cirripedia	larvae of barnacles	2.9	2.6	0.0	0.1
Evadne nordmanni	cladoceran	0.0	3.1	0.3	0.4

9. At a scale of the Northeast U.S. Continental Shelf, trends for increasing total annual zooplankton biomass since the early 1980s have been noted (http://www.st.nmfs.noaa.gov/plankton/time-series/site__nmfs-sne/index.html). A species shift since 1990 has also been seen, with smaller-bodied taxa becoming more prominent (Kane 2007). A shift in seasonality for some species, such as *Calanus finmarchicus*, to expressing peak abundance earlier in the season, and holding that peak further into the season was also observed. These trends are noted for the entire northeast shelf region, and so it can be presumed that these apply to the Offshore Ocean SAMP area region, though such change is not readily apparent based on existing data for the Ocean SAMP area; robust study on this topic has not been undertaken however. Since zooplankton are at the base of the food chain and a source of energy for myriad species, it can be expected that temporal changes in zooplankton abundance and species composition may propagate up the food chain influencing abundances of higher trophic level species.

250.1.4. Microbes

1. Microbial ecology is relatively unstudied in the Ocean SAMP area, though some work has been undertaken in neighboring Narragansett Bay (Marston 2008; Staroscik and Smith 2004). Those findings are presented here as a potential, though not proven, proxy for Rhode Island Sound, given there is no other known information to consider. Further research is needed to determine if the use of Narragansett Bay microbial communities as a proxy to Rhode Island Sound is reasonable and correct.

2. Several studies suggest that bacterial and phytoplankton mortality due to viruses is comparable to mortality due to zooplankton grazing, and if so, this could be an important influence on community composition (Wommack and Colwell 2000; Brussaard 2004; Suttle 2005; Weinbauer and Rassoulzadegan 2004; Marston 2008). Viruses are known to be abundant and diverse in productive coastal waters (Fuhrman 1999; Wommack and Colwell 2000; Weinbauer and Rassoulzadegan 2004; Marston 2008). Abundances of cyanophages (viruses that infect cyanobacteria, namely *Synechococcus* in Rhode Island waters) are comparable and exhibit similar seasonal patterns in Rhode Island Sound as are seen in Narragansett Bay (Marston 2008), with viral abundance peaking during summer months first in Rhode Island Sound, followed by a peak in Narragansett Bay. Furthermore, Richardson and Schoeman (2004) suggest that warming marine waters, due to changing climate, may initiate a shift from phytoplankton-based food webs to microbial-based food webs. Though no published work on microbes in the Ocean SAMP ecosystem was found, it is important to consider due to the potential to influence the amount of primary production available for consumption by higher trophic level species (i.e., zooplankton, fish, shellfish).

3. Staroscik and Smith (2004) found a high correlation between temperature and bacterial abundance, but that it was also seasonal, with abundance being highest in spring and reduced in the fall. The peak of bacterial production, measured at 68 g C m^{-2} yr^{-1}, was in late June and early July, where it remained high until water temperatures began to decline in September. Staroscik and Smith (2004) found it likely that temperature, grazing, viral lysis, and substrate availability all play a role in bacterioplankton production. Their sample station was located in lower Narragansett Bay, at the dock at the University of Rhode Island Graduate School of Oceanography; it is not known how well the observed patterns translate to Rhode Island Sound waters.

250.1.5. Fish and Invertebrate Eggs and Larvae

1. The ichthyoplankton of the Ocean SAMP area is rich and varied, showing strong seasonality for various species, no doubt linked to reproductive cycles. Report of a circulation gyre in Rhode Island Sound requires further research (see Section 240.1) to determine its influence on the ecology of the area, and how this affects larval transport throughout the area and the water column, if at all. There appear to be changes in the species found over time, but the data were not collected in a fashion that promotes direct comparison, suggesting another avenue for research, particularly in light of the impacts of climate change; more detailed analysis of the MARMAP (Richardson et al. in press) data might provide improved understanding of fish species shifts in the Ocean SAMP area (see Section 250.3).

2. Many fishes and invertebrates spend some portion of their life cycle as planktonic organisms, with tides and ocean currents, as well as behavior dictating their vertical and horizontal distribution. Spending time adrift in the plankton is an important life history strategy that promotes dispersal of populations into new areas as well as improving the chance that some larvae will settle in suitable habitat. For instance, rock crab larval forms can be advected tens of kilometers over short time spans (Clancy and Cobb 1997).

3. The timing of reproduction generally coincides with conditions most favorable to a species survival, whether it is seasonal winds that promote circulation patterns that concentrate food,

or water temperatures that best promote growth of larvae and juveniles. Alteration of the pattern and/or timing of seasonal events can alter the abundance and/or distribution of species. For example, changes in dominant copepod assemblages have been noted on both sides of the North Atlantic Ocean with increasing water temperatures (Beaugrand et al. 2002); corresponding patterns have been found for Atlantic cod (greater numbers of cod during shifts to larger copepods and fewer cod during shifts to smaller-sized copepods; Beaugrand et al. 2003; Hays et al. 2005).

4. It is interesting to note that Shonting (1969) observed bottom waters in Rhode Island Sound that moved in a rotary fashion, providing little overall positive transport in any given direction. Hyde (in prep) also suggests the existence of gyre-like circulation in Rhode Island Sound, and if so then this could restrict interaction with Narragansett Bay, though she found that the probability of larval transport into Narragansett Bay from Rhode Island Sound was directly related to proximity to the mouth of the bay. Modeled results by Codiga and Ullman (2010) suggest that deep flow is weak but consistently onshore during fall and winter months, and mainly east to west flowing during spring and summer (see Figure 2.16 and Figure 2.17). Therefore, it is likely that larvae and eggs trapped in bottom waters may be primarily contained in the gyre-like circulation of Rhode Island Sound mitigating transport outside of the Ocean SAMP area, though this topic needs more focused study to draw robust conclusions as it is unclear if a true gyre exists, as has been hypothesized.

5. Pfieffer-Herbert (in prep) found that ichthyoplankton (fish eggs and larvae) may have undergone a shift in species composition over time. Figure 2.23 suggests that the Narragansett Bay–Rhode Island Sound interface area has seen a decrease in the bay anchovy (*Anchoa mitchellii*) since the late 1980s, with none being found during surveys in the late 1990s. Cunner (*Tautogolabrus adspersus*) has increased in abundance over that same time span; other species change has also occurred (e.g., other in Figure 2.23). Interestingly, Collie et al. (2008) have noted a decrease in adult cunner in the same general area over the past 10–15 year time span. Further work is clearly needed to update these findings with contemporary data, and to relate these to changes in the fish community (see Section 250.3).

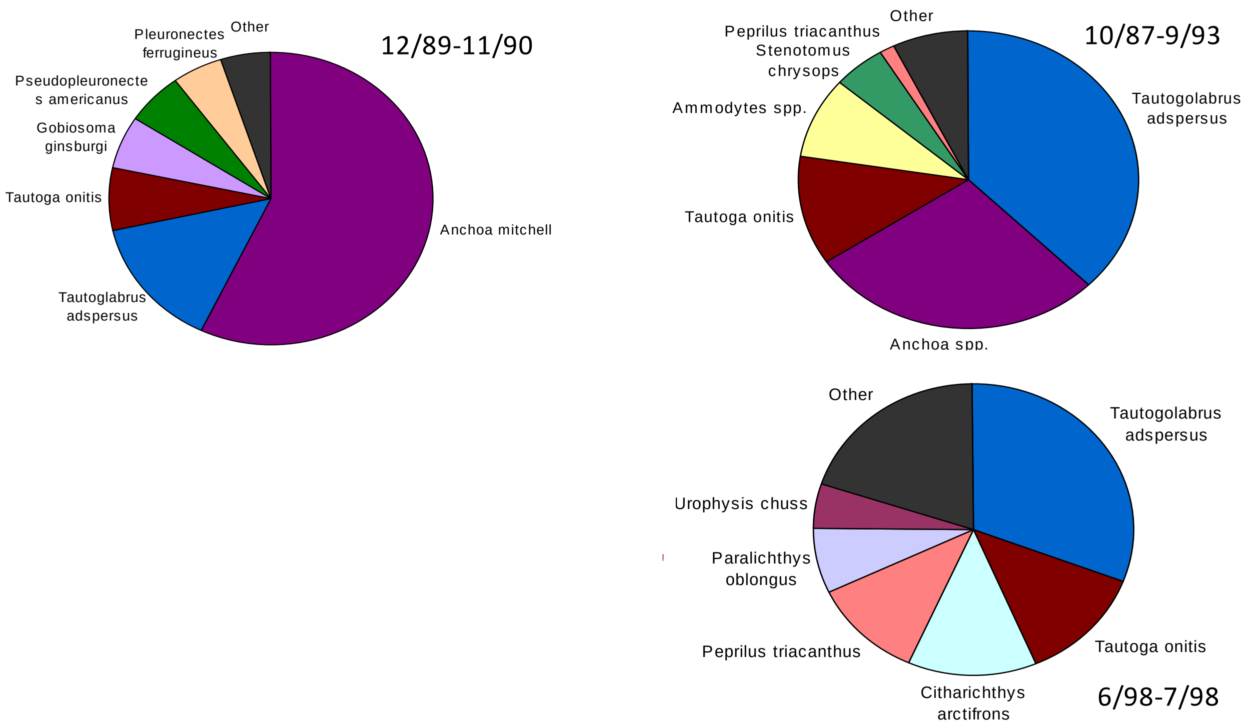


Figure 2.23. Ichthyoplankton abundance at the mouth of Narragansett Bay/Rhode Island Sound at various points in time (from Pfieffer-Herbert in prep).

6. Katz et al. (1994) found that modeled passive drift from the offshore Ocean SAMP area into Rhode Island Sound would move lobster larvae towards shore, and that if active swimming by the larvae were accounted for, the larvae could readily reach the shoreline (Figure 2.24). Given this finding, it can be presumed that actively swimming larvae, though it would be highly species specific, could utilize current flows in the Offshore Ocean SAMP area region as an effective population dispersal mechanism to inshore habitats. Based on known current patterns for Rhode Island Sound, this would be particularly true for areas located in the eastern portion of Rhode Island Sound.

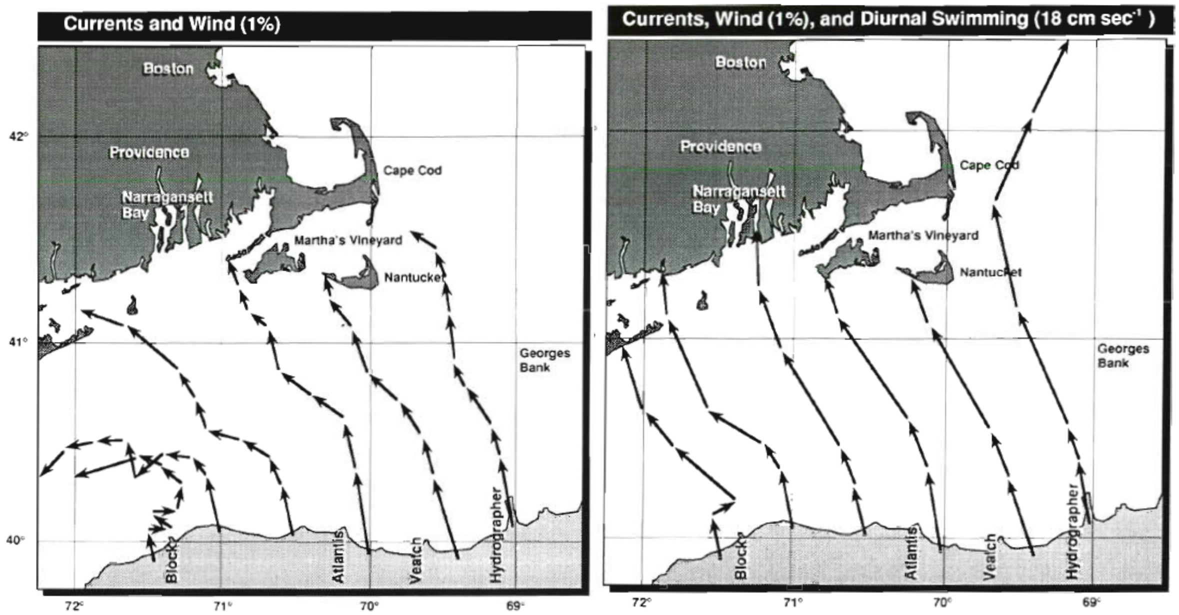


Figure 2.24. Lobster larval transport from the edge of the Continental Shelf into Rhode Island Sound and Block Island Sound (from Katz et al. 1994).

7. Merriman and Sclar (1952) conducted surveys of fish eggs and fish larvae in Block Island Sound, and found a seasonal assemblage of species represented (Table 2.5). Mackerel and weakfish were the most abundant species, and it was suggested these species spawn in Block Island Sound. Pipefish, sea horse, brassy sculpin, lumpfish, wrymouth and goosefish were all considered to be accidentals. Merriman and Sclar (1952) considered scup to have only limited spawning area in Block Island Sound, and that tautog were generally a more inshore species and less common to Block Island Sound waters. Hake and yellowtail flounder were common, but the lack of eggs and larvae suggested that they spawn elsewhere. While fluke were found, Merriman and Sclar (1952) noted this species was a more southerly spawner. They also suggested that mackerel, cod, butterfish, weakfish and cunner were the only fish with pelagic eggs that spawn in Block Island Sound with any regularity and abundance. Silver, squirrel and white hake, and yellowtail flounder, were considered to spawn to the east and southeast of Block Island Sound; tautog and windowpane flounder were suggested to spawn inshore in shallow waters.

Table 2.5. Seasonality of fish eggs and larvae in Block Island Sound (Merriman and Sclar 1952).

Month	Eggs	Larvae
January	Cod	Herring, Long-horn sculpin
February	Cod	Cod, Long-horn sculpin
March	Cod	Cod, Long-horn sculpin
April	Mackerel	Lumpfish, Wrymouth, Cod, Long-horn sculpin, Brassy sculpin, Hake, Yellowtail flounder
May	Mackerel, Butterfish	Lumpfish, Cod, Hake, Yellowtail flounder, Brassy sculpin, Mackerel, Butterfish
June	Goosefish, Cunner, Butterfish, Mackerel, Weakfish	Hake, Mackerel, Cunner, Butterfish, Yellowtail flounder, Windowpane flounder
July	Cunner, Butterfish, Weakfish	Sea horse, Pipefish, Hake, Windowpane flounder, Yellowtail flounder, Scup, Tautog, Whiting, Weakfish, Butterfish, Cunner
August	Cunner, Butterfish, Weakfish	Hake, Yellowtail flounder, Butterfish, Cunner, Whiting, Weakfish
September	Butterfish, Weakfish	Herring, Hake, Butterfish, Whiting, Weakfish
October	Weakfish	Herring, Hake, Butterfish, Whiting, Weakfish
November	Cod	Herring, Hake, Whiting, Fluke
December	Cod	Herring, Fluke

8. The Marine Resources Monitoring, Assessment and Prediction Program (MARMAP; Richardson et al. in press) collected ichthyoplankton samples at a suite of stations in Rhode Island Sound and Block Island Sound between 1978 and 2007. These data are presented in Table 2.6, and show distinct seasonality with regard to species abundances. While there are differences in sample area (Block Island Sound (Merriman and Sclar 1952) vs. Ocean SAMP area (Richardson et al. in press)), there are distinct differences in the predominant species sampled. For instance, sand lance (*Ammodytes*) is a species not mentioned in the Merriman and Sclar (1952) survey, yet it is the most abundant winter species in the MARMAP data. Cod, a very prevalent species in the Merriman and Sclar data, is not mentioned in the MARMAP data. It would be of interest to undertake more specific treatment of the MARMAP data, doing various analyses that would check for species shifts over time for comparison to Pfeiffer-Herber (in prep) findings, and to changes in fish abundances (see

Section 250.3). Further research is needed to explore differences and/or correlations between these data sets, and to examine other variables that may be influencing these species shifts.

Table 2.6. MARMAP (Richardson et al. in press) ichthyoplankton data collected since 1978. The number of stations sampled has decreased from a high of 28 stations since the mid-1980s.

		Percent of Total Number			
Taxa	**Common name**	**Winter Jan-Mar**	**Spring Apr-Jun**	**Summer Jul-Sep**	**Fall Oct-Dec**
Ammodytes	sand lance	97.5	1.1	0.0	43.6
Scomber scombrus	Atlantic mackerel	0.0	72.9	0.1	0.0
Urophycis	hake	0.0	0.0	25.1	4.6
Tautogolabrus adspersus	cunner	0.0	0.7	26.8	0.0
Citharichthys arctifrons	Gulf Stream flounder	0.0	0.0	19.0	1.8
Paralichthys dentatus	summer flounder/fluke	0.0	0.0	1.5	23.1
Merluccius bilinearis	silver hake	0.0	0.9	7.8	6.1
Limanda ferruginea	yellowtail flounder	0.2	15.8	0.1	0.0
Scophthalmus aquosus	windowpane flounder	0.0	3.4	1.5	4.3
Peprilus triacanthus	butterfish	0.0	0.0	5.1	0.3
Etropus	smallmouth flounder	0.0	0.0	3.1	3.4
Hippoglossina oblonga	four spot flounder	0.0	0.0	4.7	0.1
Clupea harengus	Atlantic herring	0.0	0.0	0.0	6.6
Bothidae	left eye flounders	0.0	0.0	0.3	4.9
Tautoga onitis	tautog/blackfish	0.0	0.2	2.3	0.0
Etropus microstomus	smallmouth flounder	0.0	0.0	1.9	0.8
Enchelyopus cimbrius	fourbeard rockling	0.0	2.4	0.7	0.4
Pseudopleuronectes americanus	winter flounder	2.2	2.6	0.0	0.0

250.1.6. Harmful Algal Blooms

1. Harmful Algal Blooms (HABs) are a rapid increase and accumulation of toxic or otherwise harmful phytoplankton in a specific area and in quantities that pose threats to ecosystems and/or human health. Concentrations of algae in the water column can exceed thousands of cells per milliliter, and depending upon the organism involved, can discolor the water to create a “red tide” or “brown tide” event. Harm to the ecosystem can result from massive die-off of phytoplankton, which during microbial-mediated decomposition depletes oxygen in the water column leading to hypoxic (very little oxygen) or anoxic (no oxygen) conditions which can be stressful and/or lethal to aquatic organisms. *Alexandrium fundyense*, a common species of harmful algae in New England waters causes paralytic shellfish poisoning (PSP) in humans when contaminated shellfish are consumed, and has been responsible for the closure of shellfish beds to protect human health (Anderson et al. 2005).

2. Red tides are a frequent occurrence along the coast of Maine, and are becoming more common in Massachusetts waters (Anderson et al. 2005); warming waters due to changing climate have been reported as at least partially responsible for the increasing occurrence of HABs (Bricker et al. 2008). HABs have also been shown to be triggered by increases of

nutrients from outside sources (Smayda 2008), such as increased anthropogenic or atmospheric inputs of nitrogen (Paerl et al. 2002). Typically, bloom events occur in summer months when water is warmest and phytoplankton production highest. While HABs have not been documented in the Ocean SAMP area, there are a high number of potentially harmful species present (Hargraves and Maranda 2002), and therefore the Ocean SAMP area should not be considered immune to such threats, particularly given changing climate and noted warming trends.

250.2. Benthic Ecosystem

1. The Ocean SAMP area is located at the boundary region of two biogeographic provinces, also known as eco-regions—the Acadian to the north and the Virginian to the south (see Section 200 for descriptions)—with direct, broad connection to the Atlantic Ocean. The dynamic oceanography of the Ocean SAMP area, coupled with its geologic history and geographic juxtaposition, shapes the nature and dynamics of the existing benthic communities. Although there have been several surveys of the benthic fauna, and recently some detailed studies in selected areas, most done in impacted areas such as dredge material disposal sites, there is relatively little contemporary information on benthic communities. Consequently, our understanding of spatial and temporal dynamics, and the implications for ecosystem functioning, are somewhat rudimentary as well as fragmented.

2. The benthic environment is an important element of coastal marine ecosystems. The benthos provides structure for myriad organisms, such as polychaetes and amphipods, to colonize the substrate, add organic matter to the sediments, and provide a source of food for benthic invertebrates and fishes. The benthos also plays an important role in nutrient cycling within marine systems. The benthic environment is further used in the disposal of wastes, and the Ocean SAMP benthos has functioned in this capacity as a site for the disposal of dredged materials from Narragansett Bay. The Ocean SAMP area was also the site of an oil spill, and though the scale of the spill was small, it was considered locally to be a significant disturbance event.

3. Benthic communities in the Ocean SAMP area are largely dominated by various species of benthic, tube-dwelling amphipods. The bivalve *Nucula*, as well as various species of polychaetes, mysids and cumaceans, fill out benthic community species composition. Rhode Island Sound and Block Island Sound share many species, but directed experimental work needs to be done to test for differences in dominant species and overall community make up between these two ecosystems. Such research would also provide input to sediment type–species relationships, which at present are only tenuously known. Having this information would greatly assist in a better understanding of the ecology of the region, and could be a start towards the development of ground-truthed benthic habitat maps for the Ocean SAMP area.

4. Several contemporary side-scan surveys have been made in Rhode Island Sound in relation to dredged materials site monitoring (Battelle 2003c), and also independently by the U.S. Geological Survey (McMullen et al. 2007; 2008). There was also a survey that was conducted in the western portion of Block Island Sound (Poppe et al. 2006). These side-scan surveys reveal high resolution details of the sedimentary patch structure of the sea floor in

Rhode Island Sound and Block Island Sound. This benthic patch structure is quite complex and comprised of a variety of topographic features shaped by the dynamic sedimentary environments (erosional, sorting and reworking, and transport, see Section 210). The biologic sampling and field ground-truthing needed to correlate side-scan imaging to benthic habitat types and probable species assemblages has not been undertaken, but would provide a very useful ecological assessment and resource management tool.

5. Based on observed benthic change between surveys completed in 1991 and 1994, Driscoll (1996) suggested that anthropogenic effects have greater impact on reworking benthic surface sediments in Block Island Sound than large storms after finding an increase in the distribution and density of trawl door scars caused by fishing gear dragged across the seafloor in their survey area. Fishing can have local impacts on habitat as well as more wide-spread impacts on species biodiversity due to re-suspension of particulates, chemical impacts causing changes in nutrient cycling, and biological impacts from changes in species composition (DeAlteris et al. 2000). Of interest to note is that the dominant benthic invertebrates of the Ocean SAMP area—tube-dwelling, amplescid amphipods—appear to do well in disturbed areas; it is unclear if fishing activity that disturbs the bottom is having either a positive or negative impact, if any, on these species. This is any area were further study is needed.

