How is Our Bay?

Five Years of Environmental Monitoring of Cape Cod Bay

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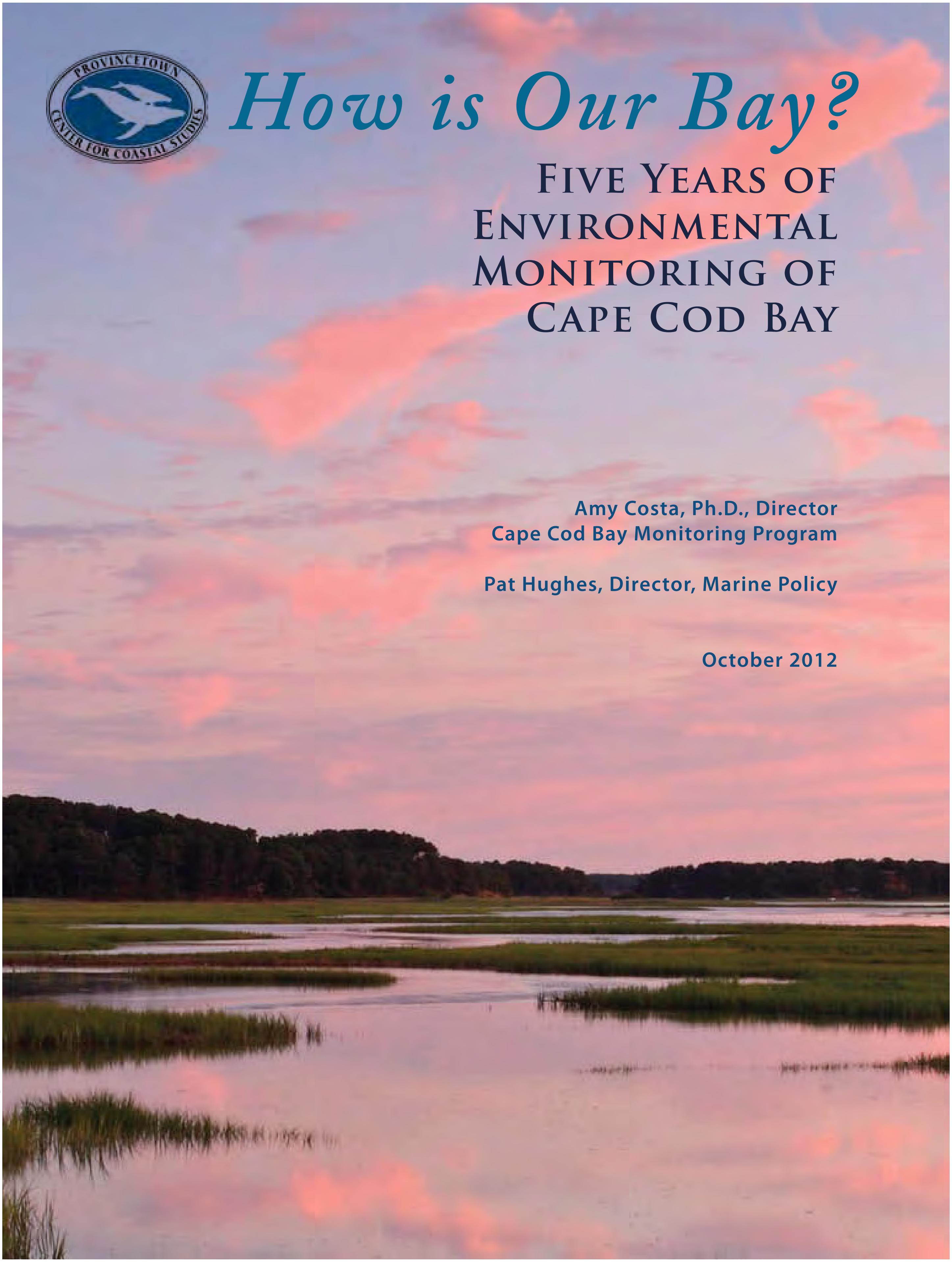

Photo: Jesse Stuart Mechling

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Cape Cod Bay defines the character of the towns around it. It is the foundation for the sense of place and quality of life experienced by residents and visitors alike, yet it is fragile and easily threatened by human activity.

The Cape Cod Bay Monitoring Program (CCBMP) at the Provincetown Center for Coastal Studies (PCCS), initiated in 2006, focuses on the health of Cape Cod Bay. It tracks changes in water quality and related indicators of ecosystem health. The findings of the CCBMP provide consistent, scientifically-sound, credible information that can be used as a tool for wise management decisions by communities and individuals that wish to move forward with the health and dynamics of the ecosystem in mind.

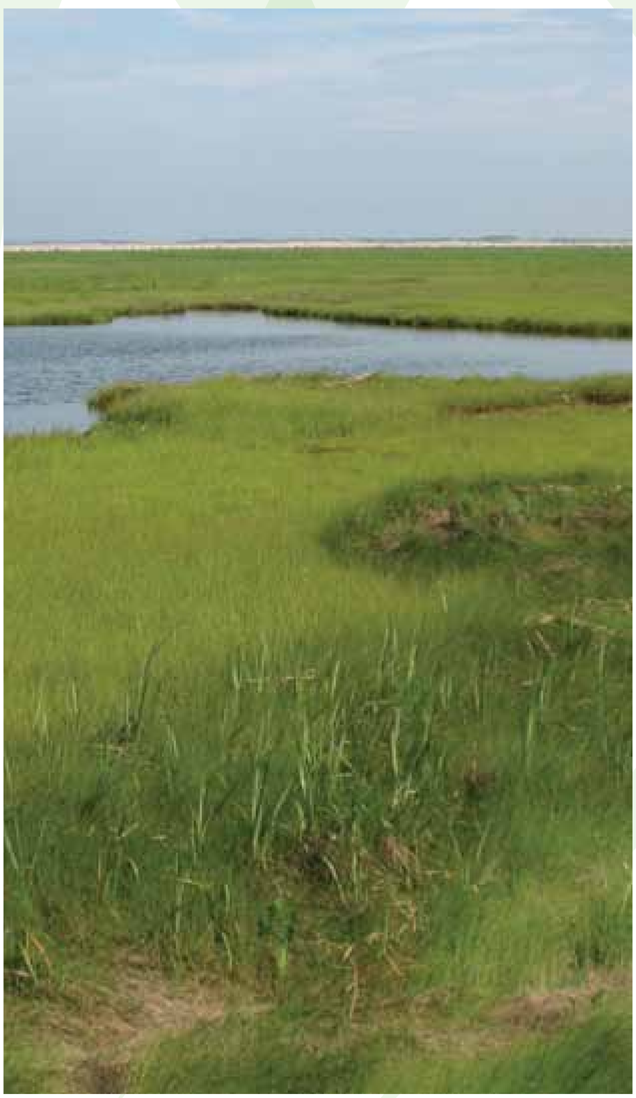

Photo: Elizabeth Bradfield

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Bay Culture & Economy: An Overview

The region's first inhabitants, the Pokonaks, were known as the "people of the bay." The ponds, streams, estuaries and open waters supplied them with food, items to trade and means of transportation. As the non-Native American population increased, the towns around Cape Cod Bay became renowned for shipbuilding, whaling and cod fishing.

Then as now, the region's economy is inextricably linked to the environmental health and productivity of Cape Cod Bay. Today, tourism and fishing, both recreational and commercial, contribute a minimum of $1.5 billion a year to the region's economy. These industries are dependent on good water quality and the protection of coastal and marine habitats. Poor water quality, for example, can reduce oxygen levels and water clarity; this can result in loss of important habitat and reduced food production for fish and shellfish. In surveys of tourists in coastal areas, 65% identified clean water and clean beaches as the most important factors for an enjoyable vacation (Preissler, 2009).

Basics of Bay Ecology & Ecosystem Dynamics

The profusion of life in coastal and ocean waters is controlled by a complex relationship among temperature, salinity, oxygen and nutrients (mainly measured by nitrogen and phosphorous). Changes in one or more of these components can impact the timing and rate of biological productivity of the system in general, as well as the productivity of specific individual plant and animal species. There are natural, seasonal changes in the coastal ecosystem in response to changes in water temperature and availability of nitrogen and phosphorous. For example the increasing hours of daylight in the spring stimulates more biological activity than occurs in the darker winter months. There are also changes from one year to the next which are influenced by many factors, including changes in the amount of precipitation and air temperature.

Threats to the Bay's quality and habitats come primarily from human activities in the Bay's watershed. There are hundreds of thousands more residents in the Bay's watershed and much more developed land than even 40 years ago. How we live in the watershed directly affects Cape Cod Bay, as the groundwater and waters from the region's rivers and streams carry wastewater, stormwater and other pollutants to the Bay.

The interconnection between the watershed and Cape Cod Bay calls attention to the importance of monitoring environmental conditions throughout the Bay and integrating these data into comprehensive watershed action plans. Continuing to monitor the health of Cape Cod Bay will provide invaluable data that can be used to guide management decisions and to strengthen environmental policies of local, regional and state governments.

Photo: Cape Cod Commission (www.capecodcommission.org); used with permission

Wellfleet Harbor is used by commercial and recreational boaters

What We Have Learned

This report discusses the findings of water quality monitoring from 2006-2010 at over 50 stations throughout the Bay from Duxbury to Provincetown (Figure 1). The report also discusses elements of the CCBMP added in 2007: monitoring eelgrass habitat quality and the presence of marine invasive species.

Key findings from the CCBMP for the years 2006-2010 are:

- Improvement in conditions at 55% of the stations monitored
- No change at 6% of the stations
- An overall decline in environmental conditions at 40% of the stations monitored, primarily in the inshore and nearshore regions of the Bay
- A pattern of deteriorating conditions each year in the summer months in the inshore and nearshore stations
- Variations in the health and growth of eelgrass throughout the Bay
- An increase in the number and extent of invasive species in the Bay
- Detectable levels of specific pharmaceutical compounds at four of five sites sampled in 2010

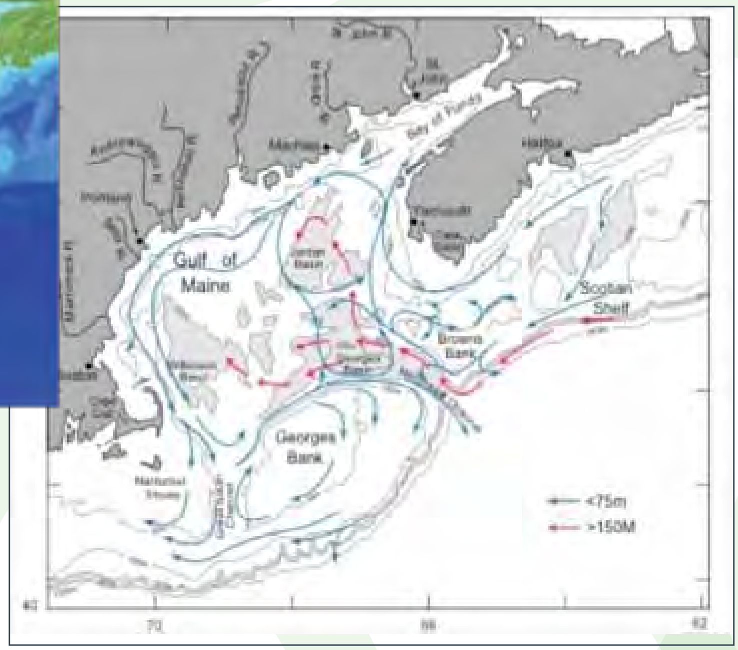
In the following pages, we will describe the details of our findings. Brief descriptions of selected efforts by towns and others to understand and improve coastal water quality in three smaller watersheds within the larger Cape Cod Bay watershed will be presented as well. The report concludes with an overview of selected federal, state, regional and local programs and activities to be used as a resource for obtaining additional information about the Bay and the management of its watershed and natural resources.

We hope this report will be used by local governments, regional planning agencies and citizens as a tool to initiate and support actions to restore and protect the Bay's watershed and its resources.

Collecting and monitoring water samples at the Jones River site

How is Our Bay?

Two views of the Gulf of Maine's topography and circulation patterns. Cape Cod Bay is a vital part of this larger North Atlantic ecosystem



Graphic: Miller, et al. 1998

Cape Cod Bay: A Global Treasure

Cape Cod Bay is part of the much larger Gulf of Maine system that contains some of the world's most productive waters. Surface water within the Bay moves in a counter-clockwise pattern driven by the prevailing circulation of the Gulf of Maine, drawing nutrient-rich ocean water into Cape Cod Bay. While strong tides move water around in the Bay, it can take about a month for a full exchange of water to occur. The Bay is an ecologically rich complex of coastal and marine habitats. Beaches, wetlands and offshore waters are home to plant and animal communities that include commercially valuable species of finfish and shellfish, marine mammals, sea turtles and birds.

Cape Cod Bay was designated as a state ocean sanctuary in 1970 to "prohibit activities that may significantly alter or endanger the ecology or appearance of the ocean, seabed or subsoil." This designation recognized the vitality and importance of the Bay's resources to the state. In 1994 the federal government designated most of Cape Cod Bay as critical habitat for the North Atlantic right whale, one of the most endangered whales in the world; Massachusetts followed in 1997. The Bay is also an important area for the humpback whale, which is designated as endangered both federally and by the state. Cape Cod Bay is described as a global hotspot for endangered sea turtle strandings and large stretches of its shoreline are internationally recognized as important feeding and resting areas for migrating shorebirds.

The 2010 Massachusetts Ocean Management Plan designates ten habitats as special, sensitive or unique areas (SSUs)[2] that require a higher degree of regulatory protection. Cape Cod Bay supports eight of these special, sensitive and unique habitats. All of Cape Cod Bay and a number of its harbors have been designated by the U.S. Environmental Protection Agency as No-Discharge Zones, prohibiting the discharge of sewage from boats.

CAPE COD BAY

- Encompasses approximately 600 square miles of surface water
- Has 57% of the total Massachusetts general shoreline
- Is over 200 feet at its deepest as it opens into Massachusetts Bay
- Has a mean tidal range of 9 feet to 10 feet
- Fills a depression formed by a retreating glacial ice lobe during the close of the last "Ice Age" some 15,000 years ago
- Is at the southern edge of the Gulf of Maine ecosystem, which stretches up into the Bay of Fundy

Evidence of the Bay's intrinsic value can be found in the wide range of people and animals that rely on its rich resources:

Fishery Resources

Cape Cod Bay has been federally designated as essential fish habitat (EFH)[3] for more than 36 species of fish and shellfish, including cod, striped bass, mackerel, sea scallops, winter flounder and yellowtail flounder. The Bay supports important anadromous fish runs of alewives and blueback herring, including the Jones River in Kingston, Stony Brook in Brewster and the Herring River in Wellfleet.

Commercial fisheries in Cape Cod Bay are diverse, targeting many species including cod, haddock, whiting, flounders, tuna, striped bass and black sea bass as well as invertebrates such as lobsters, surf clams, sea scallops and other shellfish. A number of harbors around the Bay support fishing fleets, including Plymouth, Sandwich, Barnstable, Rock Harbor (Orleans/Eastham), Wellfleet, Pamet and Provincetown.

Cape Cod Bay's recreational fisheries pursue a wide range of species and operate from charter, party and private vessels as well as the shore itself. Striped bass are a favored target, as are bluefish, flounders, black sea bass, tautaug and tuna.

Cape Cod Bay is also known for its shellfish aquaculture. Oysters and quahaugs are grown in Duxbury Bay, Barnstable Harbor, on the tidal flats of Dennis and Brewster, and in Wellfleet Bay, waters off of Truro and Provincetown Harbor.

Marine Mammals and Turtles

Most of Cape Cod Bay, as noted above, is a federally- and state-protected habitat for the critically endangered North Atlantic right whale and is a significant feeding area for the humpback whale, which is endangered on both the federal and state levels. Other whales that regularly use Cape Cod Bay are the federally endangered fin whale and minke, sei and pilot whales. In addition to these larger marine mammals, the Bay is frequented by white-sided and common dolphins, harbor porpoise and gray and harbor seals. Harp and hooded seals are sighted in the Bay during the winter months.

The state-listed threatened diamondback terrapin, the only brackish water species of turtle in Massachusetts, inhabits the shallow estuarine systems of Barnstable and Wellfleet Harbors and nests in the adjacent sandy areas.

Of the six species of sea turtles in U.S. waters, four visit Cape Cod Bay and all are endangered. Sea turtle standings occur in Cape Cod Bay most often in late October and November. Most stranded sea turtles are juveniles of more tropical species, including the federally endangered Kemp's ridley, green and loggerhead turtles. The federally endangered leatherback turtle is a regular summer and fall visitor in the Bay. Unlike the tropical species, leatherbacks utilize Cape waters to forage on jellyfish.

Birds

Cape Cod Bay is a rich feeding area for birds throughout the year. Spring through fall, the shoreline of Cape Cod provides nesting and resting sites for a majority of the North Atlantic population of the federally endangered roseate tern. Roseate, common, arctic and least terns fish the waters of the Bay during nesting and/or migration.

Duxbury-Plymouth Bay and First Encounter Beach in Eastham (among others) are internationally recognized as important bird areas (IBAs) for migrating shorebirds that feed on small mollusks, marine worms and other invertebrates. These include the piping plover, other plover species, oystercatchers, sanderlings and red knots. In the fall and winter, the Bay supports pelagic seabirds—birds that spend most of their lives on and over the oceans—such as shearwaters, razorbills, dovekies, storm petrels and gannets.

Photo: Jesse Stuart Mechling

Northern right whale breaching in Cape Cod Bay

How is Our Bay?

The Bay's Watershed

The Bay's watershed is almost as large as the Bay itself—546 square miles compared with 600 square miles of the Bay's surface area. The two largest sole-source aquifers in the state—Plymouth-Carver (199 square miles) and Cape Cod (440 square miles)—lie within the Cape Cod Bay watershed, supplying drinking water every day to hundreds of thousands of people.

Much of the soil in the Bay's watershed is composed of a porous mixture of sands, gravel and clays. Porous soils allow pollutants to easily enter groundwater, making the groundwater highly susceptible to contamination from a number of sources, including but not limited to road runoff, septic systems, leaking storage tanks and fertilizers and pesticides. In addition to entering the groundwater, these pollutants ultimately end up in Cape Cod Bay.

Jones River Watershed

Photo: PCCS/LightHawk

The Bay's Economy

The environment *is* the economy for coastal communities around Cape Cod Bay. Coastal tourism and recreation, recreational and commercial fishing and boating, whale- and wildlife-watching and other forms of ecotourism all depend on a clean and productive Bay. According to the U.S. Travel Association, in 2009 domestic tourists spent approximately $1.5 billion in Barnstable and Plymouth counties alone and generated approximately $65 million in local tax receipts.

Cape Cod Bay supports a sizable commercial fishing industry. Reported commercial fishery landings from harbors around the Bay were estimated at close to $8.5 million for 2007, and the Massachusetts Division of Marine Fisheries estimated the value of shellfish aquaculture in the area at $7 million. Recreational fishing is big business around the Bay, too, where thousands of people enjoy catching flounder, cod, tuna, bluefish and striped bass. Analyses conducted by the federal government estimated that over $770 million was spent on recreational fishing in 2006 (Industrial Economics, Inc. et.al, 2009).

A recently-completed survey by the Massachusetts Ocean Partnership reports that recreational boating in the southeast coastal region of the state—Barnstable, Bristol, Nantucket and Dukes counties—had an estimated value of $121 million in 2010.

Each of these activities has indirect and significant impacts on the regional economy. For example, a 2006 report assessing the coastal and marine economies of Massachusetts found that for every dollar spent in the commercial seafood industry, 70 cents are further generated within the economy (Donahue Institute, 2006). A 2009 analysis of the impact of tourism in Massachusetts found a similar impact. On average, for every one dollar spent on travel in Massachusetts, an additional 60 cents was generated in secondary sales in 2009 (U.S. Travel Association, 2009).

CCB WATERSHED FACTS

- At 546 square miles it is almost as large as the surface area of the Bay itself.
- It contains over 1,000 freshwater ponds; at least 75 are state-designated great ponds (10 or more acres).
- It includes the two largest sole-source aquifers in Massachusetts: Cape Cod (440 sq.miles) and Plymouth-Carver (199 sq. miles).

Why Monitor Cape Cod Bay?

