UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

This document contains Chapter 3: Northeast NEPs of the National Estuary Program National Coastal Condition Report. The entire report can be downloaded from ***http://www.epa.gov/owow/oceans/nepccr/index.html***

National Estuary Program Coastal Condition Report

Northeast NEPs

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CHAPTER 3

NORTHEAST NATIONAL ESTUARY PROGRAM COASTAL CONDITION

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Background

The Northeast Coast region extends from Maine southward to Virginia and contains the largest number of NEP estuaries (12) per region in the United States (Figure 3-1). Tides throughout the Northeast Coast region occur twice a day and range from highs of 18 feet in areas of northern Maine to 10 feet in southern Maine, diminishing to less than 3 feet in southern Virginia (NOAA, 1985).

Within the Northeast Coast region, there are two distinct and unique geological areas. The first area, referred to as the Gulf of Maine, extends from the Canadian border south to Cape Cod, MA. Estuaries in the Gulf of Maine were formed by ancient glaciers that scoured much of the soil cover from the land, leaving rocky shorelines, thin soils, and deeply carved channels through which rivers today flow out to the ocean. These estuarine systems are similar in many ways to fjords. As a result of the strong tidal flows and the shape of the basins in the Gulf of Maine estuaries, circulation within these systems is tidally dominated (NOAA, 1985).

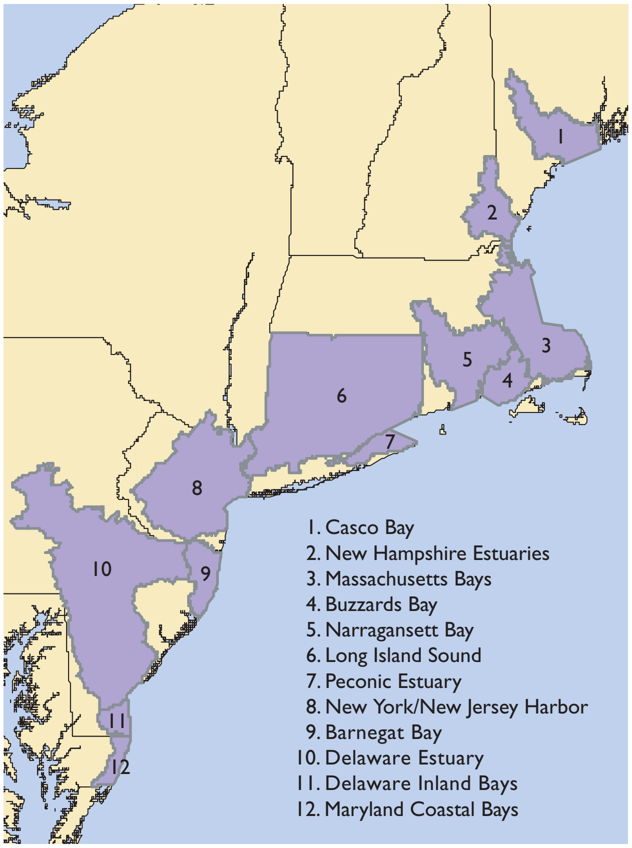


Figure 3-1. The Northeast Coast region is home to 12 NEP estuaries.

The Northeast Coast region's second geological area extends from Cape Cod, MA, south to Virginia. The topography of this area was less affected by ancient glaciers; rather, rising sea level resulting from melting glaciers drowned the mouths of ancient rivers flowing across the continental shelf, which created coastal plain estuaries. In these coastal plain estuaries, the volume of water introduced by tidal action is large compared to freshwater river inflow, with tides in the estuaries serving as the dominant force influencing circulation (NOAA, 1985). In addition to its basin and coastal plain estuaries, the Northeast Coast region also has several shallow lagoon systems where circulation is largely wind-dominated (Day et al., 1989).

The 12 Northeast Coast NEP estuaries are very different in their geological and physical characteristics. On average, water depth is greater than 56 feet from Maine to New York, but only 20 feet from New York to Delaware. Light can penetrate to 33 feet or more in the northern waters of the region, where there is less suspended sediment, but to less than 7 feet south of New Jersey, where thicker soils in the mid-Atlantic contribute greater amounts of sediment to coastal waters. As a result, seagrass communities in the southernmost waters of this region are often light-limited and more sensitive to human development (Thayer et al., 1984; Roman et al., 2000).

Freshwater inflows into the Northeast Coast NEP estuaries typically carry low amounts of sediment because of the extensive stretches of heavy forest and the rocky nature of the soils that predominate in the region's estuarine drainage areas. Sediment loading to Northeast Coast estuaries increases southward as the coastal plain widens and agricultural activity increases. Precipitation patterns also influence freshwater input from rivers flowing into these estuaries, and annual precipitation (averaging 40 to 44 inches) increases only slightly from north to south. Freshwater inflows to the Northeast NEP estuaries tend to coincide with variations in winter snow melt, with high-flow periods occurring from March through May in the northern portions of the region and slightly earlier in the year in the central and southern portions of the region. Freshwater inputs to the NEP estuaries throughout the region are lowest from July through September. Along the East Coast, the Northeast NEP estuaries contribute about 65% of all freshwater discharges to coastal waters (NOAA, 1985).

Population Pressures

The population of the 75 NOAA-designated coastal counties coincident with the NEP study areas of the Northeast Coast region increased by 24% during a 40-year period, from 30.5 million people in 1960 to 37.9 million people in 2000 (Figure 3-2) (U.S. Census Bureau, 1991; 2001). This increase resulted in a population density of 1,055 persons/mi^2 in 2000 for these coastal counties; however, the population densities of the region's individual NEP study areas varied considerably in 2000, from a high of 3,097 persons/mi^2 for the New York/New Jersey Harbor to a low of 98 persons/mi^2 for the Maryland Coastal Bays (U.S. Census Bureau, 2001). The population density of the Northeast Coast region was much higher than the densities exhibited the Southeast Coast (168 persons/mi^2), Gulf Coast (287 persons/mi^2), and West Coast (421 persons/mi^2) regions. Development and population pressures are especially strong surrounding most of the Northeast NEP estuaries, which are close to some of the oldest cities in the United States. These cities—located along the nation's most heavily populated corridor between Washington, D.C., and Boston, MA—are historic and current centers of commerce and industry, and the nearby NEP estuaries are popular areas for commercial and recreational fishing and other activities for city residents.

NCA Indices of Estuarine Condition—Northeast Coast Region

Based on data collected for the NCA, the overall condition of the collective NEP estuaries of the Northeast Coast region is rated poor (Figure 3-3). EPA summarizes conditions in the 12 Northeast Coast NEP estuaries, and these statistical summaries facilitate coastal condition comparisons among different NEP estuaries within the region. As part of the NCA, more than 550 Northeast sites were assessed during 2000 and 2001, and 18 sites in the Peconic Estuary were also surveyed in 2002. Each site was visited once during the summer season; therefore, the picture that emerges from the NCA study is a "snapshot" rather than a description of long-term conditions. The NCA approach provides an accurate assessment of conditions in the relatively stable realm of the sediments and biological communities; however, it does not address short-term water

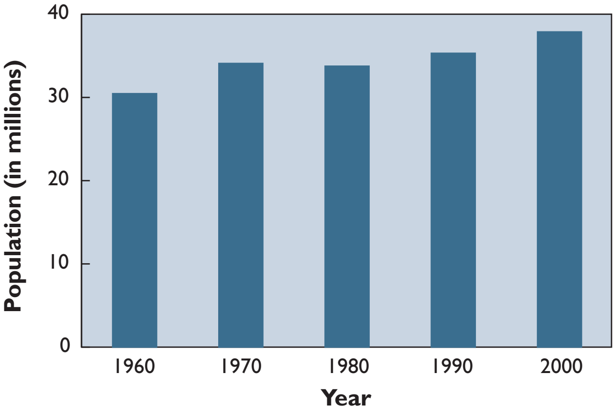


Figure 3-2. Population of NOAA-designated coastal counties of the Northeast Coast region's NEP study areas, 1960–2000 (U.S. Census Bureau, 1991; 2001).

quality conditions, such as changes in the water column that may occur weekly or daily during the summertime survey period.

EPA assessed the Northeast Coast NEP estuaries using four indices that respectively evaluate water quality, sediment quality, benthic condition (i.e., the status of the invertebrate community that lives in or on the sediments), and fish tissue contaminant levels. These indices were rated good, fair, or poor based on the criteria outlined in Chapter 1 (Tables 1-24, 1-25, and 1-26), and a category of missing was applied when data were unavailable. Figure 3-4 shows the percent of NEP estuarine area in the Northeast Coast region rated good, fair, poor, or missing for each parameter considered. For all parameters except the fish tissue contaminants index, results were expressed as the percentage of estuarine area falling within a category for each NEP. The fish tissue contaminants index was not weighted by area, but was reported as the percentage of fish analyzed.

The water quality index for the collective NEP estuaries of the Northeast Coast region is rated fair, and the sediment quality, benthic, and fish tissue contaminants indices for this region are rated poor based on the criteria used in this report. These regional-scale ratings facilitate comparisons among NEP estuaries in different regions of the country.

Natural and anthropogenic features and pressures in the Northeast Coast region strongly influence the manner in which pollutants accumulate and are processed in estuaries, as well as the structure and condition of estuarine fish and benthic communities. The major estuaries of the Northeast Coast region—those associated with the Connecticut, Hudson, and Delaware rivers—have watersheds that are relatively small compared with estuaries along the Southeast Coast and Gulf Coast regions; therefore, estuaries of the Northeast Coast are more affected by local sources of pollution and stresses than estuaries in the other regions. In addition, NEP estuaries in the Northeast Coast region are situated along the most densely populated coastline in the country (U.S. Census Bureau, 2001). Estuarine sediment contamination levels tend to be highest where sediments deposit near urban centers, and nutrient concentrations in developed areas are greater than in pristine areas. In New England, the dominant nutrient input is from WWTPs in urban centers and from atmospheric deposition of nitrogen for non-urban sites. In the mid-Atlantic, agricultural runoff and animal operations are important sources of nutrients, in addition to atmospheric deposition and urban sources.

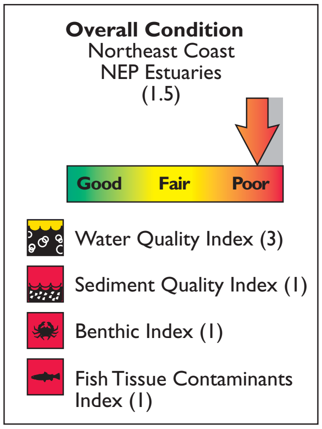


Figure 3-3. The overall condition of the Northeast Coast NEP estuarine area is poor (U.S. EPA/NCA).

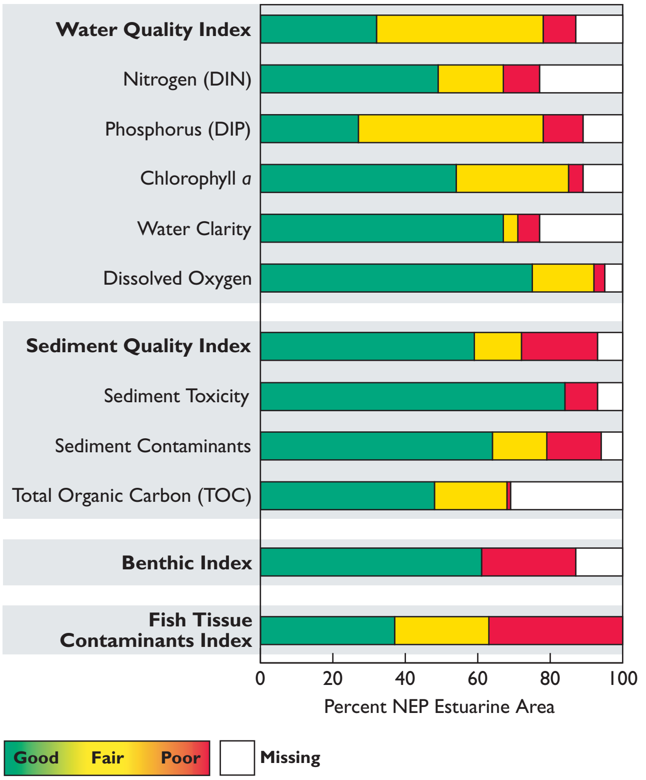


Figure 3-4. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Northeast Coast region (U.S. EPA/NCA).

Water Quality Index

The water quality index for the collective NEP estuaries of the Northeast Coast region is rated fair (Figure 3-5). The index was based on five component indicators measured in the NCA: three indicators that estimate the extent of estuarine eutrophication (DIN, DIP, and chlorophyll *a* concentrations) and two that evaluate conditions that are key to estuarine health (water clarity and dissolved oxygen concentrations). Generally, there was a north to south pattern in the Northeast region's water quality index, which degraded southward.

Dissolved Nitrogen and Phosphorus | The Northeast Coast region is rated fair for both DIN and DIP concentrations. Based on the thresholds indicating impairment, 10% of the Northeast Coast NEP estuarine area was rated poor for DIN concentrations, and data were unavailable for 23% of the estuarine area. A north to south gradient was generally evident in the DIN data, with large areas of the Delaware Estuary, Delaware Inland Bays, and Maryland Coastal Bays exhibiting poor or fair condition for this component indicator.

Eleven percent of the Northeast Coast NEP estuarine area was rated poor for DIP concentrations, and data for this component indicator were unavailable for 11% of the estuarine area. More than 62% of the region had poor or fair DIP levels; however, there was no clear pattern with latitude for DIP. There are important questions regarding the process by which nutrients cause phytoplankton blooms and what levels of these nutrients are detrimental in estuaries; however, neither the frequency nor the location of measurements in the NCA survey were sufficient to address these questions.

Chlorophyll a | The Northeast Coast region is rated good for chlorophyll *a* concentrations. Only 4% of the region's NEP estuarine area was rated poor for this component indicator, and 31% of the area was rated fair. Chlorophyll *a* data were unavailable for 11% of the Northeast Coast NEP estuarine area. The north to south gradient observed for DIN data was also generally evident in the chlorophyll *a* data, with large areas of the Delaware Estuary, Delaware Inland Bays, and Maryland Coastal Bays exhibiting poor or fair condition for this component indicator.

This report discusses two different approaches for characterizing estuarine condition:

Approach 1 – The NCA provides unbiased, quality-assured data that can be used to make consistent "snapshot" comparisons among the nation's NEP estuaries. These comparisons are expressed in terms of the percent of NEP estuarine area in good, fair, or poor condition.

Approach 2 – Each individual NEP collects site-specific estuarine data in support of local problem-solving efforts. These data are difficult to compare among NEPs, within regions or nationally, because the sampling and evaluation procedures used by the NEPs are often unique to their individual estuaries. However, these evaluations are important because NEP-collected data can evaluate spatial and temporal changes in estuarine condition on a more in-depth scale than can be achieved by the NCA snapshot approach.

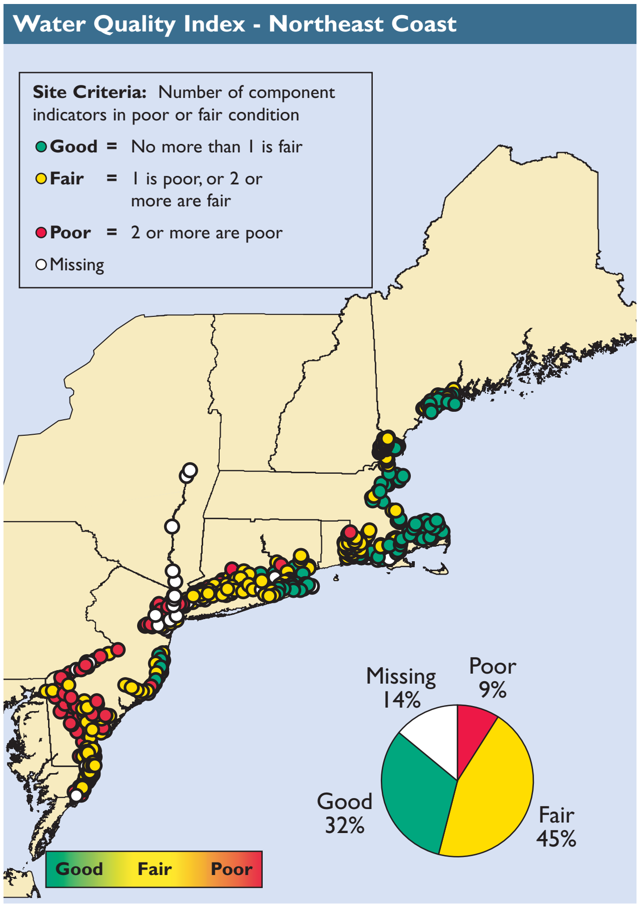


Figure 3-5. Water quality index data for the Northeast Coast NEP estuarine area (U.S. EPA/NCA).

Water Clarity | The Northeast Coast region is rated good for water clarity. NCA data show that poor water clarity occurred in only 6% of the Northeast NEP estuarine area; however, data from 23% of the area were unavailable. Poor water clarity was prevalent only in the more southernly NEP estuaries of the Northeast Coast region, including Barnegat Bay, Delaware Estuary, the Delaware Inland Bays, and the Maryland Coastal Bays. Diminished water clarity is commonly observed in these estuarine systems, to some extent because of natural processes such as tidal resuspension of fine sediments.

Dissolved Oxygen | The Northeast Coast region is rated good for dissolved oxygen concentrations. Seventy-five percent and 17% of the region's NEP estuarine area were rated good and fair, respectively, for dissolved oxygen concentrations, and only 3% of the estuarine area was rated poor. Depleted dissolved oxygen concentrations were measured in portions of Long Island Sound, Narragansett Bay, New York/New Jersey Harbor, and Buzzards Bay.

Sediment Quality Index

Sediment quality for the Northeast Coast region was calculated using three component indicators of sediment condition measured by the NCA: sediment toxicity, sediment contaminants, and sediment TOC. The sediment quality index for the collective estuaries of the Northeast Coast region is rated poor (Figure 3-6), primarily because 21% of the NEP estuarine area monitored was rated poor due to sediment toxicity or sediment contaminants concentrations.

The Northeast Coast NEP estuaries with the poorest sediment quality condition were generally situated near major urban centers (e.g., New York/New Jersey Harbor, western Long Island Sound, upper Narragansett Bay, and the waters of the Delaware Estuary in the vicinity of Philadelphia). At these locations, impaired ratings were usually triggered by sediment contamination, such as high concentrations of metals, PCBs, and/or DDT.

Sediment Toxicity | The Northeast Coast region is rated poor for sediment toxicity because 9% of the region's NEP estuarine area was rated poor. Eighty-four percent of the area was rated good for this component indicator, and NCA data on sediment toxicity were unavailable for 7% of the Northeast Coast NEP estuarine area.

Sediment Contaminants | The Northeast Coast region is rated fair for sediment contaminant concentrations because 15% of the region's NEP estuarine area was rated poor for this component indicator. In addition, 15% of the area was rated fair, and 64% of the area was rated good. NCA data on sediment contaminant concentrations were unavailable for 6% of the Northeast Coast NEP estuarine area.