6. Maps of benthic habitat can be an important element in understanding ecosystem dynamics, but are challenging to develop. While various classification schemes have been proposed, most existing schemes are based on physical factors such as bathymetry, sediment grain size, sediment texture and/or topographic features. Regardless of the scheme, the intent is to assist in the identification of habitats of key importance to the ecosystem, and to guide both future research efforts as well as management initiatives. Several proxy maps have been developed for use in considering the ecology of Rhode Island and/or Block Island Sounds using sediment composition, and most recently “surface roughness,” a basic measure, interpreted from sidescan sonar imaging, of the unevenness of the seafloor bottom topography.

7. Figure 2.25 shows bottom sediment distribution interpreted from ocean quahog distribution data in Rhode Island Sound, and benthic habitat can sometimes be inferred based on preferences of species found in the area for specific sediment types. Zajac (in prep) developed a first order compilation of benthic species–sediment type relationships (Table 2.7) based on the published literature, and this could be related to Figure 2.25 as a first approximation of benthic species distribution in Rhode Island Sound. Without groundtruthing however, such an exercise should be considered only guidance for further research, and no implications should be assumed. Given the broad distribution of silt, silty-sand, and fine sand in Rhode Island Sound, it is not surprising that ampleliscid amphipods, which appear to prefer these sediment types, are the most broadly distributed benthic invertebrate.

Table 2.7. First approximation of species preferences, based on the published literature, for habitats in the Ocean SAMP area (adapted from Zajac in prep).

Sediment Type	Species Association
Silt & Silty Sand	Amphipod–*Ampelisca agassizi, A. Vadorum*; Bivalve–*Nucula proxima*
Coarse Sand/ Sand–Gravel	Amphipod– *Byblis serrata, Acanthohaustorius millsi*; Polychaete–*Aricidea catherinae*
Mud	Amphipod– *Leptocheirus pinguis*

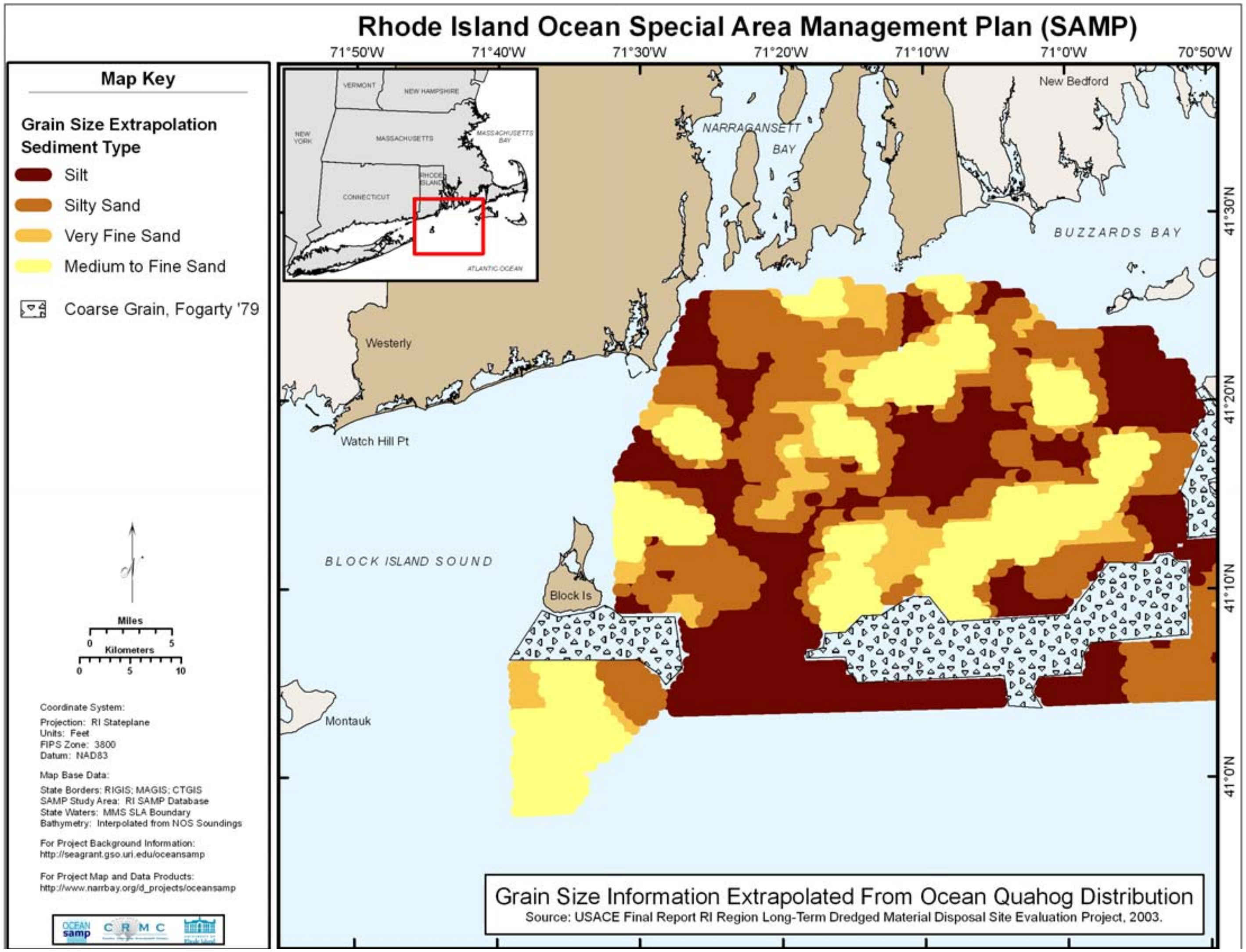


Figure 2.25. Grain size distribution in Rhode Island Sound as extrapolated from ocean quahog distribution (Fogarty 1979).

8. Habitat diversity promotes species diversity—the more complexity a habitat contains the greater the number of species the habitat can generally support (Eriksson et al. 2006). A potential proxy for habitat complexity in marine benthic ecosystems could be surface roughness. The presumption is that the rougher the bottom, the greater the vertical complexity, which could be equated with the promotion of increased species diversity. King and Collie (2010) have developed a first-order interpretation of bottom roughness from sidescan sonar images for the Ocean SAMP area (Figure 2.26). Until further interpretation accompanied by groundtruthing occurs, increased surface roughness, as shown in Figure 2.26, should be considered only as providing the potential for habitat that promotes increased species diversity and/or abundance. Furthermore, species correlations to “roughness patterns” cannot be assigned. While only a first, rough approximation, areas of high surface roughness appear to generally correspond to glacial moraines; these areas are often hot spots for commercial and recreational fishing activity, which while not necessarily suggesting increased diversity, does suggest highly productive areas of the Ocean SAMP area seafloor, and that the moraines are important fish habitat. Further research would be needed to elucidate why these areas attract fish—is it food, shelter, current flow, or otherwise?

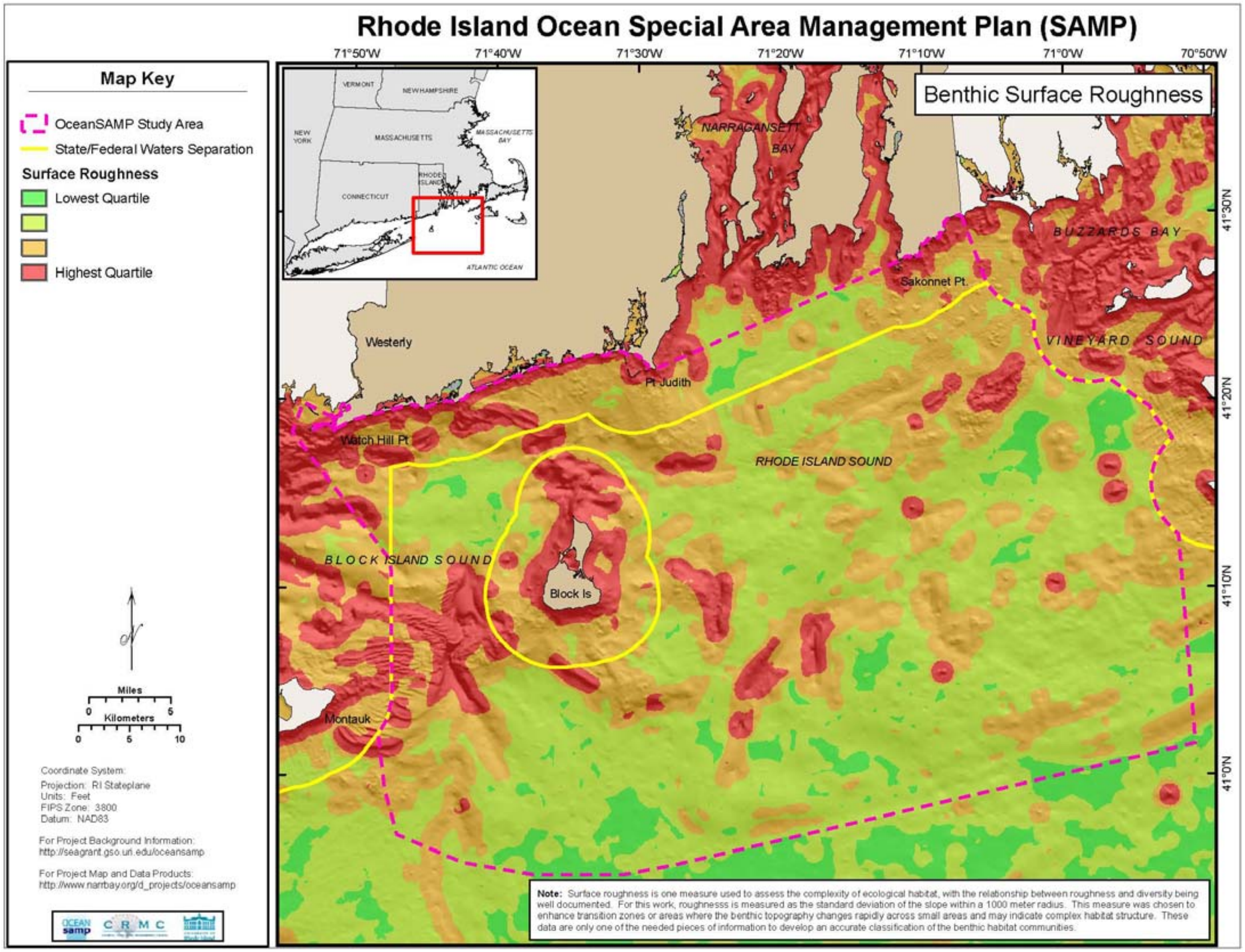


Figure 2.26. Benthic surface roughness as a first approximation proxy for habitat complexity in the Ocean SAMP area (King and Collie 2010).

9. The Rhode Island Sound Disposal Site (RISDS), located in Rhode Island Sound approximately 17 km south of Point Judith (Figure 2.21), received four million cubic meters of dredged materials removed during the Providence River and Harbor Maintenance Dredging Project between April 2003 and January 2005. Wilson et al. (2009) found that sediment in the disposal site often had a black coloration, but low dissolved oxygen concentrations (e.g., hypoxic conditions) were not found. Wilson et al. (2009) also found that species diversity in the disposal site was lower than nearby reference sites, but noted that the benthic community was recovering relatively rapidly with Stage II (intermediate, post disturbance community) and III (stable equilibrium community) infauna present in abundance three to four years post-disturbance.

10. Dredged materials from the Providence River channel had been disposed of in Rhode Island Sound previously at a site 4 miles south of Newport at the mouth of Narragansett Bay (Figure 2.21; Saila et al. 1972). Between December 1967 and September 1970, approximately 8.2 million cubic yards of dredged materials were deposited on this site. The benthic community structure described by Saila et al. (1972) at reference sites is similar to those noted by Wilson et al. (2009), suggesting recovery of the benthic ecosystem from the disposal disturbance event at this site as well.

11. A spill of No. 2 fuel oil occurred in the nearshore Ocean SAMP area (Figure 2.21) during January of 1996 and toxicity levels detrimental to benthic invertebrates were found in the sediments immediately following the disturbance. It is unclear if toxicity threats to benthic invertebrates continue to exist, but based on the time span since the spill it could be assumed that it would be minimal; Ho (1999) found rapid recovery of the benthic community within the year following the spill. It is not known if ecological impact might occur from the disturbance of sediments in areas previously impacted by the spill.

250.2.1. Invertebrates

1. Invertebrate species make up a large proportion of the biota found in the benthic ecosystem, and they play an important role as a food source for fishes. The invertebrate community is often quite patchy, largely because of the highly diverse nature of the sediment types that have been transported, sorted, and deposited in specific areas on the seafloor landscape. Sediment type is an important determinant regarding the form of benthic community that will exist in marine aquatic ecosystems. The patchwork nature of the benthic community similarly sets the stage for the distribution of fishes and larger organisms.

2. The dominant benthic invertebrates of the Ocean SAMP area tend to be several species of amphipods that inhabit a variety of habitat types in a patchy distribution. Bivalves, polychaetes and mysids are also significant components of the benthic invertebrate fauna of the Ocean SAMP region.

3. Theroux and Wigley (1998) conducted an expansive survey (geographically), but those data are now more than a decade old, and at a scale too broad for specific use in the Ocean SAMP area. Given contemporary reports of rapid ecological change as a result of changing climate, follow-up work for comparative purposes would be an asset in understanding the ecology of the Ocean SAMP area.

4. Published accounts suggest that the macrobenthic fauna in the Ocean SAMP area is comprised of several species groups that show varying affinities to certain bottom types (adapted from Zajac in prep; see Table 2.7). There appears to be possible seasonality, as well as change due to sediment transport and reworking, though separation of the two has not been attempted:

    a. Steimle (1982) found that there was an assemblage associated with silty fine sands dominated by several species of ampeliscid amphipods (e.g., *Ampelisca agassizi*) and the nut clam, *Nucula proxima.*

    b. An assemblage found in coarser sands was dominated by several other amphipod species (e.g., *Byblis serrata*, *Acanthohaustorius millsi*) and several polychaete species (e.g., *Aricidea catherinae*). This latter assemblage was fairly distinct in February, but by September, assemblages at the sandy and gravely stations were more variable.

    c. Steimle (1982) noted that the assemblages he found were similar to those defined by Pratt (1973) for different sediment types but did vary, likely due to complex topography and sediment patch structure as shaped by oceanographic processes.

    d. Steimle (1982) suggested that benthic communities were relatively stable over decadal periods, as the assemblages found in 1976 were similar to those found in the late 1940s.

    e. Hale (2002) reviewed this earlier work as well as studies conducted by the U.S. Environmental Protection Agency (EPA) as part of the Environmental Monitoring and Assessment Program in the early 1990s and by the National Marine Fisheries Service (NMFS) (Steimle 1990; Theroux and Wigley 1998) for the area around Block Island. In general, the benthic communities described in these studies were similar to those found in previous surveys, with dominant species including several amphipods, the bivalves *Nucula*, *Mytilus*, and *Arctica* and several polychaete species, including *Prionospio steenstrupia*, *Nephtys incisa*, and *Clymenella torquata*. The relative dominance of these species varied with geographic location, sediment type, and organic content (Hale 2002).

5. The American lobster (*Homarus americanus*) is a large benthic invertebrate living in the Ocean SAMP area, and is of great commercial importance in the region. This large invertebrate is a major scavenging species, and that is noted to be increasing in abundance in the area since the early 1980s (Collie et al. 2008; see Section 250.3). See Chapter 5, Fisheries, for detailed life history or the American lobster.

250.2.1.1. Block Island Sound

1. Savard (1966) noted a gravel/sandy-gravel cover on the ridge (moraine) running between Montauk Point and Block Island, the ridge and shallow area to the north of Block Island, and in the deep channels of western Block Island Sound. Silty-sand was found to cover most of the east-central plain of Block Island Sound and the protected shallows east of Gardners

Island. Sand was found to cover most of the western and central areas of the sound, and the floor of the channel that cuts through the Montauk–Block Island ridge. Patches of gravelly-sand or silty-sand were found scattered throughout the sandy-bottomed area. Savard also found that mean sediment size decreased with distance from shore toward the center of Block Island Sound, with coarsest sediments found along the Montauk–Block Island ridge and parallel to the Rhode Island shore in the northern portion of Block Island Sound. Well-sorted sediment was found in southwestern Block Island Sound near Cerberus Shoal, moderately-sorted sediment was found north of the Montauk–Block Island ridge and in western Block Island Sound. Savard did not collect biological data and so species mapping to sediment type cannot be done until sediment–species relationships are better defined.

2. Steimle (1982) found the amphipods *Ampelisca agassizi* and *A. vadorum*, and a bivalve, *Nucula proxima*, to dominate silt and silty-sand sediments. Steimle (1982) noted that, based on previous reports of benthic fauna of Block Island Sound, that *Ampelisca* has dominated the benthic fauna for at least half a century, suggesting that the benthic community had been somewhat stable over that time frame. Work from Byron and Link (in press) on diet composition of fish species suggest that benthic communities have been stable across the entire Northeast Atlantic Shelf ecosystem, which includes the Ocean SAMP area, for the past 30 years despite widespread disturbance to the benthic habitat by both natural and anthropogenic forces.

3. Smith (1950) found the amphipod *Leptocheirus pinguis* to be very well adapted to muddy bottom areas in Block Island Sound. He found the tubes to be quite easily constructed and not very permanent—individual amphipods were seen to leave a burrow and build a new one when needed rather than travel back to an existing tube, suggesting the species to be quite mobile and adaptable. Smith (1950) suggests that fish trawl disturbance on the bottom does not harm this species of amphipod, and in fact suggests that such disturbance enhances conditions by putting detritus into the water column where it can be accessed as food; loss of dwelling tube was not problematic for this species.

4. Deevey (1952a) conducted limited sampling of benthic organisms during surveys. She found ampeliscid amphipods to be very abundant in bottom samples, more so than any other types except for the caprellid amphipod *Aeginella longincornis*. The mysid, *Neomysis americana*, was found to be very abundant in Block Island Sound during late summer, as were various species of cumacean. The decapods *Cragon septemspinosus* and *Dicheleopandalus leptocerus* were abundant during fall months. All of these species are important prey items for many fish species residing and migrating through the Ocean SAMP area.

5. Sediments composed of coarse sand and/or gravel had distinct fauna of mixed amphipods and polychaetes, which often varied seasonally (Steimle 1982). Steimle considered this finding as showing the patchiness of the benthic habitats in Block Island Sound and that it was a reflection of the complex topography. Steimle’s Table 1 (Steimle 1982) provides a full listing of benthic invertebrates sampled during the survey conducted; Steimle also noted that the species assemblage found resembled those reported from the inner continental shelf and/or other sounds in New England, and as reported by Pratt (1973).

250.2.1.2. Rhode Island Sound

1. Wilson et al. (2009) found reference sites in Rhode Island Sound to be typical of shallow-water New England benthic habitats, and that they were dominated by the bivalve *Nucula annulata*; the amphipods *Crassicorophium crassicorne*, *Ericthonius fasciatus*, *Ampelisca agassizi, Unciola irrorata,* and *Lepthocheirus pinguis;* and sabellid polychaetes; there is considerable similarity in species with those reported for Block Island Sound.

2. Benthic infaunal studies were conducted in Rhode Island Sound as part of the U.S. Army Corps of Engineers' Long-term Dredged Material Disposal Site Evaluation Project at four sites in 2001, and at two sites in 2003 (Battelle 2002a, 2003a; adapted from Zajac in prep):

    a. In 2001 all four sites were numerically dominated by the amphipod, *Ampelisca agassizi*, and the clam, *Nucula annulata*—comprising approximately 54 percent of the total infaunal abundance—and had relatively high abundances of the annelid worms, *Polygordius* sp., *Tharyx acutus*, *Oligochaeta* spp., *Ninoe nigripes*, *Levinsenia gracilis*, and *Exogone hebes*; the crustaceans *Byblis serrata* (Amphipoda) and *Eudorella pusilla* (Cumacea); and the clam *Nucula delphinodonta* (Battelle 2002a).

    b. Classification analyses indicated that almost all sampling stations at all four sites showed a 60 percent similarity. The exception was two sampling stations at one of the sites just south of Narragansett Bay, both of which had relatively high silt content and these were only roughly 25 percent similar to the other sites. There were no other distinct clusters of sites, but there was some clustering of stations within sites, suggesting that benthic infaunal communities in Rhode Island Sound may not vary greatly over scales of tens of kilometers. Any variations that may occur may be due to small-scale differences in sea floor structure or other processes (Zajac in prep).

    c. An additional survey was conducted in 2003 at one site overlapping with one of the 2001 survey sites. The infaunal communities found were generally similar to those found in 2001 (Battelle 2003a), although there were some differences that might be attributed to seasonal variation. In addition to benthic grab samples, candidate disposal sites were surveyed using sediment profiling imagery. The data collected were analyzed using a disturbance/succession model developed by Rhoads et al. (1978) and Rhoads and Germano (1986). Using this model, the analyses suggest that the successional stages of the communities vary considerably over relatively small spatial scales (Battelle 2002b; 2003b), suggesting frequent disturbance events.

3. The ocean quahog (*Arctica islandica*) and sea scallop (*Placopecten magellanicus*) are large bivalves found in the Ocean SAMP area (see Chapter 5 for distribution and life history characteristics). Both species are found broadly throughout the area, often at high densities. As filter feeding bivalves, these organisms are capable of filtering large volumes of water and reducing particulate matter and plankton concentrations; the impact of feeding habits on the Ocean SAMP area ecology, however, are not known.

250.3. Fishes

1. There is a diverse and dynamic fish community in Ocean SAMP area waters, but the structure of the fish community has undergone recent major change from a community dominated by demersal (near bottom) species to one dominated by pelagic (water column) species (Collie et al. 2008). A corresponding trend towards fish species with a preference for warmer water temperatures suggests that broad-scale warming trends may be a significant driving force of this fundamental ecosystem level change. More research is needed to understand how other ecosystem variables outside of water temperature are being altered over time, and how the Ocean SAMP ecosystem at large is responding.

2. Fish play an important role in food web dynamics as higher-order predators within the ecosystem. Fish utilize the abundant stocks of producers—phytoplankton—and lower-order consumers such as zooplankton, converting their organic matter into larger "packages" of high-quality protein that then become available as food to birds, marine mammals, and large fishes and apex predators such as tuna and sharks. Fish are an important food and an important element of the economy of the state of Rhode Island with regard to both commercial and recreational fisheries. This chapter considers fish from the perspective of their role in the ocean ecosystem; for information on fisheries and the life histories of important commercial and recreational species, see Chapter 5, Fisheries.

3. Circulation and salinity play a role in fish species distribution and abundance. For instance, Merriman and Sclar (1952) noted a correlation between salinity in Block Island Sound and years of heavy spawning for at least certain species of fish. In one year of their survey the salinity in Block Island Sound was 2‰ higher than in other years, which corresponded to being a year during which a heavy spawn was noted. Similar heavy spawning was not seen in other years when salinities tended to be lower. Merriman and Sclar (1952) found that precipitation and runoff were both lower during the year of high salinity/heavy spawning. Three years later they noted an increase in the catch of weakfish (a species with high reproductive success during the high salinity event), again suggesting correlation between these events. Merriman and Sclar (1952) noted however, that there were not enough data to make correlations with a large degree of certainty, though they did suggest causality.