Cape Cod Bay is a complex ecosystem. Monitoring helps us to understand how the Bay and its conditions change over time. Monitoring expands our understanding of how human activities and management actions affect the Bay. It is important to know if the water quality conditions of the Bay are continuing to support or impact its productivity. While there are a complex set of factors that influence the biological productivity of the oceans, one critical factor is whether its waters are relatively free of pollutants—that is, chemicals and nutrients.

An excess of nitrogen and phosphorous, but especially nitrogen in coastal waters, leads to eutrophication or a polluted condition. Eutrophication is caused by excess nutrients and is expressed by symptoms such as increased chlorophyll *a* (measured by the abundance of algae), decreased dissolved oxygen and a decrease in eelgrass abundance. Monitoring concentrations of nitrogen and phosphorous, chlorophyll *a*, dissolved oxygen and the presence and condition of eelgrass over time and throughout the Bay provides scientific data that can be used to assess the eutrophic condition of the Bay ecosystem.

Eelgrass beds act as a refuge and nursery for juvenile fish and shellfish, many of which are commercially important species in this region. Diversity and abundance of marine life is greater in areas that support healthy eelgrass, yet eelgrass beds are quite sensitive to disturbance and pollution.

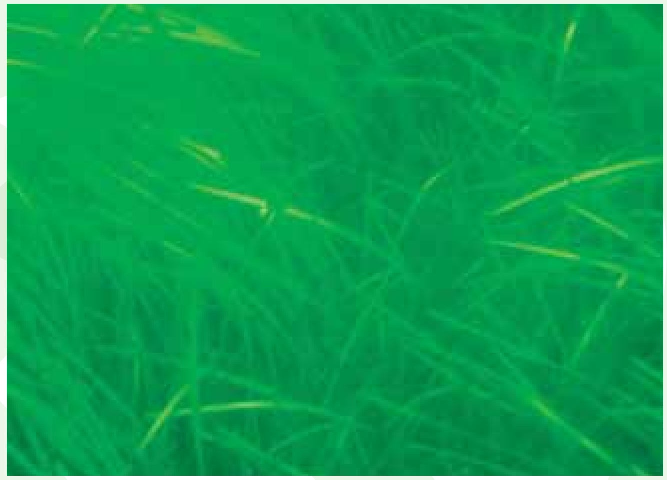
The Impacts of Pollution

Residents and visitors are experiencing the consequences of decreased water quality in the Bay—cloudy water, fewer fish and shellfish, less eelgrass and more and different kinds of seaweed. This has not only ecological but economic consequences, given the importance of tourism and fishing to the region's economy.

The Power of Good Information

The Cape Cod Bay Monitoring Program (CCBMP) provides information to make informed, scientifically-based decisions about the protection of the Bay. As towns around the Bay take steps to reduce the amount of pollutants in groundwater, wastewater and stormwater, the results of the CCBMP can be used, along with other data, to assess the success of these actions.

These five years of measurements of the Bay's water and habitat quality can be compared with future



Eelgrass bed

measurements to determine changes in the Bay's condition—whether it shows improvements or degradation. In the future, PCCS plans to develop a set of parameters that can serve as indicators of the health of the Cape Cod Bay ecosystem.

Nationally, water quality monitoring is recognized as a critical element of protecting and improving water quality. PCCS's long-term monitoring of water quality in Cape Cod Bay:

- Provides baseline water quality data for Cape Cod Bay
- Maps the distribution of nutrients both nearshore and offshore
- Identifies sources of pollution (nutrients)
- Traces spatial (horizontal, vertical) and temporal (tidal, seasonal, inter-annual) changes in water properties and nutrient concentrations

PCCS has been tracking the health of Cape Cod Bay for over 25 years, assessing the quality and quantity of zooplankton as well as changes in oceanographic conditions associated with the North Atlantic right whale. With coastal water quality problems increasing in occurrence and frequency in recent years, i.e. shellfish closures and nuisance algae to name a few, PCCS expanded its monitoring program Bay-wide in 2006 and began monitoring for nitrogen and phosphorous. This more comprehensive program is designed to address water quality issues on an ecosystem level by sampling offshore stations, nearshore stations (located along the coastline) and inshore stations (less than one mile from the coastline).

How Is the Monitoring Done?

PCCS conducts water quality sampling and analysis throughout the year in Cape Cod Bay. Using PCCS research vessels, eight offshore stations are sampled once a month, year round. There are 30 nearshore stations that are sampled from a boat once every two weeks, from May through October. The inshore stations are sampled from the shore by citizen scientists and vary in number from 15-25 annually. Most sites are visited weekly, from May through October. A select few are sampled year round every two weeks (See Figure 1).

At all stations, water temperature, salinity, dissolved oxygen and pH are measured *in situ*. Water samples are collected from the surface waters and, for all stations greater than one meter in depth, near bottom water samples are collected as well. These samples are then taken to PCCS's state-certified laboratory and analyzed for nitrate+nitrite, orthophosphate, ammonia, total nitrogen, total phosphorous, chlorophyll *a*, pheophytin and turbidity.

Adding Eelgrass to the Equation

Eelgrass is one of the most productive plant communities on the planet and functions as the base of an intricate food web. To increase our understanding of the health of the Cape Cod Bay ecosystem, PCCS expanded its monitoring to assess additional elements that are closely related to water quality. An eelgrass habitat studies program was begun in 2007 in collaboration with LightHawk, a volunteer-based not-for-profit aviation corporation. PCCS scientists conduct aerial surveys three times a year to document the presence/absence and extent of coverage of eelgrass during the spring, summer and fall.

In addition to these broad scale surveys, more targeted boat-based research is conducted at select sites. This includes monitoring environmental conditions (light and temperature), biological parameters (shoot density and epiphytic biomass) and geological characteristics (grain size) in and around eelgrass beds. Using these data, small-scale transplanting has been attempted with the goal of aiding in the expansion of a remnant eelgrass bed. Because eelgrass is sensitive to changes in water quality, the condition of eelgrass beds in the shallower waters of Cape Cod Bay is an additional indicator of environmental change.

An Eye on Invasives

The presence and species composition of marine invasive species can also be an indication of potential problems related to water quality and ecosystem health. Invasive species are non-native to an area but thrive in their new environment. Under the direction of the Massachusetts Aquatic Invasive Species Program within the Massachusetts Coastal Zone Management Program, PCCS has trained volunteers to identify sixteen known marine invasive species and seven potential invasives at three sites in the Bay.

Two invasives of notable concern are *Codium fragile*, a spongy branch-like green seaweed that has been in this area for more than 25 years, and *Didemnum sp.*, a colonial tunicate that was first observed in Massachusetts in 1988. Both of these species pose a threat to eelgrass by either shading eelgrass plants from light or fouling the individual eelgrass blades, which causes breakage and prevents other native species, such as scallop spat, from colonizing.

Pharmaceuticals

The most recent expansion to the CCBMP focuses on the detection of organic wastewater contaminants—pharmaceuticals—in Cape Cod Bay. These include medicines, personal care products and cleaners, and they consist of thousands of different types of chemical compounds. Cape Cod is particularly prone to the introduction and persistence of these types of contaminants due to its older population, geology and prevalent reliance on septic systems.

In the spring of 2010, PCCS conducted preliminary research to determine whether there are detectable levels of a select few of these contaminants in Cape Cod Bay itself as well as several creeks and embayments that drain into the Bay. Six samples were collected from five sites (see Figure 1 for sampling locations). In collaboration with researchers from University of Massachusetts Boston, each of these samples was tested for carbamazepine, sulfamethoxazole and trimethoprim.

Carbamazepine is classified as an anticonvulsant/mood stabilizer. Trimethoprim and sulfamethoxazole are antibiotics. These compounds were chosen not for what they are, but because their chemical composition is such that they are resistant to natural degradation processes. Thus they tend to remain in the environment a very long time—a year or more—and continue to be released into the environment through use, excretion and disposal.

The results indicate that four of the five sites had a detectable level of at least one of the contaminants. PCCS is building on these initial results and testing for additional contaminants at multiple sites over a longer period of time. This more detailed spatio-temporal data may help to identify the sources of these pharmaceuticals and how best to minimize their environmental impacts. Since the results of this limited survey are preliminary, they are not detailed in this report. However, as our research continues, we will publish our findings and make them widely available to the public.

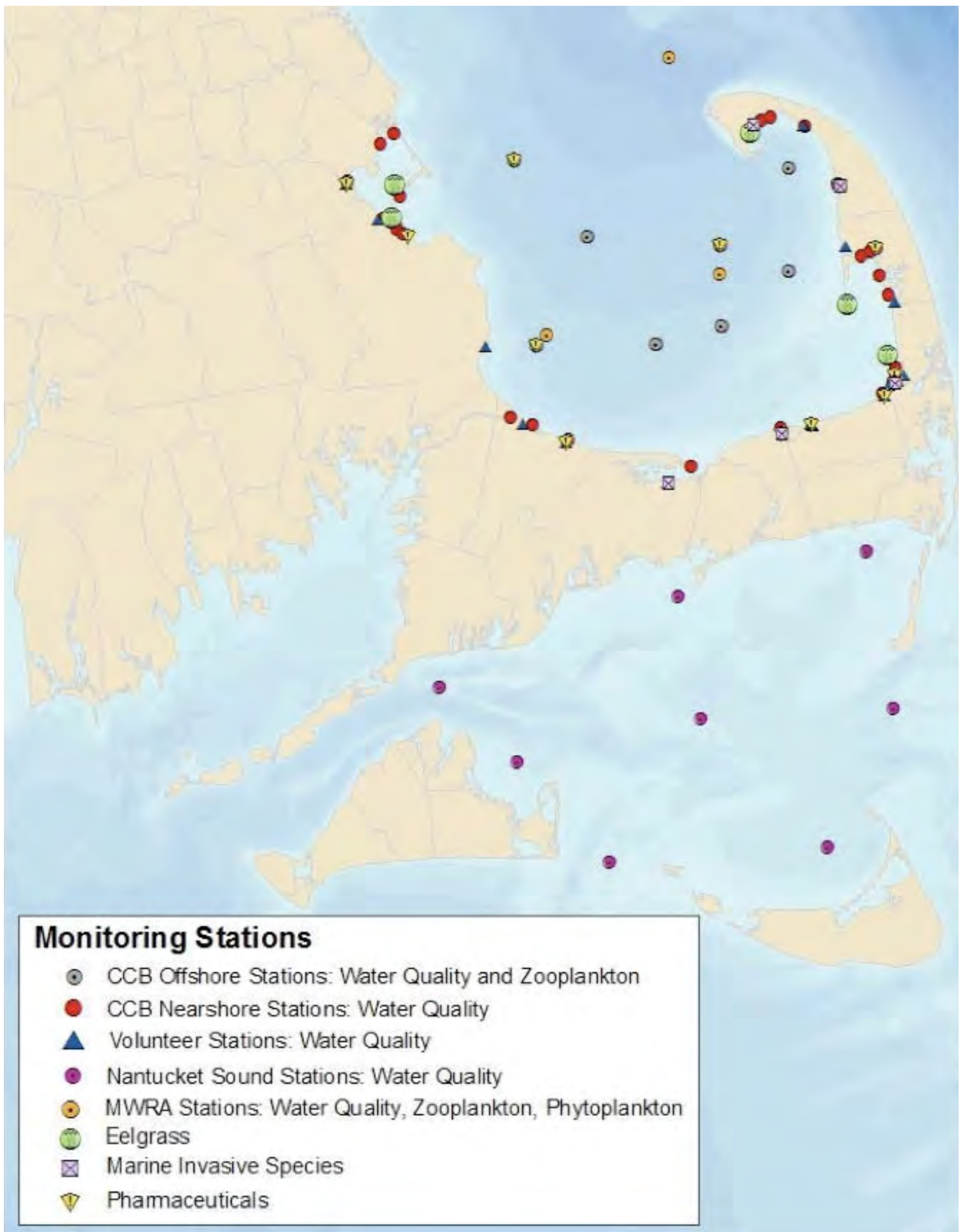


Figure 1. PCCS sampling station locations

What Does the Monitoring Tell Us about the Bay?

Cape Cod Bay is a dynamic environment. It undergoes natural as well as human-induced change, and this variability occurs on many different scales—geographic, seasonal and inter-annual. In general, patterns observed in nutrient cycling and productivity in open coastal waters are quite different than those seen in enclosed, shallow embayments (Cebrian and Valiela 1999). A comparison of the patterns observed in the water quality parameters measured at the offshore stations of Cape Cod Bay (i.e. open coastal waters) and the nearshore and inshore stations (enclosed, shallow embayments) illustrates these differences (Figures 2 & 3). The CCBMP data suggest an overall decline in environmental conditions in 40% of the stations monitored; most of these are in the inshore and nearshore regions of the Bay.

While five years is a short time scale for determining changes in water quality, these data from 2006-2010 begin to reveal variability and hint at some trends. Each year during the summer months there is a degradation of water quality in the nearshore stations, with an increase in concentrations of nitrogen, chlorophyll and turbidity. The further inshore the station, the greater the degradation in water quality conditions. At the same time, the data suggest that there are some signs of improvement at some nearshore sampling stations. For example, at both stations monitored in Duxbury, concentrations of nitrogen, chlorophyll and turbidity have shown a declining trend over the course of this five-year study period.

Understanding the variability from year to year as well as within a year provides a baseline from which to assess the environmental condition of Cape Cod Bay and against which future changes can be compared.

Seasonal Changes in the Cape Cod Bay Ecosystem: Understanding the Patterns

The offshore and nearshore waters of Cape Cod Bay exhibit seasonal changes distinct from one another due primarily to water depth, temperature and salinity. As explained below, the more open waters of Cape Cod Bay have a different pattern of primary productivity than that of the nearshore waters. This overall pattern is consistent from year to year even while the timing and intensity of the pattern, such as when the waters begin to warm and by how many degrees, can vary.

Seasonality in Open Coastal Waters of Cape Cod Bay

In offshore, more open coastal waters (represented by the eight offshore monitoring stations), two peaks in primary productivity occur. The cycle begins in the spring, when waters are well mixed from the surface to the bottom and nutrients from bottom waters are readily available in the surface waters.

As light becomes more available, phytoplankton—microscopic, photosynthetic organisms—take advantage of these conditions and their biomass rapidly increase. Later in the spring and early summer, as the temperature difference between surface and bottom waters increases and the water column becomes stratified, the supply of nutrients is cut off, terminating the spring plankton bloom.

Water temperatures continue to increase during the summer months, resulting in a period of strong stratification, depleted surface nutrients and low phytoplankton biomass. A second, fall bloom of phytoplankton occurs when the water column stratification deteriorates due to cooling weather and increased wind events. This mixing supplies nutrients to the surface waters again, resulting in the development of a fall increase in phytoplankton biomass.

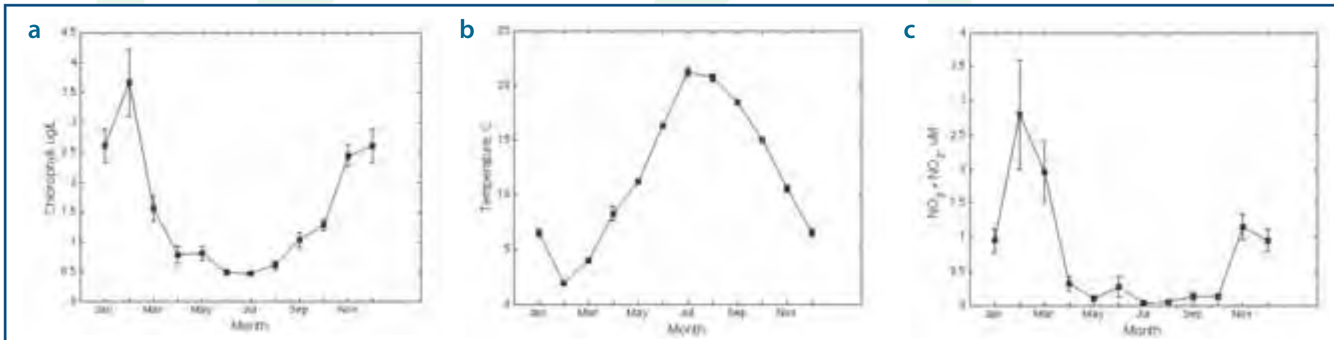


Figure 2: Monthly averages of a) chlorophyll *a*, b) temperature and c) nitrate+nitrite calculated from all 5 years of data (2009-2010) from the offshore stations.

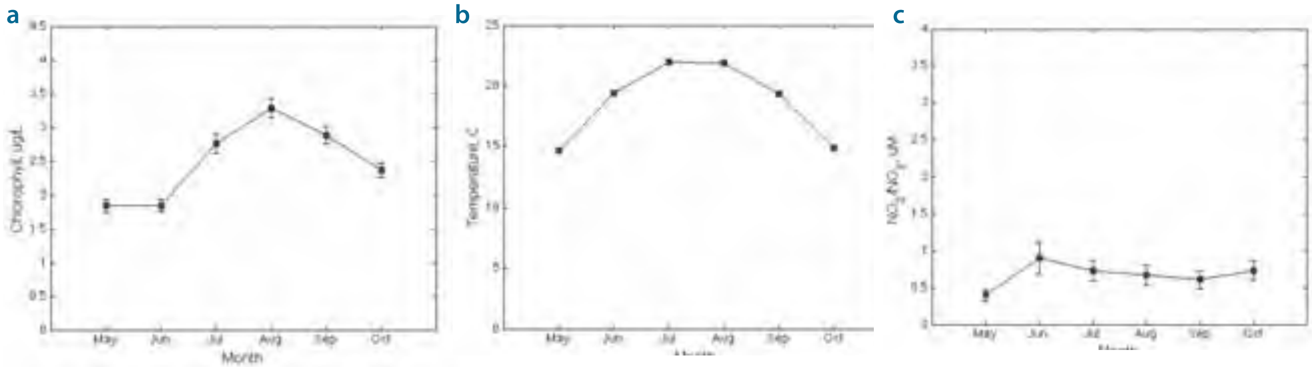


Figure 3. Monthly averages of a) chlorophyll *a*, b) temperature and c) nitrate+nitrite calculated from all 5 years of data (2006-2010) from the nearshore stations.

Seasonality in Enclosed Coastal Ecosystems: Estuaries and Nearshore Regions of Cape Cod Bay

Enclosed coastal ecosystems such as the tidal creeks and estuaries that empty into Cape Cod Bay exhibit different seasonal trends in primary productivity than open coastal waters. Data from nearshore and inshore monitoring stations were used to assess these cycles. Enclosed coastal ecosystems typically have only one peak that occurs during the summer.

Unlike the open system of Cape Cod Bay, the creeks and estuaries are not nutrient-limited during the summer. Because these shallow waters rarely become strongly stratified, the supply of nutrients from biogeochemical processes (e.g. mineralization of organic matter and nutrient cycling) that occur at the sediment-water interface is available during the summer. This, as well as the constant supply of nutrients from anthropogenic sources such as septic systems and run-off, which often peaks during the summer months, combines with warmer temperatures and triggers a summer peak in phytoplankton biomass observed in the nearshore and inshore stations.

Trends in Water Quality

Five years of CCBMP data gives PCCS the ability to evaluate whether or not water quality conditions of Cape Cod Bay and the coastal waters of the Cape have deteriorated, improved or remained unchanged.

A Seasonal Kendall Trend Analysis Test (WQHydro) was used to evaluate the data for trends over time. This test was developed by the U.S. Geological Survey in the 1980s to analyze trends in surface-water quality throughout the United States (Hirsch et al. 1981). It has become the most frequently used test for trends in the environmental sciences (Helsel et al. 2005). This test is based on the differences between observations in the same month of different years. It then combines the individual results into one overall test for whether the dependent variable (e.g. chlorophyll, temperature, nitrogen, turbidity) changes in a consistent direction over time. It also computes magnitude and direction of the trend.

Fifty-four stations were analyzed separately for trends in a subset of the parameters: chlorophyll *a*, temperature, nitrogen (nitrate+nitrite) and turbidity. Several of the inshore stations were excluded because this test requires at least 3 years of data. The trends for these selected water quality parameters are discussed in the following sections.

For a trend to be considered statistically significant, there must be a 5% (or less) probability of experiencing the trend resulting from chance. There were very few statistically significant trends in any of the variables. This is not unexpected considering the relatively short timeline over which these data have been collected. However the data do indicate positive and negative changes in concentrations in the variables monitored.