Total Organic Carbon | The Northeast Coast region is rated good for sediment TOC. Only 1% of the Northeast Coast NEP estuarine area was rated poor for TOC concentrations, whereas 48% of the area was rated good and 20% of the area was rated fair. NCA data on TOC concentrations were unavailable for 31% of the estuarine area.

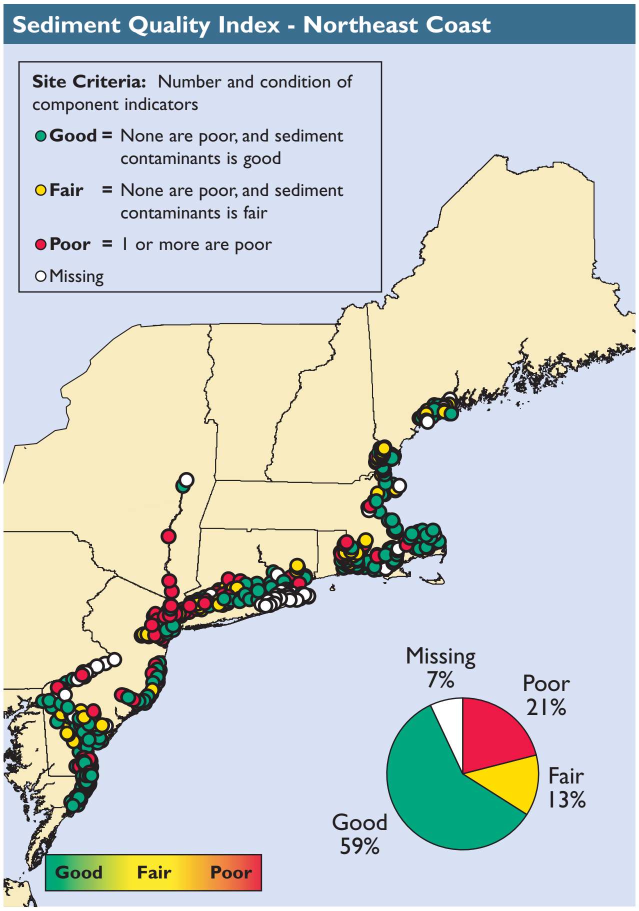


Figure 3-6. Sediment quality index data for the Northeast Coast NEP estuarine area (U.S. EPA/NCA).

Benthic Index

Sixty-one percent of the Northeast Coast NEP estuarine area exhibited acceptable benthic condition, but 26% did not; therefore, the benthic index for the collective NEP estuaries of the Northeast Coast region is rated poor (Figure 3-7). The extent of impairment was relatively uniform at all NEP sites, slightly exceeding a third of the estuarine area only in Long Island Sound, New York/New Jersey Harbor, and the Delaware Inland Bays. The benthic index for the Northeast Coast region was calculated by two methods: an established benthic index created specifically for the Virginian Province was used to evaluate conditions south of Cape Cod (Paul et al., 2001), whereas the Shannon-Weiner Diversity Index was used to evaluate locations north of Cape Cod. By both measures, greater diversity is indicative of a healthier community. Currently, a new benthic index for the waters north of Cape Cod is being developed that will account for the effects of natural habitat variations that affect species diversity.

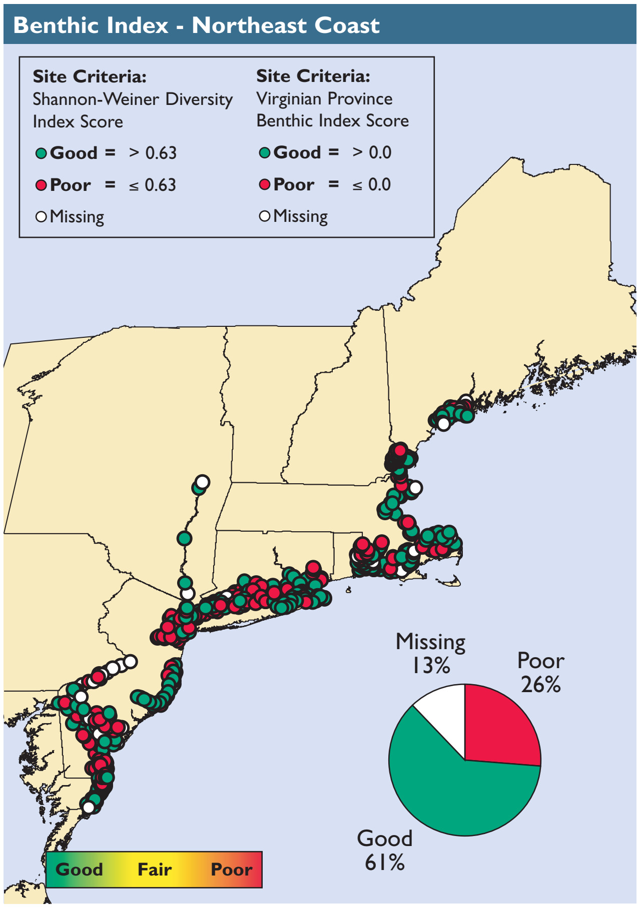


Figure 3-7. Benthic index data for the Northeast Coast NEP estuarine area (U.S. EPA/NCA).

Fish Tissue Contaminants Index

The fish tissue contaminants index for the collective NEP estuaries of the Northeast Coast region is rated poor (Figure 3-8). Thirty-eight percent of all fish samples analyzed had concentrations of chemical contaminants that exceeded EPA Advisory Guidance values for fish consumption; another 25% of the fish samples analyzed were rated fair for fish tissue contaminant levels; and only 37% were rated good. In addition, wide differences in contaminant levels were noted among the individual NEP estuaries. All of Narragansett Bay and New York/New Jersey Harbor achieved a poor or fair rating for fish tissue contaminant concentrations, as did large portions of the New Hampshire Estuaries, Buzzards Bay, Massachusetts Bays, and Delaware Estuary. In contrast, nearly all of the Delaware Inland Bays and Maryland Coastal Bays were rated good for this index, and NCA data were unavailable for Casco Bay. These results reflect concentrations in whole fish; whereas the EPA Advisory Guidance refers to edible portions of fish. Contaminant levels in whole fish can

In some areas of the Northeast, lobster tissue was analyzed for contaminants (NOAA).

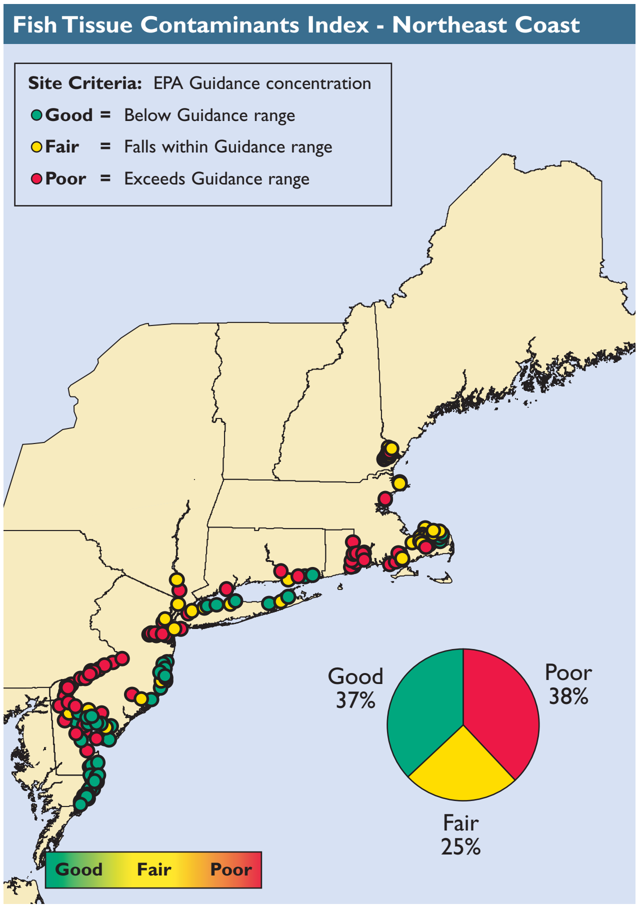


Figure 3-8. Fish tissue contaminants index data for the Northeast Coast NEP estuarine area (U.S. EPA/NCA).

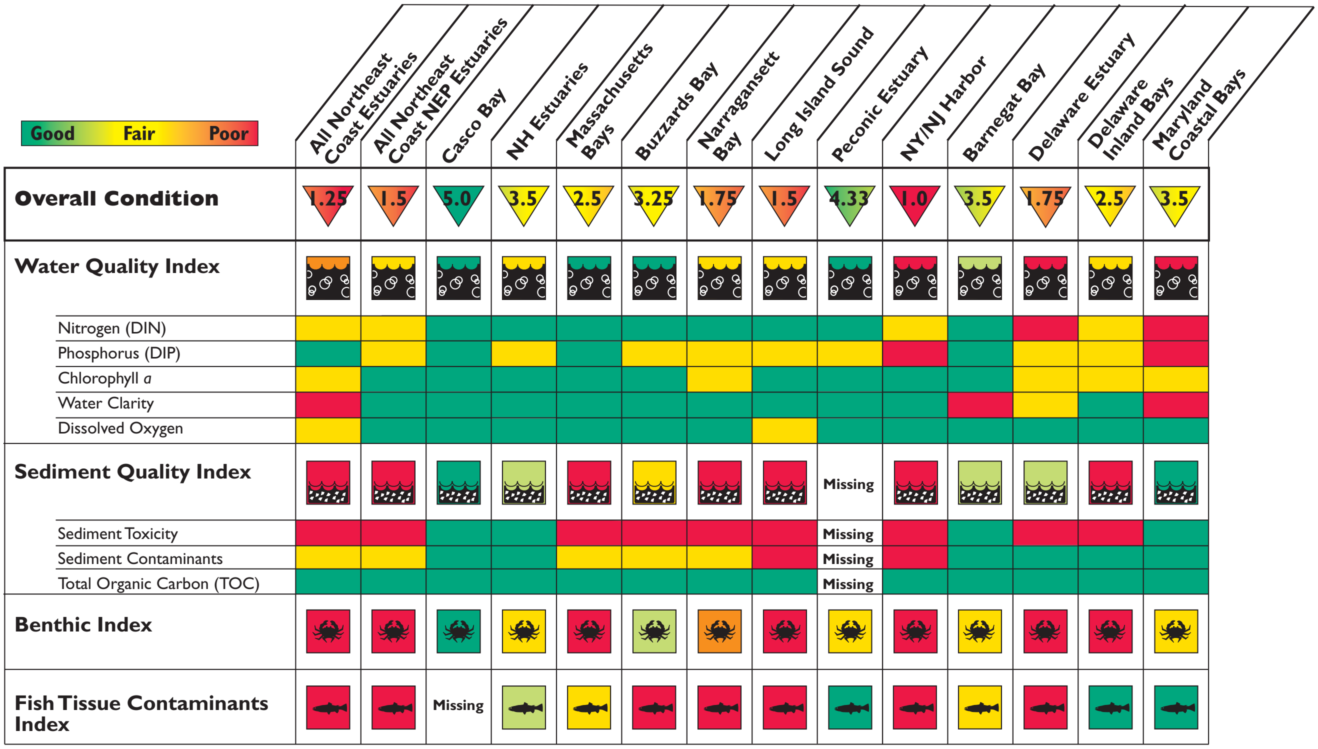
be higher or lower than levels in fillets, depending on the fish species and contaminant assessed; however, the guidelines used for this report are appropriate for some populations that consume whole fish.

NEP Estuaries and the Condition of the Northeast Coast Region

The purpose of the NEP is to identify, restore, and protect the nationally significant estuaries of the United States. Most of the 12 NEP estuaries of the Northeast Coast region need this extra protection, in part because their size and societal significance have led to intense human development and a diversity of uses, including industrial and agricultural production and international commerce and shipping, resulting in associated environmental concerns throughout their watersheds. Does the condition of the Northeast Coast NEP estuaries accurately reflect the condition of all Northeast Coast estuaries (both NEP and non-NEP)? Based on the NCA survey results, the collective Northeast Coast NEP estuaries and all Northeast Coast estuaries combined are both rated poor for overall condition, with the group of NEP estuaries receiving an overall condition score of 1.5, just slightly higher than the overall condition score of 1.25 for all Northeast Coast estuaries (Figure 3-9). Both groups of estuaries also have similar regional ratings for most of the NCA estuarine indices and component indicators.

A comparison of the NCA data shows that the collective Northeast Coast NEP estuaries are rated fair for the water quality index and poor for the sediment quality, benthic, and fish tissue contaminants indices. The group of all Northeast Coast estuaries combined are rated fair to poor for the water quality index and poor for the sediment quality, benthic, and fish tissue contaminants indices. The two groups of estuaries are rated comparably for a number of the water and sediment quality component indicators, with both groups rated good for sediment TOC concentrations, fair for DIN and sediment contaminant concentrations, and poor for sediment toxicity. However, the collective NEP estuaries are rated good for water clarity and chlorophyll *a* and dissolved oxygen concentrations and rated fair for DIP concentrations, whereas the group of all Northeast Coast estuaries are rated poor for water clarity, fair for chlorophyll *a* and dissolved oxygen concentrations, and good for DIP concentrations. Based on these ratings, the condition of the Northeast Coast NEP estuaries is relatively representative of the condition of all Northeast Coast estuaries, with the exception of water quality condition, where the group of NEP estuaries received better or equal ratings for the index and most of the component indicators.

With respect to the individual Northeast Coast NEP estuaries, 11 of the 12 estuaries received higher or comparable overall condition scores than the overall condition score for than the collective Northeast Coast NEP estuaries (1.5, rated poor). Casco Bay (5.0) and Peconic Estuary (4.33) are both rated good for overall condition; the New Hampshire Estuaries (3.5), Barnegat Bay (3.5), the Maryland Coastal Bays (3.5), Buzzards Bay (3.25), the Delaware Inland Bays (2.5),



	All Northeast Coast Estuaries	All Northeast Coast NEP Estuaries	Casco Bay	NH Estuaries	Massachusetts Bays	Buzzards Bay	Narragansett Bay	Long Island Sound	Peconic Estuary	NY/NJ Harbor	Barnegat Bay	Delaware Estuary	Delaware Inland Bays	Maryland Coastal Bays
Overall Condition	1.25	1.5	5.0	3.5	2.5	3.25	1.75	1.5	4.33	1.0	3.5	1.75	2.5	3.5
Water Quality Index	🟧	🟨	🟩	🟨	🟩	🟩	🟨	🟨	🟩	🟥	🟩	🟥	🟨	🟥
Nitrogen (DIN)	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟥	🟨	🟥
Phosphorus (DIP)	🟩	🟨	🟩	🟨	🟩	🟨	🟨	🟨	🟨	🟥	🟩	🟨	🟨	🟥
Chlorophyll *a*	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟨	🟨	🟨
Water Clarity	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟨	🟩	🟥
Dissolved Oxygen	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩
Sediment Quality Index	🟥	🟥	🟩	🟩	🟥	🟨	🟥	🟥	Missing	🟥	🟩	🟩	🟥	🟩
Sediment Toxicity	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟥	Missing	🟥	🟩	🟥	🟥	🟩
Sediment Contaminants	🟨	🟨	🟩	🟩	🟨	🟨	🟨	🟥	Missing	🟥	🟩	🟩	🟩	🟩
Total Organic Carbon (TOC)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	Missing	🟩	🟩	🟩	🟩	🟩
Benthic Index	🟥	🟥	🟩	🟨	🟥	🟩	🟧	🟥	🟨	🟥	🟨	🟥	🟥	🟨
Fish Tissue Contaminants Index	🟥	🟥	Missing	🟩	🟨	🟥	🟥	🟥	🟩	🟥	🟨	🟥	🟩	🟩

Figure 3-9. Comparison of NCA results for Northeast Coast NEP estuaries and all Northeast Coast estuaries (U.S. EPA/NCA).

and the Massachusetts Bays (2.5) are each rated fair; and Narragansett Bay (1.75), Delaware Estuary (1.75), and Long Island Sound (1.5) are each rated poor. Only one Northeast Coast NEP estuary, New York/New Jersey Harbor, received an overall condition score (1.0, rated poor) that is lower than the overall score for the collective Northeast Coast NEP estuaries.

A review of the NCA data for the water quality index and component indicators shows that this index is rated good for Casco Bay, the Massachusetts Bays, Buzzards Bay, and Peconic Estuary; good to fair for Barnegat Bay; fair for the New Hampshire Estuaries, Narragansett Bay, Long Island Sound, and Delaware Inland Bays; and poor for New York/New Jersey Harbor, Delaware Estuary, and the Maryland Coastal Bays. The poor water quality ratings were caused primarily by elevated DIN and/or DIP concentrations in all three estuaries and by degraded water clarity and elevated chlorophyll *a* concentrations in Delaware Estuary and the Maryland Coastal Bays. A north to south gradient was generally evident in the DIN data for the Northeast Coast NEP estuaries, with Casco Bay, the New Hampshire Estuaries, the Massachusetts Bays, Buzzards Bay, Narragansett Bay, Long Island Sound, Peconic Estuary, and Barnegat Bay rated good for this component indicator; New York/New Jersey Harbor and the Delaware Inland Bays rated fair; and Delaware Estuary and Maryland Coastal Bays rated poor. No clear pattern was observed with latitude for DIP concentrations in the Northeast Coast NEP estuaries, with Casco Bay, the Massachusetts Bays, and Barnegat Bay rated good for this component indicator; the New Hampshire Estuaries, Buzzards Bay, Narragansett Bay, Long Island Sound, Peconic Estuary, Delaware Estuary, and the Delaware Inland Bays rated fair; and New York/New Jersey Harbor and the Maryland Coastal Bays rated poor. Casco Bay, the New Hampshire Estuaries, the Massachusetts Bays, Buzzards Bay, Long Island Sound, Peconic Estuary, New York/New Jersey Harbor, and Barnegat Bay are rated good for chlorophyll *a* concentrations. Narragansett Bay, Delaware Estuary, the Delaware Inland Bays, and the Maryland Coastal Bays are rated fair. None of the Northeast Coast NEP estuaries are rated poor for chlorophyll *a* concentrations. A north to south gradient was generally evident in the chlorophyll *a* data, with large areas of Delaware Estuary, the Delaware Inland Bays, and the Maryland Coastal Bays exhibiting fair condition for this component indicator. Narragansett Bay was the only estuary rated fair for this component indicator that exhibited an exception to this latitudinal trend.

Although the water clarity rating is good for the Northeast Coast NEP estuarine area and for 9 of the 12 individual NEP estuaries, the Delaware Estuary is rated fair and Barnegat Bay and the Maryland Coastal Bays are rated poor for this component indicator. Poor water clarity was prevalent only in the more southernly NEP estuaries of the Northeast Coast region. Diminished water clarity is commonly observed in these estuarine systems, to some extent because of natural processes such as tidal resuspension of fine sediments. Accordingly, the reference levels used to rate water clarity are different for the naturally turbid Delaware Estuary, where greater turbidity was required to merit a fair or poor rating than the criteria for neighboring estuaries. An important determination involving water clarity is the level of turbidity due to excess soil erosion or phytoplankton blooms caused by human activity; however, the NCA data alone were not sufficient to answer this question. Dissolved oxygen concentrations are rated good for 11 Northeast Coast NEP estuaries, but are rated fair for Long Island Sound. Depleted dissolved oxygen concentrations were measured in areas of Long Island Sound, Narragansett Bay, New York/New Jersey Harbor, and Buzzards Bay.