4. Food is a major determining factor in maintenance of healthy populations, and the importance of the benthic ecosystem as a food source to fish populations in the Ocean SAMP area is not trivial. Smith (1950) found that bottom invertebrates made up 81% of the total food of bottom fishes in Block Island Sound. Squid made up another 7.1% of the total, and fish comprised the remaining 11.9%. In fact, Smith (1950) found that only 25% of the bottom invertebrates sampled were *not* important as sources of food for fishes in Block Island Sound. Of the bottom invertebrates eaten by bottom-dwelling fishes, 90.2% were crustaceans, 3.5% were annelids, and the remainder a mix of hydrozoans, gastropods, echinoderms and other organisms. The amphipods *Leptocheirus pinguis* and *Unciola irrorata*, the crab *Cancer irroratus*, and the shrimps *Cragon septemspinosa* and *Upogebia affinis*, made up 78% of the biomass eaten by the bottom fishes sampled.

5. Amphipods are very abundant benthic invertebrates, and are an important members of the Ocean SAMP benthic community, providing an abundant, accessible food source to the fish community. Smith (1950) found that crustaceans in general made up about 90% of the bottom invertebrates eaten by fish, with amphipods making up 60%. One amphipod species—*Leptocheirus pinguis*—made up 46% of the bottom invertebrates eaten by fish in Block Island Sound.

6. Despite their abundance, Smith (1950) found some very selective, preferential feeding on amphipods by several species of fish. For instance, sculpin preferred to prey upon male *Leptocheirus pinguis* amphipods, while skates showed no preference. Smith (1950) provides an in-depth evaluation of amphipod–fish predator–prey relationships and how they affect population ecology of the amphipod species.

7. While amphipods may provide the primary source of food to bottom-feeding fishes, other species are also taken as food and are important contributors to the Ocean SAMP area food web. The rock crab (*Cancer irroratus*) was the second most important food source for bottom fishes, but only immature forms (to 5 cm carapace width) were eaten (Smith 1950). The mysid *Neomysis americana* was found to be both abundant and important as a fish food item, particularly for sea robins (Richards et al. 1979). The hydroid *Obelia articulata* was found by Smith to be an important springtime source of food for flounder.

8. In a fisheries survey in Block Island Sound conducted by Smith (1950), the following benthic fishes were found to be the most abundant: common skate (*Raja erinacea*), big skate (*Raja diaphanes*), winter flounder (*Pseudopleuronectes americanus*), windowpane flounder (*Lopnopsetta aquosa*), whiting (*Merluccius bilinearis*), longhorn sculpin (*Myoxocephalus octodecimspinosus*), eel pout (*Macrozoarus americanus*) and the common sea robin (*Prinotus carolinus*). Chapter 5, Fisheries, provides a brief overview of seasonality and biomass estimates for a variety of commercially important/valuable species found in the Ocean SAMP area, as well as individual life history descriptions. Chapter 5, Section 520 also provides a table that gives a first order identification of the various habitat requirements of commercially important/valuable species in the Ocean SAMP area. These data are not site specific; until benthic sediment/habitat mapping is completed for the Ocean SAMP area benthic habitat affinities for fishes cannot be addressed with surety.

9. Brown (in prep), based on Northeast Fisheries Science Center trawl survey results (fall sampled since 1963, spring since 1968, winter and summer since 1992), found 119 species of fishes and 9 species of crabs; 55 species occurred in less than 1% of the tows. Table 2.8 shows the percentage of tows containing various species, while Table 2.9 shows the biomass of various species taken in the same tows. Some species, winter flounder for instance, appear to be broadly distributed (e.g., found in 89% of the tows) but only in very small numbers (e.g., 3.2% of the total biomass). Others, spiny dogfish for instance, appear to be very numerous, but found in dense concentrations rather than scattered about.

Table 2.8. Percent occurrence of species landed in trawls taken in Block Island Sound (from Brown in prep).

Species	Percent of Tows
Winter flounder	89.0
Little skate	83.8
American lobster	77.1
Windowpane flounder	72.2
Silver hake	65.0
Winter skate	53.1
Longhorn sculpin	52.8

Table 2.9. Percent biomass of species landed in trawls taken in Block Island Sound (from Brown in prep).

Species	Percent Biomass
Spiny dogfish	41.0
Little skate	14.3
Winter skate	8.4
Ocean pout	5.0
Scup	3.9
Winter flounder	3.2
Loligo squid	2.3

10. Sanders (1952) noted an interesting use of the Ocean SAMP area as a winter refuge for Atlantic herring (*Clupea harengus*). In a survey of Block Island Sound, the species was present from January to mid-March, but in two distinct groups: spent adults (e.g., post-spawning) and immature adolescents. The spent adults were dominant through early February, at which point immature adolescent fishes dominated. Of interest is that Sanders (1952) notes that the herring restricted their distribution to a narrow band of the coldest water just south of Block Island, between 2 and 4°C, dispersing widely once waters warmed; the fish did not feed often while in the coldest water, but did switch to a totally planktonic diet once dispersed from the cold water refuge. Sanders (1952) suggests the fish use this as an adaptive strategy to slow metabolism over the winter months to conserve energy. Once the herring began feeding again, a large copepod, *Pseudocalanus minutus*, made up 70% or more of the food items ingested, and was noted to be the food of preference for the Atlantic herring in Block Island Sound waters.

11. Brown (in prep) characterizes the major demersal (e.g., living near but not necessarily on the bottom) and pelagic fish and invertebrates as residents or migrants of the Ocean SAMP area (Figure 2.27). The majority of the pelagic species are seasonal users of the area, with most of those arriving during spring and leaving during the fall. Relatively few major species are resident in the Ocean SAMP area. This suggests that the overall fish community of the Ocean SAMP area largely follows a seasonal cycle of abundance. Water temperature and food availability are no doubt major elements in shaping fish abundance patterns, both of which also exhibit strong seasonality. In general terms, early spring sees the start of a major influx

of migratory species to the area, reaching a maxima in later summer then declining throughout the fall season. This pattern is similar to those noted for zooplankton and ichthyoplankton communities.

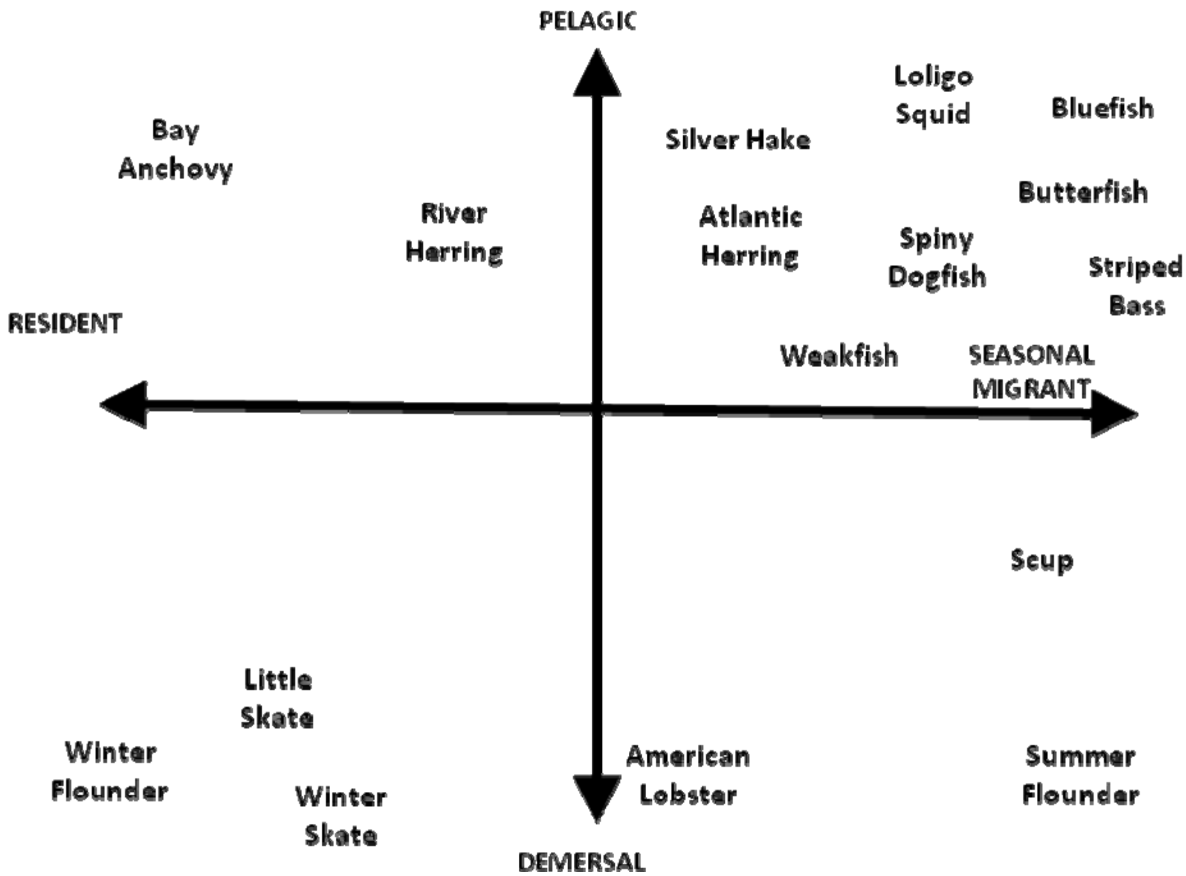


Figure 2.27. Seasonal composition of major fish and invertebrate species in the Ocean SAMP area (from Brown in prep).

12. While surveys have shown the seasonal nature of the migrations of fishes into and out of the Ocean SAMP area, Collie et al. (2008) have found a more fundamental shift in species abundances that have significant implications at ecosystem scales. Collie et al. (2008) have found a progressive shift in the species composition of the fish community at a sampling station located in Rhode Island Sound at the mouth of Narragansett Bay. Demersal fishes dominated in the 1960s, but during the 1970s benthic invertebrates (e.g., lobster, crabs) increased dramatically in abundance (Figure 2.28). During the 1980s, a major rise in the abundance of pelagic fishes and squid was noted, and by 1994, 50% of the species sampled were pelagic species. Though some demersal fish species have recently increased in abundance, the fish community remains dominated by pelagic species in the sampling area and there is no indication that species composition is moving towards that seen in the 1960s (e.g., dominated by demersal fishes). This is a fundamental shift in ecosystem composition, and effects upon the larger ecosystem are not known. Figure 2.29 shows increase and decrease of various species at the mouth of Narragansett Bay, again reinforcing the species

shift from demersal to pelagic species. Figure 2.30 shows change over time for several species; squid and the little skate have undergone particularly dramatic increases in population size in recent times.

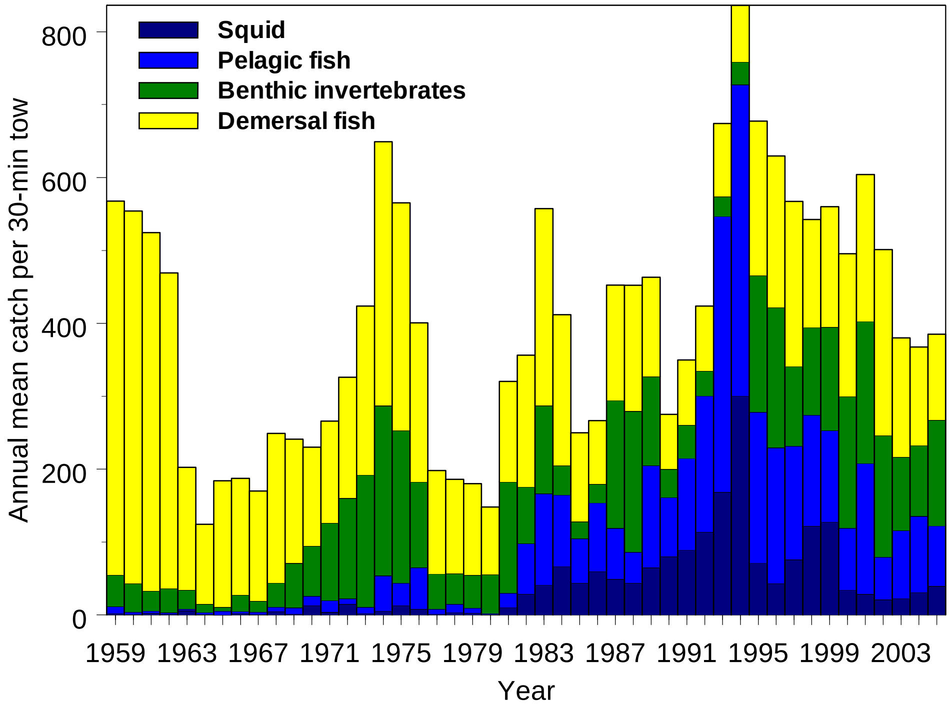


Figure 2.28. Trawl catches at Whale Rock at the mouth of Narragansett Bay/Rhode Island Sound (from Collie in prep), showing the increase in pelagic fish and squid since 1980.

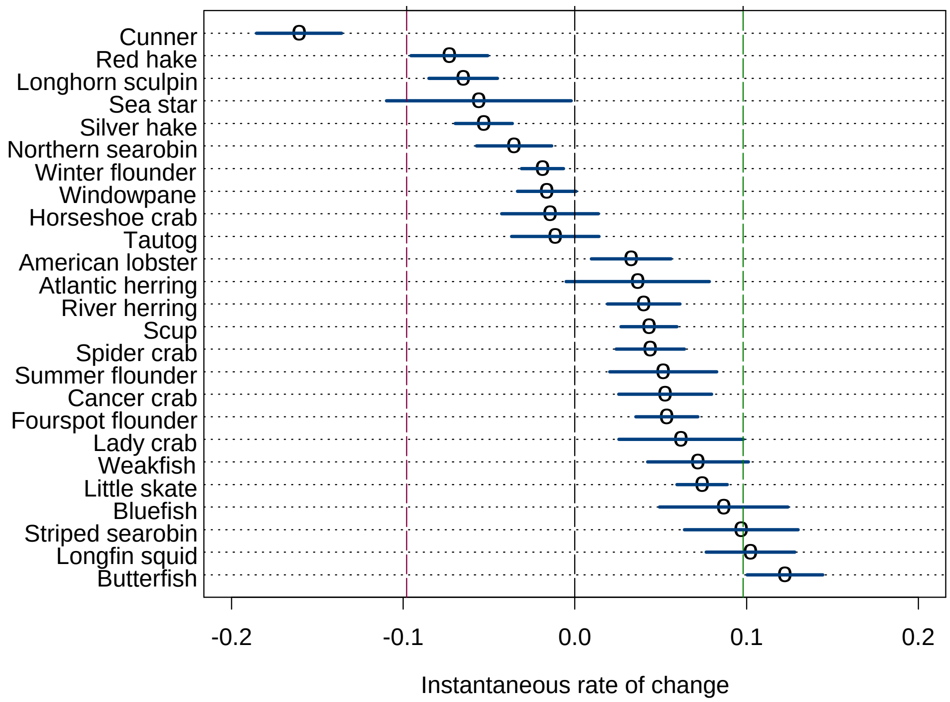


Figure 2.29. Rate of increase/decrease of species collected at Whale Rock at the mouth of Narragansett Bay/Rhode Island Sound (from Collie in prep). Left of 0.0 is decreasing in abundance, to the right increasing.

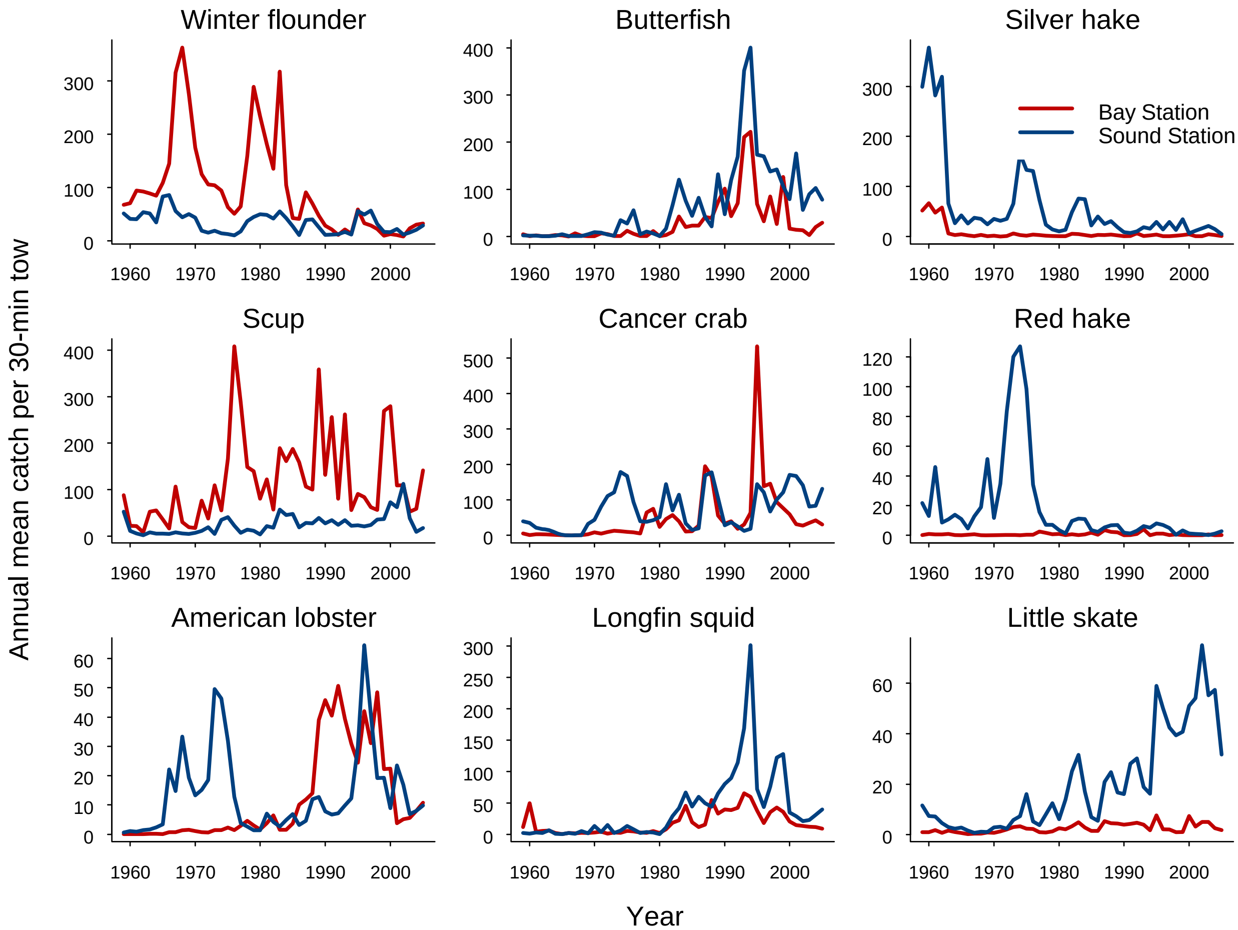


Figure 2.30. Annual mean abundance of nine species collected at Whale Rock at the mouth of Narragansett Bay/Rhode Island Sound (from Collie in prep).

13. Collie et al. (2008) also found a decrease in body size of the fish species represented, and that species composition tended towards ones with preference for warmer water temperatures (Figure 2.31). This may be indicative of regional shifts in fish species as a result of changing climate, particularly warmer water temperatures (Nye et al. 2009). Collie et al. (2008) noted that they expect a continuation of the shift to warm water pelagic species, perhaps over time developing a fish community more similar to that of Delaware Bay or Chesapeake Bay. Perry et al. (2005) have documented similar shifts in both commercially and non-commercially valuable fish species, with an average latitudinal shift in distance of 175 km (108 mi; range from 48 km (30 mi) to 403 km (250 mi)). Some species, cod for instance, may move further northward while southern species and migrants might become more abundant; winter flounder in particular will be more vulnerable and may undergo reduction in its distribution and availability in the area (Rose 2005).

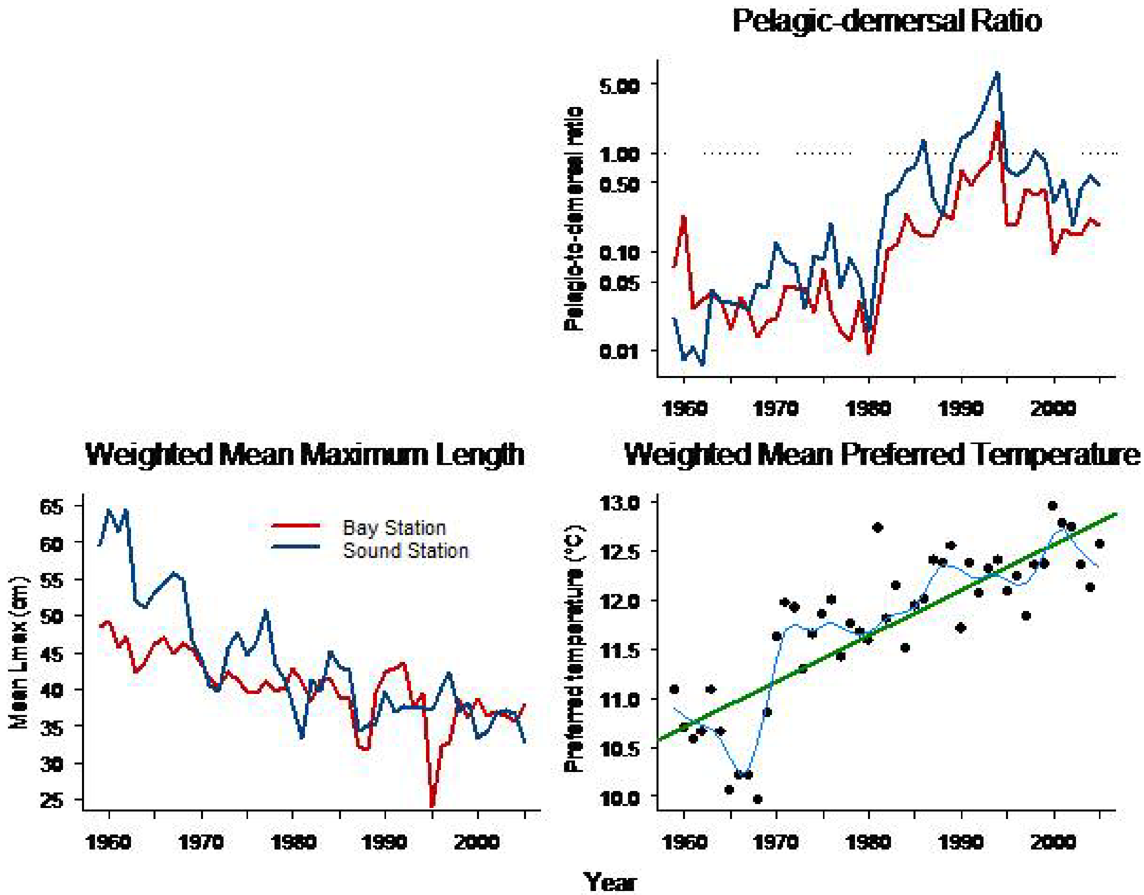


Figure 2.31. Community metrics for long term trawl samples collected at Whale Rock at the mouth of Narragansett Bay/Rhode Island Sound. Note the distinct decrease in fish length and the increase in preference for warmer water temperatures (from Collie in prep).