For all parameters, the results of the Seasonal Kendall Trend Analysis Test, regardless of their magnitude or statistical significance, are plotted. Results are detailed in Appendix A.

Assessment of Ecosystem Health

A subset of the parameters that are monitored for water quality by PCCS was selected to address changes in the overall health of the Cape Cod Bay ecosystem. The selected chemical parameters are chlorophyll *a*, temperature, nitrogen (nitrate+nitrite) and turbidity. The other environmental parameters discussed in this report that are key components of the Cape Cod Bay Monitoring Program and directly related to water quality and ecosystem health are eelgrass habitat, invasive species and pharmaceuticals.

Chlorophyll *a*: Primary Productivity

Primary productivity is estimated by measuring the concentration of chlorophyll *a* in the water. Chlorophyll *a* is the green pigment in most phytoplankton and plant cells that absorbs light energy. Phytoplankton is the foundation of the marine food web. It supports zooplankton such as copepods, which are primary food for everything from larval fish to baleen whales, including the endangered North Atlantic right whale.

Because of the direct relationship between chlorophyll *a* and phytoplankton, measuring chlorophyll *a* will give an accurate estimation of the amount of phytoplankton biomass in the water.

Phytoplankton biomass is dependent on a number of variables including temperature, light levels and nutrient availability. Changes in these variables over time (seasonally and inter-annually) and space will therefore affect levels of chlorophyll *a*.

Measuring chlorophyll *a* concentrations was incorporated into the monitoring program in 2007. A fluorometer is used to measure chlorophyll concentrations (μg/L) in the water samples.

Photo: Cape Cod Commission (www.capecodcommission.org); used with permission

Fishing boats in Sandwich Harbor

Seasonal Variation in Chlorophyll *a*

Seasonal patterns in chlorophyll concentrations are driven primarily by two factors: light and nutrients.

As previously noted, the offshore waters typically experience two blooms in phytoplankton, one during the late winter/early spring (February-March), and a second, less intense bloom during the fall (October-November) (Figure 4). During the summer, although there is plenty of light, depletion of nutrients in the surface waters and poor vertical mixing in the water column limits phytoplankton production. During the late fall/early winter, when the water column stratification weakens and increased winds bring nutrients up to the surface waters, light levels can be limiting to phytoplankton growth.

In the nearshore waters, both nutrient concentrations and light levels are high during the spring, summer and fall, so phytoplankton growth is rarely limited. Phytoplankton growth may even become excessive as a result of the high input of nutrients during the summer. In some cases, algae blooms can have adverse effects on the ecosystem, human health or the economy.

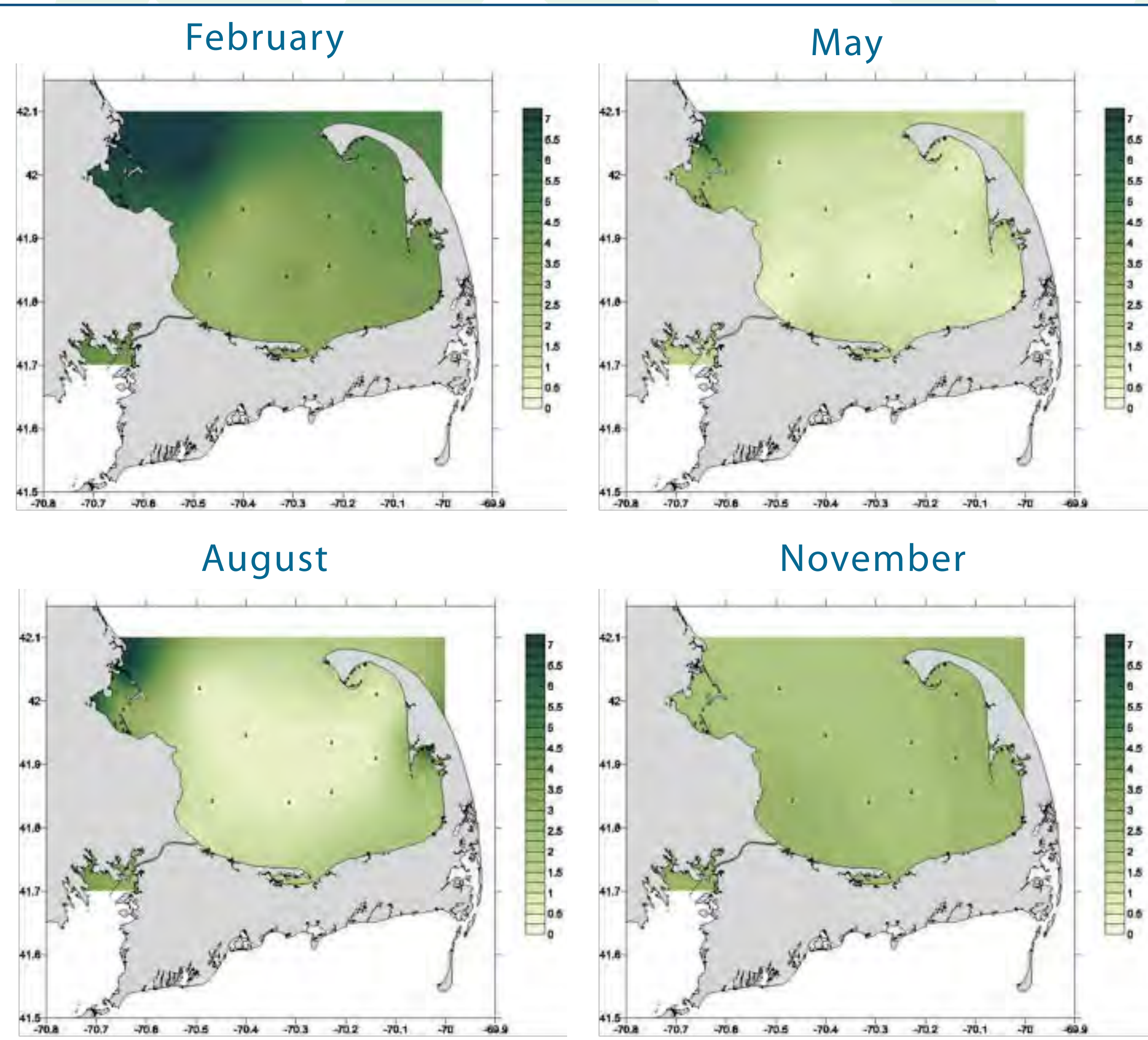


Figure 4. Surface contour plots of chlorophyll *a* concentrations (µg/L). Plots for February and November include only data from the eight offshore stations. Plots for May and August include data from all 54 stations (nearshore and offshore).

How is Our Bay?

Inter-Annual Variation in Chlorophyll *a*

The nearshore stations are only sampled from May to October, so averages do not include the cooler months (November-April). As a comparison, average chlorophyll concentrations for the offshore stations using only data collected from May through October are shown in addition to averages calculated using all months (Figure 5).

Average chlorophyll concentrations of the nearshore stations (sampled May-October) were higher for all years compared to the same time series for the offshore stations. Including data for all twelve months from the offshore stations resulted in higher concentrations and greater variability among years. Including all months captures both the spring and fall phytoplankton blooms that occur in the open coastal waters, thereby increasing the overall average concentration. Variability among years increases as well because the magnitude of the blooms varies greatly from year to year.

For both the offshore and nearshore stations, average chlorophyll levels varied from year to year. Average levels decreased from 2007 to 2009, but increased in 2010. The similar trends in average chlorophyll concentrations observed at both the offshore and nearshore stations were unexpected because of the different seasonal cycles and associated factors that control phytoplankton productivity in offshore waters versus nearshore waters. Continued monitoring will determine if these patterns are related or coincidental.

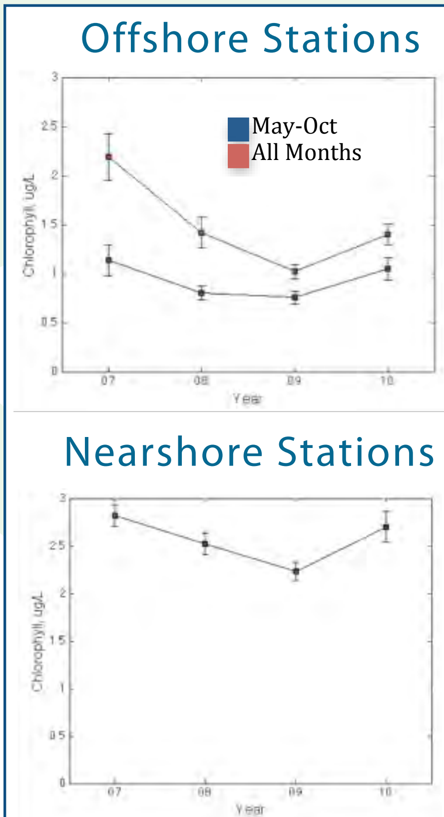


Figure 5. Annual average concentrations of chlorophyll measured at offshore stations (May-October and January-December) and nearshore stations (May-October).

Trends in Chlorophyll *a*

Although there are significant differences in average chlorophyll concentrations from one year to the next, the trend analysis did not indicate statistically significant trends at the majority of the monitoring sites (Figure 6). In other words, average chlorophyll concentrations are significantly different from year to year, however they are not consistently going up or down over this five-year period at a statistically significant rate.

The trend analysis for chlorophyll indicated a significant decreasing trend ($p \leq 0.05$) at only four stations (Appendix A). Although not statistically significant, 38 stations showed at least a slight decreasing trend in chlorophyll, 8 showed no trend and 8 showed an increasing trend in chlorophyll levels.

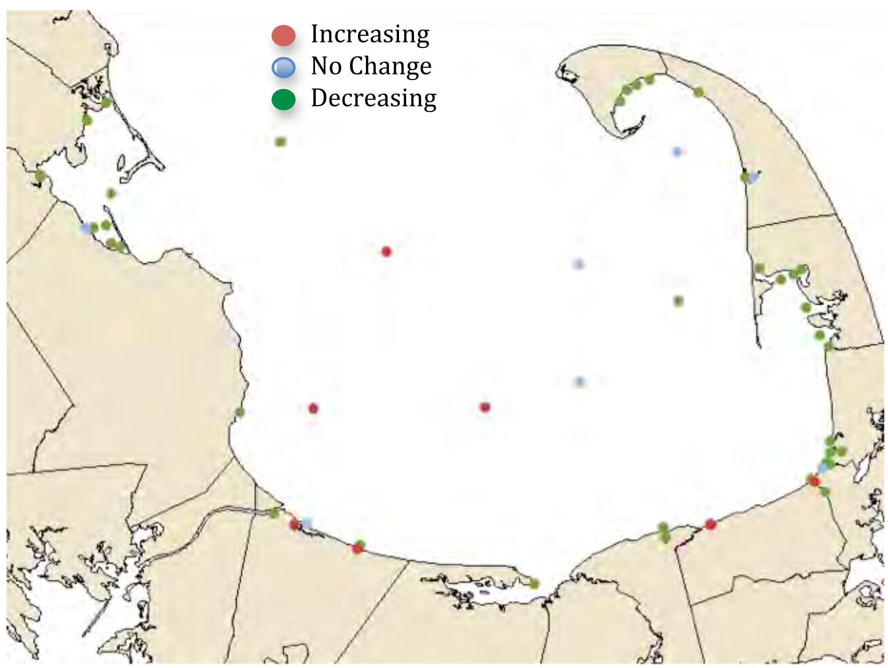


Figure 6. Results of the Seasonal Kendall Trend analysis for chlorophyll *a* concentrations. Red dots symbolize increasing trends, blue dots symbolize no trend in the data and green dots symbolize decreasing trends.

Temperature

Temperature is defined as the response of a solid, liquid or gas to the input or removal of heat energy (Garrison, 2002). The ocean has a wide range of temperatures from almost 38˚C (100˚F) in shallow tropical coastal waters to nearly freezing at the poles. The greatest seasonal variability in temperatures occurs in temperate coastal waters such as Cape Cod Bay.

Water temperature is an important property of the marine environment, influencing many physical (density), chemical (capacity to hold dissolved oxygen, sensitivity to toxic wastes) and biological (metabolic processes, photosynthesis) processes as well as dictating the types, distribution and abundance of marine flora and fauna.

Measuring water temperatures of surface and bottom waters indicates the degree of stratification in the water column, an important characteristic that affects nutrient availability and productivity. Monitoring temperature levels and, more importantly, changes in the levels provides a direct indication of potential problems.

At all stations, surface water temperatures are recorded during each monitoring event. At the deeper stations (> 2m), a temperature profile of the water column is taken. At some locations, underwater temperature sensors are deployed for continuous recording throughout the year.

Seasonal Variation in Temperature

Seasonal patterns in temperature are well defined (Figure 7). The coldest water temperatures typically occur during February. Sea ice is not uncommon in the shallower areas of the bay during this month. As the days lengthen and the sun's rays become more direct, the water temperatures respond rapidly. In July and August, surface temperatures can warm up to 25˚C (77˚F). In the fall, not only do the days become shorter and the sun's energy less intense, but winds break down the stratification of the water column, mixing the cooler bottom waters up into the surface layer. This can often cause rapid cooling of the surface waters.

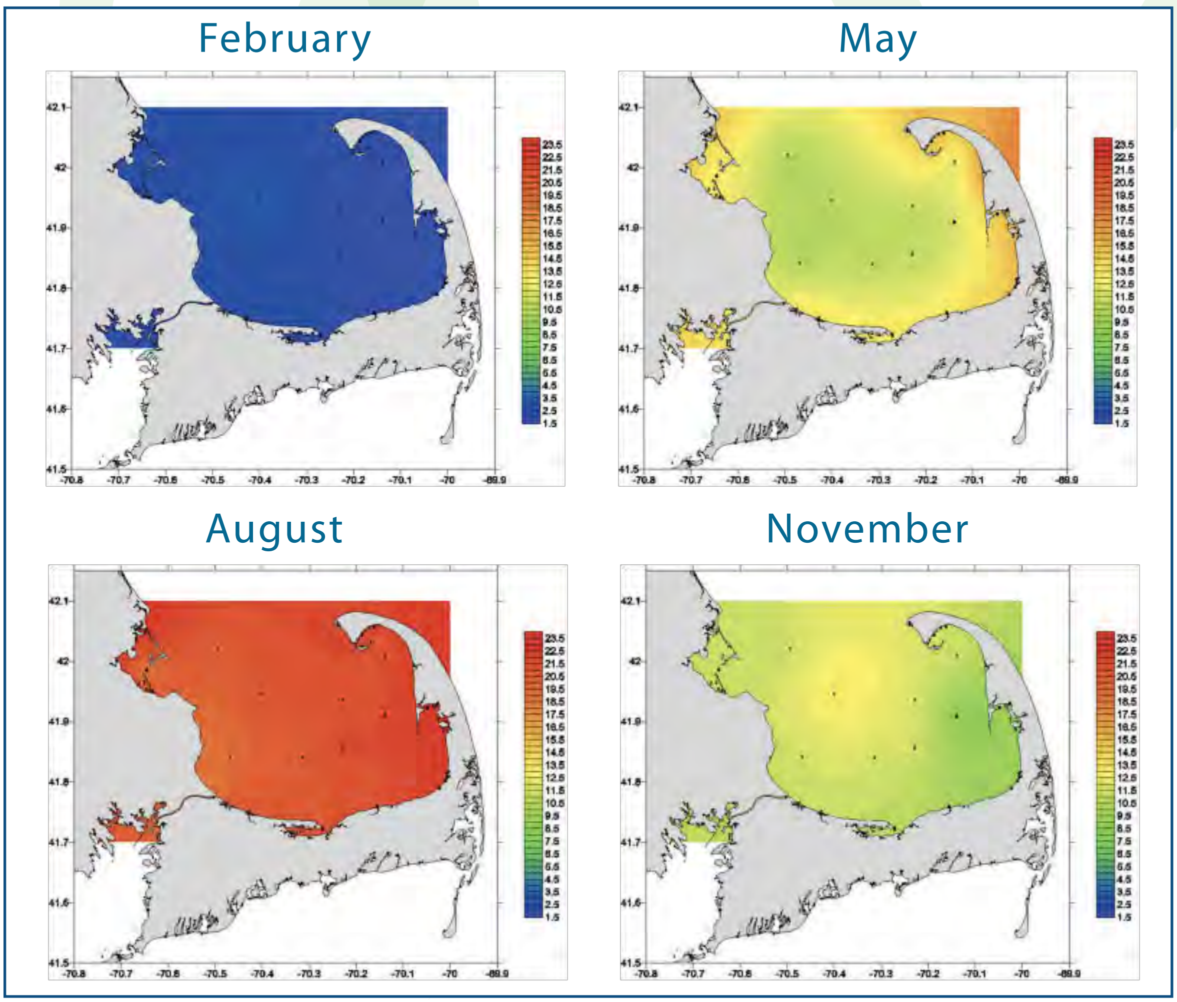


Figure 7. Surface contour plots of water temperature (°C). Plots for February and November include only data from the eight offshore stations. Plots for May and August include data from all 54 stations (nearshore and offshore).

Inter-Annual Variation in Temperature

The average water temperatures vary from one year to the next. In the following figure, 2006 is not included because sampling began in May of that year. Surface temperatures (shown in blue) include the upper two meters of the water column. Near bottom temperatures (shown in red) include those measured at depths greater than 20 m. Surface water temperatures, being more influenced by air temperatures and weather patterns, show more inter-annual variability than near bottom temperatures (Figure 8).

Average surface water temperatures for the nearshore stations are warmer than the offshore stations (Figure 9). A comparison of the averages of temperatures from May-October shows similar patterns over the years for offshore and nearshore stations. Including all months in the offshore station averages captures the colder months of the year, thereby decreasing the average annual temperature.

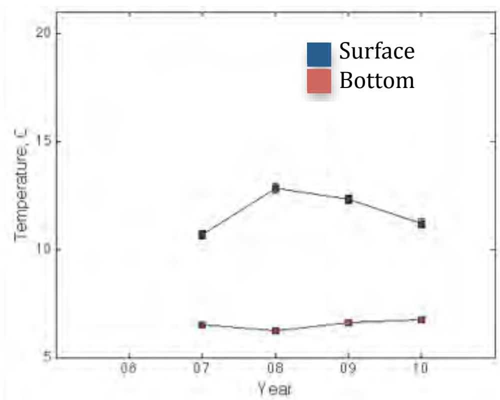


Figure 8. Average surface and near bottom temperatures measured each year at the offshore stations.

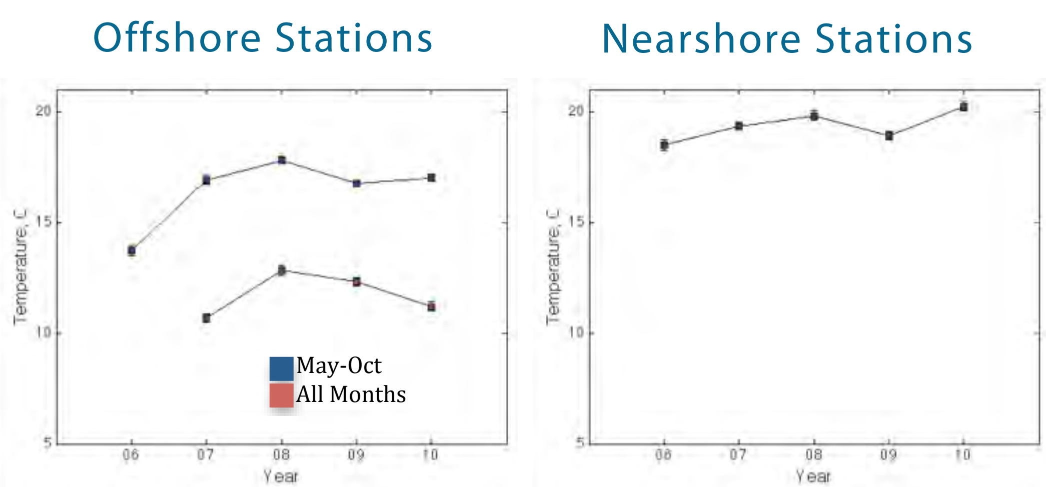


Figure 9. Annual average surface temperatures measured at offshore stations (May-October and Jan-December) and nearshore stations (May-October).