The sediment quality index and component indicator ratings for the individual Northeast Coast NEP estuaries range from good to poor. The sediment quality index is rated good for Casco Bay and the Maryland Coastal Bays; good to fair for the New Hampshire Estuaries, Barnegat Bay, and Delaware Estuary; fair for Buzzards Bay; and poor for the Massachusetts Bays, Narragansett Bay, Long Island Sound, New York/New Jersey Harbor, and the Delaware Inland Bays. Typically, sediment toxicity and/or sediment contaminant concentrations were responsible for a poor sediment quality index rating because all of the Northeast Coast NEP estuaries are rated good for sediment TOC. None of the sediment quality component indicators were assessed for the Peconic Estuary.

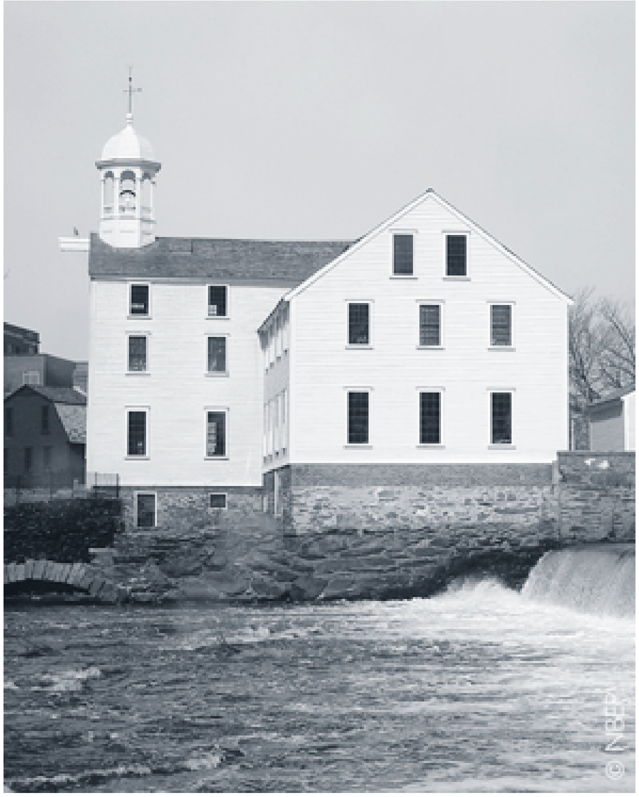
The north to south pattern of degraded condition seen with some of the water quality component indicators was not apparent with the sediment quality component indicators. Rather, the NEP sites with the poorest condition were generally situated near major urban centers (e.g., New York/New Jersey Harbor, western Long Island Sound, upper Narragansett Bay, and the portion of Delaware Estuary near Philadelphia). At these locations, the impaired ratings were usually triggered by sediment contamination, most often high concentrations of metals (in particular, mercury, silver, and nickel), PCBs, and DDT. With respect to the sediment quality component indicators, sediment toxicity is rated good for Casco Bay, the New Hampshire Estuaries, Barnegat Bay, and the Maryland Coastal Bays and poor for the Massachusetts Bays, Buzzards Bay, Narragansett Bay, Long Island Sound, New York/New Jersey Harbor, Delaware Estuary, and the Delaware Inland Bays. Sediment toxicity was generally not observed in more than 11% of an NEP's estuarine area, with the exception of New York/New Jersey Harbor, where sediments were rated poor in 25% of the NEP estuarine area. The NCA survey did not assess sediment toxicity in the Peconic Estuary. Sediment contaminant concentrations are rated good for Casco Bay, the New Hampshire Estuaries, Barnegat Bay, Delaware Estuary, the Delaware Inland Bays, and the Maryland Coastal Bays; fair for the Massachusetts Bays, Buzzards Bay, and Narragansett Bay; and poor for Long Island Sound and New York/New Jersey Harbor. The NCA did not assess sediment contaminants in the Peconic Estuary. Finally, all of the Northeast Coast NEP estuaries are rated good for sediment TOC concentrations, although relatively large areas of Casco Bay and the New Hampshire Estuaries are rated fair for this component indicator. The northern NEP estuaries of the Northeast Coast region generally had the greatest occurrence of high TOC concentrations; however, some analysts caution that high TOC levels are not necessarily a definitive indication of sediment degradation. The NCA survey did not assess sediment TOC for the Peconic Estuary.

The benthic index ratings for the Northeast Coast NEP estuaries range from good to poor. The benthic index is rated good for Casco Bay; good to fair for Buzzards Bay; fair for the New Hampshire Estuaries, Peconic Estuary, Barnegat Bay, and the Maryland Coastal Bays; fair to poor for Narragansett Bay; and poor for the Massachusetts Bays, Long Island Sound, New York/New Jersey Harbor, Delaware Estuary, and the Delaware Inland Bays. Some of the estuaries north of Cape Cod (e.g., Acadian Province) did not score well based on the NCA method used to determine the health of benthic communities south of Cape Cod; therefore, the Shannon-Weiner Diversity Index of benthic community health was used for estuaries in the Acadian Province (see Chapter 1, *Benthic Index*)

The final estuarine index, the fish tissue contaminants index, is rated good for Peconic Estuary, the Delaware Inland Bays, and the Maryland Coastal Bays; good to fair for the New Hampshire Estuaries; fair for the Massachusetts Bays and Barnegat Bay; and poor for Buzzards Bay, Narragansett Bay, Long Island Sound, New York/New Jersey Harbor, and Delaware Estuary. NCA data were unavailable to evaluate fish tissue contaminant levels in Casco Bay.

The overall condition score for the collective NEP estuaries of the Northeast Coast region (1.5) was lower than the overall condition scores for the collective NEP estuaries of the Southeast Coast (4.0), Gulf Coast (2.75), or West Coast (2.5) regions and comparable to the score for Puerto Rico (1.5). This low overall condition score is not unexpected because many Northeast Coast NEP estuaries were designated to the program because of their societal importance to the nation as major centers of commerce and international trade and as commercial or recreational fishery areas since the 1700s. In addition, the counties surrounding the Northeast Coast NEP estuaries have some of the highest population densities in the country.

Population pressures, measured as population density (number of persons/mi^2), correlated fairly well with the overall condition scores for the individual Northeast Coast NEP estuaries. For example, the study areas of the New York/New Jersey Harbor and Long Island Sound had the highest population densities of 3,097 and 2,170 persons/mi^2, respectively, and are both rated poor for overall condition, receiving the lowest overall condition scores of 1.0 and 1.5, respectively. The three Northeast Coast NEP study areas with the lowest population densities— Maryland Coastal Bays (98 persons/mi^2), Casco Bay (138 persons/mi^2), and the New Hampshire Estuaries (216 persons/mi^2)— are rated fair (3.5), good (5.0), and fair (3.5) for overall condition, respectively. However, Peconic Estuary, with a moderately high population density (1,558 persons/mi^2), had one of the highest overall condition scores (4.3, rated good) for the Northeast Coast NEPs, although sediment quality was not evaluated for this estuary.



Slater Mill Pawtucket, RI, is considered the birthplace of the American industrial revolution (NBEP).

Casco Bay Estuary Partnership

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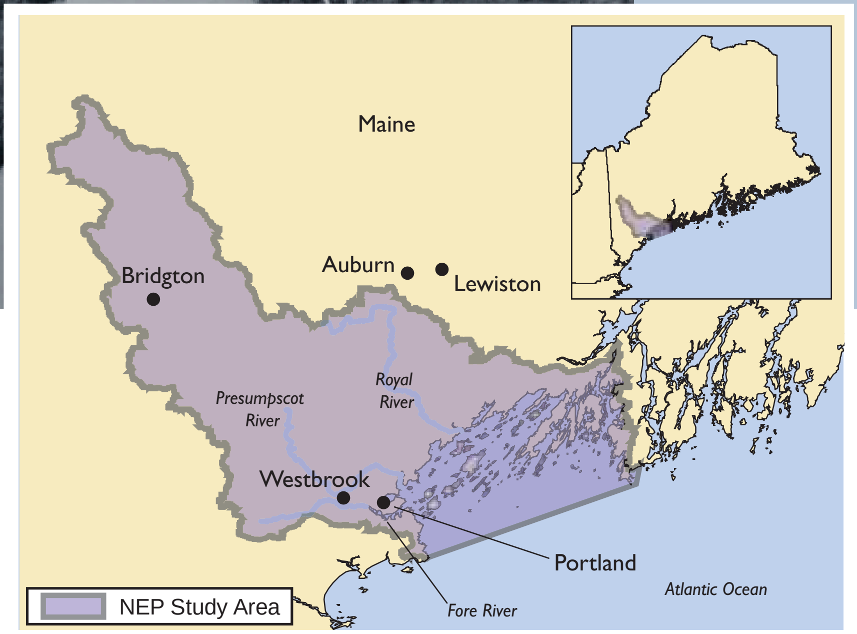


Casco Bay Estuary PARTNERSHIP

www.cascobay.usm.maine.edu

Background

The watershed of Casco Bay contains only 3% of Maine's land mass, but about a quarter of the state's population. This NEP study area encompasses 41 municipalities and extends over a 985 mi^2 area. The Bay itself has 578 miles of shoreline, including 758 islands (CBEP, 2000). Three major rivers—the Royal, Presumpscot, and Fore— flow into the Bay. Casco Bay has relatively low water temperatures and high flushing rates, compared to some other estuaries of the Northeast Coast region (Pearce et al., 1996). A 1994 study estimated the annual value of Casco Bay's fishing industry at $120 million, with tourism and recreation around the Bay generating another $250 million each year (CBEP, 2000).

Starting in 1990, a diverse coalition began to shape a plan for Casco Bay's future as part of EPA's NEP. The *Casco Bay Plan* (CBEP, 1996) now fuels collaborative projects around the watershed involving municipal and state officials, community groups, businesses, and citizens. The Casco Bay Estuary Partnership (CBEP; formerly the Casco Bay Estuary Project) coordinates these efforts. Since the plan was adopted, area residents and groups have taken measures to protect wildlife habitat, improve water quality, reduce pollution from stormwater runoff and combined sewer overflows (CSOs), reduce toxic pollution, and protect and restore clam flats and swimming areas.

Environmental Concerns

Although Casco Bay's waters may appear relatively pristine to the casual observer, toxic pollution in the Bay is a concern. Casco Bay still contains toxics from industries that operated more than a century ago, contaminating sediments, fish, shellfish, and wildlife (CBEP, 1994). Volunteer water quality monitoring has taken place since 1993, and data show that the Bay's water quality is generally good, although cause for concern remains in certain areas. Low dissolved oxygen has been identified in a few areas, and the CBEP is conducting further studies to determine the nature and causes of these hypoxic events.

Population Pressures

The population of the 5 NOAA-designated coastal counties (Androscoggin, Cumberland, Oxford, Sagadahoc, and York) coincident with the CBEP study area increased by about 48% during a 40-year period, from 0.44 million people in 1960 to 0.65 million people in 2000 (Figure 3-10) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the CBEP study area is higher than the population growth rate of 24% for the collective NEP-coincident coastal counties of the Northeast Coast region. In 2000, the population density of the CBEP's 5 NEP-coincident coastal counties was 138 persons/mi^2, dramatically lower than the population density of 1,055 persons/mi^2 for the collective NEP-coincident coastal counties of the Northeast Coast region (U.S. Census Bureau, 2001). The CBEP-coincident coastal counties had the second-lowest population density of any of the Northeast Coast NEP estuaries (only the coastal counties coincident with the Maryland Coastal Bays Program were lower at 98 persons/mi^2).

NCA Indices of Estuarine Condition—Casco Bay

The overall condition of Casco Bay is rated good based on three of the four indices of estuarine condition used by the NCA (Figure 3-11). All three indices (water quality index, sediment quality index, and benthic index) are rated good for Casco Bay. No data were available to calculate a fish tissue contaminants index for this estuary. Figure 3-12 provides a summary of the percentage of estuarine area rated good, fair, poor, or missing for each parameter considered. This assessment is based on data from 30 NCA sites sampled in the CBEP estuarine area in 2000 and 2001. Please refer to Tables 1-24, 1-25, and 1-26 (Chapter 1) for a summary of the criteria used to develop the rating for each index and component indicator.

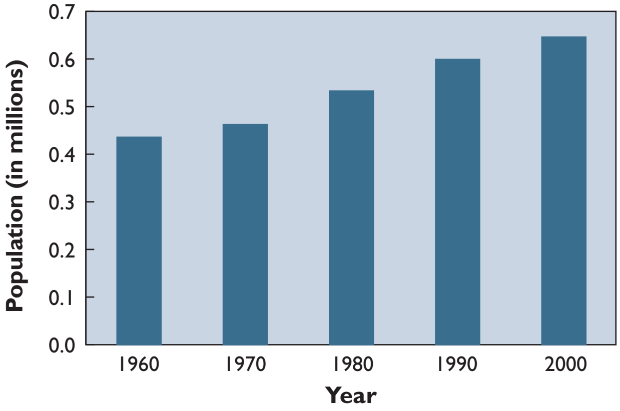


Figure 3-10. Population of NOAA-designated coastal counties of the CBEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

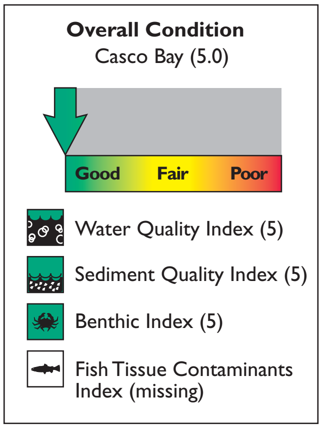


Figure 3-11. The overall condition of the CBEP estuarine area is good (U.S. EPA/NCA).

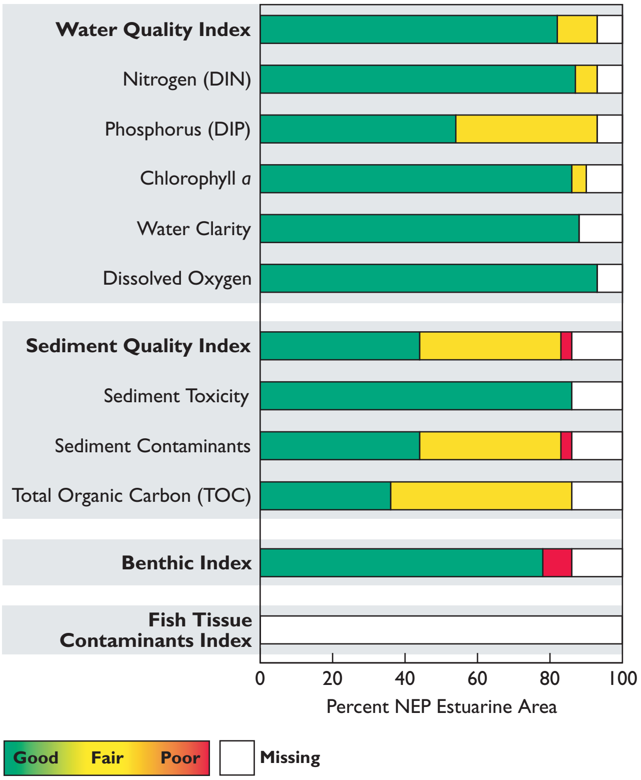


Figure 3-12. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Casco Bay (U.S. EPA/NCA).

Water Quality Index

Based on data from the NCA survey, the water quality index for Casco Bay is rated good (Figure 3-13). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Casco Bay has one of the best ratings for water quality among the Northeast Coast NEP estuaries. DIN and chlorophyll *a* concentrations were uniformly low, less than 0.1 mg/L and 5 µg/L, respectively, and DIP concentrations were less than 0.01 mg/L in all areas of Casco Bay. Water clarity was satisfactory everywhere in the Bay, and there were no incidences of depleted dissolved oxygen.

Dissolved Nitrogen and Phosphorus | Casco Bay is rated good for both DIN and DIP concentrations. Eighty-seven percent of the estuarine area was rated good for DIN concentrations, and 6% of the area was rated fair. No area of Casco Bay was rated poor for DIN concentrations. Fifty-four percent of the Bay's estuarine area was rated good for DIP concentrations, and no area of Casco Bay was rated poor for this component indicator. NCA data on DIN and DIP concentrations were unavailable for 7% of the CBEP estuarine area.

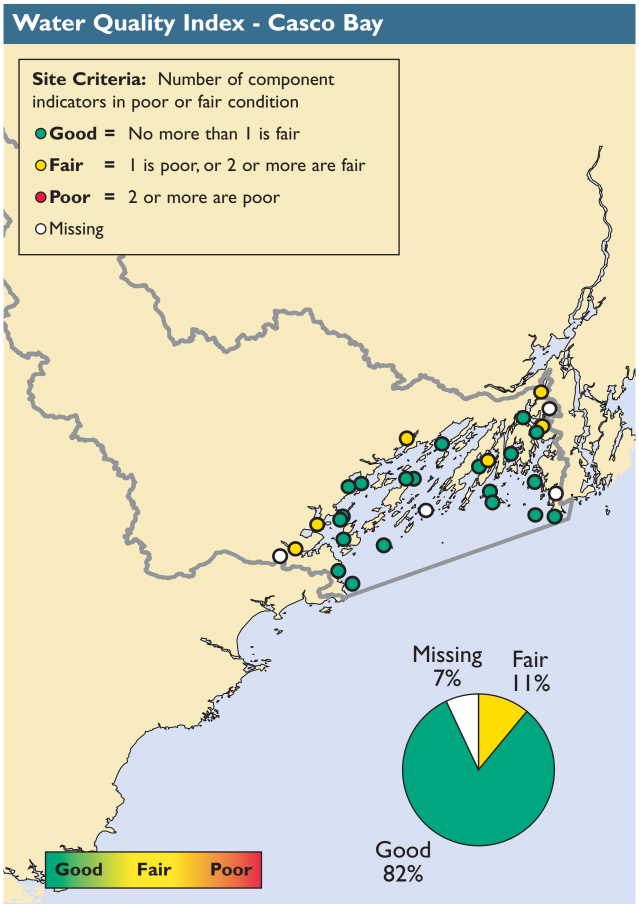


Figure 3-13. Water quality index data for Casco Bay (U.S. EPA/NCA).

Chlorophyll a | Casco Bay is rated good for chlorophyll *a* concentrations. Eighty-six percent of the estuarine area was rated good for this component indicator, 4% was rated fair, and none of the area had poor chlorophyll *a* concentrations. NCA data on chlorophyll *a* concentrations were unavailable for 10% of the CBEP estuarine area.

Water Clarity | The water clarity rating for Casco Bay is good. Water clarity was rated poor at a sampling site if light penetration at 1 meter was less than 10% of surface illumination. None of the estuarine area was rated poor or fair for water clarity, and 88% of the area was rated good. NCA data on water clarity were unavailable for 12% of the CBEP estuarine area.

Dissolved Oxygen | Casco Bay is rated good for dissolved oxygen concentrations, with 93% of the Bay's estuarine area rated good for this component indicator. No area of Casco Bay was rated poor for dissolved oxygen concentrations, and NCA data on this component indicator were unavailable for 7% of the CBEP estuarine area.