14. Similar change in fish community composition is being noted at various scales and geographic locations. Nye et al. (2009) took an in-depth look at the potential impacts of changing climate on fisheries in the Northeast Atlantic, and found that 24 of the 36 stocks assessed had a statistically significant response to warming water temperatures. The waters over the Continental Shelf have undergone a 10-year span of consistent warming, with the largest change being noted in bottom waters. Based on findings from analysis of a continuous, 40-year trawl survey (1968–2007), Nye et al. (2009) suggest several basic responses to climate change: a shift in distribution of the species to the north (e.g., range expansion for warm-water species; range contraction for cold-water species) or a vertical shift in species distribution to deeper water (e.g., cold-water species). Cold-water species that are at the southern extent of their range, for example cod, will be most impacted and may decline in abundance (Frank et al. 1990; Drinkwater 2005; Nye et al. 2009). Alewife, American shad, silver hake, red hake and yellowtail flounder all have exhibited range contraction. Cusk, a species that uses Block Island Sound as an important nursery area (Fahay 1992), is a species noted to be at particular risk as it is at the southern edge of its

range in the Ocean SAMP region (Nye et al. 2009). Nye et al. (2009) also found the relationship to hold for species with little or no commercial value (e.g., sea ravens, longhorn sculpin). These overall trends are of significant importance in the Ocean SAMP area as it is at the geographic boundary of two distinct eco-zones and change may be dramatic. While these changes are already noted, other change, such as increased early life mortality due to increased temperatures, or changed circulation patterns as a result of warming that transport eggs and/or larvae to unfavorable habitat, could significantly impact fish populations in the Ocean SAMP area. This is an area that is open for new research efforts.

250.4. Marine Mammals

1. Marine mammals—whales, dolphins, seals—are large predators within the Ocean SAMP ecosystem. Toothed whales, dolphins and seals are typically fish and squid eaters, entering the Ocean SAMP area on either an occasional or seasonal basis. Baleen whales also feed on schooling fishes, though some baleen whales, the right whale for instance, feeds exclusively on patches of zooplankton. Changes in distribution and/or abundance of marine mammal prey items—squid, fish, zooplankton—as a result of changing climate, may influence the distribution and abundance of marine mammals in Ocean SAMP waters. See Chapter 3, Climate Change, for further details.

2. Available data results from sightings, strandings, and/or fishery bycatch data (Kenney and Vigness-Raposa 2009). There are 50 species of marine mammals known from the North Atlantic Ocean (Kenney and Vigness-Raposa 2009), and all are protected under the U.S. Marine Mammal Protection Act. In addition, some marine mammals are classified as endangered or threatened, and therefore protected under the U.S. Endangered Species Act. Single manatees have been sighted in Rhode Island waters, but can be considered as stragglers from southern waters.

250.4.1. Cetaceans

1. Cetaceans include whales, dolphins, and porpoises; they largely use only the water column component of the Ocean SAMP area, following and feeding upon various prey items. Due to their large size, they are capable of consuming large quantities of fish and plankton. Kenney and Vigness-Raposa (2009) report thirty (30) cetaceans in the Ocean SAMP area: ten (10) that can be considered common to abundant, four (4) considered as regularly noted, and sixteen (16) as rare (Table 2.10).

Table 2.10. The occurance of marine mammals and sea turtles in Continental Shelf waters, which includes, but is not restricted to, waters in the Ocean SAMP area. (Kenney and Vigness-Raposa 2009).

Species	Occurrence
North Atlantic right whale	Common
Humpback whale	Common
Blue whale	Rare
Fin whale	Common
Sei whale	Regular
Bryde's whale	Rare
Minke whale	Common
Sperm whale	Common
Pygmy sperm whale	Regular
Dwarf sperm whale	Rare
Northern bottlenose whale	Rare
Cuvier's beaked whale	Rare
Blainville's beaked whale	Rare
Gervais' beaked whale	Rare
Sowerby's beaked whale	Rare
True's beaked whale	Rare
Beluga whale	Rare
Harbor porpoise	Common
Long-finned pilot whale	Common
Short-finned pilot whale	Rare
Killer whale	Rare
False killer whale	Rare
Risso's dolphin	Common
Atlantic white-sided dolphin	Common
White-beaked dolphin	Regular
Common bottlenose dolphin	Common
Short-beaked common dolphin	Common
Striped dolphin	Regular
Atlantic spotted dolphin	Rare
Pan-tropical spotted dolphin	Rare
Harbor seal	Common
Gray seal	Common
Harp seal	Common
Hooded seal	Regular
Ringed seal	Rare
West Indian manatee	Rare
Leatherback sea turtle	Common
Loggerhead sea turtle	Common
Kemp's ridley sea turtle	Regular
Green sea turtle	Rare

2. For baleen whales, Kenney and Vigness-Raposa (2009) report that fin, humpback and minke whales occur year round throughout continental shelf waters, but all are relatively rare in the Ocean SAMP area. Figure 2.32 shows relative abundances of various species of baleen whales

in the Ocean SAMP area. Right whales, a particularly endangered species with approximately 400 individuals remaining, can be common offshore during spring and fall migration, but are not common in the Ocean SAMP area. Waters outside of the Ocean SAMP area see greater abundances of marine mammals, with the fin whale being the most common, and with some visitation into the Ocean SAMP area during summer months with sightings primarily in deeper waters. Baleen whales appear to utilize the area to the east of Nantucket Sound/Vineyard Sound more heavily than they do the Ocean SAMP area (Figure 2.32).

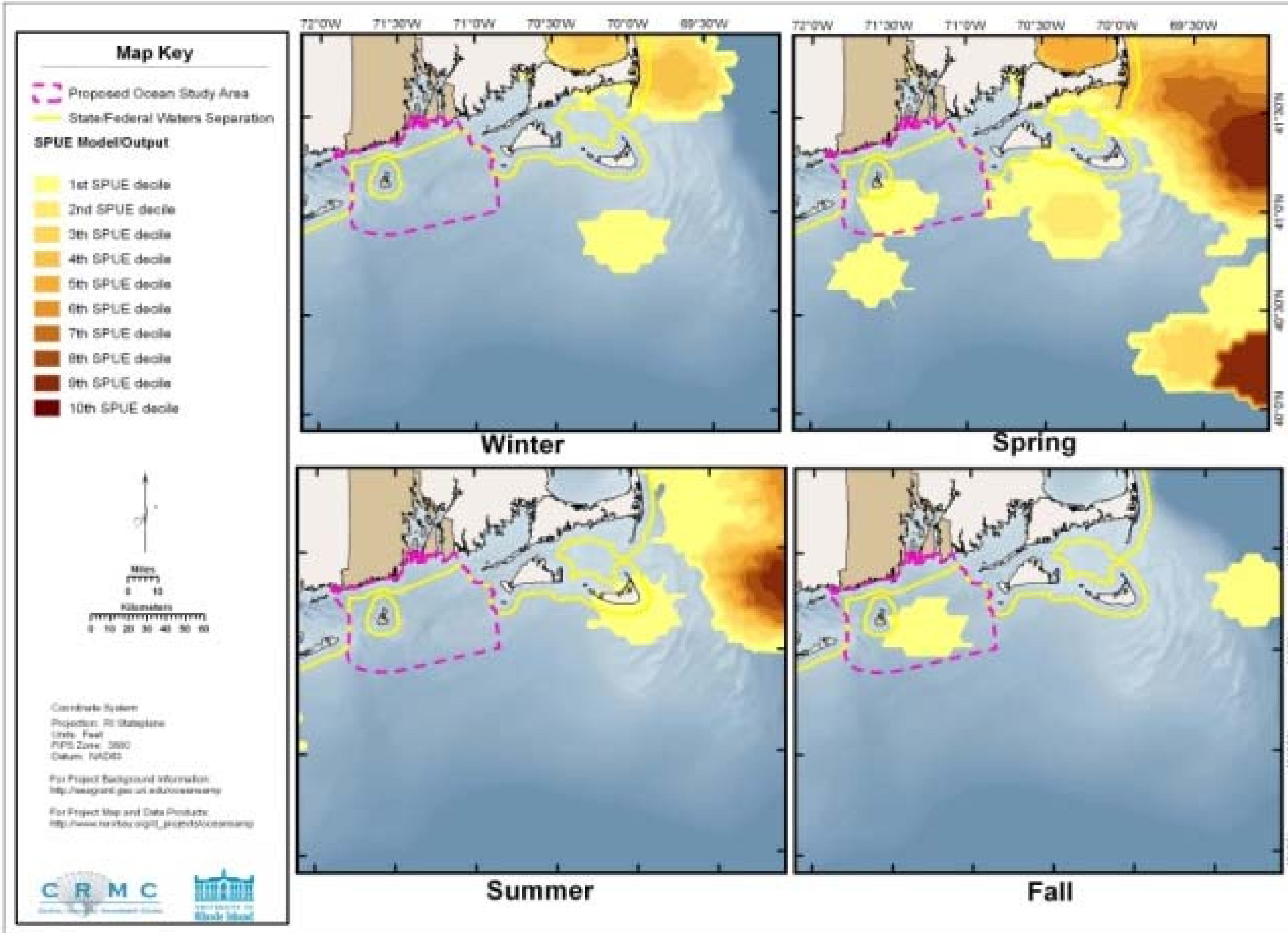


Figure 2.32(a). Modeled seasonal relative abundance patterns of right whales in the Ocean SAMP area, corrected for uneven survey effort (from Kenney and Vigness-Raposa 2009). Darker areas on the map represent areas of higher abundance; the darker the color the greater the relative abundance.

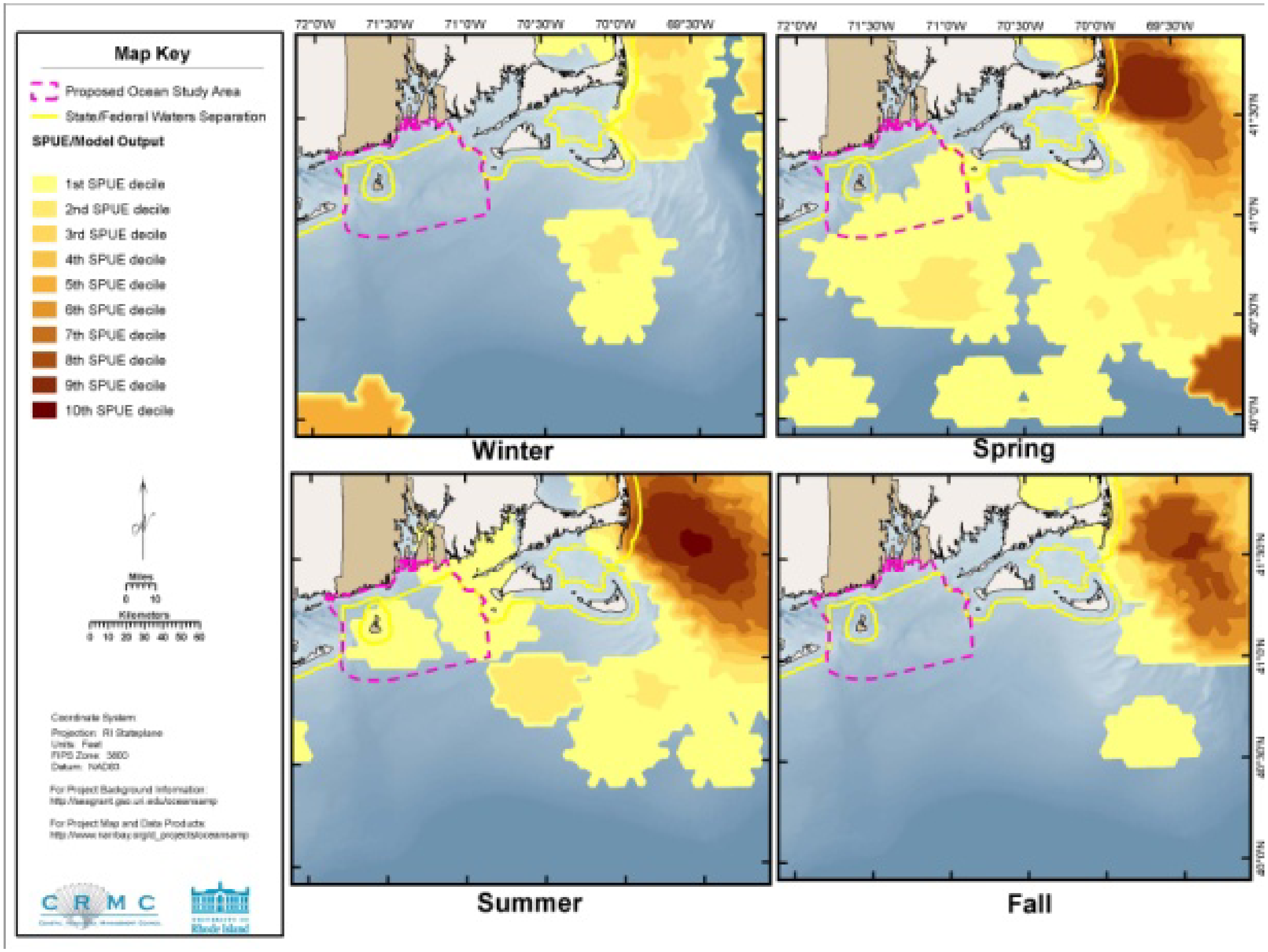
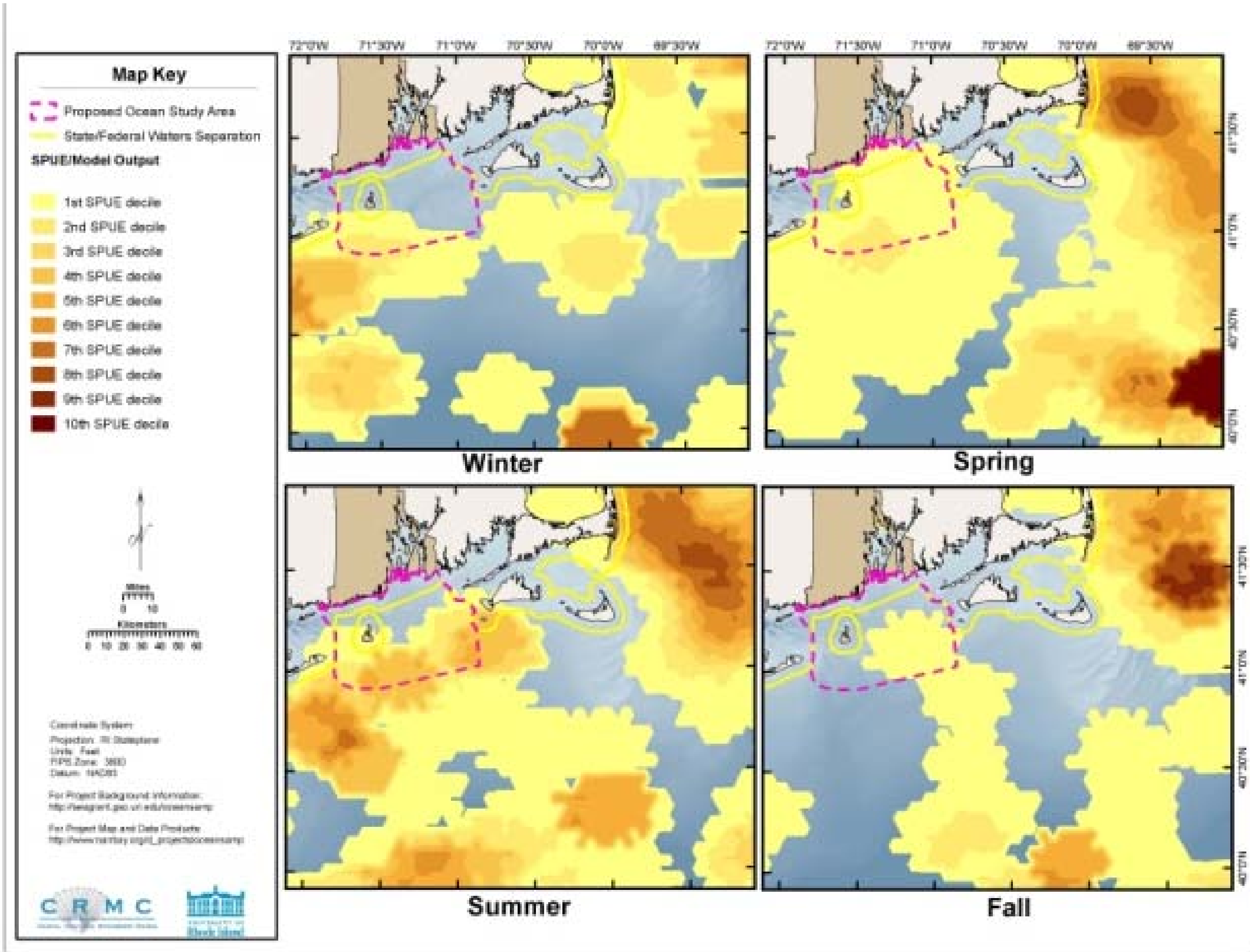


Figure 2.32(b). Modeled seasonal relative abundance patterns of humpback whales in the Ocean SAMP area, corrected for uneven survey effort (from Kenney and Vigness-Raposa 2009). Darker areas on the map represent areas of higher abundance; the darker the color the greater the relative abundance.



2.32(c). Modeled seasonal relative abundance patterns of fin whales in the Ocean SAMP area, corrected for uneven survey effort (from Kenney and Vigness-Raposa 2009). Darker areas on the map represent areas of higher abundance; the darker the color the greater the relative abundance.

3. For toothed whales, the harbor porpoise is the most common, along with the common dolphin and the Atlantic white-side dolphin; pilot whales are also found on occasion in Ocean SAMP area waters, but are more generally found farther offshore. Figure 2.33 shows relative abundances of various species of toothed whales in the Ocean SAMP area. Toothed whales appear to utilize the area to the east around Nantucket Sound/Vineyard Sound, and offshore waters over the Continental Shelf, more heavily than they do the Ocean SAMP area (Figure 2.33).

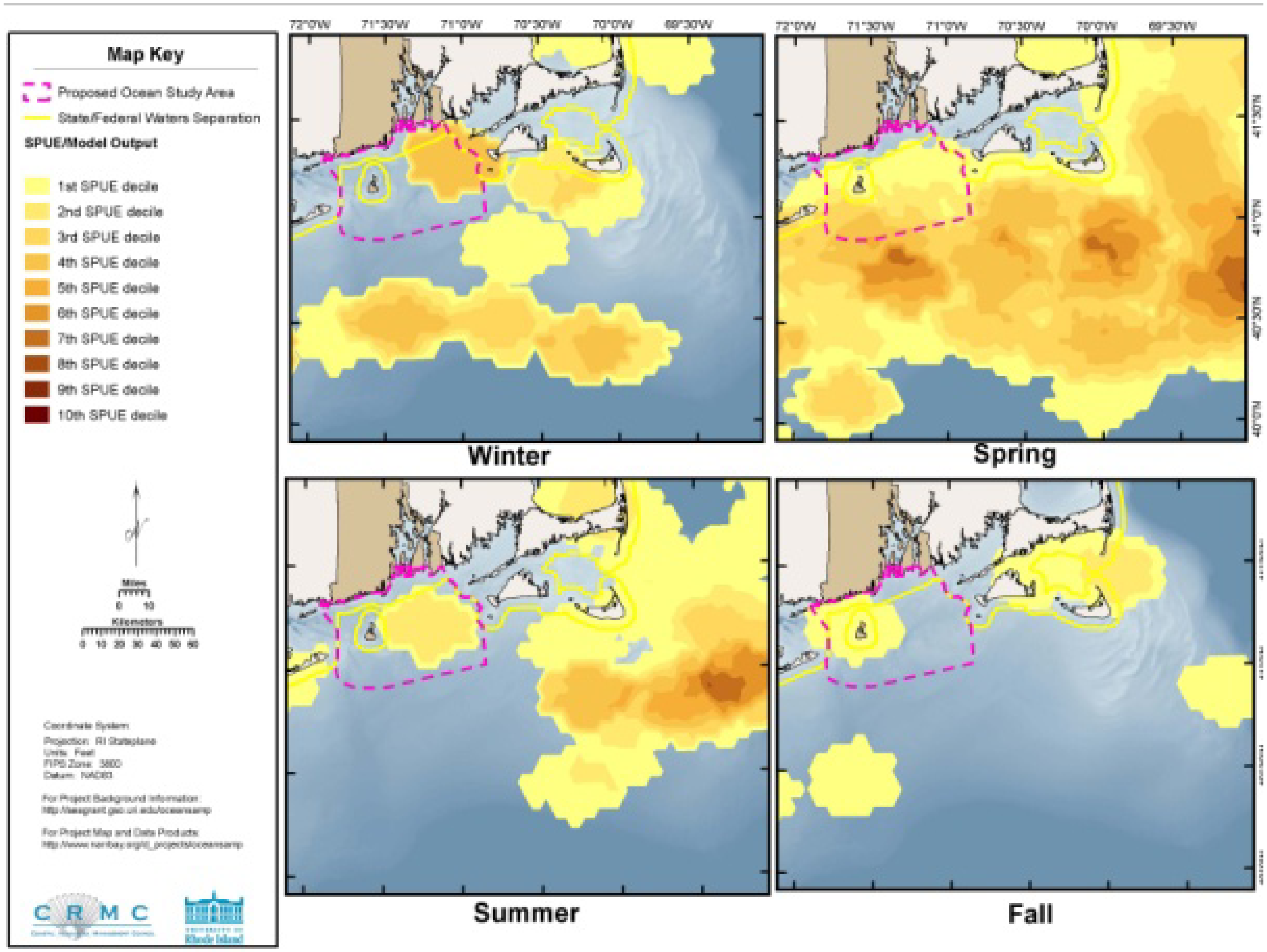


Figure 2.33(a). Modeled seasonal relative abundance patterns of harbor porpoise in the Ocean SAMP area, corrected for uneven survey effort (from Kenney and Vigness-Raposa 2009). Darker areas on the map represent areas of higher abundance; the darker the color the greater the relative abundance.