Trends in Temperature

The trend analysis for surface water temperatures indicated a significant warming trend ($p \leq 0.05$) at three stations (Appendix A). Although not statistically significant, 31 stations showed at least a slight warming trend, 9 showed no trend, and 14 showed a cooling trend (Figure 10).

It would be helpful to put these trends into a context beyond this report. Broader studies of the area have suggested trends. For example, the State of the Gulf of Maine Report from 2010 asserts: "The rate of increase of coastal sea surface temperatures (SST) in the Gulf of Maine is similar to the rise in global mean SST of about 0.7°C over the last century" (Trenberth et al. 2007; Shearman 2010). However, the rate of increase has accelerated in recent years, and regional studies indicate that sea surface temperatures in this region have increased by about 0.23°C from 1982 to 2006 (Belkin 2009)." [4]

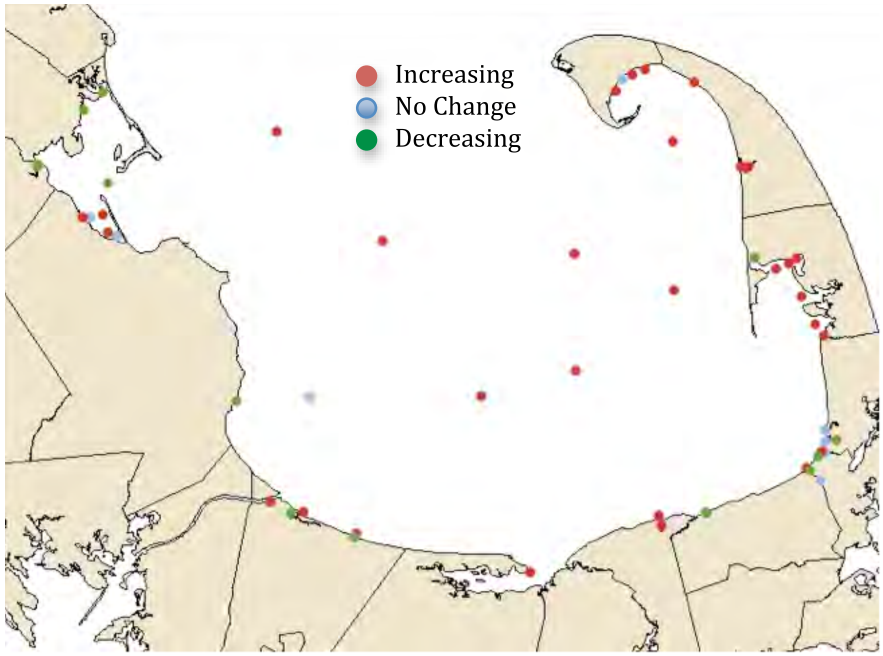


Figure 10. Results of the Seasonal Kendall Trend analysis for temperature. Red dots symbolize increasing trends, blue dots symbolize no trend in the data, and green dots symbolize decreasing trends.

Only continued monitoring can reveal future changes and show whether Cape Cod Bay parallels or diverges from the Gulf of Maine's temperature trends in the long term.

Photo: Cape Cod Commission (www.capecodcommission.org); used with permission

Nitrogen: Boon and Burden

Nitrogen can be found in the marine environment in a variety of inorganic compounds including nitrate (NO_3^-), nitrite (NO_2^-), nitrous oxide (N_20), molecular nitrogen (N_2) and ammonia (NH_4^+). There are also many different types of organic compounds that contain nitrogen, such as amino acids and proteins. These types of compounds are released by living organisms and decaying organic matter.

The measurement of nitrogen is a key component of the CCBMP. Samples from surface and bottom waters are analyzed for several different nitrogen compounds including nitrate+nitrite, ammonia and total nitrogen.

Most of the nitrogen that enters coastal waters on Cape Cod is from anthropogenic (human) inputs and is in the form of dissolved inorganic nitrogen (DIN) such as ammonia, nitrate and nitrite. These inputs originate primarily from wastewater, runoff and atmospheric deposition.

Dissolved inorganic forms of nitrogen are biologically available for uptake by primary producers such as algae and phytoplankton. Excessive amounts of these forms of nitrogen entering our waters are behind most major problems affecting coastal ecosystems, such as eutrophication, phytoplankton blooms and hypoxia (low oxygen). This report therefore focuses on the dissolved inorganic forms of nitrogen (nitrate+nitrite).

Seasonal Variation in Nitrogen ($NO_3^-+NO_2^-$)

Factors influencing the levels of nitrogen in the offshore waters are different from those that affect nitrogen levels in the nearshore waters (Figure 11).

Nitrogen measured in the surface waters of the offshore stations comes primarily from nutrient-rich, deep waters. It is brought to the surface through mixing and upwelling. In these bottom waters, there is a constant supply of nutrients from the decomposition of organic matter, and there is little to no uptake of these nutrients at depth.

The water column is well mixed during the winter, and nutrient levels remain high in the surface waters. As stratification sets in during the spring, surface nutrients are used up by phytoplankton and remain depleted throughout the summer. When the water column mixes again in the fall, nutrients are replenished in the surface waters.

Sources of nitrogen to the nearshore waters are primarily anthropogenic. Nitrogen enters these waters via runoff and groundwater, both of which typically have elevated levels of nitrogen due to pollution from wastewater, fertizilers and other human-derived sources. For the nearshore stations, levels of nitrogen remain high throughout the year but often increase during the spring and summer, coincident with increased human activity in the coastal towns bordering Cape Cod Bay.

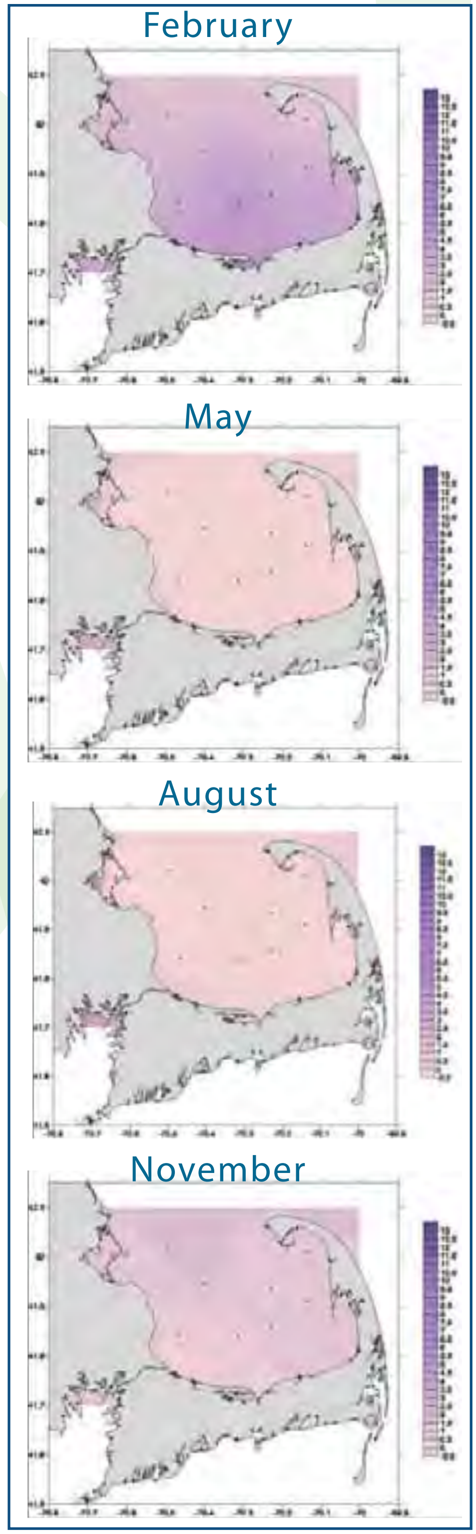


Figure 11. Surface contour plots of nitrate+nitrite levels (μM). Plots for February and November include only data from the eight offshore stations. Plots for May and August include data from all 54 stations (nearshore and offshore).

Inter-Annual Variation in Nitrogen (NO_3^-+NO_2^-)

Average concentrations of nitrogen varied from year to year in both the offshore and nearshore waters (Figure 12). Averages of concentrations measured from May through October are higher and more variable for the nearshore stations but follow similar patterns to the offshore stations, decreasing from 2006-2008 and increasing in 2010.

Including all months in the calculations increases the annual averages for the offshore stations due to the increased levels of nutrients mixed into the surface waters during the late winter/early spring and again in the fall, events that are not captured in the May-October averages. In 2008, there was a significant increase in the annual average due to the high nitrogen concentrations measured during January and February of that year. These higher levels of nitrogen seen in the winter months of 2008 were possibly due to the lack of a strong winter/spring phytoplankton bloom as well as high precipitation and river flows in early 2008 (Libby et al. 2009).

Trends in Nitrogen (NO_3^-+NO_2^-)

The trend analysis for nitrogen concentrations indicated a significant decreasing trend ($p \leq 0.05$) at only two stations (Appendix A). However, although not statistically significant, 23 stations showed at least a slight decreasing trend in nitrogen, ten showed no trend, and 21 showed an increasing trend in nitrogen concentrations (Figure 13).

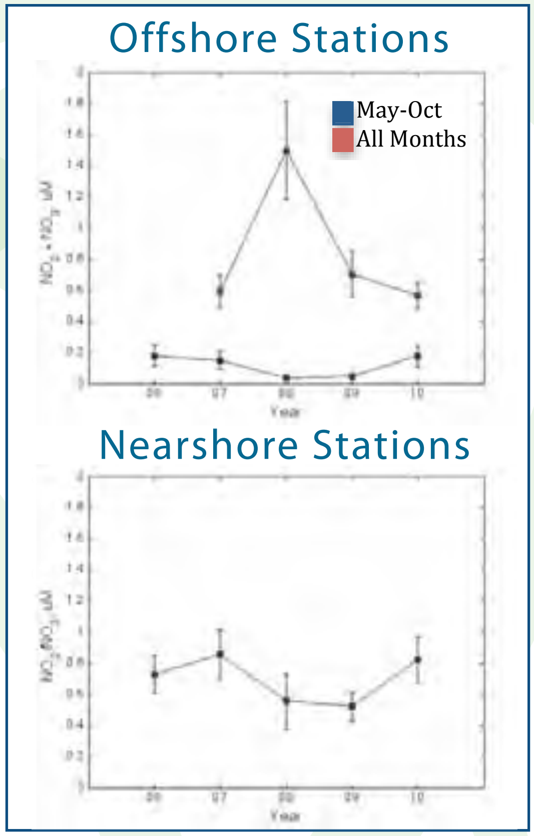


Figure 12. Annual average nitrogen concentrations measured at offshore stations (May-October and Jan-December) and nearshore stations (May-October).

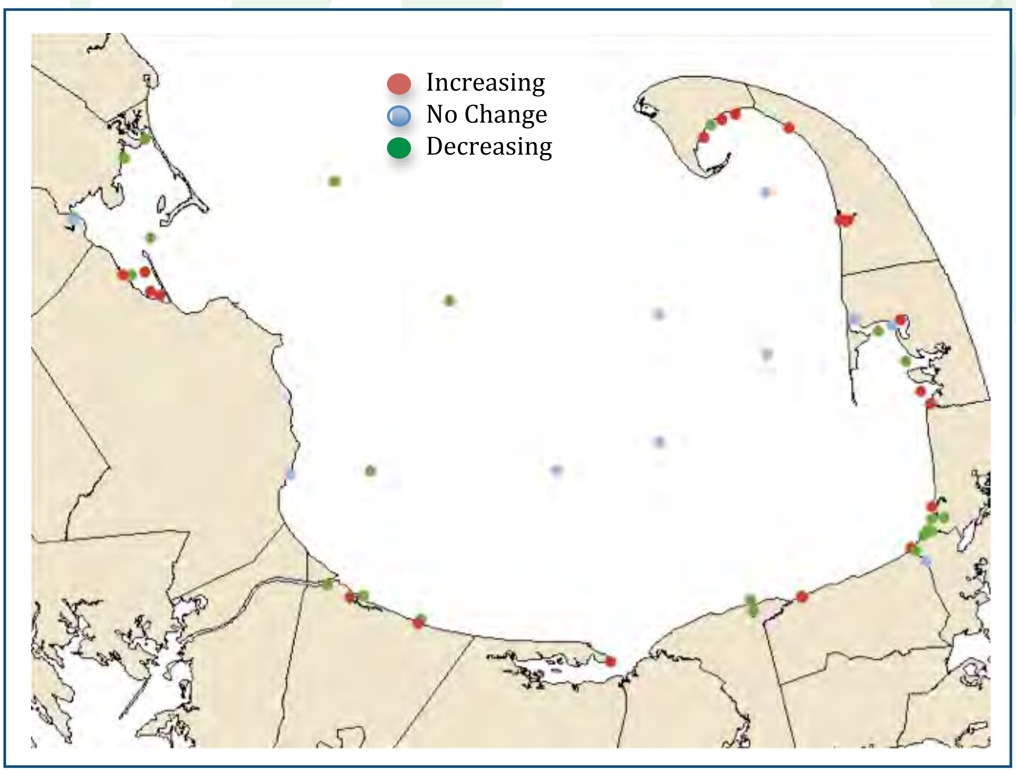


Figure 13. Results of the Seasonal Kendall Trend analysis for nitrogen. Red dots symbolize increasing trends, blue dots symbolize no trend in the data and green dots symbolize decreasing trends.

How is Our Bay?

Turbidity

Turbidity is a measure of water clarity or how much the material suspended in the water column decreases light penetration. Suspended material may consist of both inorganic sediment and organic matter such as phytoplankton. High levels of turbidity can result from natural disturbances such as storms, wave action and bottom feeding animals as well as anthropogenic disturbances such as urban runoff, waste discharge, dredging and boating.

Highly turbid waters are detrimental to the entire ecosystem, from sediment quality to water chemistry to the survival of plants and animals. Some of the negative impacts associated with high levels of turbidity include lowered rates of photosynthesis due to reduced light availability, smothering of benthic organisms and alteration of bottom material and sediment size.

Measuring turbidity was incorporated into the CCBMP in 2007. Turbidity is measured with a secchi disk at the deeper stations, and water samples from all stations are taken back to the lab for measurement with a turbidity meter.

Seasonal Variation in Turbidity

The offshore stations typically had much lower levels of turbidity than the nearshore stations (Figure 14). Turbidity levels in offshore surface waters are more influenced by phytoplankton blooms than sediments. These blooms typically occur during the late winter/early spring and again in the fall. Therefore, turbidity levels in offshore waters are lowest during the summer. Turbidity levels at nearshore stations are influenced by both suspended sediments and chlorophyll. Levels are slightly higher during the spring, perhaps due to higher precipitation resulting in more runoff, and remain high throughout the summer.

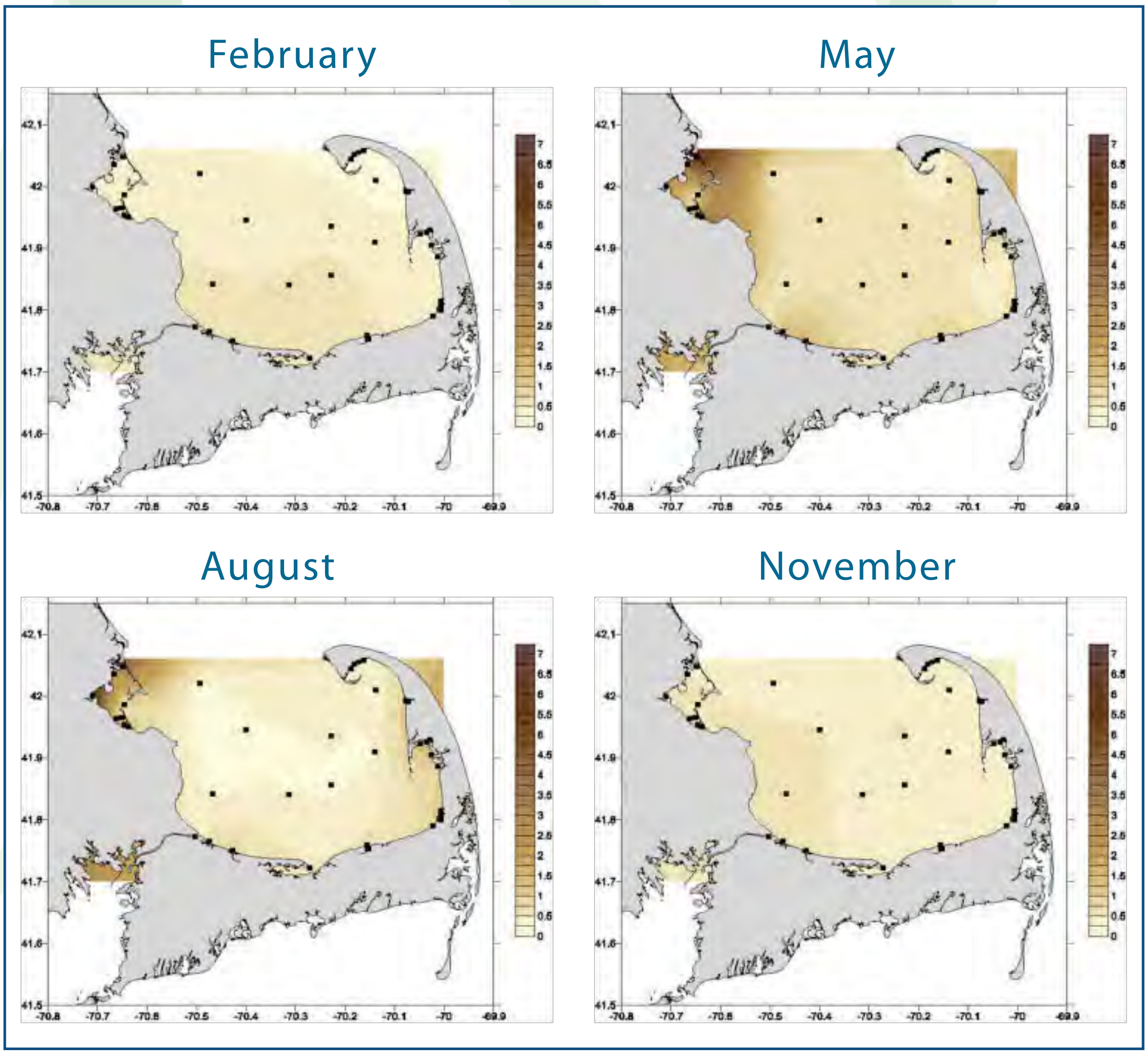


Figure 14. Surface contour plots of turbidity levels (NTU). Plots for February and November include only data from the eight offshore stations. Plots for May and August include data from all 54 stations (nearshore and offshore).

Inter-Annual Variation in Turbidity

For all years, average turbidity levels at offshore stations are much lower (<1 NTU) compared to the nearshore stations where annual average turbidity levels are >1 NTU (Figure 15).

Patterns among years are different for the offshore versus the nearshore stations due to the different factors affecting water clarity described previously.

Trends in Turbidity

The trend analysis indicated a significant decreasing trend ($p \leq 0.05$) in turbidity at five stations (Appendix A). However, although not statistically significant, 28 stations showed at least a slight decreasing trend in turbidity, eleven showed no trend, and 15 showed an increasing trend in turbidity levels (Figure 16).

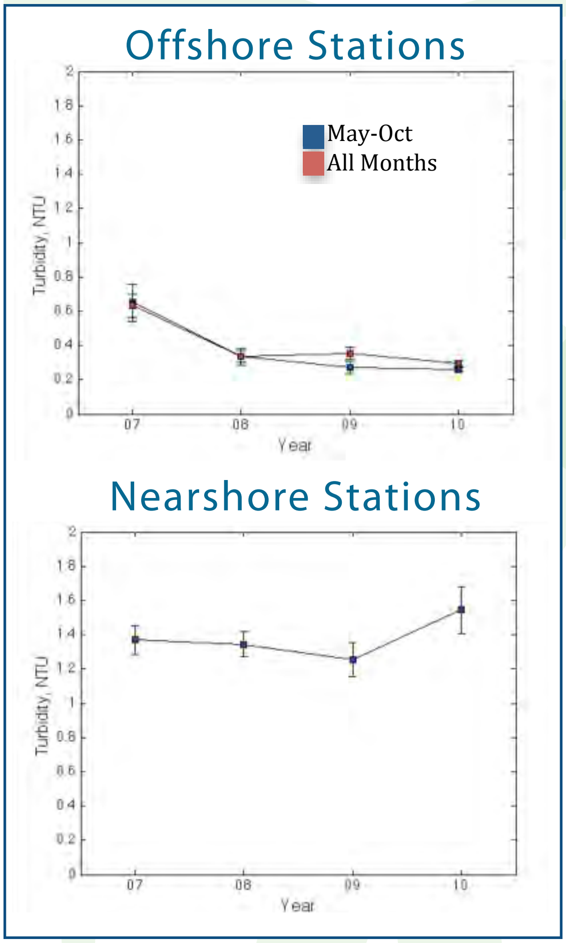


Figure 15. Annual average turbidity levels measured at offshore stations (May-October and Jan-December) and nearshore stations (May-October).