Sediment Quality Index

The sediment quality index for Casco Bay is rated good, with about 3% of the estuarine area rated poor for sediment quality and 39% rated fair (Figure 3-14). This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC. The Casco Bay sites classified as impaired showed both a moderate degree of sediment contamination by metals or PCBs and moderate levels of TOC.

Sediment Toxicity | Casco Bay is rated good for sediment toxicity. No area of Casco Bay had sediments that were toxic to amphipods, although NCA data on sediment toxicity were unavailable for 14% of the CBEP estuarine area.

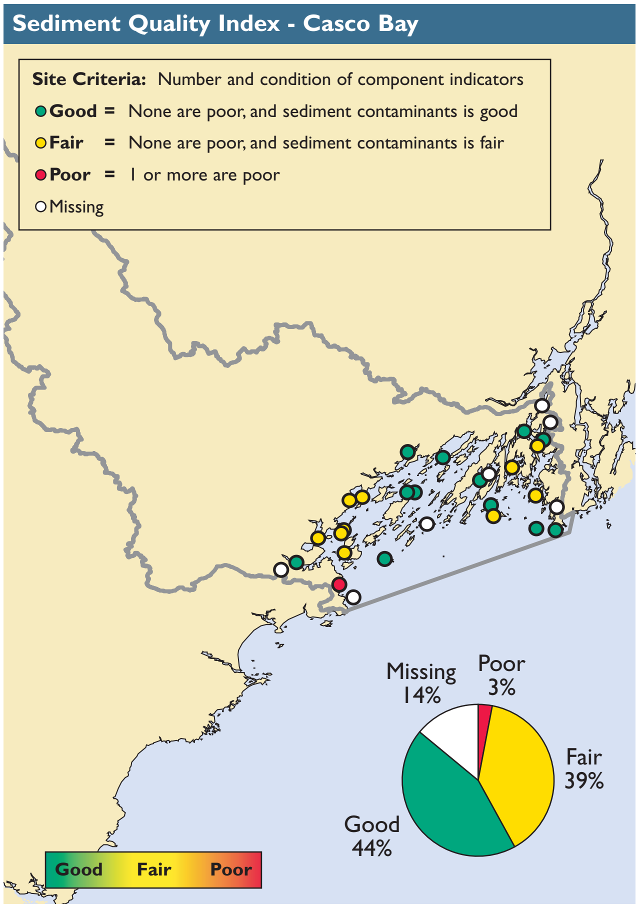


Figure 3-14. Sediment quality index data for Casco Bay (U.S. EPA/NCA).

Sediment Contaminants | The sediment contaminants rating for Casco Bay is good. Approximately 3% of the estuarine area was rated poor for sediment contaminant concentrations, and 39% of the CBEP estuarine area was rated fair.

Total Organic Carbon | Casco Bay is rated good for sediment TOC, with 36% of the estuarine area rated good for TOC concentrations and 50% of the area was rated fair. No area of Casco Bay was rated poor for TOC.

Benthic Index

Only 8% (five sites) of the estuarine area of Casco Bay had unsatisfactory benthic condition, as measured by the Shannon-Weiner Diversity Index (Figure 3-15); therefore, Casco Bay is rated good for benthic condition. Seventy-eight percent of the area was rated good for benthic condition, indicating that Casco Bay exhibited a relatively high degree of species diversity for the Northeast Coast region. Most NCA sites that received a poor rating for benthic condition were also moderately contaminated with pollutants and exhibited moderate TOC levels.

Fish Tissue Contaminants Index

No fish were collected as part of the NCA surveys in 2000 and 2001; therefore, a fish tissue contaminants index for Casco Bay was not developed for this report.

Benthic Index - Casco Bay

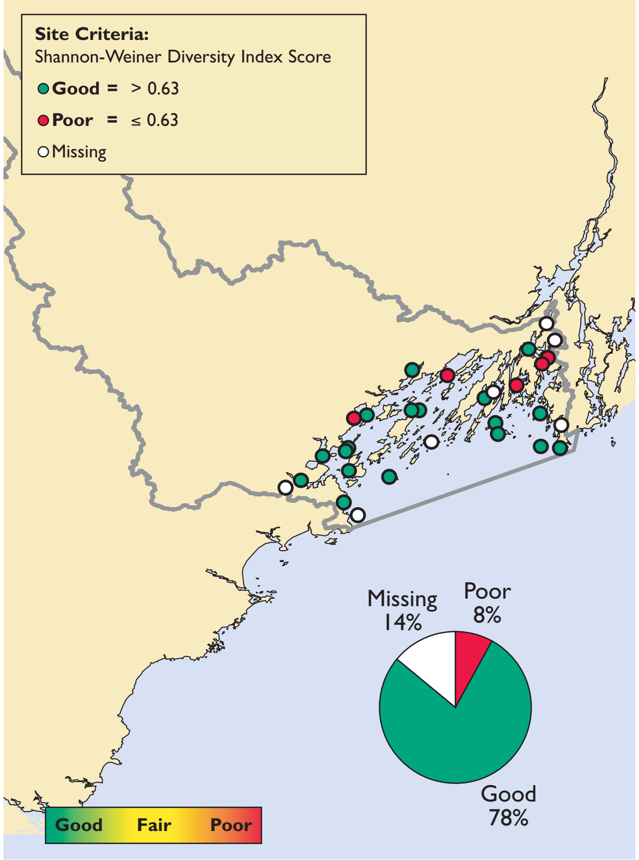


Figure 3-15. Benthic index data for Casco Bay (U.S. EPA/NCA).

Casco Bay Estuary Partnership Indicators of Estuarine Condition

Water and Sediment Quality

The group Friends of Casco Bay, with support from the CBEP, has monitored surface waters at 106 sites throughout the Bay since 1993. Through Friends of Casco Bay, 300 trained volunteers have tested water samples annually from April through October for water temperature, dissolved oxygen, pH, salinity, and water clarity. This sampling effort represents the only long-term collection of Casco Bay water quality data, providing an invaluable resource for municipal and state planners, as well as local conservation and shellfish commissions (CBEP, 2000). The results of this sampling indicate that the water quality in Casco Bay is good; however, low dissolved oxygen levels are a concern in some areas. These areas include locations with restricted circulation or with potentially heavy nutrient loadings from point or non-point sources (CBEP, 2005). Test results help communities around the Bay clean up existing pollution sources and prevent future contamination from occurring. Consistent use of water quality tests can also help address environmental concerns, such as red tide outbreaks and elevated bacterial counts, which can cause area closures for swimming, fishing, and shellfish harvesting.

The CBEP has also studied chemical contamination in the surface sediments of Casco Bay, including heavy metals, PCBs, pesticides, tributyltin (TBT), dioxins and furans, and PAHs. In general, some toxic pollutants were found in Bay sediments far from waterborne sources, suggesting deposition from the air as dry particles or in rain and snow. Elevated heavy metal concentrations were most commonly found near Portland, ME. PCBs were found in Fore River sediments, and TBT levels were highest near boating centers. Dioxins and furans were measured in low levels throughout the Bay, with the highest concentrations detected in sediments near the Presumpscot River. PAHs were the most prevalent contaminant in Casco Bay sediments and often occurred at high concentrations when compared to PAH levels in sediments from other bays around the United States (CBEP, 2000).

Habitat Quality

Casco Bay hosts a variety of habitats, including salt marshes, eelgrass beds, tidal creeks, islands, rocky shores, and estuarine waters. The most prevalent habitat in the study area is intertidal mudflats. In 1995, up to one-third of the Bay's wildlife habitat was endangered by human development; however, it appeared that few of the highest-value habitats faced imminent threats (CBEP, 2000). As a response, the CBEP began tracking the acreage of protected lands in the Bay area. Since 1997, the acres of protected land in the Casco Bay watershed have increased by almost 50%. These protected lands provide habitat for a variety of birds, fish, and other wildlife. For example, Flag Island is a protected 41-acre island in Casco Bay and provides habitat to more than 600 nesting pairs of common eiders (CBEP, 2005).

The CBEP also tracks the number of acres in large tracks of undeveloped, natural land located within the study area as an indicator of habitat quality. This indicator provides insight into the degree of habitat fragmentation in the Bay area. Larger habitat blocks are more likely to support healthy, genetically diverse wildlife populations and are especially important to such animals as the bobcat, Northern goshawk, or wood thrush, which require larger areas of uninterrupted habitat. Overall, large tracts of unfragmented, natural lands do exist in the CBEP study area, although they are growing increasingly scarce due to development. Most of these tracts are located in the upper watershed; however, substantial tracts do exist in more developed areas (CBEP, 2005).

Eelgrass, a type of seagrass, is an important habitat for fish, shellfish, and waterfowl. Casco Bay has the largest and densest concentration of eelgrass beds mapped along the coast of Maine (CBEP, 2000). The extent of eelgrass in Casco Bay has increased in recent years, with the overall acreage of eelgrass in the Bay increasing from 7,056 to 8,248 acres between 1993 and 2001; however, several areas have experienced substantial local losses in eelgrass coverage during this time period (CBEP, 2005).

Living Resources

Casco Bay is home to a variety of waterbirds, including common eiders, gulls, and great blue herons. In addition, the Bay contains 50 seabird-nesting islands and 6 heron nurseries (CBEP, 2000). The CBEP tracks the number of waterbirds in Casco Bay as an environmental quality indicator to assess environmental impacts on the birds. In 2000, the Maine Department of Inland Fisheries and Wildlife, FWS, and CBEP worked together to conduct a series of waterbird surveys in the Bay. The data collected from this survey series will provide the baseline for future waterbird population evaluations of Casco Bay (CBEP, 2005).

The CBEP has studied contamination levels in the tissues of blue mussels and lobsters, and the Maine Department of Environmental Protection (DEP) and the Gulf of Maine Program also sample mussels at additional sites in Casco Bay. Through this long-term testing, the CBEP can assess whether toxic contaminant levels in the Bay are increasing or decreasing. Shellfish are filter feeders and concentrate pollutants from the water. By testing the tissues of mussels and lobsters for chemical contaminants, scientists can evaluate the presence of toxics that may affect human health.

The CBEP has monitored mussels at eight locations and lobsters at two sites and found that the contaminant levels in mussel tissues from some locations exceeded the state level for posting health advisories (based on eating shellfish once a week). Elevated levels of the contaminants lead, PAHs, PCBs, dioxins, and furans were detected in some mussels, and further tests are being performed to confirm these results (CBEP, 2000).

Casco Bay Estuary Partnership

Trends in Toxic Chemicals in Casco Bay Sediments

The presence of toxic chemicals in the sediments of Casco Bay serves as an indicator of overall contamination of the Bay's marine ecosystem. When toxic chemicals are introduced to the Bay from rivers, stormwater runoff, point-source discharges, and atmospheric deposition, many do not readily degrade or disperse. Instead, these chemicals adsorb to sediment particles and settle to the bottom of the Bay, where they may persist for a long time. Even when clean sediments are deposited on top of contaminated sediments, dredging and biological activity can bring the contaminants back to the surface.

Bottom-dwelling (benthic) animals play an important role in the food chain, recycling organic matter and serving as a food source for groundfish (e.g., flounder, cod, and haddock), lobsters, and crabs. These benthic organisms can suffer adverse effects from their exposure to and ingestion of contaminated sediments and, as prey of groundfish, may provide a conduit for introducing these contaminants into the food chain. Fish and large crustaceans that feed on contaminated benthic organisms may experience inhibited growth and reproduction, disease vulnerability, and even death. As the contaminants move up the food chain, humans who eat seafood contaminated by toxic chemicals can also be at risk. For example, the presence of dioxins in Casco Bay—largely a byproduct of pulp and paper mills—has resulted in elevated dioxin concentrations in the liver (tomalley) of lobsters. A public health advisory against eating lobster tomalley has been in effect in Maine since 1992 (Maine DEP, 2004). The Maine Department of Health and Human Services has also issued guidelines for the consumption of saltwater fish contaminated by mercury and organic chemicals, such as PCBs.

When scientists first studied the sediments of Casco Bay in 1980, they were surprised to find a wide array of toxic contaminants, including heavy metals and organic chemicals. In 1991, the CBEP commissioned a baseline study to assess sediment contamination levels at 65 sites in the Bay using state-of-the art analytical methods. Sampling sites were selected based on depth, circulation, sediment type, and historical contaminants data, such as the locations of industrial facilities and other point-source discharges. Samples were analyzed for heavy metals, PAHs, PCBs, and pesticides (Kennicutt et al., 1992). In 1994, sediments from 28 of the original study sites and 5 new sites were analyzed for butyltins, dioxins/furans, and coplanar PCBs (Wade et al., 1995). In 2000 and 2001, in partnership with EPA's NCA survey, the CBEP resampled the sediments at the original sampling locations. Scientists from Texas A&M University compared the results of the 1991–1994 sampling to the 2000–2001 studies and concluded that most toxic chemical concentrations have decreased or remained the same over time, indicating that pollution-control strategies are working in Casco Bay (see table).

In some heavily polluted areas, such as the flats of the Fore River (near Portland, ME), mollusks, small crustaceans, and other expected benthic species were absent in a 1989 sampling. Some of the hardy worms that were found had oil on their "feet" (parapodia), probably from petroleum-related contaminants (Personal communication, Doggett, 2005).

Changes in Chemical Concentrations in Sediments from the 1991–1994 to 2000–2001 Sampling Efforts in Casco Bay (Wade and Sweet, 2005)

Decreased	Increased	No Overall Change
Cadmium	Silver	Arsenic
Chromium	High molecular-weight PAHs	Copper
Mercury		Lead
Nickel		Zinc
Selenium		Planar PCB 77
Total pesticides		PAHs[2]
4,4-DDE		Dioxins/furans
4-4-DDD		
Total DDTs		
TBT[1] and butyltin		
Total PCBs		
Planar PCB 126		
Low molecular-weight PAHs		

[1] The overall decline of TBT concentrations in the Bay's sediments reflects the effectiveness of federal and Maine laws that now ban the use of paints with TBT for all uses except for vessels longer than 25 meters or those having aluminum hulls (Maine DEP, 1999). The continued use of TBT paints on large commercial vessels may explain the presence of elevated concentrations of TBT in the sediments of Inner Bay sites.

[2] Overall, the total concentration of PAHs in Casco Bay sediments has remained unchanged. This suggests that increased use of fossil fuels is balanced by environmental controls that lower the PAH inputs to the Bay (Wade and Sweet, 2005).

The Texas A&M University comparison examined the concentrations of a variety of contaminants in sediments, including metals, PAHs, PCBs, and pesticides. Heavy metal concentrations in Casco Bay are lower than levels known to cause harmful effects to organisms. Even the elevated concentrations of metals seen in Casco Bay are lower than concentrations found in the highly contaminated sediments of urban areas, such as Long Island Sound and Boston Harbor. Although concentrations are highly elevated above natural background levels, the PAH concentrations seen in the sediments of the inner part of Casco Bay ranged between the ERL and ERM concentrations (Long et al.,1995). The majority of PAHs detected in the Bay are high molecular-weight, combustion-related PAHs that sequester in fine particles, which may reduce their toxicity. PCB concentrations at almost all Casco Bay sites were below the toxic response threshold, and concentrations of pesticides were low compared to concentrations considered toxic. Butyltins, dioxins/furans, and planar PCBs were not present at toxic concentrations, and in general, the highest concentrations of toxic chemicals were found near known sources. For example, elevated butyltin concentrations (a constituent of marine anti-fouling paints) were found near boat anchorages and marinas, whereas dioxins and furans were found in elevated concentrations downstream of pulp and paper mills (Wade and Sweet, 2005).

Environmental Stressors

The CBEP uses a variety of human indicators to assess the environmental quality of Casco Bay, including the volume and frequency of CSOs, population changes, the amount of impervious cover in the watershed, and the amount of air pollution near the Bay. Annually, CSOs contribute millions of gallons of polluted water to Casco Bay; however, the volume and frequency of these overflows have decreased since 1996 (CBEP, 2005).

The human population in the Casco Bay watershed is expected to increase by 6% between 2005 and 2015. The CBEP uses population growth as an indicator of environmental stress because of the impact that related activities, such as transportation or housing construction, have on the Bay's ecosystem. For example, vehicle registrations in Cumberland County increased from about 215,000 to more than 283,000 between 1998 and 2003. Such an increase in the number of vehicles can contribute to urban sprawl patterns and increased impervious surface area (CBEP, 2005). The amount of impervious surfaces in a watershed is important because high levels of these surfaces can reduce groundwater recharge and increase flooding, erosion, and stream channel alteration. Impervious surface coverage can also be used as an indicator of stream degradation. Recent studies suggest that, when impervious surface coverage exceeds 6% to 10% of the watershed, the ability of Maine's streams to support aquatic ecological communities becomes degraded. Approximately 5.9% of the entire Casco Bay watershed is composed of impervious surfaces. It should be noted that this percentage was calculated for a large area and is not directly applicable to the 6% to 10% threshold calculated for very small watersheds (CBEP, 2005).

With grant funding from EPA and the Maine DEP, the CBEP established a coastal air monitoring site at Wolfe's Neck in Freeport, ME. Data from this site, along with results collected by the Maine DEP at an inland site in Bridgton, are helping these agencies determine patterns of air pollution in the watershed. The monitoring program has tracked the deposition of PAHs; mercury, cadmium, and other trace metals; and nitrogen, as well as the concentration of fine particulates. Data from this program and from the National Atmospheric Deposition Program suggest that the atmosphere is a significant source of pollution for Casco Bay. Rainfall sampled in Freeport, ME, contained PAHs at concentrations equal to an urban air monitoring site near Boston. These elevated levels were more common

Tern on Outer Green Island, ME (Matthew Craig).

in samples collected during the wetter seasons of spring and summer; however, the dry deposition of PAHs was much lower in samples from Freeport than from the urban site, suggesting that dry deposition is related to local sources (Golumb et al., 2001). The atmosphere is the dominant source of both nitrogen and mercury to the Bay (Figure 3-16) (Ryan et al., 2003).

Current Projects, Accomplishments, and Future Goals

Since 1990, the CBEP has had numerous accomplishments, including the following recent accomplishments:

- Initiated a coordinated habitat-restoration effort and catalyzed on-the-ground projects through seed funding, grant-writing, and technical support
- Facilitated a 14-municipality interlocal collaboration (Interlocal Stormwater Working Group) on the management of stormwater
- Facilitated the reopening of more than 300 acres of clam flats to harvesting
- Helped protect more than 3,000 acres of high-value habitat through conservation
- Presented experts on marine invasive species and stormwater management in cold climates during local and regional conferences.
- Compiled and analyzed available data on 14 indicators of the health of Casco Bay to publish the report *State of the Bay 2005*, which was released at the State of the Bay 2005 conference on November 3, 2005 (CBEP, 2005).

Conclusion

Casco Bay's overall condition appears to be rated good based on three of the NCA indices of estuarine condition and on assessment work done by the CBEP; however, some concerns have been identified as a result of monitoring work conducted during the 1990s and into the 21st century. Toxic pollution, thought to originate from legacy sources and atmospheric deposition, is a primary concern for stakeholders. In addition, relatively localized hypoxic conditions are being carefully studied, and other concerns, such as red tide outbreaks, algal blooms, and elevated bacterial counts, are also being monitored.