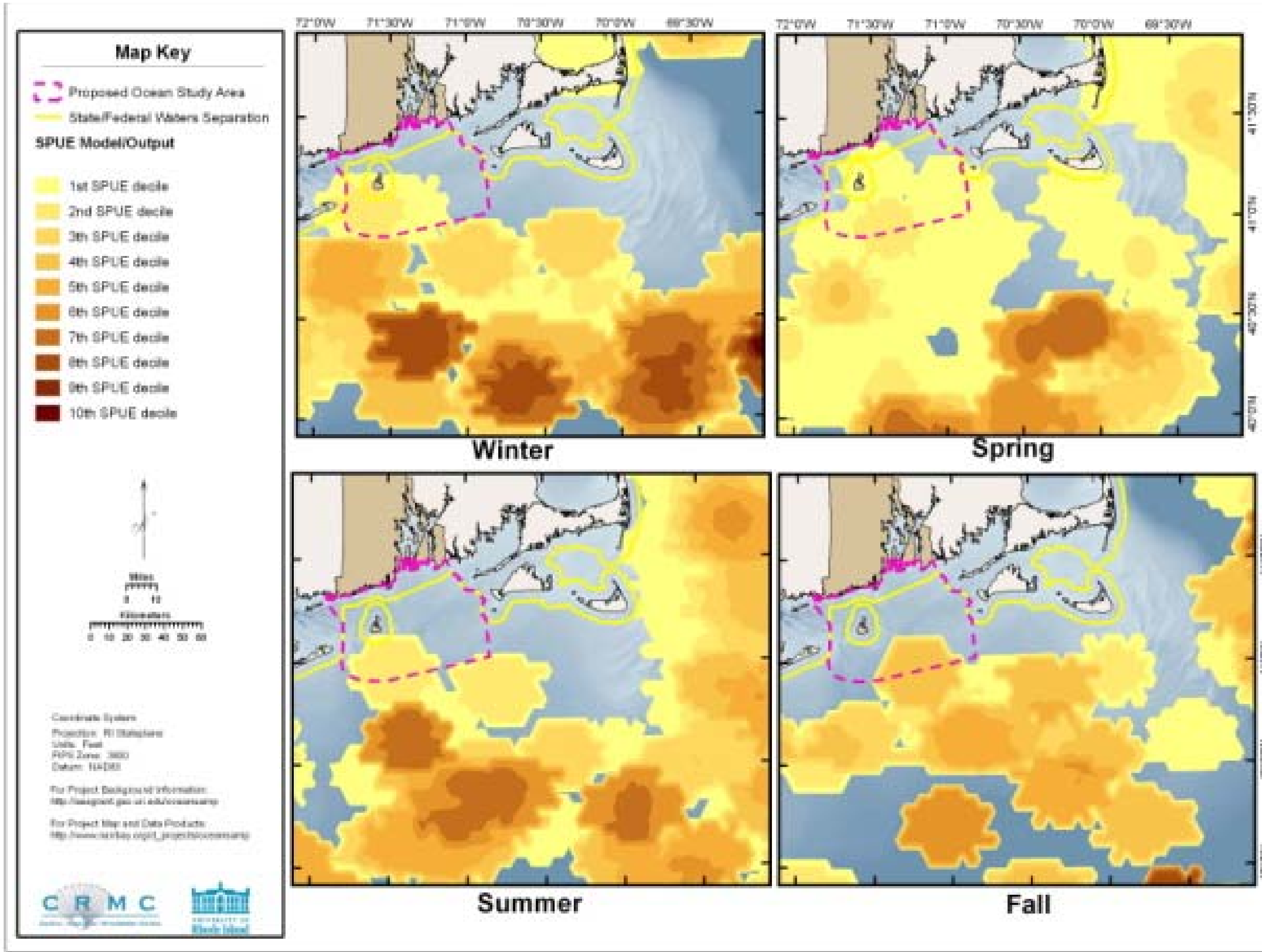


Figure 2.33(b). Modeled seasonal relative abundance patterns of common dolphin in the Ocean SAMP area, corrected for uneven survey effort (from Kenney and Vigness-Raposa 2009). Darker areas on the map represent areas of higher abundance; the darker the color the greater the relative abundance.

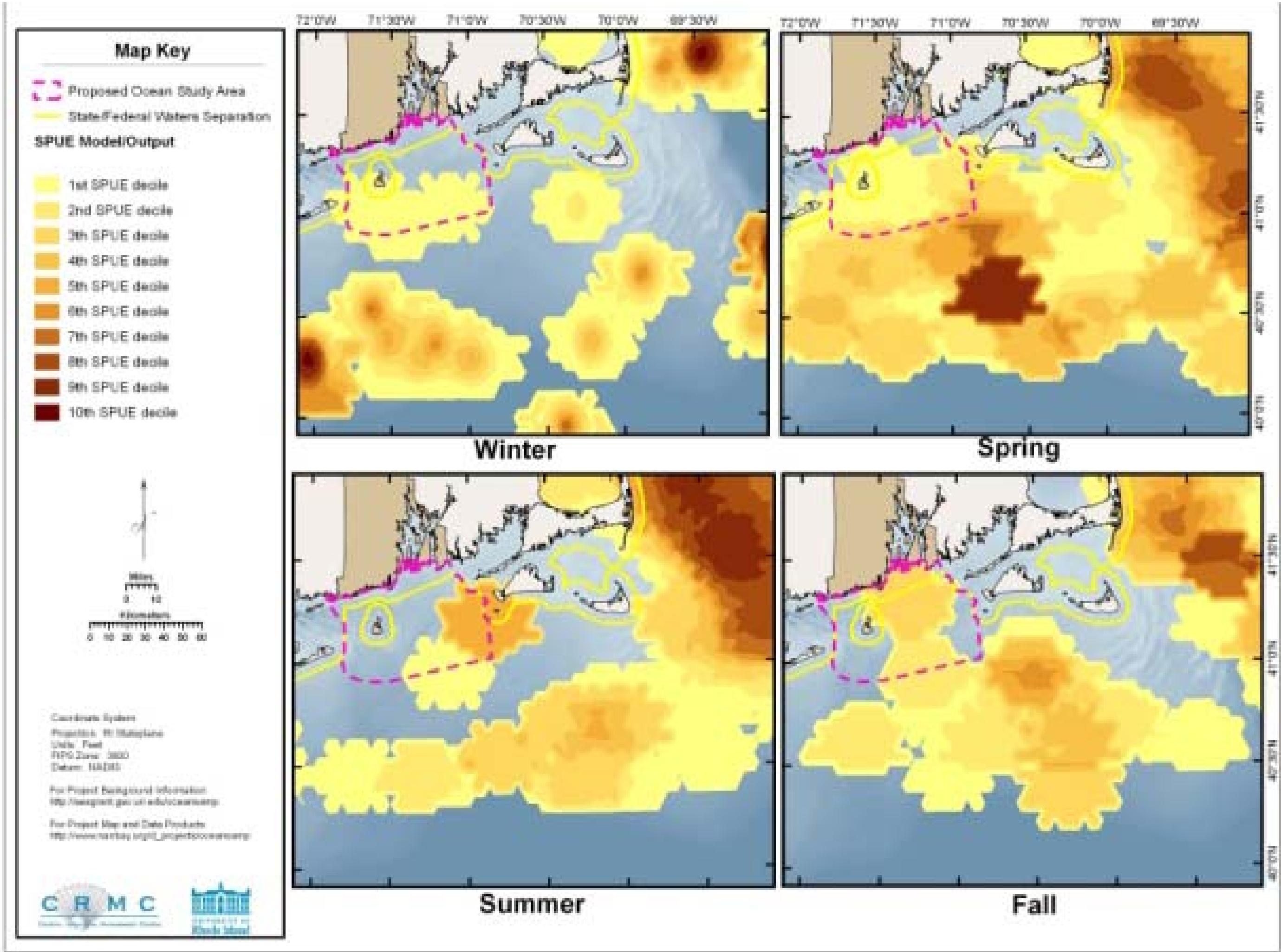


Figure 2.33(c). Modeled seasonal relative abundance patterns of Atlantic white-sided dolphin in the Ocean SAMP area, corrected for uneven survey effort (from Kenney and Vigness-Raposa 2009). Darker areas on the map represent areas of higher abundance; the darker the color the greater the relative abundance.

250.4.2. Pinnipeds

1. Pinnipeds are seasonal users of the Ocean SAMP area, and unlike cetaceans, pinnipeds also utilize the terrestrial environment, largely as “haul-out” sites used for resting. While fish are the predominant prey item of pinnipeds in this area, they have a very broad diet that includes many invertebrate species. Kenney and Vigness-Raposa (2009) report five (5) seals in the Ocean SAMP area: three (3) can be considered common, one (1) as regular, and one (1) as rare (Table 2.10). Of these species, only the gray seal and harbor seal are common, with the later being most common in the Ocean SAMP area, particularly along Block Island.

2. Harbor seals are seasonally abundant in the region from fall through spring—generally late September to early May—with numerous known haul-out sites around Narragansett Bay and on Block Island (Figure 2.34), which is the major haul-out area within Ocean SAMP boundaries. There are 6 major haul out sites on Block Island, two which are heavily used (mean # seals using the site is 8, with a maximum greater than 30) and the remaining four less so (mean # seals using the site is 1, with a maximum greater than 5), with none being located on the southern side of the island (Schroeder 2000). Harbor seals are rarely seen more than 20 km from shore, and mainly frequents bays, estuaries and inlets (Schroeder 2000). No specific food studies have been conducted on harbor seals in Rhode Island, but Payne and Selzer (1989) found sand lance to be an important food on Cape Cod. Williams (1999) found hake to be important in the Gulf of Maine, as did Wood (2000) along the mid-coast region of Maine. Olesiuk et al. (1990) found harbor seals to be opportunistic feeders, taking advantage of whatever food items are readily and easily available, though Payne and Selzer (1989) noted a preference for small schooling fishes when available, but that they will shift prey species rapidly in response to prey availability.

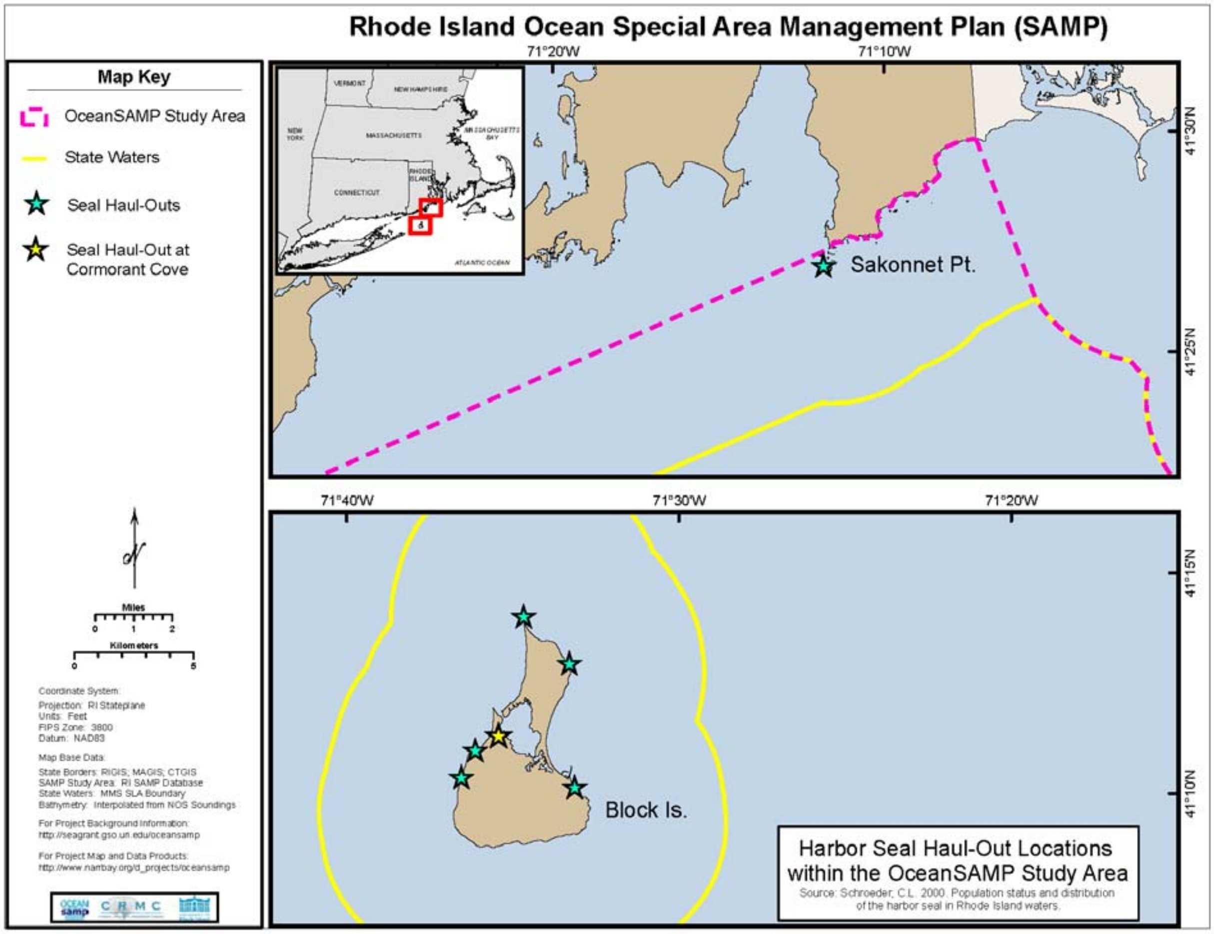


Figure 2.34. Harbor seal haul-out sites. Yellow star area on Block Island is a major seal haul out area.

3. Gray seals (*Halichoerus grypus*) are a more northerly species that ranges into southern New England waters on a seasonal basis. Ridoux et al. (2007), who studied the diet of gray seals in European waters, found them to maintain a diet of mainly fish and cephalopods, with fish making up 96% of the diet by number and 98.6% by mass. In Canadian offshore waters, Bowen and Harrison (1994) found that gray seals had a feeding range of about 80 km, and that foods eaten mimicked the prey items available. They found that by weight, sand lance made up nearly 81% of the diet, cod 11%, silver hake about 3% and flatfish and other gadoid fishes the remainder. A similar study by Bowen et al. (1993) found that herring, cod, sand lance, silver hake and squid made up 88%, by weight, of gray seal diet on the Scotian Shelf of Canada. Bowen and Harrison (1994) noted differences in gray seal diets near shore and offshore, but this could be attributed to prey availability.

250.5. Sea Turtles

1. Sea turtles are reptiles that have taken up an oceanic existence. Terrestrial resources in the Ocean SAMP area are not utilized, and sea turtles are not known to breed or nest in these waters. Available data results from sightings, strandings, and/or fishery bycatch data (Kenney

and Vigness-Raposa 2009). There are six species of sea turtles known from the North Atlantic Ocean (Kenney and Vigness-Raposa 2009). All six sea turtles are classified as endangered or threatened, and therefore protected under the U.S. Endangered Species Act.

2. Kenney and Vigness-Raposa (2009) report four (4) species of sea turtles in the Ocean SAMP area: two (2) can be considered common, one (1) as regular, and one (1) as rare (Table 2.10).

3. Kenney and Vigness-Raposa (2009) report details for leatherback sea turtles, noting that sightings generally occurred in continental shelf waters, not in the Ocean SAMP area. Those leatherback turtles that do visit the Ocean SAMP area feed upon jellyfishes and other gelatinous prey items. The few turtles that are found offshore of the Ocean SAMP area are sighted mostly in the summer and early fall, except for Kemp's Ridleys which is seen mostly in winter, probably as southbound migrants. Figure 2.35 shows the seasonal relative abundance of leatherback turtles in the Ocean SAMP area, showing the probability for visitation in the area is highest during summer and fall months.

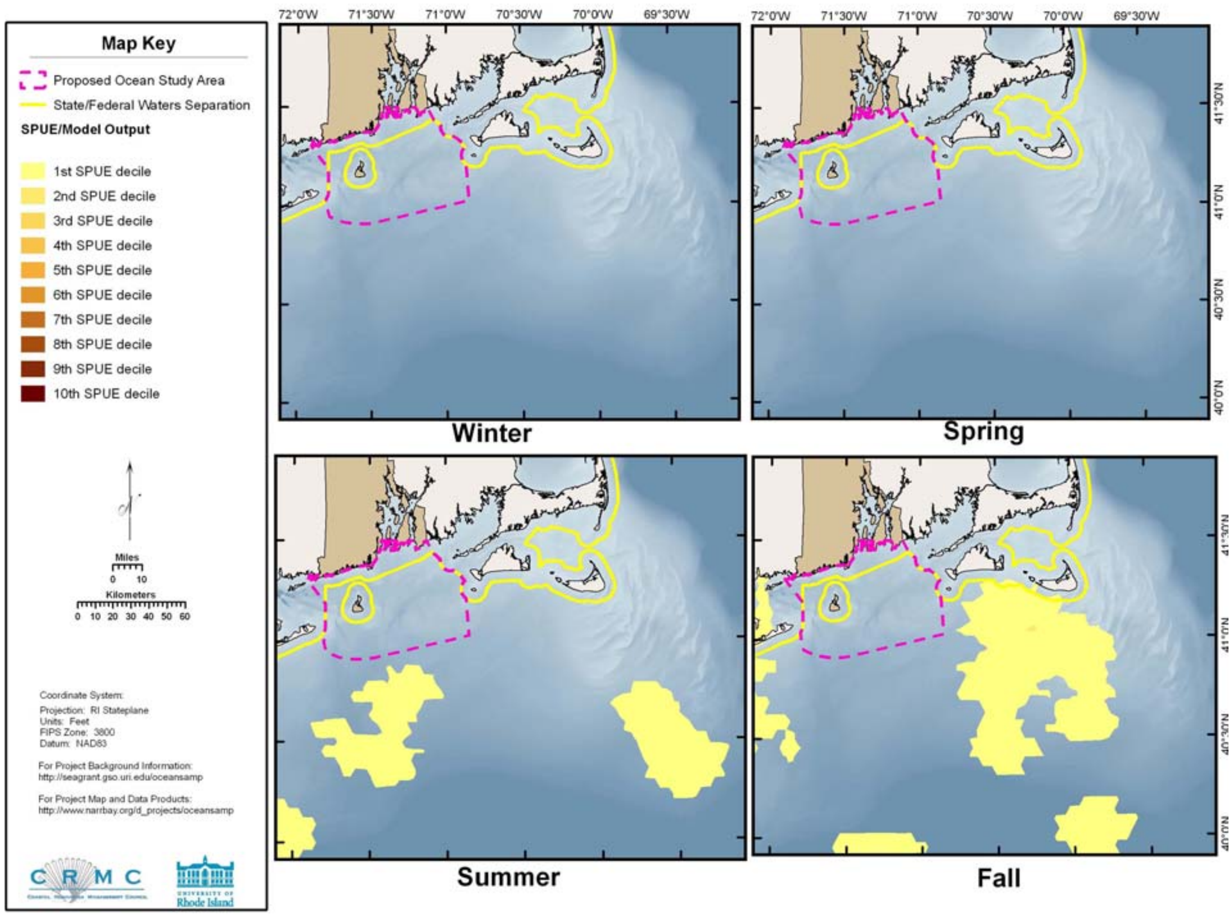


Figure 2.35. Modeled seasonal relative abundance patterns of leatherback sea turtles in the Ocean SAMP area, corrected for uneven survey effort (from Kenney and Vigness-Raposa 2009).

250.6. Avifauna

1. Birds are an element of the Ocean SAMP area ecology; they are attracted to the area for feeding purposes, utilizing the seasonal abundance of fish and invertebrates as an important resource. The impact of avifauna on the overall ecology of the Ocean SAMP area is not well studied and so how bird use shapes benthic invertebrate ecology in shallow waters is not well known and is an area of further possible research.

2. A variety of water birds utilize the water and air space of the Ocean SAMP region. Waterfowl utilizing Ocean SAMP waters include nearshore species such as geese and ducks, as well as more oceanic species such as shearwaters. Passerines (e.g., songbirds) tend to utilize Ocean SAMP air space during migrations, with Block Island serving as resting, staging or feeding site. Passerines also utilize Block Island for nesting and breeding purposes.

3. Reinert et al. (2002) found 109 species of songbirds on Block Island during the time of spring migration and 113 species during the fall migration, with 103 of the species found

during both seasons. Table 2.11 shows the most common passerine birds utilizing the terrestrial portion of the Ocean SAMP area (e.g., Block Island), and season(s) they are typically found on the island. While many species utilize Block Island as a migratory stopover, Reinert et al. (2002) found that 38% of the spring-captured species, and 21% of the fall-captured species, were species that are known to breed on Block Island. Reinert et al. (2002) provide greater detail on specific island habitat use by passerine birds. Actual use of marine waters are expected to be minimal, though tree swallows aoppear to utilize nearshore air space over water on a regular basis (Paton et al. 2010), perhaps for feeding purposes.

Table 2.11. Common songbirds utilizing Block Island, and the season(s) in which they are found on the island, and the percent of total captures for each species (Reinert et al. 2002).

Species	Scientific Name	% of Total Capture (Spring/Fall)
Gray Catbird	*Dumetella carolinensis*	17.1 / 13.2
Common Yellowthroat	*Geothlypis trichas*	13.7 / 0
Yellow-Rumped Warbler	*Dendroica coronate*	10.7 / 35.1
White-Throated Sparrow	*Zonotrichia albicollis*	6.6 / 0
Golden-Crowned Kinglet	*Regulus satrapa*	0 / 4.5
Red-Eyed Vireo	*Vireo olivaceous*	0 / 4.1

4. Winiarski et al. (2009) have found approximately 25 waterbird species that commonly inhabit and/or use the waters of the Ocean SAMP area (Table 2.12). Use of the Ocean SAMP area by any given species of waterbird, except for various gulls, is seasonal. Figure 2.36 shows waterbird seasonality in a graphical fashion. Waterbirds either overwinter in the Ocean SAMP area (e.g., common eider) or use it as summer feeding grounds, perhaps after the nesting cycle is completed (e.g., loons, scoters).

Table 2.12. Avifauna of the Ocean SAMP area as described by Winiarski et al. (2009).