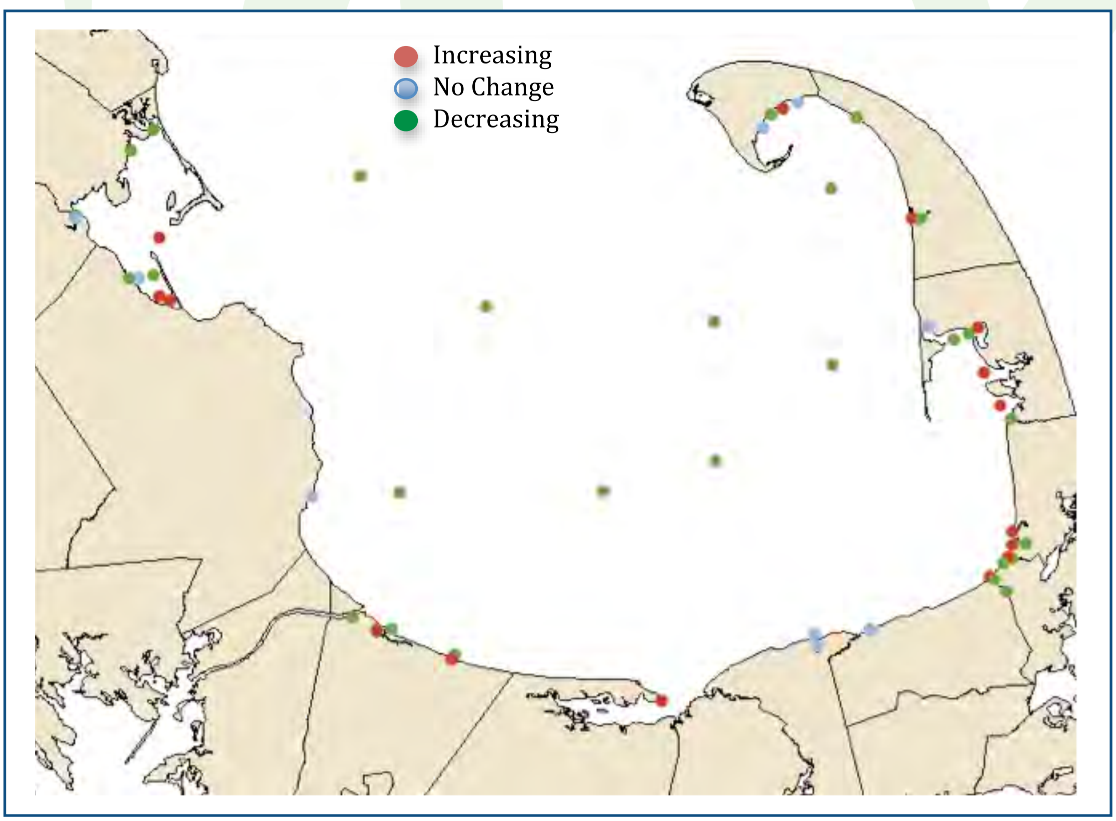


Figure 16. Results of the Seasonal Kendall Trend analysis for turbidity. Red dots symbolize increasing trends, blue dots symbolize no trend in the data and green dots symbolize decreasing trends.

Photo: Elizabeth Bradfield

Overall Trends in Water Quality in Cape Cod Bay, 2006-2010

By national standards, Cape Cod Bay is still a relatively healthy ecosystem. The National Estuarine Eutrophication Assessment published by NOAA (Bricker et al. 1999) evaluated a number of parameters to assess the degree of eutrophication of the nation's estuaries. This report evaluated existing conditions—maximum values observed over a typical annual cycle—to determine the degree of eutrophication: low, medium or high.

Despite this relatively optimistic assessment of the water quality of Cape Cod Bay when compared against the national standards, there are warning signs. When all five years of the CCBMP's water quality data are evaluated based on the overall trend calculation described below, the calculations (based on combining the scores of the individual trend analysis for chlorophyll, temperature, nitrogen and turbidity) suggest that the condition is declining at 21 of the 54 stations analyzed. The condition at 30 stations is improving, and three stations show no change. Most of the degradation in water quality is occurring in the nearshore and inshore waters sampled throughout the Bay (Appendix A).

Analyzing Trends

Together, these four selected parameters can provide insight into the trends in water quality for Cape Cod Bay. The individual results of the magnitude and direction of the trend for each parameter, calculated

Comparison of Cape Cod Bay to National Estuarine Eutophication Assessment

The parameters from Bricker et al. (1999) that are comparable to the data presented in this report are:

	Chlorophyll *a* (ug/L)	Dissolved Nitrogen (mg/L)
LOW	<5	<0.1
MEDIUM	5 - 20	0.1 - 1
HIGH	>20	>1

With respect to PCCS's data, of the 2494 surface water samples analyzed for chlorophyll, 91.4% (2280 samples) fall within the low category for eutrophication assessment, 8.4% (209 samples) fall within the medium category and 0.2% (5 samples) fall within the high category.

Of the 3132 surface water samples analyzed for nitrogen, 89.5% (2804 samples) fall within the low category, 10.2% (320 samples) fall within the medium category and 0.3% (8 samples) fall within the high category.

by the Seasonal Kendall Trend Analysis Test, were combined mathematically. Chlorophyll, temperature and turbidity were given equal weight. Because nitrogen is the major pollutant in our coastal waters and is the basis for state-mandated total maximum daily loads (TMDLs), it was weighted twice that of the other three parameters

In Figure 17, the colored symbols denote the sampling stations. The colors of the symbols indicate the trend in overall condition based on the calculations described above.

The condition of stations shown in green has improved during the past five years. Stations shown in blue have shown no overall improvement or degradation. The overall condition of stations shown in red has degraded over the past five years.

Table 1: Water Quality Trends by Number of Stations

	Deteriorating	Improving	No Change
Chlorophyll	8	38	8
Nitrate+Nitrite	21	23	10
Temperature	31	15	8
Turbidity	15	28	11

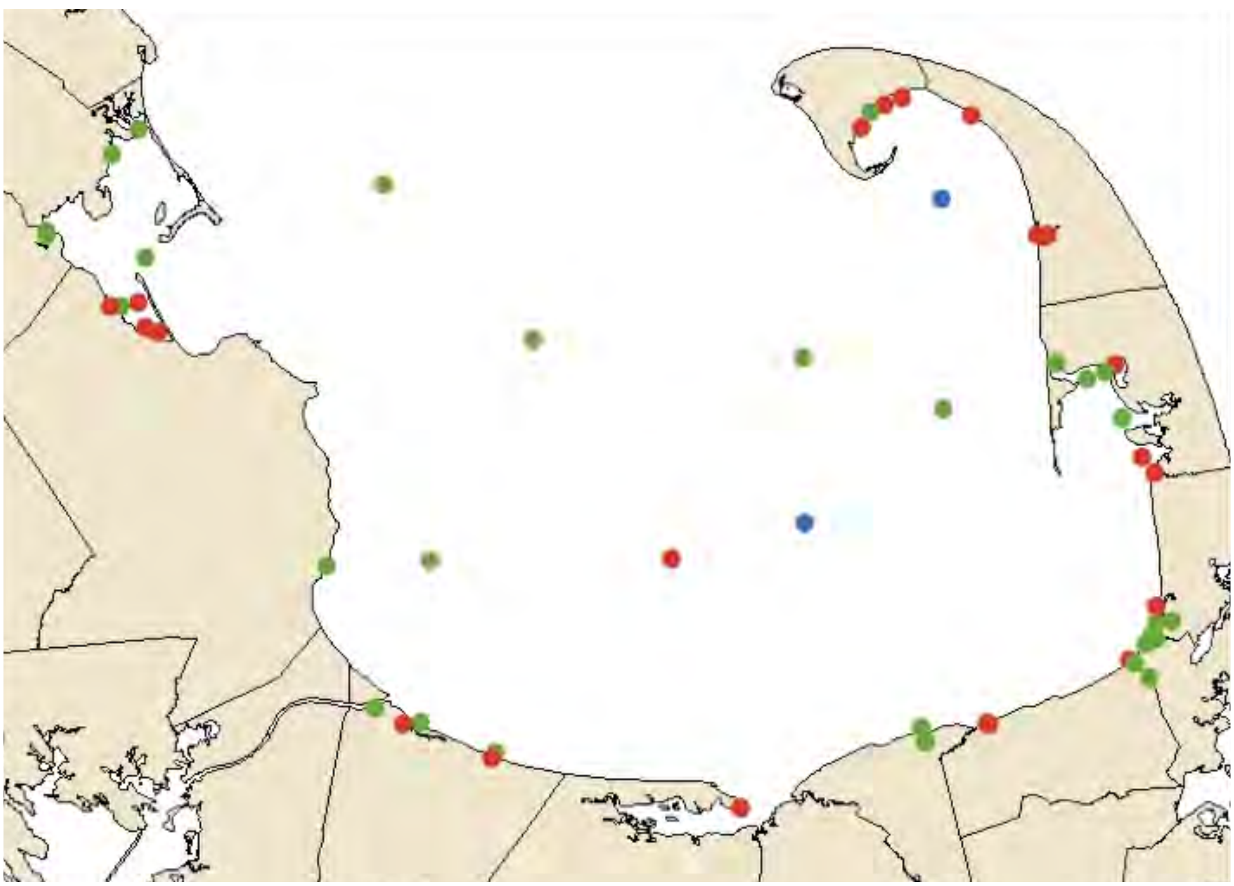


Figure 17. Overall trends in water quality as determined by combining the results of the Seasonal Kendall Trend analysis for chlorophyll, temperature, nitrogen and turbidity. Red dots: stations with an overall degradation in water quality, blue dots: stations where there is no change, and green dots: stations where water quality conditions are improving.

Eelgrass Habitat

Eelgrass beds are undeniably a critically important habitat in Cape Cod Bay. It not only provides a direct source of food for a number of grazers, such as brant geese and sea turtles, but more importantly, it serves as a source of indirect production via detritus which is consumed by numerous invertebrates and thus transferred to higher trophic levels. Diversity and abundance of marine life is greater in areas that support healthy eelgrass.

In Cape Cod Bay, eelgrass beds act as a refuge and nursery for juvenile fish and shellfish, many of which are commercially important species, including bay scallops, lobsters and striped bass. Studies in New England have documented the occurrence of 40 species of fish and nine species of invertebrates in eelgrass beds.[5] Eelgrass beds are equally important from a purely physical perspective: they help to prevent erosion by stabilizing sediments with their extensive root systems, and they aid in filtering contaminants from the water column.

Eelgrass can flourish in a wide range of habitats from intertidal to subtidal, as long as certain requirements are met. Sufficient light, unconsolidated sediments, protection from severe wave exposure and appropriate salinity and temperature are all key to eelgrass success.

Photo: Natural Resources Department, Town of Brewster

Like many shellfish, littleneck clams rely on eelgrass habitat

Eelgrass is sensitive to pollution, making it a good indicator species for monitoring changes in water quality. According to Dr. Joe Costa, Executive Director of the Buzzards Bay Project, "eelgrass has been recognized as a sensitive indicator of nitrogen loadings, and because the distribution and abundance of eelgrass beds can be easily documented with aerial photographs, it is an ideal habitat to track to monitor overall ecosystem health."

A 2004 report from the Massachusetts Ocean Management Task Force notes that poor water quality and decreased clarity result in the greatest loss of eelgrass habitat. Eutrophication (i.e., natural or artificial addition of nutrients to bodies of water and the effects of those added nutrients [National Academy of Sciences, 1969]) increases growth of algae species that grow on eelgrass and phytoplankton that absorb light in water column, thus prohibiting light from reaching eelgrass.

A recent aerial survey of eelgrass abundance in Massachusetts waters by Costello and Kenworthy (2011) indicated that the shallow water embayments in Massachusetts are losing eelgrass habitat at a rate of approximately 3% per year. Some embayments have suffered a complete loss of eelgrass. Of the embayments that were quantitatively assessed, there has been a total loss of 20% of eelgrass acreage over the past decade. The study also mapped eelgrass habitat in the open waters of Massachusetts, including Cape Cod Bay. These open waters are an important habitat for eelgrass, containing about twice the acreage of the shallow water embayments. From Costello and Kenworthy (2011):

> The open water shelves are important resources providing a large amount of fish, shellfish and wildlife habitat, as well as other important ecological services. One of the most important services they can provide is a source of new propagules from the production of flowers and seeds (Orth et al. 2006b). The large and widely distributed open water meadows are likely to be one of the most important sources of potential new recruits for the coastal embayments, especially those which were impaired or remediated (Erftemeijer et al. 2008). To a certain extent, the open water seagrass beds may appear less vulnerable to land derived stressors than the embayments; however, they are not isolated from the direct environmental effects of climate change (e.g., rising water temperature, shoreline destabilization, severe

storms) or the potential anthropogenic impacts from channel and harbor maintenance, beach renourishment and the development of alternative energy sources in the coastal zone (wind farms).

Eelgrass research was incorporated into the CCBMP in 2007. This work is ongoing and includes aerial mapping as well as monitoring environmental conditions (light, temperature, water quality), biological parameters (shoot density, epiphytic biomass) and sediment characteristics (grain size) in and around eelgrass beds.

Aerial Mapping

PCCS is collaborating with LightHawk, a volunteer-based aviation organization that provides flights to environmental organizations. With them, we are conducting aerial surveys three times a year to photo-document the presence and extent of eelgrass habitat throughout Cape Cod Bay and to capture seasonal and inter-annual changes. These flights provide an ideal platform from which to monitor for large-scale changes.

Environmental Monitoring

In 2008 PCCS began to look at finer-scale characteristics of eelgrass beds. Five sites located off of Provincetown, Eastham, Plymouth and Wellfleet were chosen based on geographic and ecological diversity (Figure 18). Additional factors considered in site selection included degree of disturbance from natural and/or anthropogenic factors.

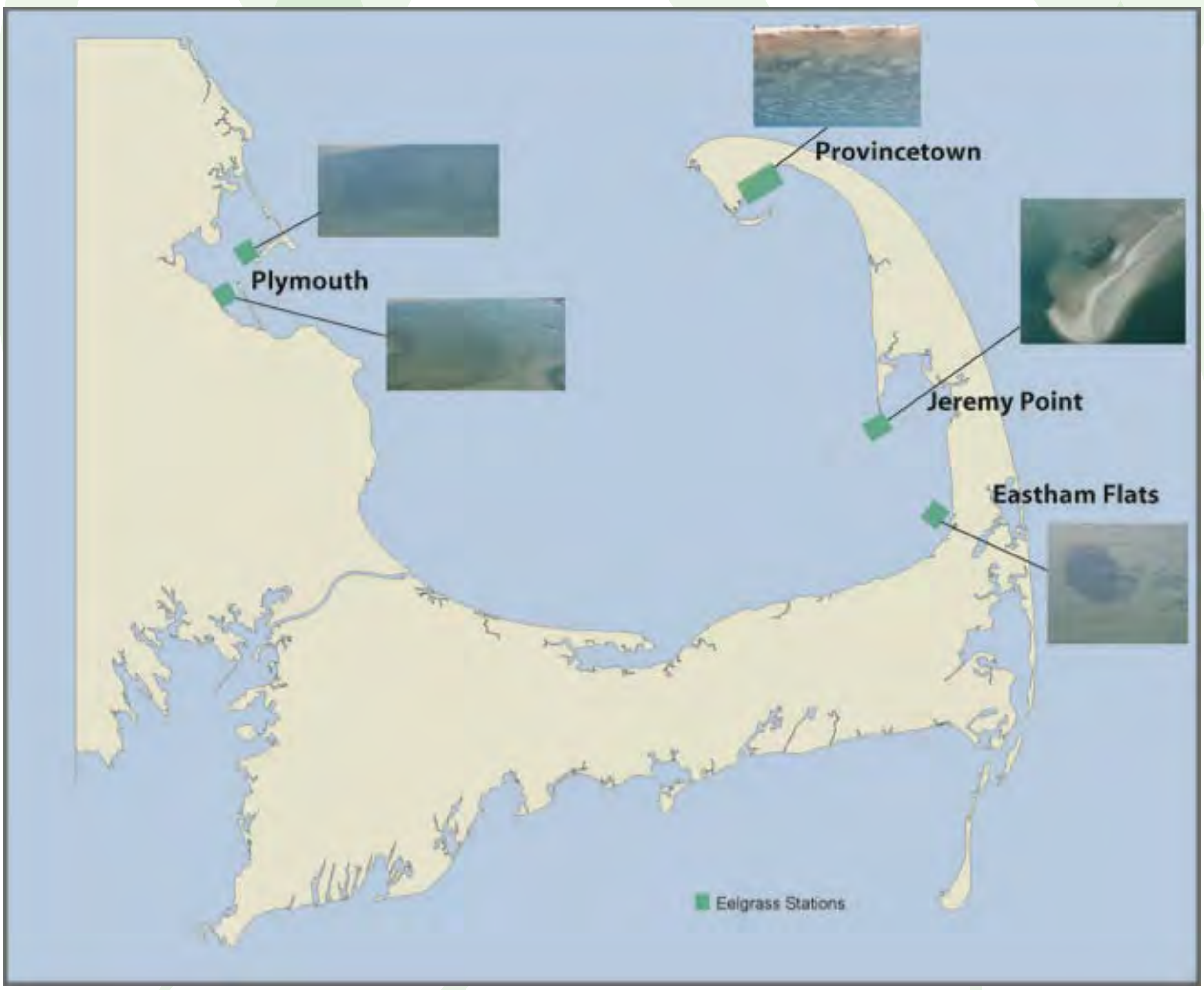
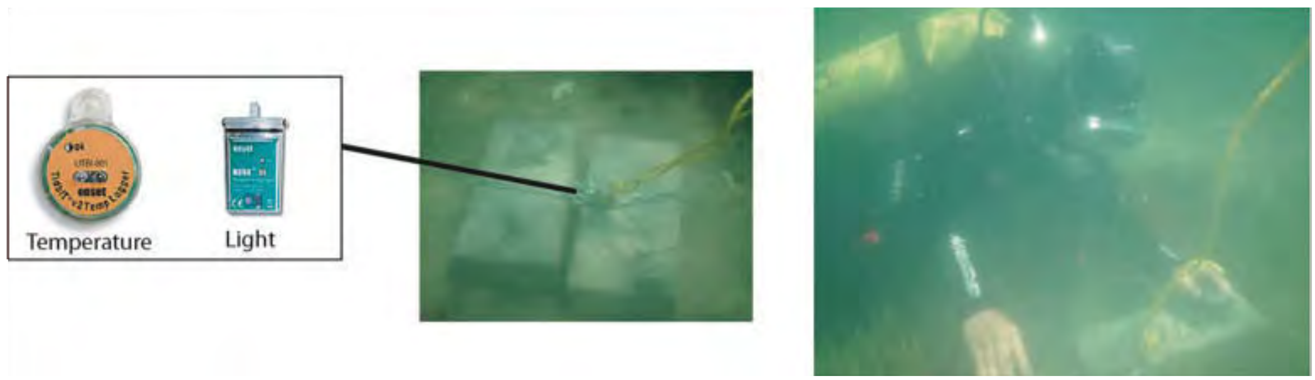


Figure 18. Map of PCCS eelgrass monitoring locations

Figure 19. Underwater sensors deployed in select eelgrass beds to continuously record temperature and light.



SCUBA divers placed underwater sensors on moored buoys in the selected eelgrass beds. These sensors continuously record light and temperature data (Figure 20), both of which are instrumental in determining the distribution, productivity and survival of eelgrass. The collection and analyses of these data from multiple sites over time give insight into the variation in eelgrass habitat health we observe at these sites.