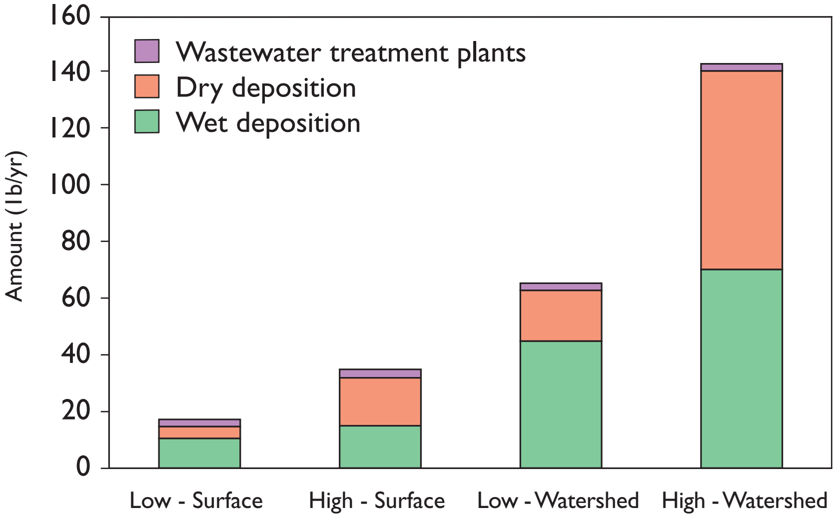
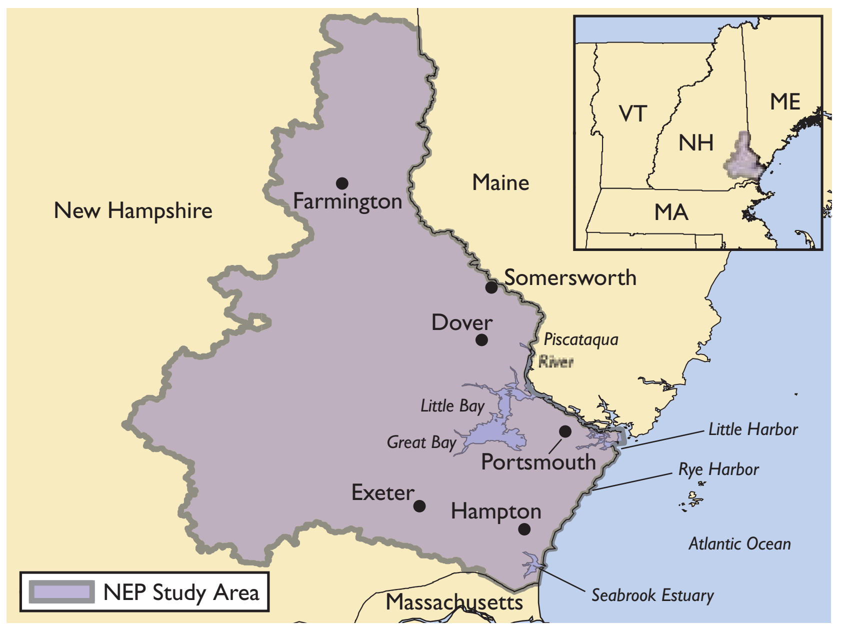


Figure 3-16. Atmospheric deposition (wet and dry) may account for 84% to 92% of the overall mercury loading to Casco Bay. The overall contribution of dry deposition to the total mercury loading on the surface of Casco Bay and on the Casco Bay watershed is estimated, and the high and low ranges of this estimate are presented on the graph (Ryan et al., 2003).

New Hampshire Estuaries Project



NewHampshire EstuariesProject

www.nhep.unh.edu

Background

New Hampshire has more than 230 miles of sensitive tidal shoreline, in addition to 18 miles of open-ocean coastline on the Gulf of Maine (NHEP, 2003). The Great Bay and Hampton-Seabrook estuaries are the largest distinct estuaries in New Hampshire. Other estuaries of importance are Little Bay, Little Harbor, and Rye Harbor, as well as portions of their tidal tributaries (NHEP, 2005).

The Great Bay Estuary covers 17 mi^2, with nearly 150 miles of tidal shoreline (NHEP, 2003). Great Bay is unusual because it is located inland, more than five miles up the Piscataqua River from the ocean. Due to this location, Great Bay's tidal exchange with the ocean is slow, requiring up to 18 days (or 36 tide cycles) for water entering the head of the Bay to move to the ocean (Jones, 2000). Oysters, clams, striped bass, bluefish, herring, smelt, lobsters, and eels are harvested from Great Bay for both recreational and commercial purposes. In addition, Great Bay is New Hampshire's principal waterfowl overwintering site and a focus area for the North American Waterfowl Management Plan (NHEP, 2005).

Hampton-Seabrook Harbor encompasses 480 acres of open water at high tide. This coastal estuary is characterized by extensive salt marshes and is separated from the ocean by a series of barrier beaches. The Harbor is surrounded by a 5,000-acre salt marsh, which is the largest contiguous salt marsh in the state, and Hampton Beach is one of the busiest tourist attractions in New Hampshire (NHEP, 2003). Several thousand residents purchase shellfish licenses each year, primarily to dig softshell or steamer clams locally.

Environmental Concerns

After a long history of industrial and sewage pollution, water quality in the New Hampshire Estuaries has shown significant improvements during the past two decades (Jones, 2000); however, bacterial and nutrient contamination, toxic contaminants, the loss or fragmentation of wildlife habitat, degraded salt marshes, and declines in oyster and clam populations continue to be high-priority problems for water quality, habitat, fish, and wildlife.

Population Pressures

The population of the 3 NOAA-designated coastal counties (Carroll, Rockingham, and Strafford) coincident with the New Hampshire Estuaries Project (NHEP) study area increased by more than 148% during a 40-year period, from 0.17 million people in 1960 to almost 0.43 million people in 2000 (Figure 3-17) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the NHEP study area is almost 6 times the population growth rate of 24% for the collective NEP-coincident coastal counties of the Northeast Coast region. In 2000, the population density of these 3 NEP-coincident coastal counties was 216 persons/mi^2, almost 5 times lower than the population density of 1,055 persons/mi^2 for the collective NEP-coincident coastal counties of the Northeast Coast region (U.S. Census Bureau, 2001).

NCA Indices of Estuarine Condition—New Hampshire Estuaries

The overall condition of the New Hampshire Estuaries is rated fair based on the four indices of estuarine condition used by the NCA (Figure 3-18). Two of the assessed indices (sediment quality and fish tissue contaminants) received good to fair ratings for the New Hampshire Estuaries, whereas the other two indices (water quality and benthic) received fair ratings. Figure 3-19 provides a summary of the percentage of estuarine area rated good, fair, poor, or missing for each parameter considered. This assessment is based on data from 76 NCA sites sampled in the NHEP estuarine area in 2000 and 2001. Please refer to Tables 1-24, 1-25, and 1-26 (Chapter 1) for a summary of the criteria used to develop the rating for each index and component indicator.

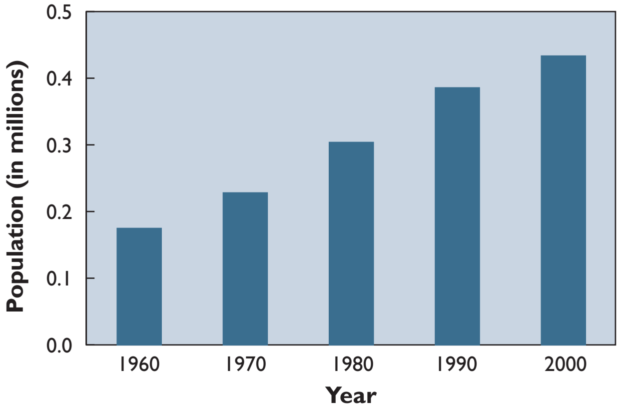


Figure 3-17. Population of NOAA-designated coastal counties of the NHEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

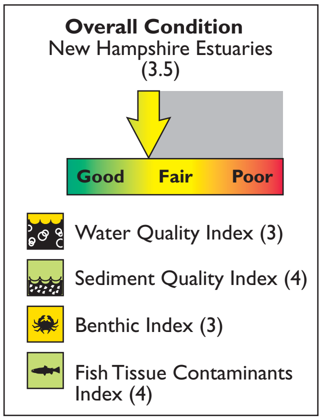


Figure 3-18. The overall condition of the NHEP estuarine area is fair (U.S. EPA/NCA).

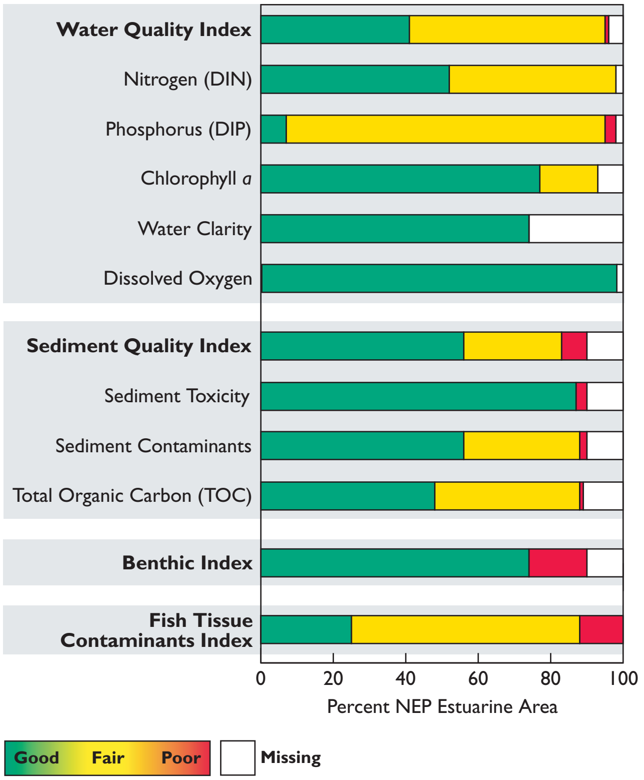


Figure 3-19. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — New Hampshire Estuaries (U.S. EPA/NCA).

Water Quality Index

Based on data collected by the NCA surveys, the water quality index for the New Hampshire Estuaries is rated fair. This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. About half of the estuarine area of the New Hampshire Estuaries was rated fair for water quality, and less than 1% was rated poor (Figure 3-20). Nutrient concentrations were moderately high, particularly for DIP, and 16% of the estuarine area had moderate chlorophyll *a* concentrations, primarily in the tributaries. The water quality condition of the New Hampshire Estuaries was relatively poor as compared to other NEPs in the Acadian Province, from Massachusetts to Maine. The larger of the New Hampshire Estuaries, the Great Bay and Piscataqua River system, formed as a drowned river valley and therefore displays different characteristics from other, more oceanic-influenced systems in the Acadian Province. There were no indications of dissolved oxygen depletion or poor water clarity in the New Hampshire Estuaries during the NCA assessment period (2000–2001).

Dissolved Nitrogen and Phosphorus

The New Hampshire Estuaries are rated good for DIN concentrations because 52% of the estuarine area was rated good and 46% of the area was rated fair for this component indicator. None of the NHEP estuarine area was rated poor for DIN concentrations. The Estuaries are rated fair for DIP concentrations, with 7% of the estuarine area rated good, 88% of the area rated fair, and 3% of the area rated poor for this component indicator.

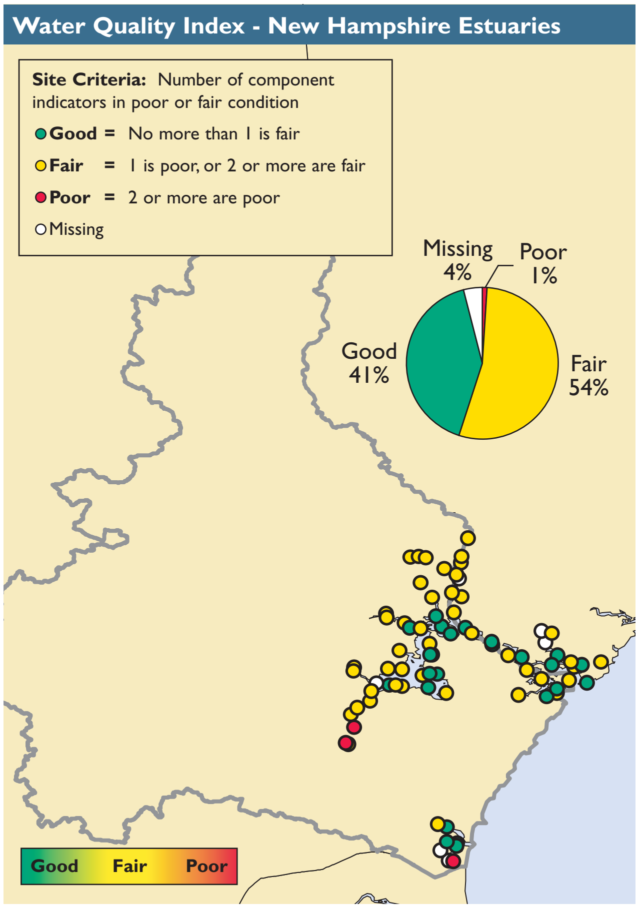


Figure 3-20. Water quality index data for the New Hampshire Estuaries, 2000–2001 (U.S. EPA/NCA).

Chlorophyll a | The New Hampshire Estuaries are rated good for chlorophyll *a* concentrations. Of the estuarine area assessed, 77% and 16% was rated good and fair, respectively, and none of the area was rated poor. NCA data on chlorophyll *a* concentrations were unavailable for 7% of the NHEP estuarine area.

Water Clarity | Water clarity in the New Hampshire Estuaries is rated good. None of the estuarine area was rated poor for water clarity, and 74% of the area was rated good; however, NCA data on water clarity were unavailable for 26% of the NHEP estuarine area.

Dissolved Oxygen | The New Hampshire Estuaries are rated good for dissolved oxygen concentrations. Ninety-eight percent of the estuarine area was rated good for dissolved oxygen concentrations, and none of the area was rated poor. NCA data on dissolved oxygen concentrations were unavailable for 2% of the NHEP estuarine area.

Sediment Quality Index

The sediment quality index for the New Hampshire Estuaries is rated good to fair, with 7% of the estuarine area rated poor, 27% rated fair, and 56% rated good for sediment quality (Figure 3-21). This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC. One site in Portsmouth Harbor proved to be toxic to amphipods; however, sediments were sandy at this site, which may have contributed to the low amphipod survival. Most of the survey sites characterized as impaired had sediments with moderate to high concentrations of metals, PAHs, and DDT, and nearly all of the contaminated sites also had moderate levels of TOC.

Sediment Toxicity | The New Hampshire Estuaries are rated good for sediment toxicity, with only 3% of the estuarine area rated poor for this component indicator. NCA data on sediment toxicity were unavailable for 10% of the NHEP estuarine area.

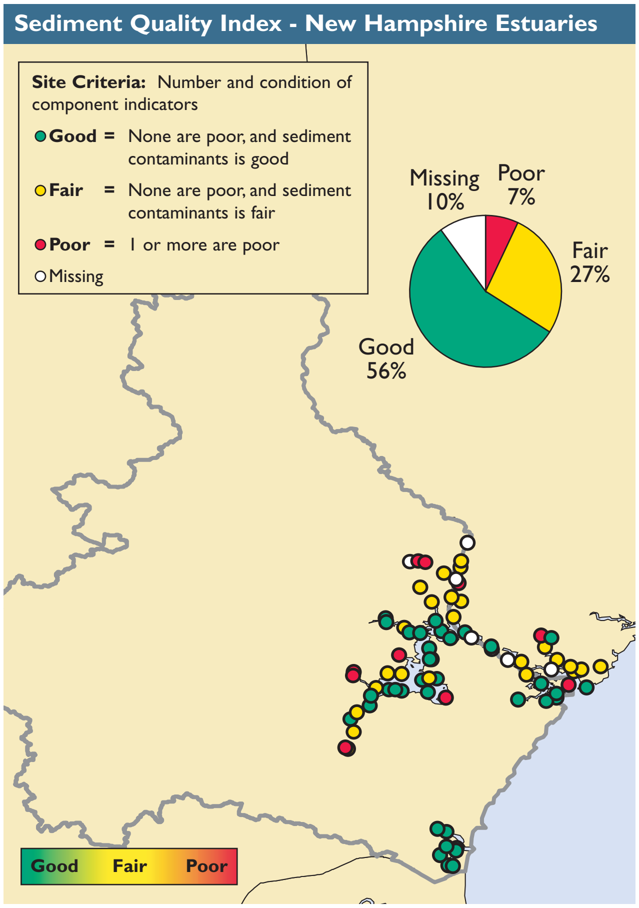


Figure 3-21. Sediment quality index data for the New Hampshire Estuaries, 2000–2001 (U.S. EPA/NCA).

Sediment Contaminants | The New Hampshire Estuaries are rated good for sediment contaminant concentrations. Approximately 2% of the estuarine area was rated poor for sediment contamination, and 32% of the area was rated fair.

Total Organic Carbon | Another measure of sediment quality is sediment TOC, and the New Hampshire Estuaries are rated good for this component indicator. Forty-eight percent of the estuarine area was rated good for TOC concentrations, and 40% of the area was rated fair. Only 1% of the estuarine area was rated poor, and NCA data on sediment TOC concentrations were unavailable for 11% of the NHEP estuarine area.

Benthic Index

The benthic index for the New Hampshire Estuaries is rated fair, with 16% of the estuarine area showing poor benthic condition as measured by the Shannon-Weiner Diversity Index (Figure 3-22). This rating indicates a level of diversity comparable with other NEP estuaries in the Northeast Coast region. Most of the sites with a poor benthic index rating also had moderate or high concentrations of sediment contaminants. In addition, some of the low diversity sites occurred in waters where salinity was relatively fresh (less than 20 ppt), which indicates a site where natural salinity fluctuations could be a natural stressor, causing a reduction in benthic species diversity.

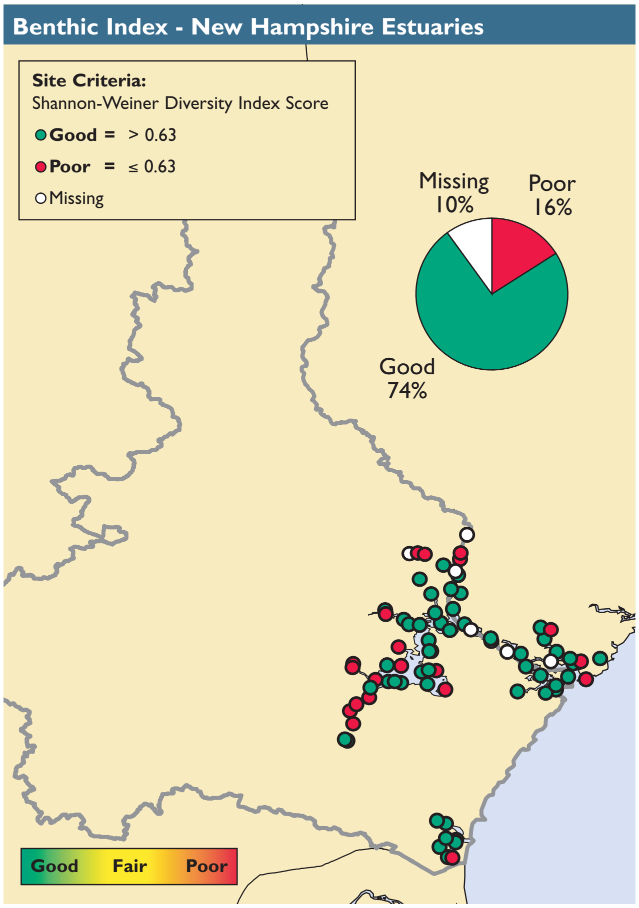


Figure 3-22. Benthic index data for the New Hampshire Estuaries, 2000–2001 (U.S. EPA/NCA).