Common Name	Scientific Name	Seasonal Use
Eider, Common	*Somateria mollissima dresseri*	Nov–Apr
Gannet, Northern	*Morus bassanus*	
Gull, Bonaparte's	*Chroicocephalus philadelphia*	
Gull, Great Black-backed	*Larus marinus*	Mar–Jul
Gull, Herring	*Larus argentatus*	All Year
Gull, Laughing	*Leucophaeus atricilla*	Aug–Sep
Gull, Ring-billed	*Larus delawarensis*	
Loon, Common	*Gavia immer*	Nov–Jun
Loon, Red-throated	*Gavia stellata*	Nov–May
Scoter, Black	*Melanitta nigra americana*	Dec–Apr
Scoter, Surf	*Melanitta perspicillata*	Dec–Apr
Scoter, White-winged	*Melanitta deglandi*	Jan–Apr
Shearwater, Cory's	*Calonectris diomedea*	Jun–Aug
Shearwater, Greater	*Puffinus gravis*	
Shearwater, Manx	*Puffinus puffinus*	
Shearwater, Sooty	*Puffinus griseus*	
Storm-Petrel, Wilson's	*Oceanites oceanicus*	Jun–Jul
Tern, Black	*Chlidonias niger*	
Tern, Common	*Sterna hirundo*	Apr–Sep
Tern, Forster's	*Sterna forsteri*	
Tern, Least	*Sternula antillarum*	May–Aug
Tern, Roseate	*Sterna dougallii*	Jul–Aug

5. Winiarski et al. (2009) have found, based on a review of the literature, that most sea ducks typically forage in water of 5 to 20 m depth (Figure 2.37) where bivalves and other forage is available. Sea ducks will therefore be largely found in nearshore habitats where water depth allows efficient feeding. While bathymetry is known for the Ocean SAMP area, benthic community composition is not and therefore preferred/critical waterbird forage areas cannot be readily identified. Winiarski et al. (2009) also noted a trend of decreasing avian diversity with distance from land, further reinforcing the importance of nearshore habitat for these avian species.

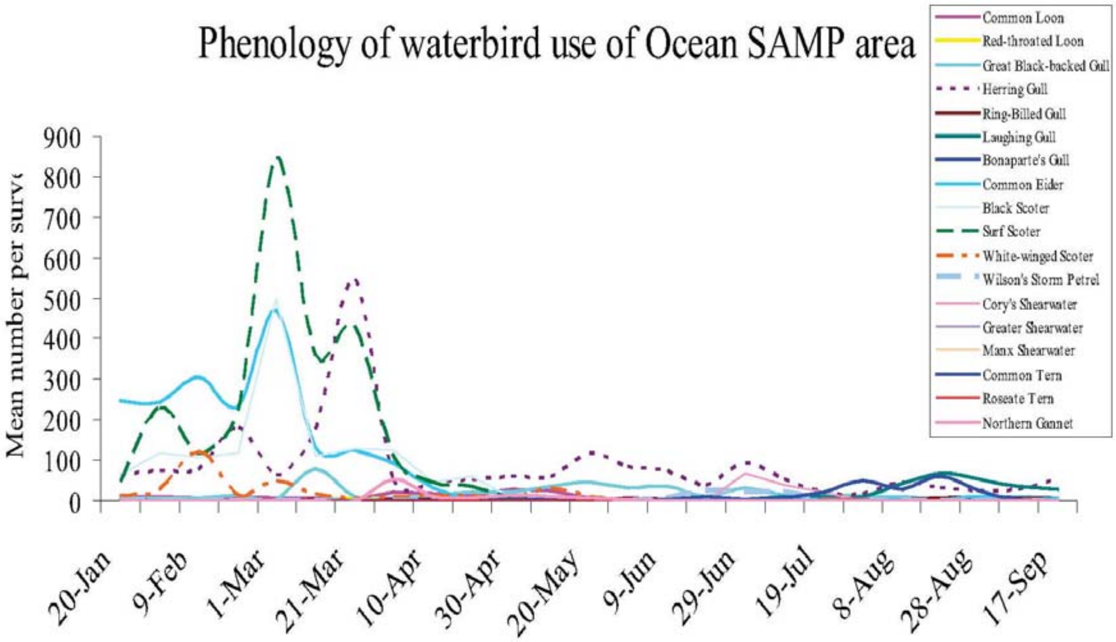


Figure 2.36. Seasonality of avifauna in the Ocean SAMP area (from Winiarski et al. 2009).

6. Figure 2.38 shows the seasonality of waterbird use in the Ocean SAMP area, according to bird type, and providing greater definition than could be shown in Figure 2.36, which is useful in showing, at the same scale, seasonality of bird use in the Ocean SAMP area. Gull use of the area is year round, while sea ducks appear to use the Ocean SAMP area as overwintering grounds. Shearwaters and storm-petrels appear later in the season, probably using the Ocean SAMP area as a feeding ground.

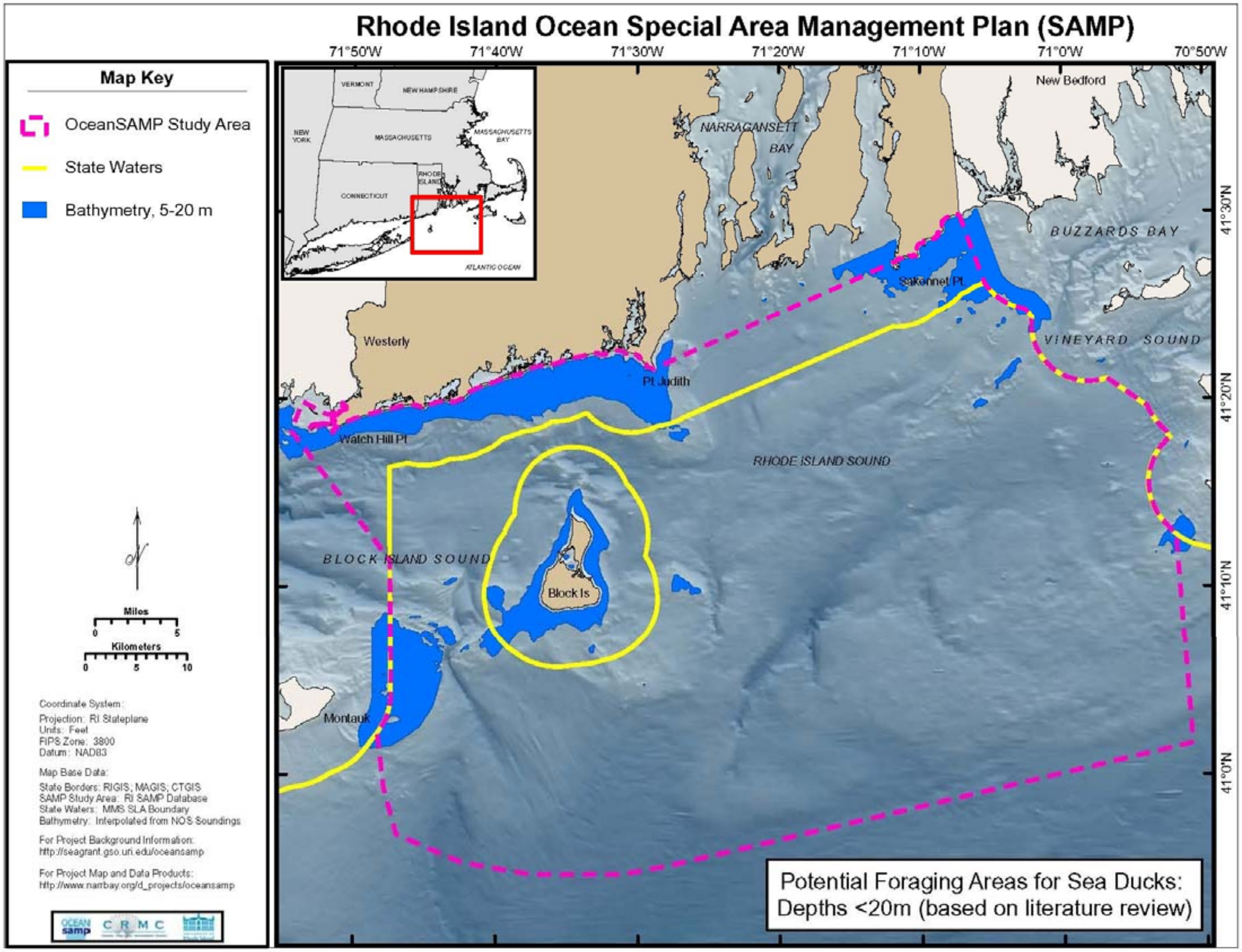


Figure 2.37. Use of the Ocean SAMP area by diving ducks, showing they mainly utilize shallow-water, nearshore habitats. Since benthic community composition is not know, this map shows only most used water depth, not preferred foraging sites.

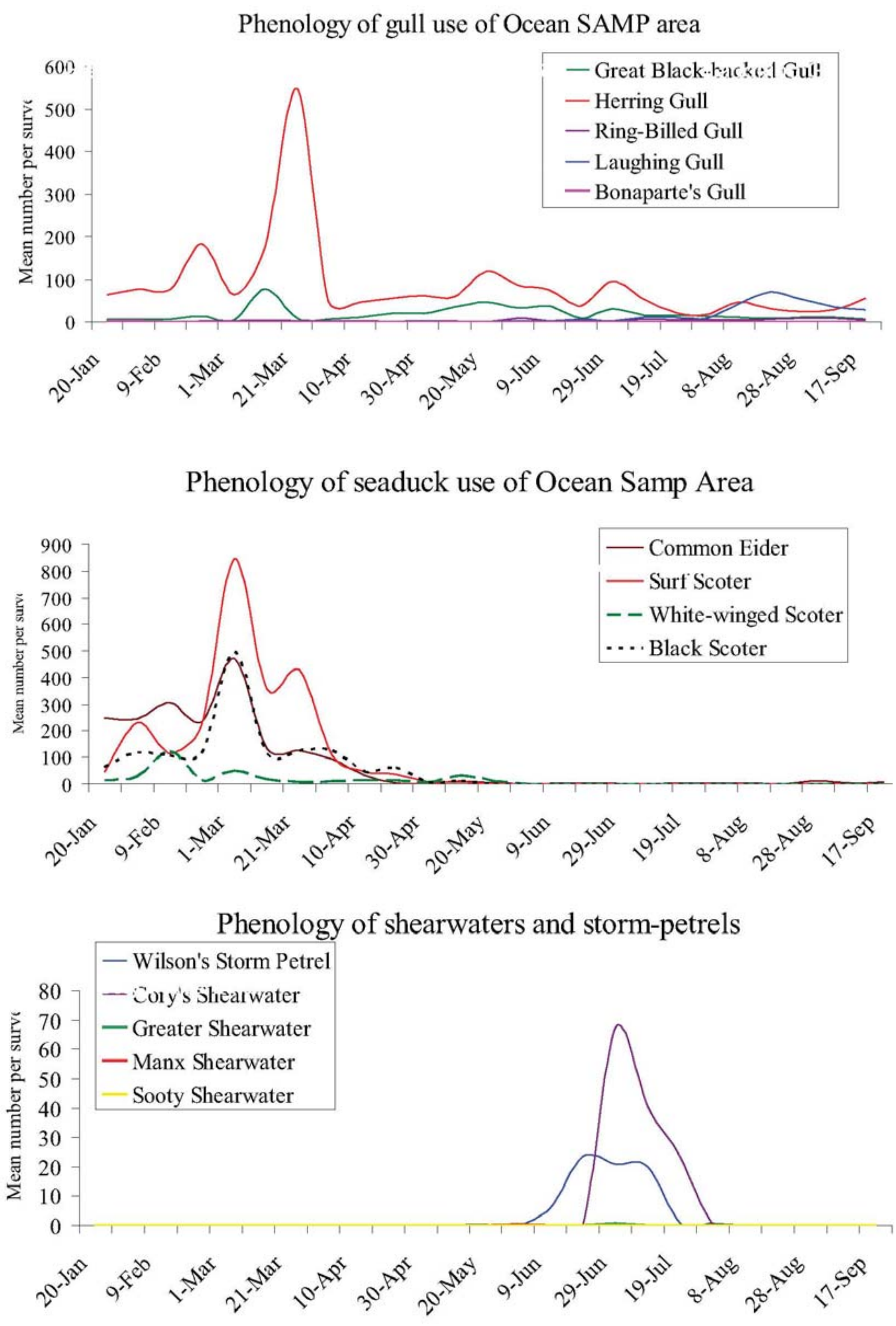


Figure 2. 38. Seasonal use of the Ocean SAMP area by gulls, sea ducks, shearwaters and storm-petrels (from Winiarski et al. 2009).

7. Paton et al. (2010), based on both land-based and boat-based survey counts, have identified the most common bird species using Ocean SAMP waters (Figure 2.39). Common eider are the most abundant user of nearshore waters, followed by the herring gull and surf scoter. Offshore waters are utilized most heavily by herring gulls, followed by Wilson's storm-petrels, northern gannets, and black-backed gulls. Gulls appear to be one of the major users of Ocean SAMP waters, both inshore and offshore, and throughout the seasons.

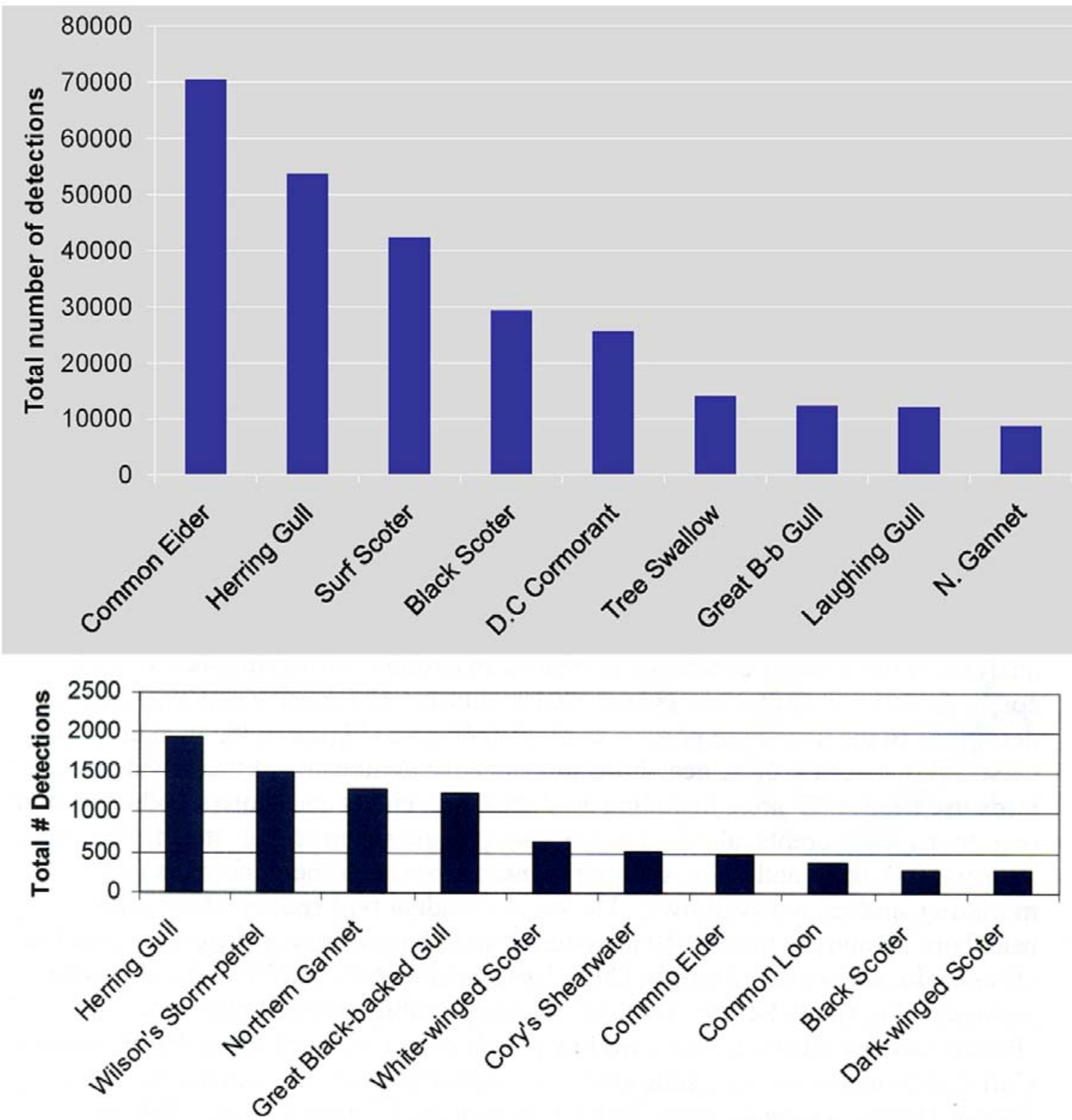


Figure 2.39. Most abundant waterbirds found nearshore (top panel) and offshore (bottom panel) in the Ocean SAMP area, based on land-based (Jan 2009–Jan 2010) and boat-based (Mar 2009–Jan 2010) survey counts (from Paton et al. 2010).

8. Various species of tern are found throughout the Ocean SAMP area (Winiarski et al. 2009; Paton et al. 2010), and utilize marine waters for foraging purposes. Nearly all occurrence of tern species however, is over the waters north of Block Island, increasing with nearness to the Rhode Island coastline. Terns do not appear to significantly utilize more open, deeper water areas of Block Island Sound, Rhode Island Sound or the Offshore Ocean SAMP area. Impact of their feeding on fish ecology of the Ocean SAMP area is not known.

9. Paton et al. (2010) report the following patterns of avian use of Ocean SAMP area waters, based on aerial survey results, for the period of late November 2009 through late February 2010l:

    a. Loons were found to be scattered throughout the area, though thinly throughout most of the central portion of Rhode Island Sound. Densest concentrations occurred along the Rhode Island south shore shoreline, around Block Island shoreline, and in the area west of Block Island bordering Montauk Point and the opening to Long Island Sound. Shallower waters appear to be preferred, most likely for foraging purposes.

    b. Scoters and common eider showed concentrations around the west side of Block Island, along the Rhode Island south shore shoreline, and around the Sakonnet shoreline bordering Rhode Island Sound. Few were found over the open waters of Block Island Sound, Rhode Island Sound or the Offshore Ocean SAMP area. Scoter appeared to be most abundant during the November through January time span; eider appeared to use the area throughout the surveyed time span. Shallower waters appear to be preferred, most likely for foraging purposes.

    c. Alcids (dovekies, murres, puffines, guillemots) were found scattered throughout the area, though densest concentrations occurred in deeper waters south of Block Island and throughout the central portions of Rhode Island Sound and south onto the Offshore Ocean SAMP area. Use of Ocean SAMP waters by these types of avifauna appears to be reduced towards late February, and largely for rafting purposes.

    d. Northern gannets were scattered throughout the area, though thinly throughout the central and eastern portions of Rhode Island Sound and the inner portions of Block Island Sound. Occurrence in waters north of a line from Montauk Point to Martha's Vineyard was mainly during November/December, with occurrence of this species during January/February largely limited to deeper waters at the southern extent of Block Island and Rhode Island Sound, and over the Offshore Ocean SAMP area.

10. A large population of harlequin ducks (*Histrionicus histrionicus*) winters in Rhode Island coastal waters (January to March), which is the southern extent of their range. Harlequin ducks were generally not observed more than 50 m offshore (Caron and Paton 2007), where they dive underwater to forage on mollusks and crustaceans. It is possible for this species to be impacted regarding possible range constriction due to changing climate/warming temperatures.

Section 260. Emerging Issues

260.1. Native Species Explosions

1. Explosions of native, opportunistic species can be initiated by one or several conditions, such as changes in primary productivity, fishing pressure, habitat availability, competition, and/or predator-prey interactions. Changing climate can also be a main instigator of native species explosions by either tightening or loosening restrictions due to thermal tolerances, and allowing population levels to increase, perhaps dramatically. Although native species explosions are known to occur in the Ocean SAMP area, few are studied and/or well documented in the literature.

2. The ctenophore *Mnemiopsis leidyi* has been extensively studied in the region, where it is known to be a voracious, non-selective consumer of plankton. In Narragansett Bay, studies by Martin (1965, 1970) found that *Skeletonema* abundance declined coincident with an increase in the abundance of the ctenophore *Mnemioposis leidyi*, but he found the ctenophore in high abundance only during the later study. Increases of *M. leidyi* are being observed throughout the northeastern United States continental shelf area (Link and Ford 2006), with population increases correlated to warming waters as a primary causative factor (Kremer 1994; Costello et al. 2006). The occurrence of *M. leidyi* in the Ocean SAMP is not known, and further research needs to be conducted to determine presence and impact, if any, upon the ecology of the Ocean SAMP area.

260.2. Invasive species

1. The contemporary rate of invasive species introductions is mostly a result of human transportation systems working at global scales. Increased speed and movement of people and cargo due to the mechanization of travel has increased the opportunities for invasive organisms to be introduced at scales unimaginable naturally (CRMC et al. 2007). Ship ballast water is an obvious, though not the only, transport vector of marine invaders. Non-native species are readily transported via packing material used by the recreational bait and commercial shellfish industries, and via live-market fish for both aquarium use and as food items. Winds and currents also transport organisms, as do birds and other wildlife moving through the area.

2. Ascidians (sea squirts, tunicates) are a group of organisms that are seeing rapid human-mediated expansion of their ranges, and are becoming firmly established in many communities, often at the expense of displacing native species (Bullard et al. 2007). The colonial ascidians *Didemnum* spp. are particularly aggressive invasive tunicates, of unknown origin, that arrived in the New England region in the late 1980s and have become firmly situated in the aquatic community from Eastport, Maine to Shinnecock, New York (Bullard et al. 2007). These species have been found covering large areas of ocean bottom on Georges Bank, in portions of Fishers Island Sound, and in a few locations in Block Island and Rhode Island Sound (Bullard et al. 2007; Valentine et al. 2007). There are no known, consistent predators of these invasives, which grow rapidly on hard structure to depths of 80 m. These species have the potential to significantly alter benthic ecosystem ecology, and perhaps several fisheries as well if they become widespread in the Ocean SAMP area..

3. In response to invasive species threats, Rhode Island assembled a comprehensive plan that lays out management strategies intended to prevent the introduction and spread of invasive species (CRMC et al. 2007). The plan identifies a basic list of invasive and potentially invasive species (Table 2.13) as threats to Rhode Island waters; the occurrence or abundance of these species in the Ocean SAMP area is not well documented.

Table 2.13. Listing of invasive and potentially invasive marine species according to CRMC et al. (2007).

Species	Scientific Name	Type of Organism
European green crab	*Carcinus maenus*	crustacean
Codium	*Codium fragile* spp.	algae
Red algae	*Grateloupia turuturu*	algae
SSO	*Haplosporidian costalis*	shellfish pathogen
MSX	*Haplosporidian nelsoni*	shellfish pathogen
Asian shore crab	*Hemigrapsus sanguineus*	crustacean
Lace bryozoan	*Membranipora membranacea*	bryozoan
Derma	*Perkinsus marinus*	shellfish pathogen
Quahog Parasite Unknown QPX		shellfish pathogen
Caulerpa	*Caulerpa taxifolia*	algae
Pacific oyster	*Crassostrea gigas*	mollusk
Chinese mitten crab	*Eriocheir sinensis*	crustacean
Nori	*Porphyra yezoensis*	algae
Veined rapa whelk	*Rapana venosa*	mollusk

260.3. Marine Diseases

1. Marine diseases are not widely studied in the Ocean SAMP area. However, increasing water temperatures and changing water salinities due to changing climate are creating conditions that are often favorable to the spread of disease organisms (Kennedy et al. 2002).