Habitat Characterization

In 2009, PCCS collected additional data from three of the five selected sites (Jeremy Point, Eastham Flats and the southernmost site in Plymouth) on eelgrass habitat and the plants themselves, including information on shoot density, shoot length, epiphytic load and sediments.

Shoot density and length are measures of eelgrass biomass and provide an estimate of above-ground productivity and structural complexity. Dense and long shoots tend to provide a better habitat and contribute more organic matter to the detrital food web.

Epiphytes are organisms that settle and grow on other surfaces. Epiphytes of eelgrasses include algae, bacteria, fungi, sponges, bryozoans, tunicates, protozoa, hydroids, crustaceans and mollusks. Epiphytes provide food for many marine organisms. However, if epiphytic growth becomes too dense on eelgrass blades, it negatively affects the eelgrass by shading it and competing for nutrients. What is “too dense?” The answer depends on many factors, such as the health of the bed, the age and size of the grass blades, the turbidity of the water and more.

Surface sediment samples are collected to determine the grain size and their distribution in and around the eelgrass beds. Although eelgrass can colonize any area providing that the sediments are unconsolidated, some substrates are better than others. Sediment grain size directly affects the rate of aeration in the substrate, which is important for successful rooting and growth of eelgrass (Candal 2005). In well-established eelgrass beds, sediments are typically fine with a high organic content. However, in areas targeted for restoration, coarser grain size is preferred, because transplants may need more oxygenated substrates (Leschen et al. 2010).

Observations and Results

The aerial surveys of eelgrass habitat conducted by PCCS and LightHawk, following the findings of Costello and Kenworthy, have concentrated on open water areas of Cape Cod Bay. Although our mapping is not quantitative, there has been clear evidence of decline in some areas and expansion in others. While certain areas that have been denuded of eelgrass recover over the course of one growing season, other areas that in our early surveys supported dense growth remain only sparsely covered in eelgrass at present. These changes in abundance are likely natural variations common to eelgrass beds found in high energy environments such as the open waters of Cape Cod Bay (Bell et al. 2006).

The fieldwork PCCS has conducted on environmental parameters and habitat characteristics in eelgrass beds in Cape Cod Bay has yielded information important to understanding the seasonal and inter-annual variability observed in the aerial surveys. Time of day, season, tidal cycles, weather and wind strength and direction all influence water temperatures and light availability, thereby impacting the distribution, productivity and survival of eelgrass.

There were striking differences observed in the different beds studied in Cape Cod Bay. For example, shoot length varied greatly among sites, with lengths ranging from less than 10 cm in some areas (Jeremy Point) to over a meter long at others (Plymouth and Kingston Bays). The epiphytic load on the eelgrass shoots also varied among the sampling sites (Figure 20). Over the course of the growing season, epiphytic load increased at most locations. There were notable differences among sites in both the types of epiphytes and their biomass. On average, the Plymouth site had less epiphytic growth than the other sites.

Figure 20. Ephiphtyes colonizing eelgrass blades in the different monitoring sites: a) Eastham Flats, b) Jeremy Point, c) Plymouth.

Grain size was finest at Plymouth, with sediments mostly <0.25 mm, and coarsest at Jeremy Point, with the majority of sediments ranging between 1.0-0.5 mm. At the Eastham Flats eelgrass bed, most sediments were of medium grain size, ranging between 0.25-0.5 mm (Figure 21).

In general, among the sites studied, there were notable differences in biological, physical and environmental characteristics. In open water eelgrass beds, the level of exposure impacts the structure and morphology of the eelgrass habitat. More exposed beds, such as the one located off of Jeremy Point, have coarser sediments, shorter shoots and are very patchy. The more sheltered beds, such as the ones in Plymouth and Kingston Bays, have finer, more organic-rich sediments, denser coverage and longer shoots. The bed on the Eastham Flats falls between the other two sites with respect to exposure, and this is evident in the habitat characteristics. Despite the differences, all sites support healthy eelgrass beds that have adapted to their respective environmental conditions.

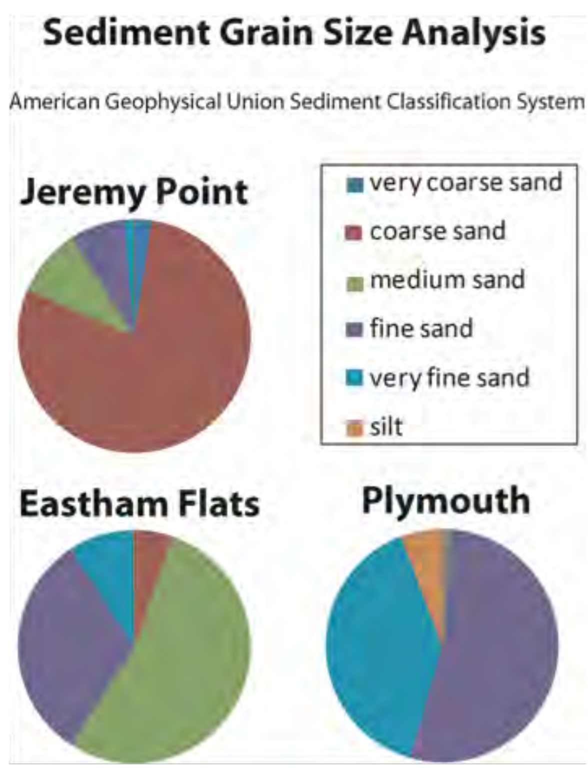


Figure 21. Results of sediment grain size analysis from 3 eelgrass beds.

How is Our Bay?

Of concern, however, is the evidence of physical destruction to eelgrass habitat in Cape Cod Bay. Photographs taken during our aerial surveys clearly document scars in eelgrass beds from commercial fishing practices, such as hydraulic dredging. Also, the chains of traditional moorings found in harbors throughout Cape Cod Bay have denuded eelgrass, leaving very characteristic circular scars (Figure 21).

PCCS/LightHawk

Figure 22. a) mooring block, chain and scar in eelgrass bed. The light color is bare sand surrounded by darker eelgrass bed. b) aerial view of Provincetown Harbor. The light circular patches are areas that have been denuded of eelgrass by mooring chains.

PCCS survey boat heading out for a day of sampling

Invasive Species

Invasive species are organisms that are "non-native (or alien) to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health" (ISAC 2006). These species often flourish in the environment they've been introduced to because, unlike in their native environments, there may not be predators or other natural controls to keep the species in check.

A cement block encrusted with several species of invasive tunicates (*Botrylloides violaceus, Botryllus schlosseri, Didemmun vexillum, Styela clava*) recovered from one of our monitoring sites.

The ecological and economic impacts of invasive species are extensive. Studies estimate that invasive species (both aquatic and terrestrial) are costing the U.S. over $100 billion a year in environmental losses and damages. Ecologically, invasive species are detrimental to native species through competition for resources, introduction of diseases and predation. For example in some areas of Cape Cod Bay, invasive species have smothered and/or replaced eelgrass beds. Offshore on Georges Bank, colonial tunicates have formed mats on the sea floor, covering gravel habitat important for young cod and haddock.

Marine invasive species are introduced through a variety of pathways. One of the oldest sources of marine invasive species is the shipping industry. When ballast water from ships is discharged, so are the associated organisms. Aquaculture of non-native species can also accidentally introduce invasive species as well as the any parasites associated with them.

A 2010 report by the Gulf of Maine Council on the Marine Environment on marine invasives in the Gulf of Maine notes that the increase in the number and abundance of marine invasives may reflect increases in pressures on the ecosystem. In addition to the introduction of invasives from ballast water and fouling of ship hulls, pressures include the increasing and denser human population and our associated economic and social activities. Our activities can result in "pollution, habitat modification and climate change which may alter survival rates and interactions of native and non-native species" (Gulf of Maine Council 2010).

In 2007, PCCS teamed up with the Massachusetts Coastal Zone Management's Aquatic Invasives Species Program to monitor for marine invasive species through the Marine Invader Monitoring and Information Collaborative (MIMIC). Volunteers were trained to use standardized monitoring protocols to collect data on the presence and abundance of sixteen established and seven potential marine invasive species at select sites. PCCS volunteers have monitored sites in Sesuit Harbor, Rock Harbor, Wellfleet Harbor, Provincetown Harbor and Pamet Harbor.

Observations and Results

At all of these sites, several different invasive species have been identified (Table 2). A complete list of marine invasive species and sites monitored in Massachusetts' waters can be found at www.mass.gov/czm/invasives.[6]

Species	Common Name
Botrylloides violaceus	Sheath tuniccate
Botryllus schlosseri	Golden star tunicate
Bugula neritina	Purple bushy bryozoan
Caprella mutica	Skeleton shrimp
Carcinus maenas	Green crab
Codium fragile ssp. fragile	Green fleece
Diadumene lineata	Striped anemone
Didemnum vexillum	"Mystery" colonial tunicate
Diplosoma listerianum	Diplosoma tunicate
Hemigrapsus saguineus	Asian shore crab
Membranipora sp.	Lacy crust bryozoan
Styela claya	Club tunicate

Table 2. Marine invasive species identified by PCCS volunteers at harbors in Cape Cod Bay.

Invasives and Eelgrass: Keeping Watch

The alga *Codium fragile* and the tunicate *Didemmun vexillum* are of particular concern in Cape Cod Bay because both negatively impact eelgrass habitat. *Codium* has replaced productive eelgrass beds in some areas, and *Didemmun* is known as an aggressive spreader that, once established, can completely smother native flora and fauna. *Didemmun* was first detected in northern Massachusetts waters in 2007 and is now, as noted above, in a number of locations throughout Cape Cod Bay.

Controlling the introduction and spread of invasive species is a daunting challenge. Monitoring efforts are key to tracking the occurrence and expansion of these organisms. Good data are essential to addressing the impacts of invasive species.

Overall, keeping track of invasive species in conjunction with our work on water quality and eelgrass is important to understanding the interconnections of the Cape Cod Bay ecosystem

The invasive alga, *Codium fragile*, growing within an eelgrass bed

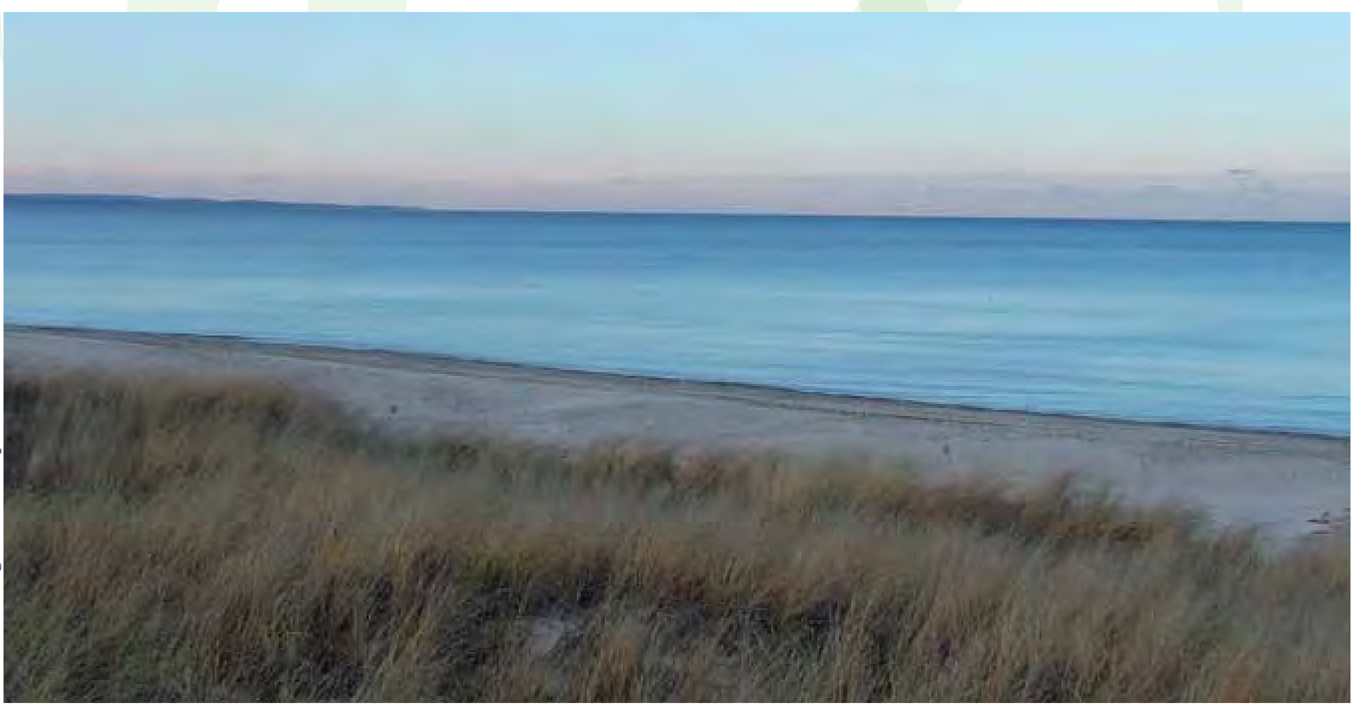


Photo: Cape Cod Commission (www.capecod-commission.org); used with permission

Pharmaceuticals

The most recent expansion to the CCBMP focuses on the detection of organic wastewater contaminants and pharmaceuticals in Cape Cod Bay. These contaminants include medicines, personal care products and cleaners and consist of thousands of different types of chemical compounds.

There is very little completed research on the human and environmental health effects of exposure to low levels of these types of compounds. The impacts to marine systems are poorly understood, although research has shown that some of these contaminants disrupt the endrocrine system of fishes (Bay et al, 2011).

Cape Cod is particularly prone to the introduction and persistence of these types of contaminants due to its porous soils and prevalent reliance on septic systems. In addition, Cape Cod has an aging population: the median age of Cape Cod residents is the highest in Massachusetts—50 as compared to the state median age of 39 (Stats Cape Cod, 2012). An older population generally means increased medication in the community and, thus, increased presence of pharmaceuticals.

In the spring of 2010, PCCS conducted a one-time sampling program to determine if there are detectable levels of select contaminants in Cape Cod Bay and in several creeks and embayments that drain into the bay. Six samples were collected from five sites (see Figure 1 for sampling locations). In collaboration with researchers from University of Massachusetts Boston, each of these samples was tested for carbamazepine, sulfamethoxazole and trimethoprim.

Carbamazepine is classified as an anticonvulsant/mood stabilizer. Trimethoprim and sulfamethoxazole are antibiotics.

These compounds were chosen because their chemical composition is such that they are resistant to natural degradation processes and have been detected in fresh water on Cape Cod.

In 2009, Silent Spring Insititute (SSI) tested for a number of chemicals including pharmaceuticals in the public drinking water supplies of six towns to learn more about how septic systems and other sources of groundwater contamination are affecting water quality on Cape Cod. In 2010 SSI continued this work, testing private drinking water supplies in seven Cape towns. These studies showed that chemicals from wastewater can seep from septic systems into groundwater and make their way into drinking water. SSI found that, in both private and public Cape Cod drinking water wells, some compounds were present at levels as high or higher than reported elsewhere in the United States (Schaider, 2011).

Observations and Results

The results of this initial field survey conducted by PCCS indicate that four of the five sites had a detectable level of at least one of the contaminants for which we tested. Because the results of this survey are preliminary, they are not detailed in this report.

Knowing that detectable levels of these contaminants are present in Cape Cod Bay waters, PCCS is building on these initial results and testing for additional contaminants at multiple sites over a longer period of time. This more extensive sampling will allow PCCS to offer more detail on ecological impacts, sources of contamination and persistence of pharmaceuticals in the Cape Cod Bay ecosystem.

Photo: Cape Cod Commission (www.capecodcommission.org); used with permission

Summer brings many visitors to Cape Cod

Photo: Elizabeth Bradfield

What are the Major Threats to the Bay's Water Quality?

The major threats to the health of Cape Cod Bay and its resources come primarily from activities within the Bay's watershed—the geographic area in which all sources of water, such as groundwater, ponds, rivers, streams, wetlands and embayments, drain into it. The bay's watershed is large—almost 600 square miles—and has experienced a 123% increase in population accompanied by increased land development over the past 50 years. The amount of land in urban and residential development in Barnstable County has tripled and comprises over 30% of the county, while in Plymouth County land in urban and residential development has nearly quadrupled and comprises nearly 28% of the county.

Contaminants in Groundwater

Much of the soil in the Bay's watershed is composed of a porous mixture of sands, gravel and clays. Porous soils provide favorable conditions for infiltration of rainfall and for extraction of groundwater for drinking water. At the same time, porous soils allow pollutants to easily enter groundwater, making it highly susceptible to contamination from a number of sources, including but not limited to road runoff, septic tanks, leaking storage tanks and fertilizers and pesticides. Ultimately, these contaminants also end up in Cape Cod Bay. The Bay's watershed encompasses the two largest sole-source aquifers in Massachusetts—Cape Cod Bay and Plymouth-Carver. Both have highly permeable soils that are at risk for contamination.

Threats to the Quality of Cape Cod Bay

Increases in:

Population ~ the year-round population in Barnstable County increased by 207% between 1960 (96,656) and 2010 (215,769).

Development ~ there was a 193% increase in housing units built in Barnstable County and a 109% increase in Plymouth County between 1960 and 2010. Year-round housing increased by 23% in Barnstable and 40% in Plymouth counties

Wastewater ~ the Cape Cod Commission estimates that 85% of the wastewater discharged into the Cape's coastal waters comes from on-site septic systems. In 2003 an estimated 32 million gallons per day of wastewater were generated by all 15 Cape Cod towns (8.5% of MWRA generation)

Impervious Surface Area ~ increased development results in more hardened surface areas and water quality begins to decline when 10% of the watershed is covered by impervious surface and severe degradation occurs at 25% The lower Jones River watershed is 17 % impervious and Plymouth Harbor is 22% impervious. For comparison, the Metro Boston area is 35% impervious.

Runoff & Impervious Surfaces

Another source of pollution to coastal waters is runoff from impervious surfaces. Impervious surfaces are hard surfaces such as roofs, roads, parking lots and compacted soil which prevent rain and melting snow from soaking into the ground. In addition to increasing the amount of runoff, impervious surfaces affect groundwater quality and quantity by preventing the natural filtration and biological processes that remove pollutants and nutrients as water soaks into the ground. Runoff carries nutrients, hydrocarbons and bacteria, discharging them into coastal waters.

The 2010 Massachusetts Bays Program's State of the Bays report notes that "a review of nationwide studies found that stream water quality begins to decline when 10% of the watershed is covered by impervious surface and that severe degradation occurs at 25%."