Fish Tissue Contaminants Index

The fish tissue contaminants index for the New Hampshire Estuaries is rated good to fair (Figure 3-23). Seventeen fish and six shellfish (e.g., lobster) samples from the New Hampshire Estuaries were analyzed for chemical contaminants. Twelve percent of the samples had high concentrations of at least one toxicant and were rated poor, and 63% had moderate levels of contaminants and were rated fair.

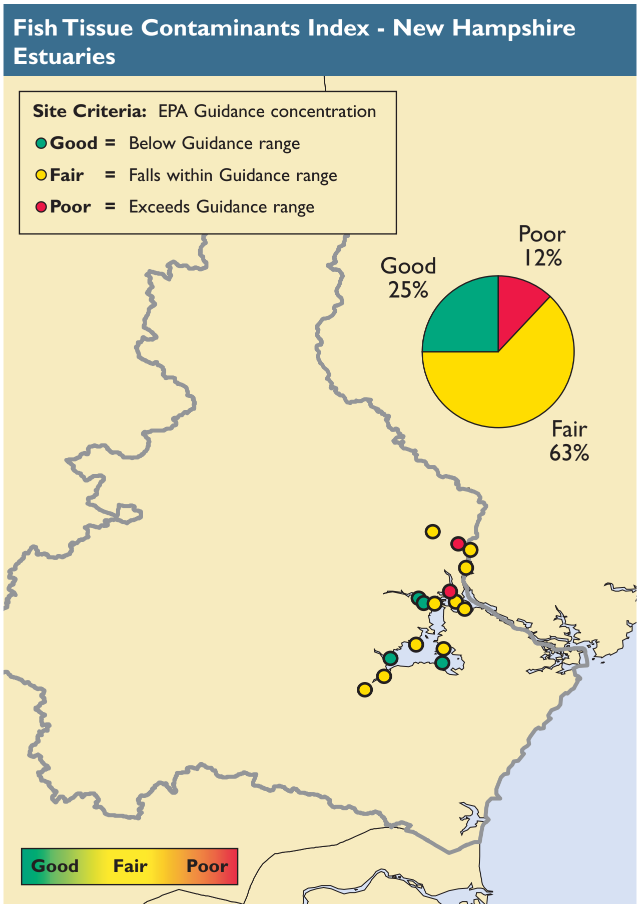


Figure 3-23. Fish tissue contaminants index data for the New Hampshire Estuaries, 2000–2001 (U.S. EPA/NCA).

New Hampshire Estuaries Project Indicators of Estuarine Condition

The NHEP tracks the health of the New Hampshire Estuaries through 34 environmental indicators that are defined in the *NHEP Monitoring Plan 2004, Version 4* (Townbridge, 2004). Every three years, the NHEP produces a report that highlights results from the key environmental indicators. The most recent report (NHEP, 2003) was issued in 2003, coincident with a State of the Estuaries conference. The 12 indicators identified in the *2003 State of the Estuaries* report are summarized in the sections below. The full report and conference proceedings are available at http://www.nhep.unh.edu.

Some of the NHEP indicators are based on data from the NCA's 2000–2001 probabilistic survey, which were used for the EPA National Indicators of Estuary Condition and will be included in the *2006 State of the Estuaries* report. The NHEP uses different standards or analysis methods for some indicators than EPA; therefore, the NHEP's conclusions will differ from the EPA report. For example, the NHEP evaluates sediment quality using a triad approach with sediment toxicity, sediment chemistry, and benthic community data, whereas EPA calculates the sediment quality index using data on sediment contaminants, sediment toxicity, and TOC. The New Hampshire Department of Environmental Services and the University of New Hampshire (UNH) have analyzed the 2000–2001 NCA data to calculate NHEP indicators and document other observations (NHDES, 2005).

Water and Sediment Quality

The NHEP reported on four indicators of water quality: bacteria concentrations, toxic contaminants in mussel tissue, nitrogen concentrations, and violations of the dissolved oxygen standard. Overall, these four indicators show that water and sediment quality in the New Hampshire Estuaries is generally good; however, there is concern about rising nitrogen concentrations.

Dry-weather fecal coliform contamination is used as an indicator of sewage contamination in the New Hampshire Estuaries. In the middle of Great Bay at Adams Point, fecal coliform concentrations decreased by 30% between 1992 and 2002 (Figure 3-24). Stronger declining trends were found at the tributary sampling sites, where decreases of 75% were observed for the same period. Despite these improvements, many shellfish bed closures still exist due to bacterial pollution (NHEP, 2003).

Blue mussels (*Mytilus edulis*) are used as a water quality indicator species for toxic contaminants from polluted waters because these shellfish accumulate contaminants in their tissues. Between 1993 and 2000, none of the samples collected from the 13 mussel-sampling sites in the New Hampshire Estuaries had toxic contaminant levels greater than U.S. Food and Drug Administration (FDA) guidelines. Levels of PCBs and the pesticide DDT are declining at the Portsmouth Harbor station, and PAH levels are increasing. The decreasing PCB and DDT concentrations are probably due to the decreased use of these chemicals following an EPA ban enacted in 1979 and 1972, respectively. PAHs are present as petroleum constituents and as residuals of the combustion of petroleum products and other organic compounds. Increased stormwater runoff from impervious surfaces (e.g., parking lots) and fuel spills into the Estuaries are two of many possible reasons for the increasing PAH concentrations in blue mussel tissues (NHEP, 2003).

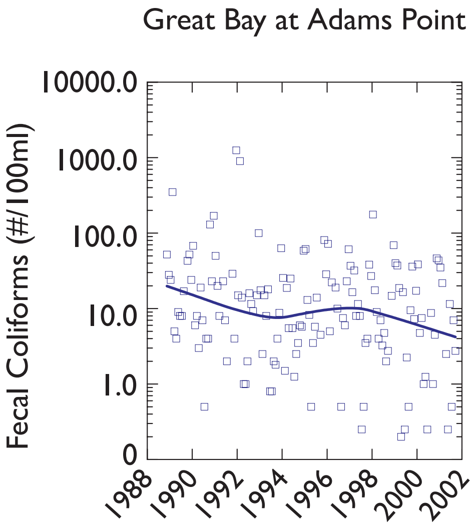


Figure 3-24. Fecal coliform concentrations between 1988 and 2002 in Great Bay at Adams Point (NHEP, 2003).

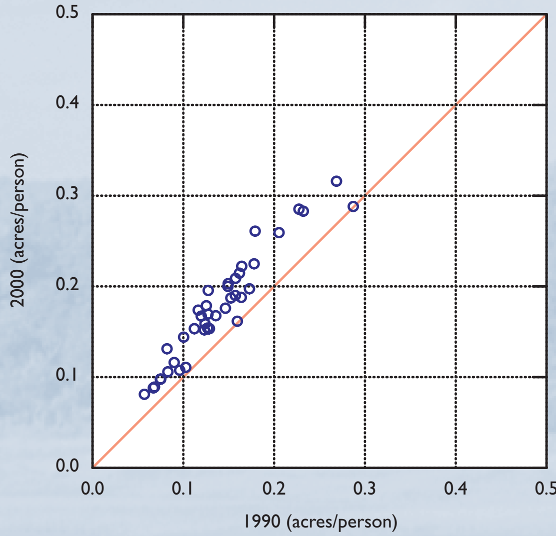
New Hampshire Estuaries Project

Mapping Impervious Surfaces in New Hampshire's Coastal Watershed

Stormwater runoff from pavement and other impervious surfaces is a major factor that affects water quality in the New Hampshire Estuaries. Shellfish beds are often closed after rain storms due to bacteria that have been washed into the Estuaries via impervious surfaces, which are a marker for high-impact human development in the watershed. To address this issue, the NHEP set out to obtain a watershed-wide map of impervious surfaces to better understand the extent of impervious surface and the possible water quality impacts.

The NHEP contracted with the UNH Complex Systems Research Center to generate maps of impervious surfaces in 1990 and 2000 from satellite imagery (Justice and Rubin, 2002). UNH used a subpixel analysis routine on Landsat Thematic Mapper data, coupled with ground-truthing surveys, to generate the maps. The NHEP totaled the area of impervious surfaces in each of the 42 coastal towns located within the NHEP study area and calculated the percent of land area covered by impervious surfaces. The map on the next page shows the 42 coastal watershed towns and their percent of imperviousness in 2000.

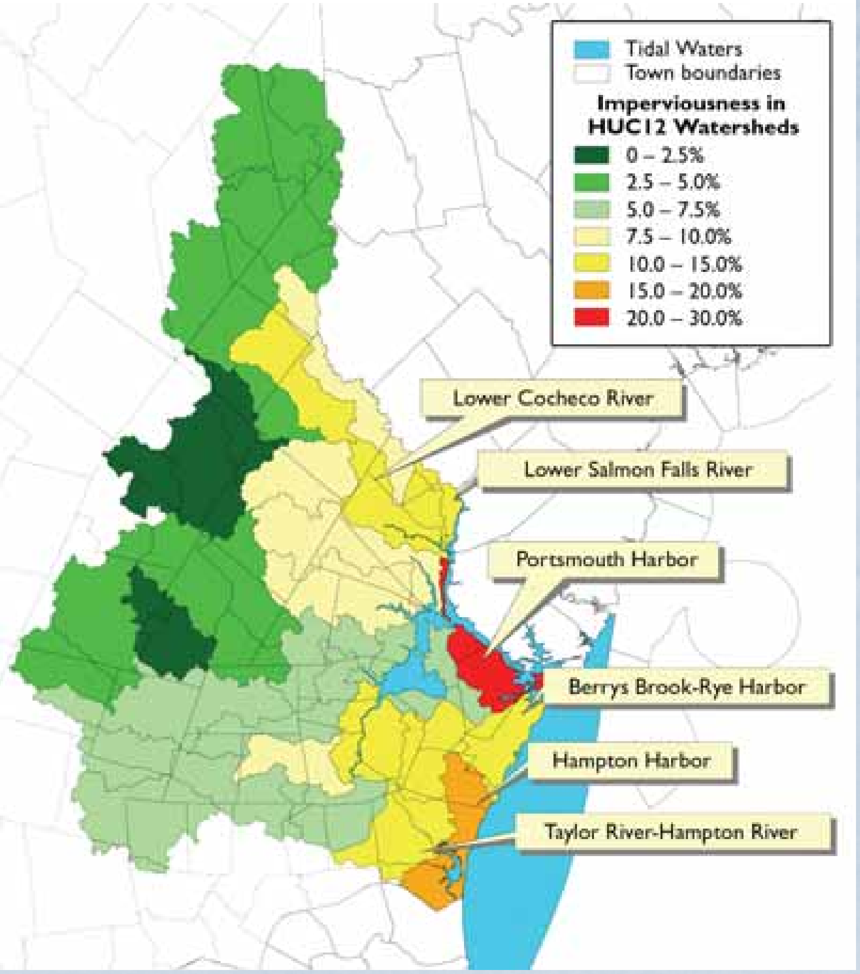
Eleven of the 42 towns had more than 10% of their land area covered by impervious surfaces. Studies conducted in other regions of the country have demonstrated water quality deterioration where impervious surfaces cover greater than 10% of the watershed area (Schueller, 1995); therefore, it is the goal of the NHEP to keep the coverage of impervious surfaces in the coastal subwatersheds to less than 10% (Townbridge, 2003). However, additional factors, such as the proximity of the impervious surfaces to waterbodies and the extent of buffer, may be more important than percent imperviousness.



Comparison of imperviousness per capita in 1990 to 2000 (Townbridge, 2003).

The impervious surface data was also used to study the pattern of "sprawl-type" development in the coastal watershed. A commonly accepted definition of sprawl is increasing rates of land consumption per person. Using the impervious surface data from 1990 and 2000, the NHEP was able to show that all of the 42 towns used more impervious surface per person in 2000 than in 1990 (the difference was statistically significant for 25 of the 42 towns). On average, the acres of impervious surface for each person in the towns increased from 0.15 acres/person in 1990 to 0.20 acres/person in 2000 (Townbridge, 2003). The figure above shows the general increase in imperviousness per capita for each town in 1990 versus 2000. All of the towns are plotted above the red line, which shows that imperviousness per capita is increasing in all the towns, even if the change is not statistically significant.

After the NHEP presented the impervious surface data at the 2003 State of the Estuaries Conference, many town officials requested detailed information for their towns. As a result, the NHEP produced a customized map of impervious surfaces and water resources for each of the 42 towns. The towns also received a fact sheet summarizing what is known about the effects of impervious surfaces on water quality. The NHEP distributed this information at a workshop for conservation commissions and planning boards in October 2004. The NHEP plans to update these impervious surface maps in 2005 and again in 2010.



Percent impervious surface in New Hampshire's coastal watershed in 2000 (NHEP, based on data from UNH Complex Systems Research Center).

Excessive nitrogen concentrations in estuaries can cause blooms of algae that change the species composition of important habitats. Monthly measurements at three long-term water quality monitoring sites have documented changes in nitrogen (as nitrate+nitrite) concentrations in the Great Bay between 1992 and 2001. Statistical tests have shown that nitrate+nitrite concentrations have increased during this period at the sites at Adams Point in Great Bay and in the Lamprey River; however, there were no statistically significant trends at the Squamscott River station. Despite the increasing concentrations of nitrate+nitrite in the New Hampshire Estuaries, there have not been any significant trends observed in the typical indicators of eutrophication (e.g., dissolved oxygen and chlorophyll *a* concentrations); therefore, the load of nitrate+nitrite to the Great Bay appears to have not yet reached the level at which the undesirable effects of eutrophication occur. The major sources of nutrient contamination to the Estuaries are WWTP effluents, malfunctioning septic systems, atmospheric deposition, and runoff from urban and agricultural areas, which are all related to population growth and the associated land development patterns (NHEP, 2003).

Fish and many other aquatic organisms need dissolved oxygen in the water to survive. The strong tidal flushing through the Estuaries and inflow from freshwater streams keeps the water well mixed and oxygenated. Dissolved oxygen levels in Great Bay and the Squamscott River consistently meet state standards. Although the standard has also been met at the Lamprey River sites 90% of the time, there have been a few instances where the standard was not met. The causes of these sporadic hypoxic events are not known. Blooms of algae, respiration of benthic organisms, and oxygen demand from WWTP effluent can deplete oxygen in the water; however, in some cases, these low concentrations may be a natural phenomenon (NHEP, 2003).

Habitat Quality

The NHEP tracks six indicators to determine habitat quality: eelgrass abundance, unfragmented forest blocks, salt marsh restoration, protected lands, impervious surfaces, and sprawl-type growth. Only the first two of these indicators are presented in this section. The other four indicators are discussed in the *Current Projects, Accomplishments, and Future Goals* section of this profile and in the NHEP Highlight article.

Eelgrass (*Zostera marina*) is an essential part of the Estuaries' ecology because it provides food for wintering waterfowl and habitat for juvenile fish (Thayer et al., 1984). The UNH Seagrass Ecology Group has mapped the distribution of eelgrass in Great Bay every year from 1986 to 2001. Eelgrass cover in Great Bay has been relatively constant for the past 10 years at approximately 2,000 acres. In 1989, there was a dramatic 85% decline in eelgrass acreage to 300 acres; however, the eelgrass beds made a rapid recovery the following year. Water clarity and water depth are the main factors affecting the presence of eelgrass, although eelgrass can also be affected by other factors (e.g., disease) on a rapid temporal scale (NHEP, 2003). For example, the dramatic density decline in 1989 was caused by an infestation of a slime mold, *Labryrinthula zosterae*, commonly called "wasting disease" (Muehlstein et al., 1991).

The fragmentation of open lands due to new roads and sprawling patterns of development can have significant consequences for habitat and hydrologic functions within the coastal watershed. As of 2001, there were 282 unfragmented blocks greater than 250 acres in the coastal watershed, the majority of which were less than 1,000 acres. In addition, there were only 4 blocks greater than 5,000 acres, and only 10% of the remaining blocks are protected from development (NHEP, 2003).

Living Resources

The NHEP reported on two wildlife indicators—oyster and clam populations—in the *2003 State of the Estuaries* report, citing both species as declining in the New Hampshire Estuaries.

Oysters are economically important because they support valuable recreational fisheries and have tremendous potential as an aquaculture species. They are also excellent bioindicators of estuarine condition because they are relatively long lived, remain stationary, and filter large volumes of estuarine water to feed. Additionally, as filter feeders, oysters play an important role in cycling nutrients, improving water clarity, and removing significant quantities of nitrogen and phosphorus from the water (NHEP, 2003). Since 1993, the oyster harvest in Great Bay has suffered a serious decline (Figure 3-25). In 2002, the standing stock in beds open for harvesting was 3,579 bushels, about 7% of the goal of 50,000 bushels. Most of the remaining standing stock is in the Adams Point, Nannie Island, and Woodman Point beds in Great Bay. The major cause of this decline is thought to be the protozoan pathogens MSX and Dermo, which have caused similar declines in oyster fisheries in Chesapeake Bay and other mid-Atlantic estuaries (NHEP, 2003).

Soft shell clams are an economic, recreational, cultural, and natural resource for the seacoast region. Recreational shellfishing in Hampton-Seabrook Harbor is estimated to contribute more than $3 million a year to the local and state economies (Jones, 2000). Soft shell clam densities in 2001 were well below the most recent 10-year average (1990–1999) and were declining in all three main clam flats. The 2001 densities at Common Island and Middle Ground were also lower than the long-term baseline densities recorded between 1974 and 1989. The source of the current decline in harvestable clam populations is unknown (NHEP, 2003); however, an NHEP study in 2001–2002 concluded that predation of juvenile clams by green crabs and strong currents in the harbor were potential factors in the juvenile clam population decline (Beal, 2002). Other observers have expressed concern that over-harvesting may also be contributing to the decline.

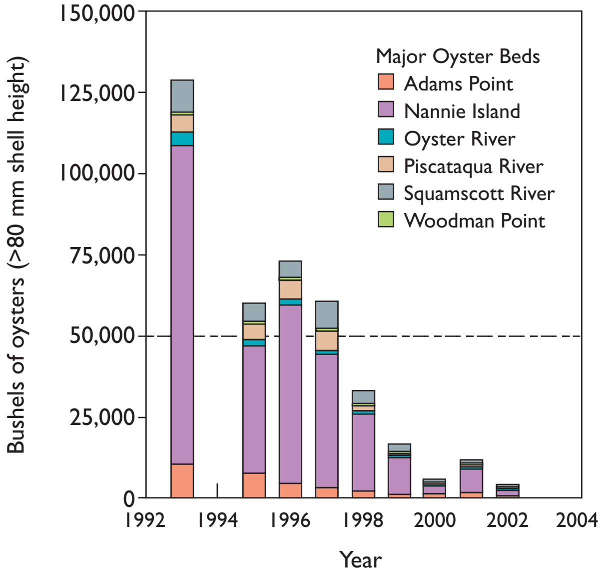


Figure 3-25. Standing stock of harvestable-size oysters in Great Bay between 1992 and 2004 (NHEP, 2003).