2. Lobster shell disease was first described 80 years ago in lobster pounds, and was associated with the bacterium *Vibrio* (Hess 1937). Shell disease is now seen in wild populations, and the bacteria in the family Flavobacteriaceae are the dominant microbes found on the shell (Chistoserdov et al. 2005). The incidence of the disease in the wild is 20 to 30%, and the location of its emergence appears to be the area including eastern Long Island Sound, Block Island Sound, and Narragansett Bay (Castro and Angell 2000). Lobsters become infected with an epizootic shell disease caused by bacteria that invade the lobster's shell through its pores. Severity ranges from black spots that develop on the shell, to holes in the shell that cause the shell and membrane to fuse together, and which can result in death of the individual (Cobb and Castro 2006). The more frequently a lobster molts, the less likely it is to have the disease, therefore younger lobsters, which molt more frequently, are more likely to be disease free than are older lobsters. Lobster disease does not appear to be contagious, healthy lobsters held in close proximity to diseased lobsters do not appear to contract the disease, which suggests that the disease is environmentally mediated and/or depends upon genetic factors in the population (Duboise and Moulton 2005). A stressful environment may facilitate the disease by compromising the immune system, changing the pathogen characteristics or bacterial community on the shell, or causing complications with the natural

molting process. While the source of shell disease remains unknown, some studies point to alkylphenols, a byproduct of industrial sources such as detergents and surfactants. It is almost certain that one or more environmental stressors are driving the widespread appearance of shell disease.

3. A rickettsia-like bacterium has been found to infect the gill area of the sea scallop, *Placopecten magellanicus*, in Block Island Sound (Gulka and Chang 1985). Heavy infection inhibits the swimming response of the scallops, which may indirectly contribute to mortality by reducing mobility and predator avoidance (Gulka and Chang 1985). It is not clear how this disease spreads or the impacts to the populations of scallops in Block Island Sound.

4. Striped bass along the Atlantic coast, and particularly in the Chesapeake Bay ecosystem, have exhibited a high prevalence—up to 75%—of mycobacteriosis, a chronic wasting disease caused by *mycobacterium* (Rhodes et al. 2004; Kaattari et al. 2005). Resulting symptoms of mycobacterios includes tumors, external lesions, swelling of the eyes, emaciation, and stunted growth. It is estimated that as many as 60 percent of striped bass within the Chesapeake Bay ecosystem have this disease. Striped bass mortality rates due to mycobacteriosis are not well known, though it does appear to play a role in making striped bass more susceptible to other sources of mortality. Furthermore, it appears that other species are also experiencing infection, with Chesapeake Bay menhaden experiencing up to 57% infection rates (Kane et al. 2007). Striped bass are a migratory species and regular visitors to the Ocean SAMP area, and it is therefore likely that *mycobacterium* have been introduced to the area, though its occurrence or impact on striped bass and/or the ecology of the Ocean SAMP area is unknown.

Section 270. Policies and Standards

270.1 General Policies

1. The Council recognizes that the primary guiding policy for the Ocean SAMP is to protect and where possible restore and enhance natural resources and ensure that impacts from future activities are avoided and, if they are unavoidable, are minimized and mitigated so they are acceptable to the scientific community and the people of Rhode Island.

2. As the Ocean SAMP is an extension and refinement of CRMC's policies for Type 4 Multipurpose Waters as described in the RICRMP, CRMC will encourage a balance among the diverse activities, both traditional and future water dependent uses, while preserving and restoring the ecological systems.

3. The Council recognizes that while all fish habitat is important, spawning and nursery areas are especially critical in providing shelter for these species during the most vulnerable stages of their life cycles. The Council will ensure that impacts from these essential fish habitats are avoided and, if they are unavoidable, are minimized and mitigated, especially for habitats that are used by recognized Threatened and Endangered finfish per the Endangered Species Act (16 U.S.C. 1531 *et. seq.*) as well as finfish listed as "Species of Concern" by the NMFS Office of Protected Resources.

4. Because the Ocean SAMP is located at the convergence of two eco-regions and therefore more susceptible to change, the Council will employ the precautionary principle to managing this area, especially as it relates to the projected effects of global climate change on this rich ecosystem.

270.2 Regulatory Standards

1. The Council designates the Ocean SAMP sea duck foraging habitat (Chapter 8, Figure 39) in water depths less than or equal to 20 meters [65.6 feet] as Areas Designated for Preservation due to their ecological value and the significant role these foraging habitats play on for these avian species. Current research indicates that there may be a permanent loss of foraging habitat for these species thus the Council shall prohibit any Large-Scale Offshore Development, mining and extraction of minerals, or other development that has been found to be in conflict with the intent and purpose of an Area Designated for Preservation.

2. Due to there high habitat value, the Council shall designate glacial moraines as Areas of Particular Concern. Applicants for Offshore Development shall avoid Areas of Particular Concern within the Ocean SAMP area. Avoidance shall be the primary goal for these areas. Any Large-scale, Small-scale, or Other Offshore Development, as required, that

cannot avoid these Areas of Particular Concern shall be required to minimize to the greatest extent possible any impact, and as necessary, mitigate any significant impact to these resources. The applicant shall be required to demonstrate why these areas cannot be avoided or why no other alternatives are available.

3. The Council shall require, for large scale projects, modeling of circulation and stratification to ensure that water flow patterns and velocities are not altered in ways that would lead to major ecosystem change. The current patterns that exist within the Ocean SAMP ecosystem play an important role in shaping ecosystem functions at all biological and ecological scales, and in shaping physical oceanographic process such as water column stratification.

4. Biological resource assessments shall be conducted according to the procedures outlined in Section 860 of the Renewable Energy Chapter and detailed in the Site Assessment Plan and the Construction and Operation Plan sections.

5. The Council and Joint Agency Working Group shall establish monitoring protocols prior to, during and post-construction to evaluate the consequences of decisions and adapt management to the monitoring results. Specific biological monitoring requirements shall be determined on a project by project basis and may include but are not limited to the monitoring of:

   i. Coastal processes and physical oceanography
   ii. Underwater noise
   iii. Benthic ecology
   iv. Avian species
   v. Marine mammals
   vi. Sea turtles
   vii. Fish and fish habitat

The applicant shall provide the Council will a monitoring report scheduled by the Council.

Section 280. Literature Cited

Anderson, D.M., Kaefer, B.A., McGillicuddy, D.J., Jr., Mickelson, M.J., Keay, K.E., Libby, P.S., Manning, J.P., Mayo, C.A., Whittaker, D.K., Hickey, J.M., He, R., Lynch, D.R., and Smith, K.W. 2005. Initial observations of the 2005 *Alexandrium fundyense* bloom in southern New England: General patterns and mechanisms. *Deep-Sea Research II* 52:2856-2876.

Asher, T.G., Grilli, A., Grilli, S.T., and Spaulding, M.L. 2009. Analysis of extreme wave climates in Rhode Island waters. 10 August 2009. University of Rhode Island. Ocean SAMP document.

Ayers, J.C. 1950. The transparency (by white Secchi disk) of the waters in and about New York Harbor. Cornell University Status Report No. 7. (cited in Williams 1969; original not seen)

Battelle, Inc. 2002a. Fall 2001 Infauna Characterization Report, Rhode Island Region, Long-Term Dredge Material Disposal Site Evaluation Project, U.S. Army Corps of Engineers, New England District, Concord, MA. www.nae.usace.army.mil/projects.ri/riltds/ridredging.htm Accessed 25 January 2010.

Battelle, Inc. 2002b. Fall 2001 REMOTS® Characterization Report. Rhode Island Region, Long-Term Dredge Material Disposal Site Evaluation Project, U.S. Army Corps of Engineers, New England District, Concord, MA. www.nae.usace.army.mil/projects.ri/riltds/ridredging.htm Accessed 25 January 2010.

Battelle, Inc. 2003a. Benthic Infauna Data for Area E and Area W, July 2003. Long-Term Dredge Material Disposal Site Evaluation Project, U.S. Army Corps of Engineers, New England District, Concord, MA. www.nae.usace.army.mil/projects.ri/riltds/ridredging.htm Accessed 25 January 2010.

Battelle, Inc. 2003b. Sediment Profile Imaging of Area E and Area W, July 2003. Long-Term Dredge Material Disposal Site Evaluation Project, U.S. Army Corps of Engineers, New England District, Concord, MA. www.nae.usace.army.mil/projects.ri/riltds/ridredging.htm Accessed 25 January 2010.

Battelle, Inc. 2003c. Survey Report for the Rhode Island Region Side-Scan Sonar and Bathymetric Survey. Long-Term Dredge Material Disposal Site Evaluation Project, U.S. Army Corps of Engineers, New England District, Concord, MA. www.nae.usace.army.mil/projects.ri/riltds/ridredging.htm Accessed 25 January 2010.

Beardsley, R.C., and Boicourt, W.C. 1981. On estuarine and continental shelf circulation in the Middle Atlantic Bight. In: *Evolution of Physical Oceanography*, pp. 198–233. Warren, B.A., and Wunsch, C. (eds.) MIT Press, Cambridge, MA.

Beardsley, R.C., Chapman, D.C., Brinks, K.H., Ramp, S.R., and Shlitz, R. 1985. The Nantucket Shoals Flux Experiment (NSFE79), I, A basic description of the current and temperature variability. *Journal of Physical Oceanography* 15:713–748.

Beardsley, R.C., Boicourt, W.C., and Hansen, D.V. 1976. Physical oceanography of the Middle Atlantic Bight. In: Gross, M.G. (ed) *Proceedings of the symposium Middle Atlantic continental shelf and the New York Bight*. American Museum of Natural History, New York. pp. 3–5.

Beaugrand, G., Brander, K.M., Allistair Lindley, J., Souissi, S., and Reid, P.C. 2003. Plankton effect on cod recruitment in the North Sea. *Nature* 426:661-664.

Beaugrand, G., Reid, Philip C., Ibanez, F., Alistair Lindley, J., and Edwards, M. 2002. Reorganization of North Atlantic marine copepod biodiversity and climate. *Science* 296:1692-1694.

Boicourt, W., and Hacker, P. 1976. Circulation on the Atlantic continental shelf off the United States, Cape May to Cape Hatteras. *Memoirs of the Royal Society of Science in Liege*. Set 6(10):187-200.

Boothroyd, J.C. in prep. Coarse-Grained Sediment Transport in Sounds, Bays, Estuaries, and Lagoons. In: *Sound Connections: The Science of Rhode Island & Block Island Sounds. Proceedings of the 7th Annual Ronald C. Baird Sea Grant Science Symposium.* Rhode Island Sea Grant, Narragansett, RI. October 2008.

Boothroyd, J.C., and Sirkin, L. 2002. The Quaternary geology of Block Island and adjacent regions. In: *The Ecology of Block Island*, pp. 13–27. Paton, P., Gould, L., August, P., and Frost, A. (eds.) The Rhode Island Natural History Survey, Kingtson, RI.

Bowen, W.D., and Harrison, G.D. 1994. Offshore diet of grey seals *Halichoerus gyrpus* near Sable Island, Canada. *Marine Ecology Progress Series* 112:1–11.

Bowen, W.D., Lawson, J.W., and Beck, B. 1993. Seasonal and geographic variation in the species composition and size of prey consumed by grey seals (*Halichoerus grypus*) on the Scotian shelf. *Canadian Journal of Fisheries and Aquatic Science* 50:1768–1778.

Bricker, S.B., Longstaff, B., Dennison, W., Jones, A., Boicourt, K., Wicks, C., and Woerner, J. 2008. Effects of nutrient enrichment in the nation’s estuaries: A decade of change. *Harmful Algae* 8:21–32.

Brown, R.W. in prep. Rhode Island Fisheries and the Ocean SAMP: Are we ready for the tradeoffs? In: *Sound Connections: The Science of Rhode Island & Block Island Sounds. Proceedings of the 7th Annual Ronald C. Baird Sea Grant Science Symposium.* Rhode Island Sea Grant, Narragansett, RI. October 2008.

Brussaard, C.P.D. 2004. Viral control of phytoplankton populations—a review. *Journal of Eukaryotic Microbiology* 51:125-138.

Bullard, S., Lambert, G., Carman, M., Byrnes, J., Whitlatch, R., Ruiz, G., Miller, R., Harris, L., Valentine, P., and Collie, J. 2007. The colonial ascidian *Didemnum sp*. A: Current distribution, basic biology and potential threat to marine communities of the northeast and west coasts of North America. *Journal of Experimental Marine Biology and Ecology* 342:99-108.

Byron, C.J, and Link, J.S. in press. Stability in the feeding ecology of four demersal fish predators in the US Northeast Shelf Large Marine Ecosystem. *Marine Ecology Progress Series*.

Caron, C.M., and Paton, P.W.C. 2007. Population trends and habitat use of Harlequin Ducks in Rhode Island. *The Journal of Field Ornitholog*y 78(3): 254-262.

Castro, K.M., and Angell, T.E. 2000. Prevalence and progression of shell disease in American lobster, *Homarus americanus*, from Rhode Island waters and the offshore canyons. *Journal of Shellfish Research* 19:691-700.

Chistoserdov, A.Y., Smolowitz, R., Mirasol, F., and Hsu, A. 2005. Culture dependent characterization of the microbial community associated with epizootic shell disease lesions in American lobster, *Homarus americanus*. *Journal of Shellfish Research* 24:741–747.

Clancy, M., and Cobb, J.S. 1997. Effect of wind and tidal advection on distribution patterns of rock crab Cancer irroratus megalopae in Block Island Sound, RI. *Marine Ecology Progress Series* 152: 217-225.

Collie, J., Wood, A., and Jeffries, H. 2008. Long-term shifts in the species composition of a coastal fish community. *Canadian Journal of Fisheries and Aquatic Science* 65:1352-1365.

Cobb, J.S., and Castro, K.M. 2006. Shell disease in lobster: A synthesis. New England Lobster Research Initiative. University of Rhode Island.

Codiga, D.L. in prep. Circulation in Block Island Sound, Rhode Island Sound, and Adjacent Waters, with Emphasis on Subsurface Flows. In: *Sound Connections: The Science of Rhode Island & Block Island Sounds. Proceedings of the 7th Annual Ronald C. Baird Sea Grant Science Symposium.* Rhode Island Sea Grant, Narragansett, RI. October 2008.

Codiga, D.L., and Aurin, D.A. 2007. Residual circulation in eastern Long Island Sound: observed transverse-vertical structure and exchange transport. *Continental Shelf Research* 27:103–116.

Codiga, D.L., and Rear, L.V. 2004. Observed tidal currents outside Block Island Sound: Offshore decay and effects of estuarine outflow. Journal of Geophysical Research doi:10.1029/2003JC001804

Codiga, D.L., and Ullman, D.S. 2010—*draft of January 2010*—Characterizing the physical oceanography of coastal waters off Rhode Island: Literature review, available observation, and a representative model simulation. Final Report Part 1 for Rhode Island Ocean Special Area Management Plan.

Collie, J. in prep. Long-term data reveal climate forcing of the Rhode Island Sound fish community structure. In: *Sound Connections: The Science of Rhode Island & Block Island Sounds. Proceedings of the 7th Annual Ronald C. Baird Sea Grant Science Symposium.* Rhode Island Sea Grant, Narragansett, RI. October 2008

Collie, J., Wood, A., and Jeffries, H. 2008. Long-term shifts in the species composition of a coastal fish community. *Canadian Journal of Fisheries and Aquatic Science* 65:1352–1365.

Cook, G.S. 1966. Non-tidal circulation in Rhode Island Sound—drift bottle and sea bed drifter experiements (1962–1963). *TM No. 369*. Naval Underwater Weapons Research Engineering Station, Newport, RI.

Costello, J.H., Sullivan, B.K., Gifford, D.J., Van Keuren, D., and Sullivan, L.J. 2006. Seasonal refugia, shoreward thermal amplification, and metapopulation dynamics of the ctenophore *Mnemiopsis leidyi* in Narragansett Bay, RI. *Limnology and Oceanography* 51:1819-1831

Cowles, G.W., Lentz, S.J., Chen, C., Xu, Q., and Beardsley, R.C. 2008. Comparison of observed and model-computed low frequency circulation and hydrography on the New England shelf. Journal of Geophysical Research 113: C09015, doi:10.1029/2007JC004394.

CRMC, URI, RINHS. 2007. Rhode Island Aquatic Invasive Species Management Plan. Approved by the Aquatic Nuisance Species Task Force. November 7, 2007. www.anstaskforce.gov/State%20Plans/RI_SAMP_Approved.pdf. Accessed 25 January 2010.

DeAlteris, J.T., Skrobe, L.G., Castro, K .M. 2000. Effects of mobile bottom fishing gear on biodiversity and habitat in offshore New England waters. Northeastern Naturalist **7**(4): 379-394.

Deevey, G. B. 1952a. A survey of the zooplankton of Block Island Sound, 1943-1946. *Bulletin of the Bingham Oceanography Collection* 13: 66-119.

Deevey, G. B. 1952b. Quality and composition of the zooplankton of Block Island Sound, 1949. *Bulletin of the Bingham Oceanography Collection* 13: 120-164.

Drinkwater, K.F. 2005. The response of Atlantic cod (*Gadus morhua*) to future climate change. *ICES Journal of Marine Science* 62:1327-1337.

Driscoll, N. 1996. Scientists study large storm and human effects in Block Island Sound. *Oceanus* 22 March 1996. Woods Hole Oceanographic, Woods Hole, MA.

Duboise, S.M., and Moulton, K.D. 2005. Defining the etiology of epizootic shell disease: the importance of genetic investigations of the associated bacterial and viral ecology. In: *Lobster Shell Disease Workshop Forum Series 051*, pp. 26-35. Tlusty, M.F., Halvorson, H.O., Smolowitz, R., and Sharma, U. (eds.) New England Aquarium, Boston, MA.

Edwards, C.A., Fake, T.A., and Bogden, P.S. 2004. A numerical model investigation of spring-summer frontogenesis at the mouth Block Island Sound. *Journal of Geophysical Research* 109 C12021, doi: 12010.11029/12003JC002132.

Emanuel, K. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. *Nature* 436:686–688.

Enfield, D.B., Mestas-Nunez, A.M., and Trimble, P.J. 2001. The Atlantic Multidecadal Oscillation and its relationship to rainfall and river flows in the continental U.S. *Geophysical Research Letters* 28:2077–2080. doi:10.1029/2000GL012745.

Eriksson, B.K., Rubach, A., Hillebrand, H. 2006. Biotic Habitat Complexity Controls Species Diversity and Nutrient Effects on Net Biomass Production. *Ecology* 87(1):246-254.

Fahay, M.P. 1992. Development and distribution of cusk eel eggs and larvae in the Middle Atlantic Bight with a description of *Ophidion robinsi* n. sp. (Teleostei: Ophidiidae). *American Society of Ichthyologists and Herpetologists* 3:799–819.

First, M.W. 1972. Municipal waste disposal by shipborne incineration and sea disposal of residues. Harvard University School of Public Health, Boston MA.

Fogarty, M.J. 1979. Assessment of the ocean quahog, *Arctica islandica*, resource in Rhode Island Sound and south of Martha's Vineyard, MA. RIDEM, Division of Fisheries and Wildlife.

Ford, T.B., and Gieg, J.A. 1995. Winter Behavior of the Common Loon (Comportamiento Invernal de Gavia immer). *Journal of Field Ornithology* 66(1):22-29.

Frank, K.T., Perry, R.I., and Drinkwater, K.F. 1990. Predicted response of Northwest Atlantic invertebrates and fish stocks to CO2 induced climate change. *Transactions of the American Fisheries Society* 119:353–365.

Fuhrman, J.A. 1999. Marine viruses and their biogeochemical and ecological effects. *Nature* 339: 541-548.

Gay, P.S., O'Donnell, J., and Edwards, C.A. 2004. Exchange between Long Island Sound and adjacent waters. *Journal of Geophysical Research*. 109, C06017, doi: 10.1029/2004JC002319.

Griscom, C.A. 1978. Currents 0.25 meters above the bottom in 10 meters of water off Charlestown, RI during two severe winter storms—24 Jan–Feb 1978: An Environmental Study of a Nuclear Power Plant at Charlestown, Rhode Island, Part Two. Division of Marine Resources, Graduate School of Oceanography, University of Rhode Island.

Gulka, G., and Cheng, P. W.. 1985. Pathogenicity and infectivity of a rickettsia-like organisms in the sea scallop, *Placopecten magellanicus*. *Journal of Fish Diseases* 8:309–318.

Hale, S.S. 2002. Marine bottom vommunities of Block Island waters. In: *The Ecology of Block Island*, pp. 131-149. Paton, P., Gould, L., August, P., and Frost, A. (eds.) The Rhode Island Natural History Survey, Kingtson, RI.

Hargraves, P.E., Maranda, L. 2002. Potentially toxic or harmful microalgae from the northeast coast. *Northeastern Naturalist* 9(1):81-120.

Hays, G.C., Richardson, A.J., and Robinson, C. 2005. Climate change and marine plankton. *Trends in Ecology and Evolution* 20 (6):337-344

He, R., and Wilkin, J.L. 2006. Barotropic tides on the southeast New England shelf: A view from a hybrid data assimilative modeling approach. *Journal of Geophysical Research* 111, C08002, doi: 08010.01029/02005JC003254.

Hequette, A., and Hill, P.R. 1993. Storm-generated currents and offshore sediment transport on a sandy shoreface, Tibjak Beach, Canadian Beaufort Sea. *Marine Geology* 113:283–304.

Hess, E. 1937. A shell disease in lobsters (*Homarus americanus*) caused by chitinovorous bacteria. *Journal of the Fisheries Research Board of Canada* 3:358–362.

Hicks, S.D., and Campbell, R. 1952. Report on physical oceanographic cruises #3 and #4, Narragansett Bay and its approaches. *Narragansett Marine Laboratory Report 52-16*, University of Rhode Island, Narragansett, RI.

Ho, K. 1999. The chemistry and toxicity of sediment affected by oil from the North Cape spilled into Rhode Island Sound. *Marine Pollution Journal* Vol. 38, Issue 4:314.

Holland, G.J., and Webster, P.J. 2007. Heightened tropical cyclone activity in the North Atlantic: Natural variability or climate trend? *Philosophical Transactions of The Royal Society A* Vol. 365, No. 1860:2695-2716.

Hollman, . 1976. A histogram analysis of the annual variations of physical and chemical parameters: 1970–1973. *Environmental Atlas of Block Island and Long Island Sound Waters 1976*. New York Ocean Science Laboratory, Montauk, NY

Hulsizer, E.E. 1976. Zooplankton of Lower Narragansett Bay, 1972-1973. *Chesapeake Science* 17(4):260-270.