According to the Center for Watershed Protection:

- an area with less than 8% impervious surfaces is considered "sensitive"
- 12-20% is considered "threatened"
- more than 20% is considered "non-supporting" or urbanized

Based on these criteria significant portions of the Cape Cod Bay watershed, specifically four coastal regions, fall within the "threatened" category due to the extent of impervious surface coverage in their watersheds. Impervious surface area coverage in individual subwatersheds of the Cape Cod Bay watershed include:

- Kingston Bay: 16% impervious
- Plymouth Harbor: 22%
- Provincetown Harbor: 10.9%
- Brewster's Cape Cod Bay subwatershed: 11.7%

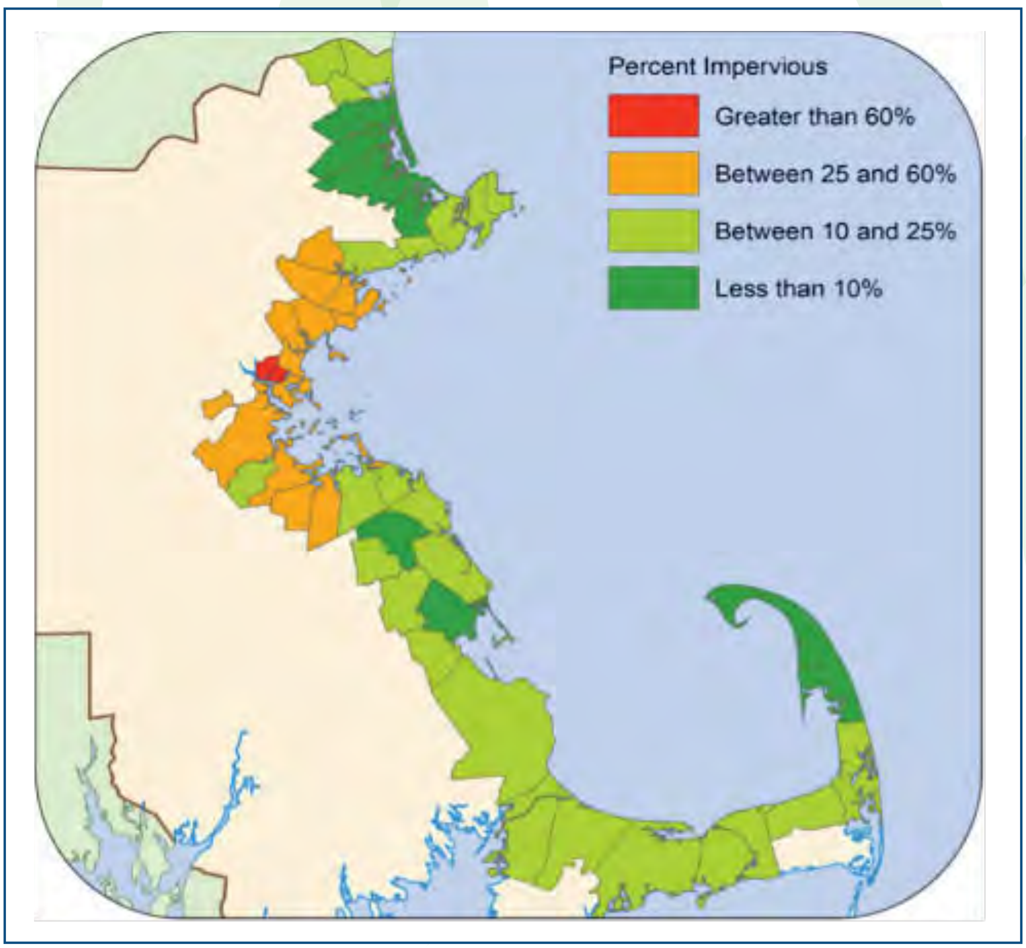


Figure 23. Percent Impervious Surface Area in Massachusetts Bay Watershed from Massachusetts Bays Program 2010 State of the Bay Report.

Nitrogen

Through its assessment of coastal watersheds, the Massachusetts Estuaries Project (MEP) is identifying the sources of nitrogen and estimating the nitrogen load from land uses, including wastewater, fertilizers and impervious surfaces. The MEP reports state that the primary nutrient causing the increasing impairment of the Commonwealth's coastal embayments is nitrogen, and the primary sources of this nitrogen are wastewater, fertilizers and changes in the freshwater hydrology associated with development. The largest contributor of nitrogen in most of the embayments with final MEP assessments is estimated to be septic systems. For example, the final report for the Namskaket Marsh Estuarine System, shared by Brewster and Orleans, identifies septic systems as contributing 53% of the nitrogen load to this coastal system (Howes, et.al. 2007).

Figure 24 presents data from the 2003 Final Report on the Cape Cod Comprehensive Regional Wastewater Management Strategy Development Project, prepared by the Cape Cod Commission's Water Resources Office. It depicts the estimates of then-current volumes of wastewater flow from the watersheds of each of Cape Cod's coastal embayments, and ultimately into the Cape's coastal waters.

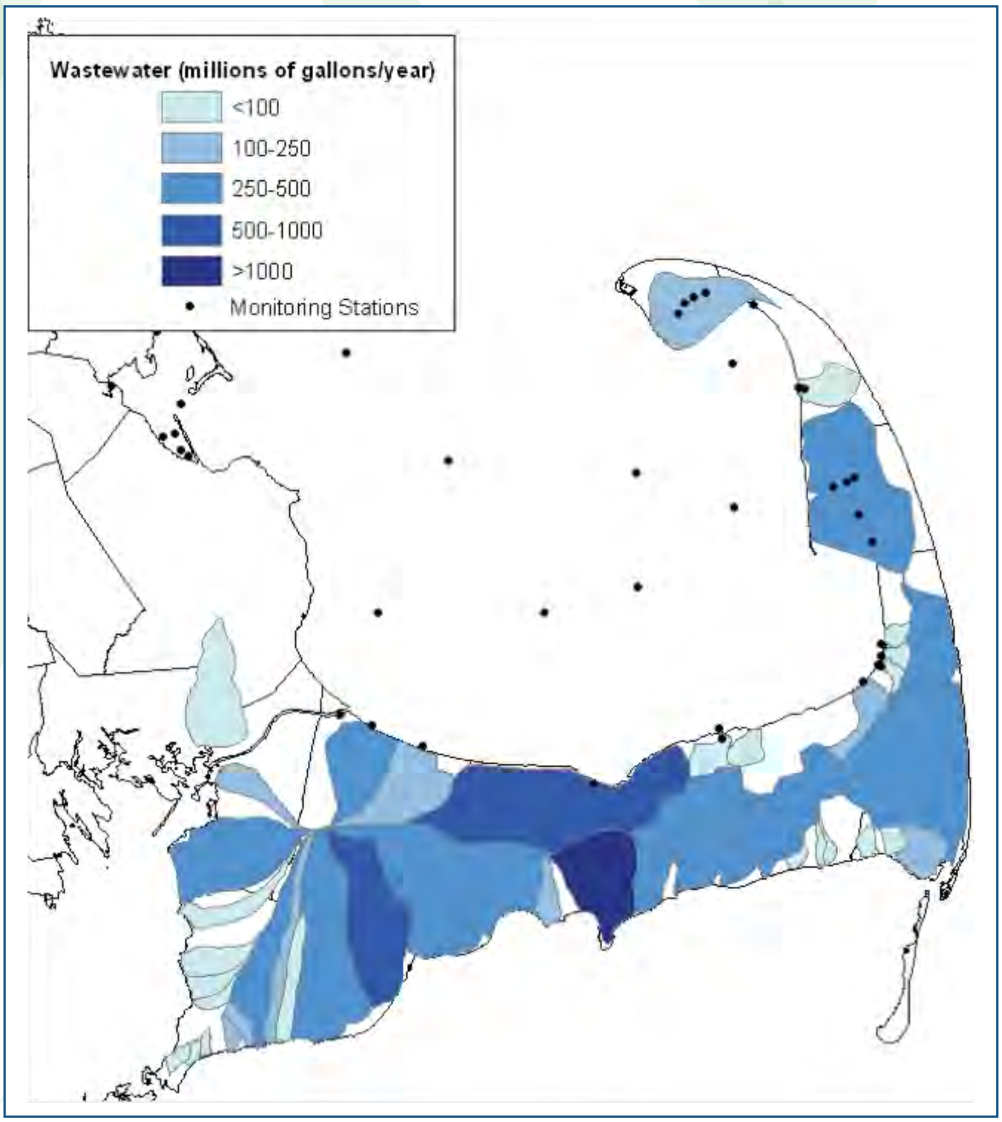


Figure 24. Map of Barnstable County's 48 major Marine Water Recharge Areas (MWRAs) and the estimated wastewater flow (millions of gallons per year). Black circles denote the locations of PCCS water quality stations monitored during the years covered in this report (2006-2010).

Habitat Destruction

Nutrient enrichment, runoff and other human-related activities impact eelgrass habitat and may create conditions conducive to invasive species establishment. With regard to eelgrass, direct impacts of human activities include destruction of habitat from boating activities, docks, mooring chains, dredging and some types of commercial fishing. Thus, in many cases, eelgrass recovery and colonization of suitable habitat is exacerbated by human interference.

The Future of Monitoring

PCCS plans to continue its monitoring of the health of Cape Cod Bay. We will analyze the data from our 2011 and 2012 field season using the Seasonal-Kendall Analysis to identify trends in water quality parameters. The data for all 7 years of sampling (2006-2012) will then be compared to the 5 years of data contained in this report. We will also update the presentation of data by coastal watershed, as shown in Figure 25.

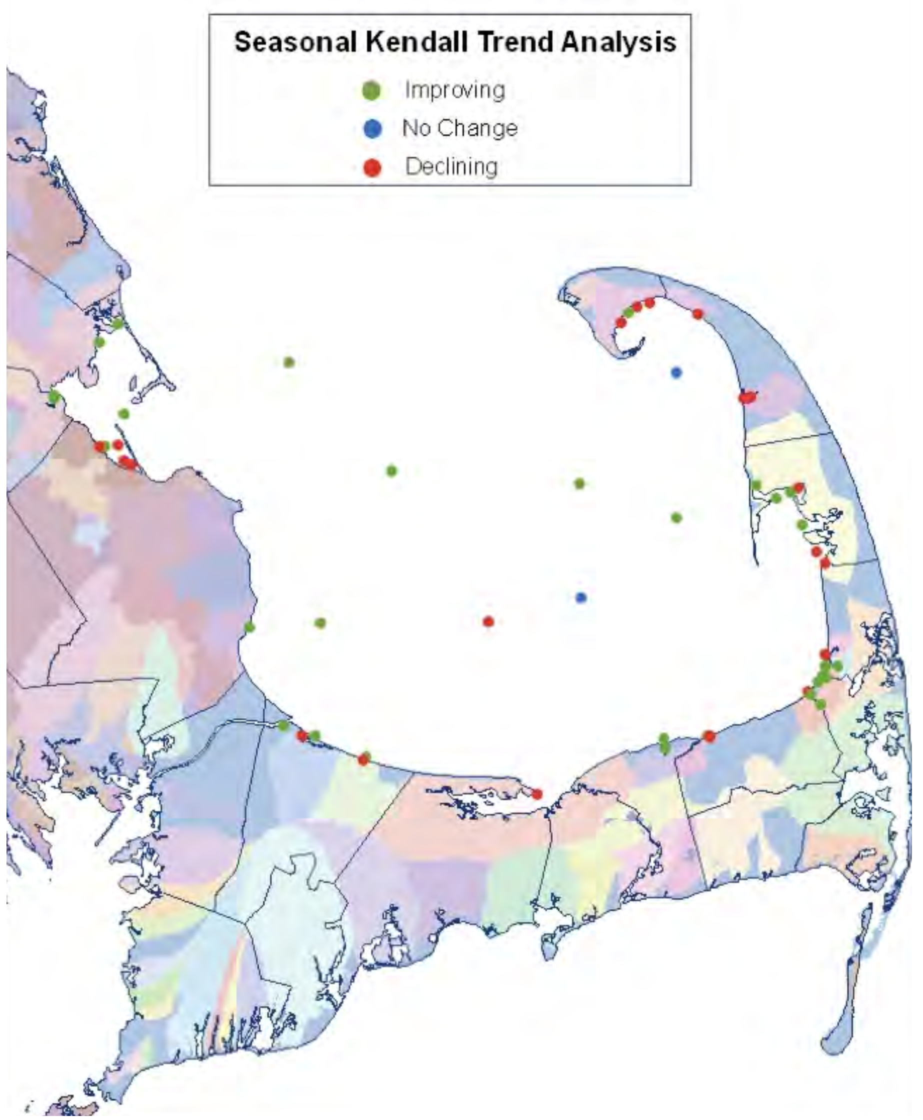


Figure 25. Map showing coastal watersheds and overall trends in water quality determined by combining the results of the Seasonal Kendall Trends analysis for chlorophyll *a*, temperature, nitrogen and turbidity (2006-2010).

Sources and Impacts of Nonpoint Pollution to Cape Cod Bay and its Watershed

Sources	Resulting Threats	Impacts
Urbanization • On-site septic systems • Road and building construction • Land clearing • Hardening of surfaces • Fertilizer and pesticide use • Destruction of natural vegetation • Wetland and riparian area destruction • Irrigation **Agriculture and Maintenance of Commercial Properties** • Fertilizer and pesticide use • Irrigation • Destruction of Natural Vegetation **Coastal-Marine Activities** • Marinas and Boatyards • Boat basins and mooring areas	• Increase in nutrients • Increase in pollutants—hydrocarbons, heavy metals, pesticides • Increase in pathogens—bacteria and viruses • Increase in erosion • Increase in deposition of sediment	• Habitat degradation and loss—wetlands, eelgrass beds, shellfish beds • Increase in water temperatures • Decrease in dissolved oxygen • Shellfish bed closures • Algal blooms • Decline in species health • Loss of species abundance • Potential increase in invasive species

A Closer Look at Three Watersheds

Several watersheds are showing signs of improving water quality. As noted earlier in this report, while none of the trends are statistically significant, a more lenient analysis of the data suggests conditions are improving at sites such as the Jones River Watershed and the Wellfleet Harbor Watershed. Other watersheds, such as Provincetown Harbor, are not faring as well and appear to be experiencing a decline in water quality conditions. A detailed examination of these three sites might provide models and ideas for other communities that are addressing their water quality problems or are interested in taking action.

Jones River Watershed

The trend analyses of two stations in the Jones River Watershed (Figure 26) show improving conditions: chlorophyll is decreasing, nitrate and turbidity levels are either decreasing (as observed at the mouth of the river) or staying nearly the same (town landing). Temperatures are also slightly decreasing (Appendix A).

Actions taken by the town and local environmental groups have likely contributed to improvements in water quality. The Town of Kingston expanded its sewer system in 2008 to include some very problematic areas that affect the Jones River watershed.[7] The Town of Kingston and the Jones River Watershed Association (JRWA) worked together on land protection efforts along the Jones River and in 2011 were successful in purchasing ten acres of upland and marsh adjacent to the estuary. Continued improvement in water quality is expected in future years as a result of the removal of the Wapping Road Dam, a project completed in the fall of 2011. This project was spearheaded and overseen by the JRWA.

Photo: PCCS/LightHawk

Figure 26. Sampling locations included in water quality analysis of the Jones River watershed.

Wellfleet Harbor Watershed

Six stations were included in the analysis of the health of the Wellfleet Harbor watershed (Figure 27). Water quality conditions appear to be improving here. While two stations (Inner Wellfleet Harbor and Sunken Meadow) showed a slight decline in water quality, four stations showed improvement. Chlorophyll levels at all stations declined. Nitrate levels declined at two, showed no change at two and increased slightly at two. Turbidity increased at three stations, showed no change at one and decreased at two stations. Water temperatures increased slightly at all stations except Herring River (Appendix A).

The Town of Wellfleet has been working to improve water quality in its coastal waters, including substantial improvements to the public marina. As part of the reconstruction of the marina, completed in 2008, catchment basins were installed to provide better runoff control at the pier and roads near the harbor. In addition, septic systems were upgraded in problem areas within the watershed.

A smaller-scale project that could contribute significantly to improved water quality in the future is an oyster reef started by the Wellfleet Wastewater Planning Committee. This 1.3 acre site is located at the mouth of Duck Creek, which drains directly into Wellfleet Harbor. The goal of the project is to use shellfish enhancement as a practical and cost-effective approach to improving water quality as well as contributing to the shellfishing industry. More information can be found in the Project Work Plan for Wellfleet Harbor Oyster Spawning Project, April 2011, Town of Wellfleet Comprehensive Wastewater Planning Committee.

Photo: PCCS/LightHawk

Figure 27. Sampling locations included in water quality analysis of the Wellfleet Harbor watershed. Blackfish Creek and Sunken Meadow stations are not visible in photograph.

Provincetown Harbor Watershed

Three of the four stations that fall within this watershed (Figure 28) are showing declines in water quality. Nitrate concentrations are increasing at three of the four stations, as are water temperatures. Although turbidity is increasing at only one station and chlorophyll levels are decreasing, overall water quality for this watershed appears to be declining (Appendix A).

The station where water quality appears to be improving, just to the east of MacMillan Pier, is the deepest station sampled in the harbor. The three other stations are in eelgrass beds with a depth of less than 1 m at low tide. PCCS will focus some of its eelgrass monitoring work in this area in the coming years to track changes in habitat health that could be caused by this declining trend in water quality.

Provincetown has taken several major steps to stop the degradation of its coastal waters, including sewering the downtown, a project begun in 2001, and converting several stormwater outfall pipes to infiltration systems. However, the effects have not yet been observed. Also of concern are the steady, and surprisingly high, rates of beach closures in Provincetown due to high *Enterococcus coliform (E. coli)* bacteria levels. *E. coli* are used as an indicator of the possible presence of human pathogens. Research is being conducted by scientists at the Woods Hole Oceanographic Institute, Massachusetts DEP and the EPA to determine whether the bacteria is from humans, birds or other animals.

Upcoming projects that could improve water quality include a paving project for Commercial Street that will use permeable materials to allow for a natural filtration process and a beach raking pilot program. The raking project could help lower the rates of beach closures by removing debris from the beaches that harbor high numbers of bacteria. Positive and negative impacts of this raking program on the beach environment are being closely monitored by PCCS.

Photo: PCCS/LightHawk

Figure 28. Sampling locations included in water quality analysis of the Provincetown Harbor watershed.

What is Being Done to Improve and Protect Cape Cod Bay and its Watershed?

This report highlights the multiple uses and high value of Cape Cod Bay and its watershed and the resources that are reliant upon clean water and healthy habitats. Concern over the protection and restoration of these resources and habitats is not new. The first European settlers to this region overfished its waters and, by the mid-1600s, were regulating fishing activity. After more than 300 years of filling in wetlands and intertidal flats, in 1963 Massachusetts was one of the first states to enact a law protecting coastal wetlands.

Over the past fifteen years, towns within the Cape Cod Bay watershed have been addressing wastewater treatment and some, including Kingston and Plymouth, have improved and expanded their municipal wastewater treatment facilities. While the CCBMP indicates a decline in overall water quality throughout the Bay, this decline is not the result of inaction.

There are a great number of local, regional, state and federal watershed planning and management efforts in the Cape Cod Bay watershed. These efforts encompass various scales from Bay-wide to site-specific. A limited selection of these efforts with web links to most is described below. These select examples are intended to be a starting point for towns and communities as they consider future courses of action and possible resources for further information and/or partnerships.

Local

Wastewater and Stormwater Efforts

Most coastal communities in the Cape Cod Bay watershed are in various stages of addressing wastewater and stormwater management. Much of the impetus for engaging in wastewater planning for many towns has been the analysis and reports of the Massachusetts Estuaries Project. In some towns, such as Orleans, local citizen groups have been active over the years in monitoring water quality in the town's ponds and estuaries and raising citizen awareness of declines in water quality and ways to address these problems.

Town departments direct their efforts towards pol-

Photo: Natural Resources Department, Town of Brewster

lution identification and remediation. For example, natural resource and public works departments in the towns of Barnstable, Dennis, Brewster, Orleans, Eastham, Provincetown and Wellfleet have worked together on controlling and treating stormwater discharges into coastal waters.

The Town of Sandwich required upgrades to septic systems and implemented stormwater treatment actions to improve coastal water quality in the harbor and Scorton Creek area. These actions allowed the Massachusetts Division of Marine Fisheries, in 2009, to re-open two shellfish harvesting areas in Sandwich totaling 210 acres. These areas had been closed due to pollution, one for over twenty years.

The Town of Plymouth is implementing a Nutrient Management Plan required by its state permit to operate its wastewater treatment facility. The treatment facility is located in the Eel River watershed, which discharges into Plymouth Harbor. The plan is multi-faceted and includes land acquisition, particularly buffer areas, stormwater treatment and wetland restoration.

In 2011 the Town of Kingston received funding from the Massachusetts Bays Program to establish baseline water quality conditions and develop preliminary design plans from which the Town will prioritize and implement storm water remediation projects. The ultimate goal is to open and/or improve approximately 1,300 acres of shellfish growing areas in Kingston Bay.

Management Plans

Some towns have developed harbor plans or management plans for coastal waters under their jurisdiction. The Town of Duxbury's Master Plan included the development of a Bay Management Plan. Appointed by the Board of Selectmen, the Duxbury Bay Management Study Committee completed a draft Duxbury Bay Management Plan in 2005. The Management Plan addresses a number of issues.

Plan highlights include recommendations for monitoring water quality, identifying storm drains for implementation of best management practices, reducing and/or eliminating town use of pesticides and fertilizers through implementation of integrated pest management plans, boating speed restrictions to protect sensitive resources such as eelgrass and salt marshes and designation of areas of critical marine habitat in which new and relocated moorings would be prohibited.

Promoting Public Awareness and Citizen Action

There are a number of grassroots organizations that focus on their town coastal waters and ponds. These organizations contribute to public discussion about protecting coastal waters and natural resources. For example the Friends of Ellisville Marsh coordinate and participate in a multi-disciplinary environmental monitoring program of Ellisville Harbor, a state-designated Area of Critical Environmental Concern with the town of Plymouth (www.ellisvillemarsh.org).