Current Projects, Accomplishments, and Future Goals

The NHEP has been successful at implementing many projects to protect and enhance the New Hampshire Estuaries. Data from two environmental indicators show that the NHEP has achieved on-the-ground results for land conservation and salt marsh restoration.

For the past five years, the NHEP has supported the Great Bay Resource Protection Partnership to conserve land in the coastal watershed. As of 2002, there were 42,585 acres of protected land in New Hampshire's coastal watershed, which represented 8.4% of the entire watershed land area (Figure 3-26). In coastal communities, 18,116 acres were protected lands in 2002, which is 13.1% of the total area of these communities. In order to reach the NHEP's goal of protecting 15% of the watershed land area by 2010, an additional 33,827 acres need to be protected in the watershed, including at least 2,685 acres in the 17 coastal communities (NHEP, 2003).

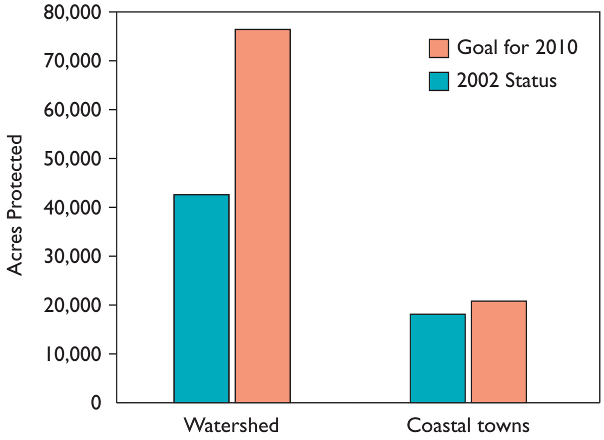


Figure 3-26. Acres of protected lands in New Hampshire's coastal watershed and coastal towns (NHEP, 2003).

Filling, ditching, draining, and restricting tidal flow degrades salt marshes, which can disrupt the marsh ecology and can result in mosquito problems, flooding, and reduced biological diversity. Restoration efforts seek to remedy these problems by improving tidal hydrology and reestablishing healthy marsh habitats. The NHEP has a goal to restore 300 acres of tidal wetlands through tidal restriction removal. Through the leadership of the New Hampshire Coastal Program (NHCP), 176.5 acres of salt marsh have been restored through tidal restriction removal (59% of the goal) since January 2000. The NHCP is currently planning another 129 acres of salt marsh restoration by tidal restriction removal, which, if completed, will surpass the NHEP goal (NHEP, 2003).

Conclusion

In the *2003 State of the Estuaries* report, the NHEP concluded that the New Hampshire Estuaries are in generally good condition. During the past decade, water quality has improved and land conservation efforts and salt marsh restoration projects have been successful; however, shellfish resources are declining in the Estuaries, and development pressures are growing throughout the watershed. In contrast, the overall condition of the New Hampshire Estuaries is rated fair, based on NCA data from 76 sites surveyed in 2000–2001.

Prescott Park and Fishermen's cooperative along the Piscataquog River in Portsmouth, NH (NHEP).

Massachusetts Bays Program

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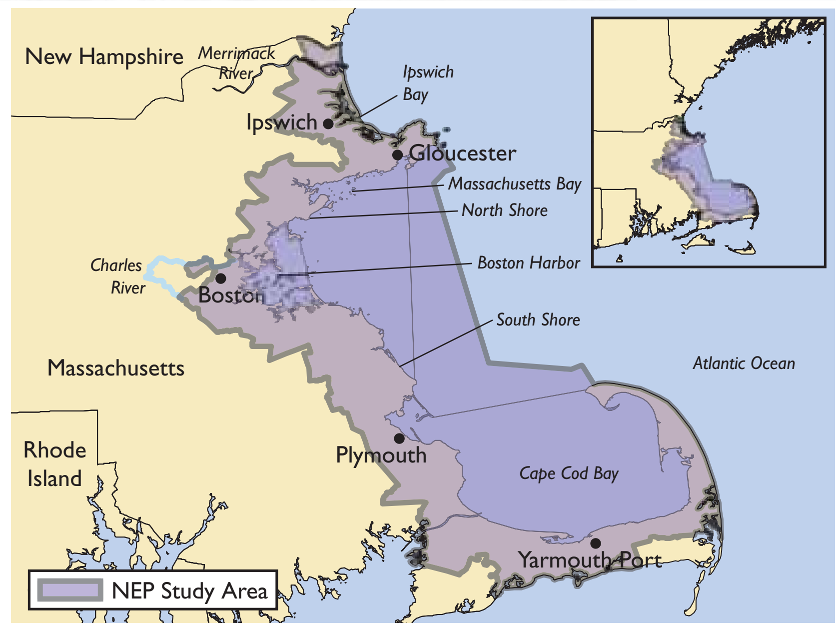

www.mass.gov/envir/massbays

Background

The Massachusetts Bays cover more than 800 miles of coastline, from the tip of Cape Cod Bay to the New Hampshire border, and serve 50 coastal communities. The Bays' NEP study area encompasses about 1,650 mi^2 and is located at the southern end of the Gulf of Maine, a large coastal sea characterized by relatively cool water and large tidal ranges (MBP, 2004b). The Bays' NEP study area includes Cape Cod Bay, Massachusetts Bay, Boston Harbor, the Merrimack River, the North and South shores, and the portion of Ipswich Bay in Massachusetts. The watershed of the Massachusetts Bays covers more than 7,000 mi^2, with the majority of freshwater that flows into the Bays coming from the Charles and Merrimack rivers (Martin et al., 1996; MBP, 2004b).

Natural habitats in the Massachusetts Bays' watershed include freshwater and saltwater marshes, tidal flats, barrier island beaches, eelgrass meadows, rocky intertidal shores, and numerous small lakes and salt ponds. Outside of Boston Harbor, the Massachusetts Bays support a rich, healthy marine ecosystem. Local wildlife refuges and marine sanctuaries are home to whales, fish, and more than 300 species of birds

(Martin et al., 1996). Finfish caught in the Bays include bluefin tuna, Atlantic cod, winter flounder, Atlantic flounder, and Atlantic herring, and harvested shellfish species include soft shell clams, oysters, bay scallops, American lobster, and blue mussels.

More than 3.8 million people live in the Massachusetts Bays' watershed, and this number is growing. Pressures from human development exacerbate environmental problems by increasing stormwater runoff, sewage-related pollution, and the effects on fragile coastal habitats. In addition, the number of housing units on Cape Cod more than doubled between 1970 and 1990, from 65,676 to 135,192. This population growth is the equivalent of adding almost 10 new housing units a day for 20 years (ANEP, 2001c). Such development is producing more impervious surfaces, and as a result, increasing the stormwater volumes and velocities that the Bays must absorb.

Boston, the major shipping port in this estuary, generates $8 billion in annual revenues and supports 9,000 jobs (MBP, 2004b). Water-based economies for this NEP study area include tourism, commercial fisheries, and local marinas, which depend directly on the resources provided by the Massachusetts Bays. Boston Harbor is a center for numerous public resources, including the shipping industry, marine research institutions, whale-watching activities, and the Harbor Island Park system. The Massachusetts coast attracts visitors from all over New England to enjoy kayaking, sailing, surfing, and hiking. The Massachusetts Department of Public Health (MDPH) posts annual beach reports at http://www.mass.gov/dph/beha/tox/reports/beach/beaches.htm.

The Massachusetts Bays Program (MBP) was launched in 1988 to address threats to the health of the Massachusetts and Cape Cod bays. In 1990, EPA accepted the MBP into the NEP. To ensure that each of the MBP's 50 communities receives its share of attention, the program partners with watershed associations and regional planning agencies to provide regional coordinators in five subregions: Upper North Shore, Salem Sound, Metro Boston, South Shore, and Cape Cod (MBP, 2004b).

Environmental Concerns

The Massachusetts Bays face a variety of environmental concerns, including increasing stormwater runoff, sewage-related pollution, and the effects of human development on fragile coastal habitats. These pressures threaten the health of the Massachusetts Bays and cause approximately 1,000 acres of the Bays' coastal and inland wetlands to be lost each year. Boston Harbor and the North Shore have historically also been affected by toxic contamination problems, including elevated levels of PAHs, copper, arsenic, lead, cadmium, mercury, chromium, nickel, zinc, PCBs, and pesticides. The status and trends of exploited fish stocks in the Massachusetts Bays is another primary concern of the MBP. Trawl surveys have helped identify declining trends in a variety of commercially important finfish (Martin et al., 1996). In addition, invasive species have caused significant economic impacts to industries that are dependent upon shellfish, groundfish, and coastal recreation. These impacts include the fouling of aquaculture facilities and the spread of diseases among native species.

Population Pressures

The population of the 6 NOAA-designated coastal counties (Barnstable, Essex, Middlesex, Norfolk, Plymouth, and Suffolk) coincident with the MBP study area increased by more that 23% during a 40-year period, from 3.4 million people in 1960 to almost 4.2 million people in 2000 (Figure 3-27) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the MBP study area is equivalent to the population growth rate of 24% for the collective NEP-coincident coastal counties of the Northeast Coast region. In 2000, the population density of these 6 coastal counties was 1,493 persons/mi^2, about 40% higher than the population density of 1,055 persons/mi^2 for the collective NEP-coincident coastal counties of the Northeast Coast region (U.S. Census Bureau, 2001). Population pressures for this NEP are likely to be high because this estuary serves a major metropolitan area and center for commerce, including major commercial fishing activities in these coastal communities.

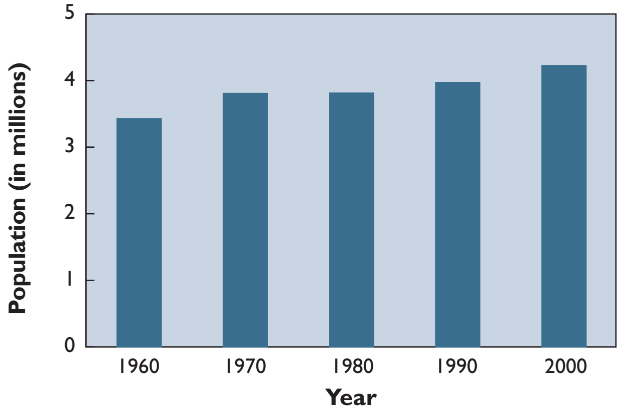

Figure 3-27. Population of NOAA-designated coastal counties of the MBP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Massachusetts Bays

The overall condition of the Massachusetts Bays is rated fair based on the four indices of estuarine condition used by the NCA (Figure 3-28). The water quality index for the Bays is rated good; the sediment and benthic indices are rated poor (although fair may be more appropriate, see later discussions); and the fish tissue contaminants index is rated fair. Figure 3-29 provides a summary of the percentage of estuarine area rated good, fair, poor, or missing for each parameter considered. This assessment is based on data from 44 NCA sites sampled in the MBP estuarine area in 2000 and 2001. Please refer to Tables 1-24, 1-25, and 1-26 (Chapter 1) for a summary of the criteria used to develop the rating for each index and component indicator.

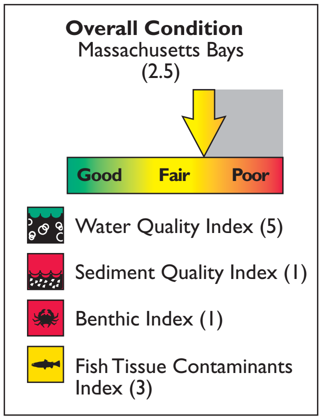

Figure 3-28. The overall condition of the MBP estuarine area is fair (U.S. EPA/NCA).

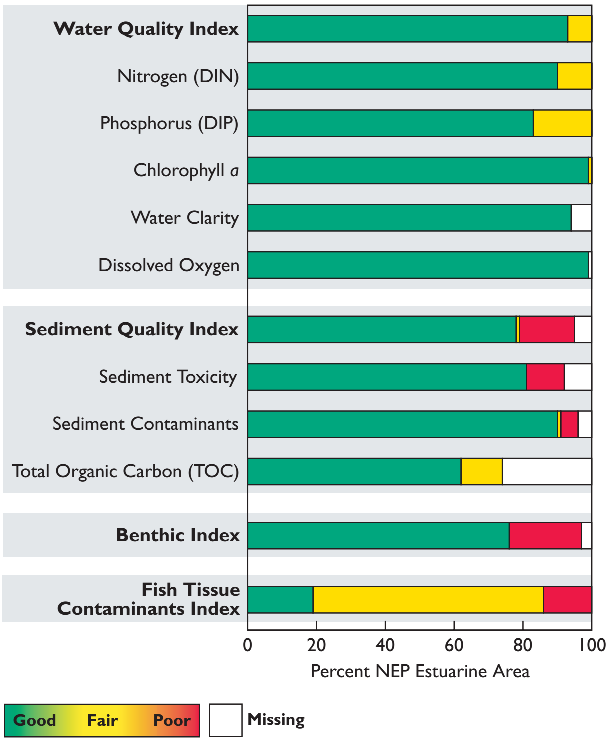

Figure 3-29. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Massachusetts Bays (U.S. EPA/NCA).

Water Quality Index

The water quality index for the Massachusetts Bays is rated good (Figure 3-30). The Massachusetts Bays have one of the best ratings for water quality among the Northeast Coast NEP estuaries, with 93% of the Massachusetts Bays' estuarine area receiving a good rating for water quality. This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen.

Dissolved Nitrogen and Phosphorus | The Massachusetts Bays are rated good for DIN concentrations. Ninety percent of the estuarine area was rated good for DIN concentrations, 10% was rated fair, and none of the area was rated poor. The Massachusetts Bays are also rated good for DIP concentrations because 83% of the estuarine area was rated good for this component indicator and 17% of the area was rated fair. None of the estuarine area was rated poor for DIP concentrations.

Chlorophyll a | The Massachusetts Bays are rated good for chlorophyll *a* concentrations. Of the estuarine area, 99% and 1% were rated good and fair, respectively, and none of the estuarine area was rated poor for chlorophyll *a* concentrations.

Water Clarity | The water clarity rating for the Massachusetts Bays is good. None of the estuarine area was rated poor for water clarity, and 94% of the area was rated good. NCA data on water clarity were unavailable for 6% of the MBP estuarine area.

Dissolved Oxygen | The Massachusetts Bays are rated good for dissolved oxygen because 99% of the estuarine area was rated good for this component indicator. No area of the Bays was rated poor for dissolved oxygen concentrations, and NCA data on dissolved oxygen concentrations were unavailable for only 1% of the MBP estuarine area.

Water Quality Index - Massachusetts Bays

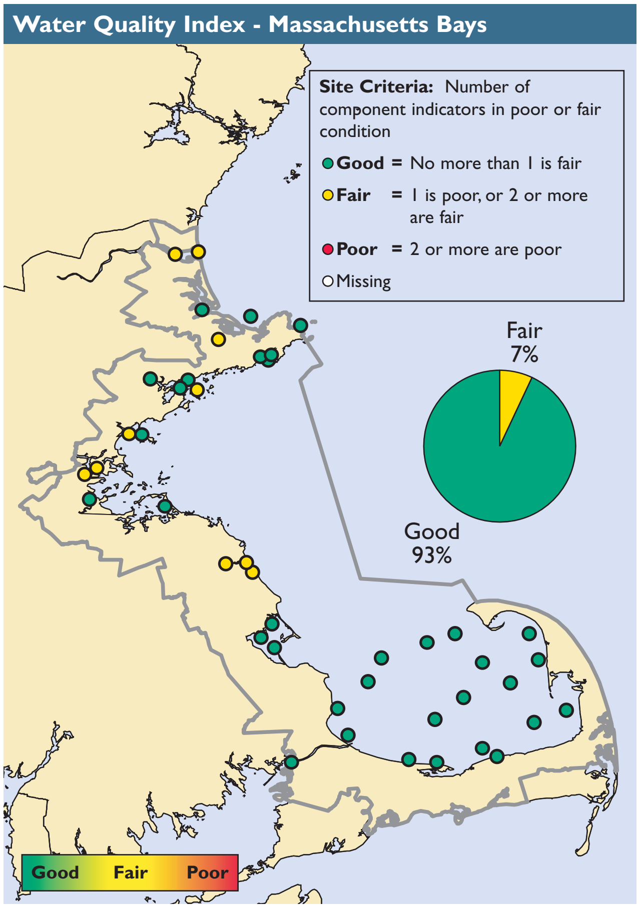

Figure 3-30. Water quality index data for the Massachusetts Bays, 2000–2001 (U.S. EPA/NCA).

Sediment Quality Index

The sediment quality index for the Massachusetts Bays is rated poor, with 16% of the Bays' estuarine area classified as poor, just slightly higher than the 15% threshold used to define this category (Figure 3-31). This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC. Sediment toxicity was evident at four sites (11% by area); however, these sites did not coincide with areas of sediment contamination. High concentrations of sediment contaminants were found at just two Boston Harbor sites, reflecting a legacy of pollution that stems from several decades of abuse. Moderate sediment contaminant concentrations were found at three additional sites, in total comprising about 5% of the Bays' estuarine area—a relatively minor record of contamination compared with other Northeast Coast NEP estuaries. TOC levels for the Bays were typical for the Northeast Coast region. The sediment quality rating of poor for the Massachusetts Bays largely reflects the absence of overlap in sites impaired for each of the three component indicators. A fair rating for the Massachusetts Bays may be a better assessment of sediment quality.

Sediment Toxicity | The sediment toxicity rating for the Massachusetts Bays is poor. Eleven percent of the estuarine area was rated poor, and NCA data on this component indicator were unavailable for 8% of the MBP estuarine area.

Sediment Contaminants | The Massachusetts Bays are rated fair for sediment contaminant concentrations. Approximately 5% of the estuarine area was rated poor, 1% of the area was rated fair, and 90% of the area was rated good for this component indicator.

Total Organic Carbon | The Massachusetts Bays are rated good for sediment TOC. Sixty-two percent of the estuarine area was rated good for TOC concentrations, 12% of the area was rated fair, and none of the area was rated poor. NCA data on this component indicator were unavailable for 26% of the MBP estuarine area.