Hyde, K. in prep. Seasonal and interannual variability of phytoplankton production in Rhode Island and Block Island Sound. In: *Sound Connections: The Science of Rhode Island & Block Island Sounds. Proceedings of the 7th Annual Ronald C. Baird Sea Grant Science Symposium.* Rhode Island Sea Grant, Narragansett, RI. October 2008.

Hyde, K.J.W., O'Reilly, J.E., and Oviatt, C.A.. 2008. Evaluation and application of satellite primary production models in Massachusetts Bay. Continental Shelf Research 28:1340-1351.

IPCC. 2007. Climate Change 2007: Synthesis Report. *Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Core writing team Pachauri, R.K., and Reisinger, A. (eds.) IPCC, Geneva, Switzerland.

Kaattari, I.M., Rhodes, M.W., Kator, H., and Kaattari, S.L. 2005. Comparative analysis of mycobaterial infections in wild striped bass *Morone saxatilis* from Chesapeake Bay. *Diseases of Aquatic Organisms* 67: 125–132.

Kane, A.S., Stine, C.B., Hungerford, L., Matsche, M., Driscoll, C., and Baya, A.M. 2007. Mycobacteria as environmental portent in Chesapeake Bay fish species. *Emerging Infectious Diseases* 13(2): 329–331.

Kane, J. 2007. Zooplankton abundance trends on Georges Bank, 1977–2004. ICES Journal of Marine Science. 64:909–919.

Katz, C.H., Cobb, J.S., and Spaulding, M. 1994. Larval behavior, hydrodynamic transport, and potential offshore-to-inshore recruitment in the American lobster, *Homarus americanus*. *Marine Ecology Progress Series* 103:265–273.

Keller, A.A., Taylor, C., Oviatt, C.A., Dorrington, T., Holcombe, G., and Reed, L.W. 2001. Phytoplankton production patterns in Massachusetts Bay and the absence of the 1998 winter-spring bloom. Marine Biology 138:1051-1062.

Kenefik, A.M. 1985. Barotropic M_2 tides and tidal currents in Long Island Sound: A numerical model. *Journal of Coastal Research* 1(2):117–128.

Kennedy, V.S., Twillley, R., Kleypas, J.A., Cowan, J.H., Jr., and Hare, S.R. 2002. Coastal and marine ecosystems and global climate change: Potential effects on U.S. resources. Pew Center on Global Climate Change. Arlington, VA.

Kenney, R.D. and Vigness-Raposa, K.J. 2009. Marine mammals and sea turtles of Narragansett Bay, Block Island Sound, Rhode Island Sound, and nearby waters: An analysis of existing data for the Rhode Island Ocean Special Area Management Plan. *DRAFT TECHNICAL REPORT* Version 2 of 31 May 2009.

Kincaid, C., Pockalny, R.A., and Huzzey, L.M. 2003. Spatial and temporal variability in flow at the mouth of Narragansett Bay. *Journal of Geophysical Research* 108(C7), 3218, doi:10.1029/2002JC001395.

King, J., and Collie, J. 2010. Geological, geophysical, benthic habitat, archaeological study in the Rhode Island Ocean SAMP study area. Appendix A: Technical reports for the Rhode Island Ocean Special Area Management Plan. RI Coastal Resources Management Council, Wakefield, RI.

Koppelman, L.E., Weyl, P.K., Gross, M.G., and Davies, D.S. 1976. *The Urban Sea: Long Island Sound.* Special Student Design/Environmental Planning Service. Praeger, NY.

Kremer, P. 1994. Patterns of abundance for *Mnemiopsis* in U.S. coastal waters - a comparative overview. *ICES Journal of Marine Science* 51:347-354.

Lillick, L. 1937. Seasonal studies of phytoplankton off Woods Hole, Massachusetts. *Biological Bulletin* 73(3):488-503.

Link, J., and Ford, M.D. 2006. Widespread and persistent increase of *Ctenophora* in the continental shelf ecosystem off NE USA. *Marine Ecology Progress Series* 320:153-159

Loder, J.W.B., Petrie, G., and Gawarkeiwicz, G. 1998. The coastal ocean off northeastern North America: a large-scale view. *The Sea* 11 (Robinson, A.R., & Brink, K.H. eds.), Wiley and Sons, NY, pp. 105-133.

Malone, T.C., and Chervin, M.B. 1979. The production and fate of phytoplankton size fractions in the plume of the Hudson River, New York Bight. Limnology and Oceanography 24:683-696.

Mann, K.H. 2000. Ecology of Coastal Waters with Implications for Management. 2nd Ed. Blackwell Science.

Mann, K.H., and Lazier, J.R.N. 2006. Dynamics of Marine Ecosystems. 3rd Ed. Blackwell. Massachusetts, USA.

Mann, M.E., and Emanuel, K.A. 2006. Atlantic hurricane trends linked to climate change. *Eos, Transactions, American Geophysical Union* 87:233.

Mann, K.H., and Lazier, J.R.N. 1996. *Dynamics of Marine Ecosystems: Biological-Physical Interactions in the Oceans.* 2nd Edition. Blackwell Science, Inc., Cambridge MA. 394 pp.

Marston, M.F. 2008. Natural viral communities in the Narragansett Bay ecosystem. In: *Science for ecosystem-based management: Narragansett Bay in the 21st century*. Desbonnet, A. and Costa-Pierce, B.A. Springer**:** 419-430.

Martin, J.H. 1970. Phytoplankton–zooplankton relationships in Narragansett Bay. IV. The seasonal importance of grazing. *Limnology and Oceanography* 15:413–418.

Martin, J. 1965. Phytoplankton-zooplankton relationships in Narragansett Bay. *Limnology and Oceanography* 10(2):185-191.

Mau, J.-C., Wang, D.-P., Ullman, D.S., and Codiga, D.L. 2007. Comparison of observed (HF radar, ADCP) and model barotropic tidal currents in the New York Bight and Block Island Sound. *Estuarine and Coastal Shelf Science* 72:129–137.

McMullen, K.Y., Poppe, L.J., Twomey, E.R., Danforth, W.W., Haupt, T.A., and Crocker, J.M. 2007. Sidescan sonar imagery, multibeam bathymetry, and surficial geologic interpretations of the sea floor in Rhode Island Sound, off Sakonnet Point, Rhode Island. U.S. Geological Survey Open File Report 2007-1150. http://pubs.usgs.gov/of/2007/1150/

McMullen, K.Y., Poppe, L.J., Denny, J.F., Haupt, T.A., and Crocker, J.M. 2008. Sidescan sonar imagery and surficial geologic interpretations of the sea floor in Central Rhode Island Sound. U.S. Geological Survey Open-File Report 2007-1366. http://pubs.usgs.gov/of/2007/1366/.

Merriman, D., and Sclar, R.C. 1952. The pelagic fish eggs and larvae of Block Island Sound. *Bulletin of the Bingham Oceanography Collection* 13: 165-219.

Mouw, C.B., and Yoder, J.A. 2005. Primary production calculations in the Mid-Atlantic Bight, including effects of phytoplankton community size structure. Limnology and Oceanography 50:1232-1243.

Munk, P., Larsson, P.O., Danielson, D., and Mokness, E. 1995. Larval and small juvenile cod *Gadus morhua* concentrated in the highly productive areas of a shelf break front. *Marine Ecology Progress Series* 125: 21–30.

Nye, J.A., Link, J.S., Hare, A.J., and Overholtz, W.J. 2009. Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. *Marine Ecology Progress Series* 393:111–129.

O'Donnell, J., and Houk, A.E. in prep. The Structure and Variability of the Hydrography of the Block Island Sound. In: *Sound Connections: The Science of Rhode Island & Block Island Sounds. Proceedings of the 7th Annual Ronald C. Baird Sea Grant Science Symposium.* Rhode Island Sea Grant, Narragansett, RI. October 2008.

Olesiuk, P.F., Bigg, M.A., Ellis, G.M., Crockford, S.J., and Wigen, R.J. 1990. An assessment of the feeding habits of harbor seals (Phoca vitulina) in the Strait of Georgia, British Columbia, based on scat analysis. Canadian Technical Report on Fisheries and Aquatic Sciences 1730.

O'Reilly, J.E., Evans-Zetlin, C., and Busch, D.A. 1987. Primary Production, p. 220-233. *In* R. H. Backus [ed.], Georges Bank. MIT Press.

Oviatt, C., and Pastore, R. 1980. Some aspects of water quality in and pollution sources to the Providence River. Report for Region I EPA. Contract #68-04-1002. Boston, MA.

Oviatt, C.A., Hyde, K.J.W., Keller, A.A., and Turner, J.T. 2007. Production patterns in Massachusetts Bay with outfall relocation. Estuaries and Coasts 30: 35-46.

Oviatt, C.A., Keller, A.A., and Reed, L.W. 2002. Annual primary production in Narragansett Bay with no bay-wide winter-spring phytoplankton. Estuarine and Coastal Shelf Science 54**:** 1013-1026.

Paerl, H.W., Dennis, R.L., Whitall, D.R. 2002. Atmospheric deposition of nitrogen: implicatons for nutrient over-enrichment of coastal waters. *Estuaries* 25(4b):677-693.

Paton, P., McWilliams, S., Winiarski, K., Harris, B., and Trocki, C. 2010. Assessing bird use of Rhode Island's offshore waters. Presentation of 04 March 2010 to the RI Audubon Society.

Payne, P.M., and Selzer, L.A. 1989. The distribution, abundance and selected prey of the harbor seal, *Phoca vitulina concolor*, in Southern New England. *Marine Mammal Science* 5(2):173–192.

Perry, A.L., Low, P.J., Ellis, J.R., and Reynolds, J.D. 2005. Climate change and distribution shifts in marine fishes. *Science* 308:1912–1915.

Pfeiffer-Herbert, A. in prep. Summary of Larval Transport in Block Island and Rhode Island Sounds. In: *Sound Connections: The Science of Rhode Island & Block Island Sounds. Proceedings of the 7th Annual Ronald C. Baird Sea Grant Science Symposium.* Rhode Island Sea Grant, Narragansett, RI. October 2008.

Pilson, M.E.Q. 2008. Narragansett Bay amidst a globally changing climate. In: *Science for Ecosystem-based Management: Narragansett Bay in the 21st Century*. Desbonnet, A., and Costa-Pierce, B.A. (eds.) Springer. pp. 35–46.

Poppe, L., DiGiacomo-Cohen, M., Smith, S., Stewart, H., and Forfinski, N. 2006. Seafloor character and sedimentary processes in Eastern Long Island Sound and Western Block Island Sound. *Geo-Marine Letters* 26:59-68.

Pratt, S.D. 1973. Benthic fauna. Pages 5-1–5-70 In: *Coastal and Offshore Environmental Inventory: Cape Hatteras to Nantucket Shoal*, pp. 5-1 – 5-70. Saila, S.B. (ed.) Marine Publication Series No. 2., University of Rhode Island, Kingston, RI.

Ramp, S.R., Brown, W.S., and Beardsley, R.C. 1988. The Nantucket Shoals Flux Experiment 3. The alongshelf transport of volume, heat, salt and nitrogen. *Journal of Geophysical Research* 93:14,039–14, 054.

Reinert, S.E., Lapham, E., and Gaffett, K. 2002. Landbird migration on Block Island: community composition and conservation implications for an island stopover habitat. In: Paton, P.W., Gould, L.L., August, P.V., and Frost, A.O. (eds), *The Ecology of Block Island. Proceedings of the Rhode Island Natural History Survey Conference, October 28, 2000*. The Rhode Island Natural History Survey, Kingston, RI. pp. 151–168.

Rhoads, D., McCall, P., and Yingst, J. 1978. Disturbance and production on the estuarine seafloor. *American Scientist* 66:577-586.

Rhoads, D.C., and Germano, J.D. 1986. Interpreting long-term changes in benthic community structure: a new protocol. *Hydrobiologia* 142:291-308.

Rhodes, M.W., Kator, H., Kaattari, I., Gauthier, D., Vogelbein, W., and Ottinger, C.A. 2004. Isolation and characterization of mycobacteria from striped bass *Morone saxatisis* from the Chesapeake Bay. *Diseases of Aquatic Organisms*. 61: 41–51.

Richards, S.W., Mann, J.M., and Walker, J.A. 1979. Comparison of spawning seasons, age, growth rates, and food of two sympatric species of searobins, *Prionotus carolinus* and *Prionotus evolans*, from Long Island Sound. *Estuaries* 2(4):255–268.

Richardson, A.J., and Schoeman, D.S. 2004. Climate impact on plankton ecosystems in the northeast Atlantic. *Science* 305:1609-1612.

Richardson, D.E., Hare, J.A., Overholtz, W.J. and Johnson, D.L. in press. Development of long-term larval indices for Atlantic herring (Clupea harengus) on the northeast U.S. Continental Shelf. ICES Journal of Marine Science.

Ridoux, V., Spitz, J., Vincent, C., and Walton, M.J. 2007. Grey seal diet at the southern limit of its European distribution: combining dietary analyses and fatty acid profiles. *Journal of the Marine Biological Association United Kingdom* 87:225–264.

Riley, G. 1952. Phytoplankton of Block Island Sound, 1949. *Bulletin of the Bingham Oceanography Collection* 13:40-64.

Riley, G.A., and Conover, S.M. 1967. Phytoplankton of Long Island. Sound 1954-1955. *Bulletin of the Bingham Oceanographic Collection*. 19:5-34.

Roff, J.C., and Evans, M.J.S. 2002. Frameworks for marine conservation—non-hierarchical approaches and distinctive habitats. *Aquatic Conservation: Marine and Freshwater Ecosystems* 12:635-648

Rose, G.A. 2005. On distributional response of North Atlantic fish to climate change. *ICES Journal of Marine Science* 62:1360–1374.

Saila, S.B., Pratt, S.D., and Polgar, T.T. 1972. Dredge Spoil Disposal in Rhode Island Sound. Marine Experiment Station. Sea Grant. National Sea Grant. Marine Technical Report No 2.

Sanders, H.L. 1952. The herring (*Clupea harengus*) of Block Island Sound. *Bulletin of the Bingham Oceanographic Collection* 13:220–237.

Savard, W.L. 1966. *The sediments of Block Island Sound*. Master of Science Thesis, University of Rhode Island.

Schroeder, C.L. 2000. Population status and distribution of the harbor seal in Rhode Island waters. Master of Science Thesis, University of Rhode Island Graduate School of Oceanography.

Shcherbina, A.Y., and Gawarkiewicz, G.G. 2008. A coastal current in winter: Autonomous underwater vehicle observations of the coastal current east of Cape Cod. *Journal of Geophysical Research* 113, C07030, doi:10.1029/2007JC004306.

Shonting, D.H. 1969. Rhode Island Sound square kilometer study 1967: flow patterns and kinetic energy distribution. *Journal of Geophysical Research* 74:3386–3395.

Shonting, D.H., and Cook, G.S. 1970. On the seasonal distribution of temperature and salinity in Rhode Island Sound. *Limnology and Oceanography* 15:100–112.

Shonting, D.H., Cook, G.S., and Morey, C.F. 1963. Oceanographic data report, Tongue of the ocean. NUOS Cruise 3, March 1962. NUOS Consec 349. U.S. Naval Underwater Ordnance Station, Newport, RI.

Sidor, I. F., Pokras, M. A., Major, A. R., Poppenga, R. H., Taylor, K. M., Miconi, R. M. (2003). "Mortality of common loons in New England, 1987 to 2000." J. Wildl. Dis. 39(2): 306-315.

Signell, R.P. 1987. Tide and wind-forced currents in Buzzards Bay, Massachusetts. M.S. Thesis. Massachusetts Institute of Technology.

Smayda, T.J. 2008. Complexity in the eutrophication-harmful algal bloom relationship, with comment on the importance of grazing. *Harmful Algae* 8:140-151.

Smayda, T.J. 1973. A survey of phytoplankton dynamics in coastal waters from Cape Hatteras to Nantucket. In: *Coastal and Offshore Environmental Inventory: Cape Hatteras to Nantucket Shoals*. Occasional Publication No. 5. Graduate School of Oceanography, University of Rhode Island, Narragansett, RI.

Smayda, T.J. 1957. Phytoplankton studies in Lower Narragansett Bay. *Limnology and Oceanography* 2(4): 342-359.

Smith, F.E. 1950. *The benthos of Block Island Sound. I. The invertebrates, their quantities and their relations to the fishes*. Ph.D. Thesis. Yale University, New Haven, CT.

Spaulding, M. 2007. http://www.crmc.ri.gov/samp_ocean/Wind_Energy_RI_EBC.pdf; accessed 11 February 2010.

Staker, R.D., and Bruno, S.F. 1977. Phytoplankton in coastal waters off Eastern Long Island (Block Island Sound) Montauk, N.Y. New York Ocean Science Laboratory.

Staroscik, A.M., and Smith, D.C. 2004. Seasonal patterns in bacterioplankton abundance and production in Narragansett Bay, Rhode Island, USA. *Aquatic Microbial Ecology* 35: 275-282.

Steimle, F.W., Jr. 1982. The benthic invertebrates of Block Island Sound. *Estuarine, Coastal and Shelf Science* 15:1–16.

Steimle, F.W., Jr. 1990. Benthic macrofauna and habitat monitoring on the Continental Shelf of the Northeastern United States. I. Biomass. *NOAA Technical Report NMFS 86*. U.S. Department of Commerce, Washington, DC.

Stone, B.D., and Borns, H.W., Jr. 1986. Pleistocene glacial and interglacial stratigraphy of New England, Long Island, and adjacent Georges Bank and Gulf of Maine. In: *Quaternary Glaciations in the Northern Hemisphere*, pp. 39–52. Sibrava, V., Bowen, D.Q., and Richmond, G.M. (eds.) Pergamon Press, Oxford, UK.

Sullivan, B.K., Gifford, D.J., Costello, J.H., and Graff, J.R. 2008. Narragansett Bay ctenophore-zooplankton-phytoplankton dynamics in a changing climate. In: *Science for ecosystem-based management Narragansett Bay in the 21st century*. pp. 485–498. Desbonnet, A., and Costa-Pierce, B.A. (eds.) Springer, NY.

Suttle, C.A. 2005. Viruses at sea. *Nature* 437: 356-361.

Taylor, M.H., Holzwarth-Davis, T., Bascunan, C. and Manning, J.F. 2009. Description of the 2008 oceanographic conditions on the Northeast U.S. Continental Shelf. U.S. Department of Commerce, Northeast Fisheries Science Center, Reference Document 09-12.

Theroux, R.B., and Wigley, R.L. 1998. Quantitative composition and distribution of the macrobenthic invertebrate fauna of the Continental Shelf ecosystems of the Northeastern United States. *NOAA Technical Report NMFS 140*. U.S. Department of Commerce, Seattle, WA.

Uchupi, E., Driscoll, N., Ballard, R.D., and Bolmer, S.T. 2001. Drainage of late Wisconsin lakes and the morphology of later Quaternary stratigraphy of the New Jersey-southern New England continental shelf and slope. *Marine Geology* 172:117–145.

Ullman, D.S., and Codiga, D.L. 2004. Seasonal variation of a coastal jet in the Long Island Sound outflow region based on HF radar and Doppler current observations. *Journal of Geophysical Research* 109, C07S06, doi: 10.1029/2002JC001660.

Ullman, D.S., and Cornillon, P.C. 2001. Continental shelf surface thermal fronts in winter off the northeast U.S. coast. *Continental Shelf Research* 21:1139–1156.

Ullman, D. in prep. Surface Current Patterns in Block Island Sound and Adjacent Waters. In: *Sound Connections: The Science of Rhode Island & Block Island Sounds. Proceedings of the 7th Annual Ronald C. Baird Sea Grant Science Symposium.* Rhode Island Sea Grant, Narragansett, RI. October 2008.

U.S. Army Corps of Engineers. 2002. Final Report. Fall 2001 Water Column Characterization Report. Rhode Island Region Long-Term Dredged Material Disposal Site Evaluation Project. U.S. Army Corps of Engineers New England District, Concord, MA.

Valentine, P., Collie, J., Reid, R., Asch, R., Guida, V., and Blackwood, D. 2007. The occurrence of the colonial ascidian *Didemnum sp.* on Georges Bank gravel habitat—Ecological observations and potential effects on groundfish and scallop fisheries. *Journal of Experimental Marine Biology and Ecology* 342:179-181.

Webster, P.J., Holland, G.J., Curry, J.A., and Chang, H.-R. 2005. Changes in tropical cyclone number, duration and intensity in a warming environment. *Science* 309:1844–1846.

Weinbaur, M.G., Rassoulzadegan, F. 2004. Are viruses driving microbial diversification and diversity? *Environmental Microbiology* 6: 1-11.

Winiarski,K., Harris, B., Trocki, C., Paton, P., and McWill, S. 2009. Assessing Rhode Island Sound's Nearshore and Offshore Avian Resource Prior to Potential Alternative Energy Development. http://www.seagrant.gso.uri.edu/oceansamp/pdf/presentation/present_paton_birds.pdf

Williams, A.S. 1969. Prey selection by harbor seals in relation to fish taken by the Gulf of Maine sink gillnet fishery. *Master of Science Thesis*. University of Maine.

Williams, R.G. 1967. The physical oceanography of Block Island Sound. A review report. *Technical Memorandum No. 2213–3367*. U.S. Navy Underwater Sound Laboratory, New London, CT.

Wilson, S.J.K, Fredette, T.J., Germano, J.D., Blake, J.A., Neubert, P.L.A., and Carey, D.A. 2009. Plan-view photos, benthic grabs, and sediment-profile images: Using complementary techniques to assess response to seafloor disturbance. *Marine Pollution Bulletin* 59:26-37.

Wommack, K.E., and Colwell, R.R. 2000. Virioplankton: viruses in aquatic ecosystems. *Microbiology and Molecular Biology Reviews* 64: 69-114.

Wood, S.A. 2000. Summary of harbor seal (*Phoca vitulina concolor*) food habits in Mid-coast Maine: Summer 2000. *Report to the Marine Environmental Research Institute* 1–11.

Worm, B., Sandow, M., Oschlies, A., Lotze, H.K., and Myers, R.A. 2005. Global patterns of predator diversity in the open oceans. *Science* 309:1365–1369.

Yin, J.H. 2005. A consistent poleward shift of the storm tracks in simulations of 21st century climate. *Geophysical Research Letters* 32: L18701, DOI:10.1029/2005GL023684.

Zajac, R.N. in prep. The ecology and dynamics of benthic communities in Block Island Sound and Rhode Island Sound: A short review and prospectus. In: *Sound Connections: The Science of Rhode Island & Block Island Sounds. Proceedings of the 7th Annual Ronald C. Baird Sea Grant Science Symposium.* Rhode Island Sea Grant, Narragansett, RI. October 2008.