The Orleans Pond Coalition has long been an advocate for the waterways of Orleans. The Coalition began monitoring fresh water quality over twenty years ago. Recognizing the importance of monitoring water quality, the Town of Orleans has taken on this responsibility. The Coalition's work has been incorporated into town and citizen actions on stormwater management and land protection (www.orleanspondcoalition.org).

For the past nine years the Town of Wellfleet has hosted an annual State of Wellfleet Harbor Conference to share information about current and ongoing research, monitoring projects and issues related to Wellfleet Harbor and its watershed. New projects and changes to ongoing projects have been initiated based on discussions at these conferences.

Regional

Barnstable County Agencies

Barnstable County agencies, specifically the Cape Cod Commission (CCC) and the Department of Health and Environment (BCDHE) have a number of programs and initiatives that relate to water quality protection, monitoring and improvement. One of the key goals of the County's Regional Policy Plan, implemented by the Cape Cod Commission and Cape Cod towns, is to maintain the overall quality and quantity of Cape Cod's groundwater to ensure a sustainable supply of high quality untreated drinking water and to preserve and improve the ecological integrity of both marine and fresh surface waters.

Early work by the CCC identified nitrogen-sensitive estuaries and embayments and led to Cape-wide nitrogen standards for wastewater treatment. The CCC has been active in regional wastewater planning initiatives and, in 2003, developed a regional assessment of wastewater planning and land-use analysis. The CCC continues to support wastewater planning and implementation efforts and is developing tools for the region to use as they explore various management alternatives and evaluate the full spectrum of existing treatment options (http://www.capecodcommission.org/index.php?id=170&maincatid=49).

In 1999, the BCDHE established the Massachusetts Alternative Septic System Test Center (MASSTC), supported with grants from state and federal sources. The Center tests new pollutant-reduction technologies and disseminates this information to towns for possible incorporation into their comprehensive wastewater planning efforts. BCDHE also maintains a tracking database for all the innovative and alternative on-site septic systems in use on Cape Cod, designed to improve tracking of performance and compliance with permit requirements. In addition, BCDHE manages the routine monitoring of public and semi-public beaches for bacteria. It maintains a yearly summary of information for all public beaches and issues annual reports to respective town boards of health (http://www.barnstablecountyhealth.org/ia-systems).

The CCC and the BCDHE, along with representatives of each town on the Cape, participate in the Cape Cod Water Protection Collaborative (CCWPC). CCWPC is organized under the auspices of Barnstable County to provide a coordinated approach to enhance water and wastewater management efforts of towns, the regional government and the broader community. The Collaborative has obtained funding from state and regional sources and invested it in studies and analyses of regional and local wastewater management approaches as well as a peer review of the Massachusetts Estuaries Project. In February 2012, the Barnstable County Commissioners directed the CCC and the CCWPC to investigate regional wastewater management planning approaches.

South Coastal Watershed Action Plan

In 2006 a collaborative effort among the Jones River Watershed Association, North and South River Watershed Association, Eel River Watershed Association, Pembroke Watershed Association and Six Ponds Watershed Association completed the South Coastal Watershed Action Plan (http://www.watershedaction.org/resources.html). Developed with funding and technical support from the Massachusetts Executive Office of Energy and Environmental Affairs, two Regional Planning Agencies and a number of citizens and town representatives, the plan's goals are to:

1. Improve water quality by addressing point- and non-point pollutions sources
2. Protect and restore natural aquatic habitats
3. Maintain and restore the natural hydrology of watersheds
4. Strengthen local capacity to protect and enjoy watersheds

Actions taken to implement the plan include:

- Removal of the Wapping Road dam, improvement of stormwater structures and purchase of riparian conservation land on the Jones River
- Completion of a restoration plan for two brooks feeding into the Jones River
- Water quality monitoring in the Jones River to identify priority stormwater improvement projects

Cape Cod Water Resources Restoration Project

The Cape Cod Water Resources Restoration Project (CCWRRP) is a collaborative effort of the U.S. Department of Agriculture's Natural Resources Conservation Service, the Cape Cod Conservation District and the Barnstable County Commissioners with cooperation from many federal, state and local agencies. The goal is to restore 1,500 acres of degraded salt marsh, improve fish access to 4,200 acres of spawning habitat and improve water quality for 7,300 acres of shellfish beds over ten years.

Approximately $24 million in federal funds and $6 million in local funding will be invested in the CCWRRP. After completing detailed environmental assessments and identifying likely sources of pollution, the cooperating agencies, local organizations and towns identified 76 sites throughout Cape Cod for possible restoration. These include 26 stormwater discharge sites, 26 tidally-restricted salt marshes and 24 obstructed fish passages. The CCWRRP's first project was completed in early 2011. Completed to date on the Cape's Bay side are:

- Salt marsh restoration at Sunken Meadow in Eastham
- Stormwater treatment of road and bridge run-off at Duck Creek in Wellfleet
- Stormwater treatment road and parking lot run-off at Saint's Landing Beach and Paines' Creek Landing in Brewster

Going forward, the towns and partner organizations will monitor the success of these projects through observations of marsh productivity and water quality testing (http://www.ma.nrcs.usda.gov/programs/CCWRRP/).

Monitoring, Restoration, and Protection of Eelgrass Habitat

Since 2003, the Cape Cod National Seashore, in cooperation with the United States Geological Survey, has been conducting long-term monitoring of eelgrass at two sites within the Seashore, Duck Harbor in Wellfleet and Little Pleasant Bay in Orleans. There has been great variability at the Duck Harbor site. In 2006, eelgrass in the deeper regions of their study area was uprooted by strong storm waves, and re-colonization was observed in 2008. To date, there is an overall downward trend in percent cover at all three depths monitored at the Duck Harbor site.

PCCS has been monitoring eelgrass habitat in Cape Cod Bay since 2007. In 2010, PCCS conducted the first attempt ever made to restore eelgrass in Cape Cod Bay. Although the monitoring data collected at the test restoration site indicated that the site was adequate to support eelgrass habitat, the survival of

Photo: Elizabeth Bradfield

the test transplants was very low. Possible causes of the low survival rate at this one site are bioturbation, physical stress and sediment dynamics. Significant sediment movements occurred at this site, burying some areas while scouring others.

The Barnstable County Cooperative Extension Marine Program, Woods Hole Sea Grant and The Nature Conservancy conducted eelgrass restoration trials in three Cape Cod coastal areas in 2011, including a site in Cape Cod Bay off of Truro. These sites were chosen based on a site suitability analysis and recommendations from an advisory committee. Similar to the results of the restoration study conducted by PCCS, a single year's monitoring results showed few transplanted plants alive at any of the three sites. Sediment instability at the Truro site appears to be the reason for its limited success.

Eelgrass habitat is very difficult to restore. Although restoration efforts have been successful in some areas in Boston Harbor (Leschen et al. 2010), most restoration projects have had limited success and are very expensive to implement. Protection of existing eelgrass habitat from anthropogenic disturbances is perhaps more practical, and this is being done on many levels. For example, disruptive commercial fishing practices are not allowed in eelgrass habitat. Many harbors are experimenting with replacing traditional moorings which destroy eelgrass with conservation moorings, which do not impact eelgrass habitat. Also, poor water quality, which is the biggest contributor to eelgrass habitat loss, is being addressed by local, regional, state and federal agencies as detailed above.

State

Massachusetts Estuaries Project (MEP)

Recognizing the productivity and importance of estuaries and coastal embayments, the Commonwealth of Massachusetts initiated the Massachusetts Estuaries Project in collaboration with UMass-Dartmouth to classify the nitrogen sensitivity of certain coastal estuaries and embayments. The MEP conducts detailed assessments of each watershed to determine sources of nitrogen and estimate the nitrogen load from land uses, including wastewater, fertilizers and impervious surfaces. The MEP identified 89 estuaries for study, ranked them in four priority categories and proposed a two-year cycle for completing studies in each category. The MEP is behind schedule and an updated timeline is not available.

At present, the MEP is conducting watershed assessments of Duxbury Harbor, Plymouth Harbor/Eel River, Ellisville Harbor, Sesuit Harbor, Namskaket and Little Namskaket Creeks, Rock Harbor and Wellfleet Harbor, Pamet Harbor, Provincetown Harbor and Hatches Harbor. Future studies will be done in Sandwich Harbor, Scorton Creek and Barnstable Harbor (http://www.oceanscience.net/estuaries/).

Massachusetts Bays Program (MBP)

Massachusetts and Cape Cod Bays received federal recognition as a national estuary in 1990 under a program directed by the U.S. Environmental Protection Agency. The MBP operates within the Massachusetts Coastal Zone Management Program and is responsible for investigating pollution in the bays and their watersheds. It is also charged with reducing this pollution through actions that include conservation and management of lands within the watersheds as well as protection and restoration of the bays' resources.

The MBP develops and updates a Comprehensive Conservation and Management Plan that identifies what needs to be done to maintain and improve the ecological integrity of the bays. The MBP provides technical assistance to local communities that, among a number of projects, have assisted in restoring anadromous fisheries in coastal rivers and tidal flow in wetlands. The MBP has a competitive grants program to which local communities and organizations may apply for funds to support resource protec-

Photo: Natural Resources Department, Town of Brewster

tion and restoration projects. The maximum grant amount is approximately $25,000 per project. The MBP released its latest State of the Bay report in 2010 (http://www.mass.gov/envir/massbays/).

Massachusetts Coastal Zone Management Program—Coastal Pollutant Remediation Grant Program

The Coastal Pollutant Remediation (CPR) Grant Program was "established in 1996 by the Massachusetts Legislature to help communities identify and improve water quality impaired by nonpoint source pollution." The CPR program provides funding to Massachusetts municipalities to assess and remediate stormwater pollution from paved surfaces or to design and construct boat waste pumpout facilities. In each of the last two years, a total of about $400,000 was available.

Projects funded in Cape Cod Bay towns include construction of bio-retention areas at a parking lot in Plymouth, stormwater treatment in Duxbury to remediate pollution to shellfish beds in Kingston Bay and boat pumpout projects in Provincetown Harbor and Sesuit Harbor (http://www.mass.gov/czm/cprgp.htm).

Massachusetts Department of Environmental Protection (MaDEP) Nonpoint Source Program (319 Program)

This program is supported with federal funds under Section 319 of the Clean Water Act. The MaDEP directs the program and manages a competitive grant program to address the "prevention, control and abatement of nonpoint source pollution." The amount of available funding varies, but has averaged approximately $1.2 million annually. The 319 Program has funded a number of projects in Cape Cod Bay towns including the operation of the Massachusetts Alternative Septic System Test Center and stormwater treatment projects in Brewster and Provincetown (http://www.mass.gov/dep/water/grants.htm).

Watershed Management Approach—Massachusetts Department of Environmental Protection (MaDEP)

The goal of this program is to protect state waters that currently meet water quality standards and to restore impaired waters. Program staff assesses the water quality of the state's water bodies, and if they are found to be impaired (i.e. not meeting state water quality standards), MaDEP develops a Total Maximum Daily Load (TMDL)—the maximum amount of a pollutant that a water body can assimilate and still meet state water quality standards.

The TMDL is a regulatory tool that the state uses to ensure that communities and other users manage their discharge for certain pollutants. MaDEP has some competitive grants programs that can be used by local governments to fund non-point source pollution prevention and control actions (http://www.mass.gov/dep/water/grants.htm).

Federal:

Federal agencies, in particular the Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA), provide funding and technical support to a variety of state programs. These include the Massachusetts Bays Program, the Coastal Zone Management Program and MaDEP's Nonpoint Source Program.

The Environmental Protection Agency is responsible for designating "No Discharge Areas" that prohibit the discharge of treated and untreated boat sewage. A number of towns and organizations have been responsible for nominating areas for designation. Designated No Discharge Areas include: all of the waters of Cape Cod Bay and those of Plymouth, Kingston and Duxbury Bays and Wellfleet Harbor (http://www.epa.gov/region1/eco/nodiscrg/).

The Waquoit Bay National Estuarine Research Reserve sponsors the Coastal Training Program (CTP) designed to provide science-based information, tools and skills to regional and local decision-makers. The CTP works collaboratively with state and regional governments and organizations and has recently focused on wastewater issues and the impacts of climate change (http://www.waquoitbayreserve.org/coastal_training.aspx).

Federal programs such as NOAA's Coastal Services Center (CSC) also provide training and develop tools that state, regional and local governments can use to help identify priority resource areas, calculate impervious surface area coverage and estimate runoff based on current land use. The CSC has been developing and continues to develop tools and trainings to evaluate the impacts of climate change and to identify actions that can be taken to address these impacts (http://www.csc.noaa.gov/)

Looking Ahead

PCCS plans to continue its monitoring of the health of Cape Cod Bay. As the PCCS studies progress, data will be made available online. In late 2012 we will release an update of the trends analysis that will incorporate data from our 2011 and 2012 field season.

You may always contact PCCS for the most current information available.

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This entire report is available in print and pdf format.

Photo: Elizabeth Bradfield

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Endnotes

1. http://www.infoplease.com/ipa/A0001801.html. Most of the tidal shoreline of creeks and estuaries are not included in the general shoreline calculation.

2. North Atlantic right, fin and humpback whale core habitat; roseate tern core habitat; special concern least tern core habitat; Leach's storm petrel important habitat; long-tailed duck important habitat; colonial water bird important nesting habitat; areas of hard/complex seafloor; eelgrass; intertidal flats and important fish resource areas. Massachusetts Ocean Management Plan, 2009 Volume I page 2.6 http://www.mass.gov/eea/ocean-coastal-management/mass-ocean-plan/

3. The Magnuson-Stevens Fishery Conservation and Management Act defines EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity."

4. Gulf of Maine Council on the Marine Environment, Page 3 of Climate Change and Its Effects on Ecosystems, Habitats and Biota. www.gulfofmaine.org/state-of-the-gulf, accessed in July 2012

5. http://www.edc.uri.edu/restoration/html/intro/sea.htm, accessed on 22 June 2012

6. *The MIT Sea Grant Hitchhikers Guide to Exotic Species* is a field guide for beachcombers, students and other interested citizens and can be found at: http://massbay.mit.edu/exoticspecies/hitchhikers/index.html

7. A map of the sewered areas is available on the Town web site at www.kingstonmass.org by clicking on the Town Directory then the Sewer Commission link and then the Map of Sewered Areas

Photo: Natural Resources Department, Town of Brewster

Appendix A: Results of Seasonal Kendall Test for Trends

Watershed	Station	Temperature		Nitrate/Nitrite		Chlorophyll		Turbidity	
		Slope	0.95*	Slope	0.95*	Slope	0.95*	Slope	0.95*
Offshore	5N	0.38	N+	0.00	N	-0.02	N	-0.04	N-
	5S	0.36	YES+	0.00	N	-0.10	N-	-0.07	N-
	6M	0.22	N+	0.00	N	0.00	N	-0.07	N-
	6S	0.23	N+	0.00	N	-0.01	N	-0.02	N-
	7S	0.34	N+	-0.01	N	0.06	N+	-0.02	N-
	8M	0.33	YES+	-0.01	N-	0.03	N+	-0.11	YES-
	9N	0.27	N+	-0.01	N-	-0.07	N-	-0.03	N-
	9S	-0.02	N	-0.01	N-	0.03	N+	-0.01	N-
Barnstable Harbor	Barnstable Harbor	0.15	N+	0.00	N+	-0.02	N-	0.02	N+
Boat Meadow	Boat Meadow	0.02	N	0.00	N-	-0.27	N-	0.05	N+
	Upper Boat Meadow	-0.35	N-	-0.04	N-	-0.22	N-	-0.79	N-
Cape Cod Bay	C3	-0.32	N-	0.00	N-	-0.20	N-	0.03	N+
	Canal	0.17	N+	-0.05	N-	-0.16	N-	-0.07	N-
	Paines	-0.17	N-	-0.63	N-	-0.03	N	-0.02	N-
	Paines A	0.62	N	0.23	N+	0.26	N+	0.10	N
	Paines Tributary	-0.50	N-	1.64	N+	0.18	N+	-0.08	N
	Pilgrim Lake	0.34	N+	0.14	N+	-0.07	N-	-0.10	N-
Duxbury	D1	-0.20	N-	-0.01	N-	-0.46	N-	-0.54	N-
	D3	-0.37	N-	-0.02	N-	-0.28	N-	-0.36	N-
Ellisville	Ellisville	-1.40	N-	-0.20	N	-0.72	N-	-0.38	N
Herring River (Eastham)	First Encounter	-0.01	N	0.00	N+	-0.21	N-	0.08	N+
Jones River	Jones River	-0.17	N-	-0.53	N-	-0.19	N-	-0.31	N-
	Upper Jones River	-0.25	N-	-0.14	N	-0.03	N-	0.22	N
Namskaket	Inner Rock Harbor	0.00	N	-0.06	YES-	-0.23	N-	-0.01	N-
	Namskaket	0.12	N+	0.00	N+	-0.16	N-	0.06	N+
	Rock Harbor	0.09	N+	-0.03	N-	-0.20	N-	0.06	N+
	Little Namskaket	0.00	N-	-0.04	N-	0.02	N	-0.19	YES-
	Inner Namskaket	-0.50	N-	-0.07	N-	0.11	N+	-0.16	YES-
	Upper Namskaket	0.25	N	0.44	N	-1.85	YES-	-2.50	YES-
Pamet River	Inner Pamet	0.74	N+	0.08	N+	-0.17	N-	-0.02	N
	Pamet	0.20	N+	0.02	N+	-0.31	YES-	0.03	N+
	Pamet River	0.45	N+	0.12	N+	-1.25	N	-0.94	N-
Plymouth	Eel River	0.19	N	0.61	N+	-0.45	N-	0.21	N+
	P1	0.00	N	-0.08	N-	-0.09	N-	0.00	N
	P2	0.25	N+	0.08	N+	-0.22	N-	0.15	N+
	P3	0.28	N+	0.04	N+	-0.05	N-	-0.13	N-
	Plymouth	0.08	N+	0.52	N+	0.02	N	-1.13	N-
Provincetown Harbor	Coast Guard	0.29	N+	0.01	N+	-0.26	N-	0.01	N
	Holiday Inn	0.25	N+	0.00	N+	-0.31	N-	0.00	N
	Ice House	0.19	N+	0.01	N+	-0.13	N-	0.01	N+
	MacMillan	0.02	N	-0.01	N-	-0.23	N-	-0.02	N-
Sandwich Harbor	Old Harbor	0.41	N+	-0.13	N-	0.00	N	-0.11	N-
	Boardwalk	0.00	N-	0.08	N+	0.21	N+	0.21	N+
Scorton Harbor	Scorton	0.56	N+	-0.07	N-	-0.20	N-	-0.04	N-
	Upper Scorton	-0.35	N-	0.08	N+	0.09	N+	0.20	N+
Sesuit Harbor	Inner Sesuit Harbor	0.23	YES+	-0.10	YES-	-0.10	N-	0.01	N
	Sesuit Harbor	0.38	N+	-0.06	N-	-0.19	N-	0.02	N
Wellfleet Harbor	Blackfish Creek	0.10	N+	0.00	N-	-0.15	N-	0.08	N+
	Great Island Channel	0.12	N+	0.00	N-	-0.12	N-	-0.03	N-
	Inner Wellfleet Harbor	0.31	N+	0.01	N+	-1.04	YES-	0.16	N+
	Sunken Meadow	0.09	N+	0.00	N+	-0.38	YES-	0.04	N+
	Wellfleet Harbor	0.25	N+	0.00	N	-0.46	N-	-0.02	N-
	Herring River	-0.25	N-	-0.01	N	-0.47	N-	-0.35	N
	North Sunken Meadow	0.51	N+	1.99	N+	-0.08	N-	-1.11	YES-

*Increasing trend, not significant (N+); Increasing tend, significant (YES+); Decreasing trend, not significant (N-); Decreasing trend, significant (YES-)

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PCCS has made every effort to ensure the accuracy of this list. If you discover an error, please contact us at 508-487-3622, ext. 104 and we will rectify it at the earliest opportunity.

Photo: Natural Resources Department, Town of Brewster

How is Our Bay?

Five Years of Environmental Monitoring of Cape Cod Bay

a report from the Provincetown Center for Coastal Studies
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Photo: Natural Resources Department, Town of Brewster

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