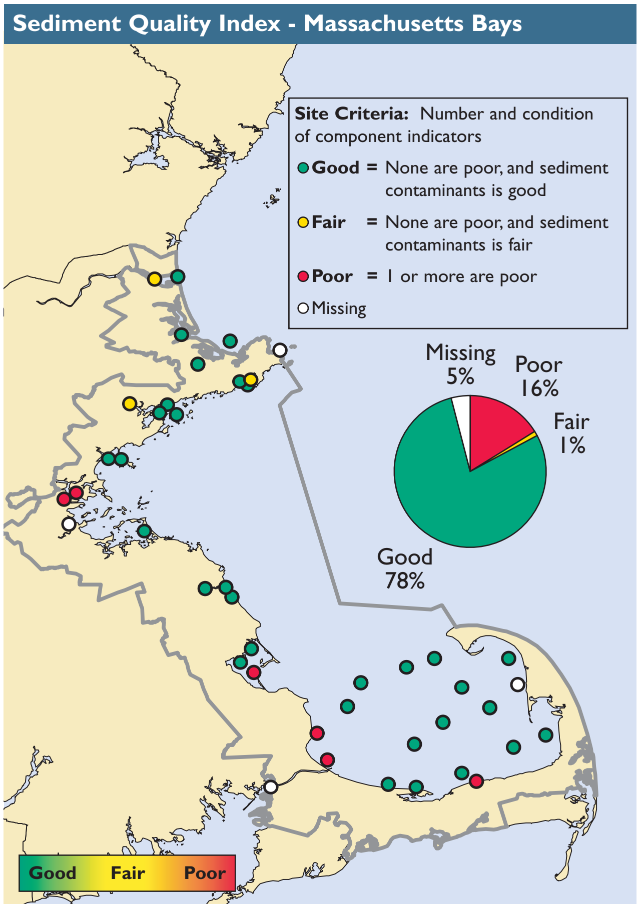

Figure 3-31. Sediment quality index data for the Massachusetts Bays, 2000–2001 (U.S. EPA/NCA).

Digging for clams (Rick Balla).

Benthic Index

The benthic index for the Massachusetts Bays is rated poor. As measured by the Shannon-Weiner Diversity Index, 21% of the Massachusetts Bays estuarine area received a poor rating because of an unsatisfactory degree of benthic diversity, just slightly greater than the threshold used to define this category (Figure 3-32); therefore, a designation of fair for the Massachusetts Bays may be a better assessment for benthic quality.

Fish Tissue Contaminants Index

The fish tissue contaminants index for the Massachusetts Bays is rated fair (Figure 3-33). Of the 20 fish samples analyzed, 17 were collected from Cape Cod Bay, and nearly 80% of the analyzed samples had moderate or high levels of PCBs.

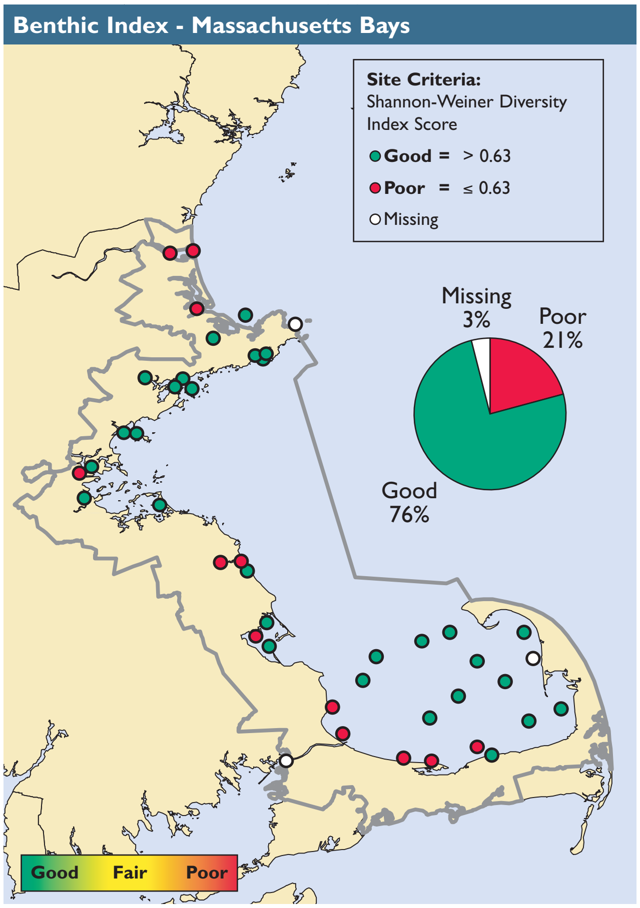

Figure 3-32. Benthic index data for the Massachusetts Bays, 2000–2001 (U.S. EPA/NCA).

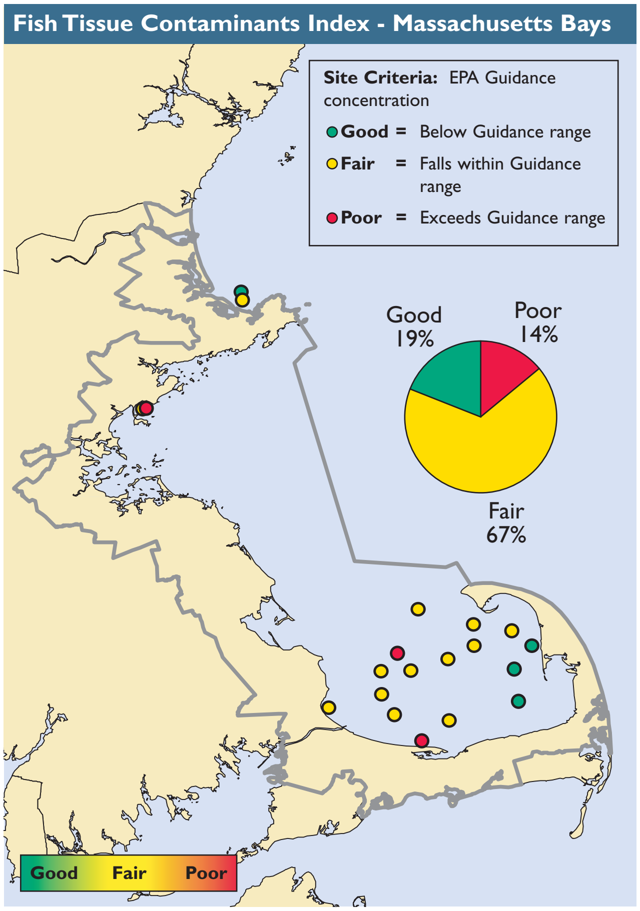

Figure 3-33. Fish tissue contaminants index data for the Massachusetts Bays, 2000–2001 (U.S. EPA/NCA).

Massachusetts Bays Program Indicators of Estuarine Condition

Water and Sediment Quality

The Massachusetts Water Resources Authority (MWRA) has collected water quality data in Massachusetts and Cape Cod bays for the Harbor and Outfall Monitoring Program since 1992. This water quality monitoring program includes continuous vertical profiles of temperature, salinity, dissolved oxygen, chlorophyll *a* (fluorescence), beam attenuation, and irradiance, ranging from the water surface to within 1.6 feet of the bottom at each site. Discrete samples from three to five different depths were collected for nutrient analyses (all forms of nitrogen and phosphorus), total suspended solids, chlorophyll *a*, and dissolved oxygen. Samples were also collected for phytoplankton and zooplankton species enumeration at representative sites throughout the Massachusetts Bays (Libby et al., 2005).

In September 2000, the MWRA terminated effluent discharges to Boston Harbor outfalls and redirected the discharges offshore via a 9.5-mile outfall to the Massachusetts Bays. Total nitrogen has decreased by 34% since the discharges to Boston Harbor were redirected, and there has been a 6% increase in mid-summer dissolved oxygen levels in near-bottom areas. Chlorophyll *a* levels decreased slightly during 2001 after the outfall relocation offshore, but increased slightly in 2002 (MBP, 2004b).

Significantly high levels of mercury have been found in sediments collected from Gloucester, Salem, and Boston harbors (MBP, 2004b). In 2004, mercury was detected in fish at levels warranting a statewide fish consumption advisory for both marine fish and freshwater fish in Massachusetts' lakes and ponds (U.S. EPA, 2005a). Public health concerns related to consumption of fish and shellfish are also being addressed through the measurement of trace metal and organic chemical concentrations in winter flounder and lobster. In addition, an ongoing project evaluates the bioaccumulation of contaminants using caged mussels deployed each summer at key locations in the Boston Harbor/Massachusetts Bay system (Wisneski et al., 2004). The impact of contaminants on the soft-bottom benthic community in the Bays is analyzed through a sampling program in both Boston Harbor and Massachusetts Bay, with annual sampling conducted at 8 sites in the Harbor and more than 20 sites in the Bay. In addition to conventional benthic community analysis, sediment-penetrating camera systems and video imagery are used to evaluate bottom conditions (Williams et al., 2005).

Habitat Quality

The MBP and the Massachusetts Office of Coastal Zone Management (Massachusetts CZM) are conducting research routinely to measure conditions in coastal wetlands on Cape Cod. In 1997, the Wetland Health Assessment Toolbox (WHAT) multi-metric protocol was developed to help estimate the overall ecological quality of wetlands habitat. The WHAT technique is a comprehensive evaluation of wetlands health before and after constructed improvements are implemented. Indicators used to evaluate wetlands habitat include water chemistry, adjacent land use, tidal influence, vegetation, aquatic macroinvertebrates, avifauna, and fish. The data collected are synthesized by the Massachusetts CZM research team to produce an overall wetlands health rating for each salt marsh site (MBP, 2000).

Many tidal marshes in this estuary system are impacted by road and highway construction and maintenance activities. Because of these impacts, the MBP's Wetland Restoration Program has attempted to coordinate with the Massachusetts Highway Department on construction and maintenance operations in coastal areas. Since 1994, nearly 35 wetland-restoration projects have been completed in the watershed, totaling more than 450 acres of wetlands. The MBP has a variety of ongoing efforts to restore wetland acreage, which provides valuable nursery and spawning grounds for fisheries and helps improve water quality. Most habitat-restoration projects have focused on restoring tidal flows, removing fill, regrading marsh topography, building creeks and pools, and suppressing the invasive reed *Phragmites australis*. The Great Marsh region along the northern shore of Massachusetts contains a tremendous wealth of aquatic habitats. Human activities that have degraded habitat value in the Great Marsh include the channelization of streams, restriction of tidal flows, and obstruction of fish passages (MBP, 2004b). The MBP has been working with other agencies and private partners to help restore and incorporate fishways in the Bays to allow river herring and shad to travel upstream for spawning. The MBP has also helped write several successful grants that have generated hundreds of thousands of dollars for fishway repair and restoration on the South Shore (NSRWA, 2005).

The MBP is helping the Massachusetts CZM develop an eelgrass health assessment index to expand monitoring of this productive habitat within the Bays. Mooring-chain scarring and dredging are two primary causes of eelgrass habitat loss in the Massachusetts Bays. The extent of nutrient over-enrichment and the subsequent reduction in water clarity impacting eelgrass habitats is another important stressor that the MBP is currently evaluating with its partners; however, there is insufficient data on eelgrass coverage to truly quantify changes over time within the Bays' system. Eelgrass is expected to recolonize Boston Harbor due to substantial improvements in water quality (MBP, 2004b).

Permanently protected open space in the watershed provides valuable remaining habitat areas because these spaces cannot be developed or converted for other uses in the future. The Massachusetts Office of Geographic and Environmental Information collects data on how much open space is maintained in the watershed. Nearly 25% of land within the 50 communities of the MBP are protected from development (MBP, 2004b). The MBP's Healthy Habitats Initiative is a multifaceted approach to resource management that links habitat protection with land-use planning. The goal of this three-year initiative is to protect critical habitat and unique community character by helping towns preserve open space, protect wetlands, prevent stormwater impacts to water quality, and manage coastal resources (MBP, 2000). The MBP has also helped develop the Green Neighborhoods Program, which promotes habitat protection through development clustering and implementation of good local and subregional land-use practices.

Human activities are restricted in some areas that provide nesting habitat for threatened bird species (Jamal Kadri).

Monitoring and Ecological Assessment of the Massachusetts Bays Ecosystem

The Massachusetts Bays are part of the larger Gulf of Maine; therefore, many of the conditions that prevail in the Gulf proper are significant to setting the conditions for Massachusetts Bay, and subsequently, Cape Cod Bay. Details about the influence of the Gulf of Maine on the physical setting of the Bays were published in an early 1990s report to the MBP (Geyer et al., 1992). The results of the probabilistically based sampling effort help to provide the regional context necessary for understanding the integrity of the Massachusetts Bays. The good NCA water quality index rating for the Bays reflects, in part, the extensive flushing by the Gulf of Maine.

This regional perspective is important for understanding the fate and transport of contaminants, as well as for evaluating the strength of local impacts. For the past 15 years, the MBP and Massachusetts CZM have monitored concentrations of chemicals in blue mussel (*Mytilus edulis*) tissue as part of the larger Gulf of Maine Gulfwatch Program. Organized and administered by the Gulf of Maine Council on the Marine Environment, Gulfwatch has mussel-sampling sites around the Gulf of Maine, from Nova Scotia to Cape Cod. Some contaminants measured by the program, such as mercury, show a broad regional input (e.g., atmospheric deposition), whereas other contaminants show clear, localized impacts (e.g., PAHs in blue mussel tissue from selected sites in Boston Harbor). Gulfwatch data are accessible at http://www.gomoos.org/chameleon/gulfwatch.

Wetland condition is another indicator of ecological integrity that the MBP and Massachusetts CZM are currently developing for application in the Massachusetts Bays. To date, there has been little systematic effort to measure, document, and describe the condition of coastal and inland wetlands in Massachusetts; however, since 1995, the MBP and Massachusetts CZM have been actively working on projects to advance wetland-assessment methods and approaches. Currently, the MBP and Massachusetts CZM are working with EPA on a three-phase coastal wetlands assessment project in selected study areas of Massachusetts and Rhode Island, exploring the potential for a more comprehensive national effort and possible alignment with the NCA surveys. An important component of the project is the development and application of a Rapid Assessment Method (RAM). Requiring both remotely sensed and on-site procedures and taking about half a day to conduct, the RAM generates data on some 22 indicators. In 2004, 23 randomly selected sites were evaluated with the RAM (see map), and another 24 sites are being examined. Some of the initial project findings indicate that increased development and land-use intensity in the 500-foot buffer zone around a salt marsh site correspond with higher abundances of invasive species, lower extent of high marsh, increased marsh fragmentation, and decreased connectivity to associated habitats (Personal communication, Carlisle, 2005). Volunteer groups are also employing assessment methods to understand the condition of selected estuarine marshes in their regions. Salem Sound Coastwatch and the Association to Preserve Cape Cod use the methods contained in a *Volunteer's Handbook for Monitoring New England Salt Marshes* (developed by the Massachusetts CZM and MBP, and available on the Web at http://www.mass. gov/czm/volunteermarshmonitoring.htm).

Lastly, the Merrimack River to the north of Massachusetts Bay is important to the biology, chemistry, and mixing within the estuarine system (Manohar-Maharaj and Beardsley, 1973). Menzie-Cura & Associates (1991; 1995) demonstrated the importance of contaminant loading from the Merrimack River to the Bays. The USGS is currently leading a team of partners that includes MBP/Eight Towns and the Bays (a Local Governance Committee for the Bays), the U.S. Army Corps of Engineers (USACE), and the Massachusetts DEP to characterize the dispersion of wastewater discharges from the Merrimack Estuary into Massachusetts Bay.

Study area and salt marsh sites randomly selected and evaluated in 2004 for the current MBP and Massachusetts CZM wetland assessment project (Massachusetts CZM and MBP, 2004).

Living Resources

The MBP does not use a formal set of indicator species to evaluate the health of fish and wildlife ecosystems in the Massachusetts Bays, but it does support the monitoring efforts of state agencies for both indigenous and invasive species populations across the system. Several endangered and threatened species are dependent on the Bays' habitats, including the North Atlantic right whale, blue whale, fin whale, sei whale, humpback whale, Kemp's ridley sea turtle, shortnose sturgeon, roseate tern, loggerhead sea turtle, and piping plover (Martin et al., 1996). The right whale population has been slow to rebound, with only a 2.5% growth rate per year (MBP, 2004b). The Stellwagen Bank National Marine Sanctuary is one of the most critical areas in the North Atlantic for whales, dolphins, and porpoises. Other areas of the Massachusetts Bays attract a large diversity of bird species; the Parker River National Wildlife Refuge is a barrier island habitat for more than 300 avian species, including snowy owls, Canada geese, egrets, storm petrels, and cormorants (Martin et al., 1996). Despite modest efforts at restoration, it appears that river herring population levels are substantially below historic levels and well below the production capacity of spawning habitats in lakes and ponds of the Massachusetts Bays' watershed (Purintan et al., 2003). Populations of smelt and alewives have also declined in recent years. Landings of shellfish have declined in several towns along the Massachusetts Bays' coastline, and 15 towns north of Boston Harbor are closed to shellfishing (MBP, 2004a).

Two invasive species of particular concern in the Bays are the Asian shore crab and the Pacific tunicate, which can impact the health of the scallop fishery (MBP, 2004b). Recent activities to help control marine invasive species have included surveys of marine habitats and pathways for the introduction of invasive species; public awareness campaigns; analyses of regional legislation for invasive species; and workshops on response strategies for aquatic pests. More than 26 invasive species of plants and invertebrates were found in a 2000 survey of the Massachusetts Bays (MBP, 2004b).

Environmental Stressors

Some of the major sources of pathogens in the Massachusetts Bays include marine sanitation devices, CSOs, and urban stormwater runoff. Disease-causing viruses and bacteria from these sources regularly close bathing beaches and shellfish-harvesting areas. An average of 44 beach closures occurred each year between 1988 and 1991 at South Shore, North Shore, and Boston Harbor due to pathogen contamination. Each year, an estimated 10,000 people become ill from ingestion of the bacteria-contaminated waters of this estuary (Martin et al., 1996). In recent years, there has been a significant reduction in the number of CSOs in the MBP estuarine area (MBP, 2004b).

Wastewater discharges can also introduce contaminants to the Bays. The number of permitted discharges to the Bays has decreased in the last 14 years as a result of local water conservation programs (MBP, 2004a), but overall discharge flow increased between 1991 and 2004 due to cooling-water use by area power plants (MBP, 2004b).

Ferries in Boston, MA (Ben Fertig).

Current Projects, Accomplishments, and Future Goals

The MBP has had a number of successful programs and uses benchmarks that measure progress toward the goal of restoring and maintaining the health of the Bays. To combat stormwater pollution, the MBP installed high-tech "StormTreat" systems for stormwater discharge at two sites, which has been very successful. The Shellfish Clean Waters Initiative is currently monitoring the effectiveness of these treatment systems for possible use at other sites. In 1996, the town of Duxbury completed construction of a shared sewer/septic system with a $32,000 grant from the MBP. This project reduced bacteria levels to a safe range, leading to the reopening of 99 acres of productive shellfish beds (MBP, 2000). Another method used by the MBP to reduce pathogen pollution involved initiating a Betterment Bill, which provides loans to landowners to replace failing septic systems (Martin et al., 1996).

In 2003, the COASTSWEEP Program organized cleanups with local coordinators and more than 3,000 volunteers, cleaning up 35,000 pounds of trash and marine debris from 155 locations estuary-wide (APNS, 2005). In August 2003, the MBP worked with 7 other NEPs and the Massachusetts Institute of Technology Sea Grant Program to conduct a rapid survey for marine invasive species in the northeastern United States, focusing on fixed docks and piers at 20 different sites between Casco Bay, ME, and the New York/New Jersey Harbor (MBP, 2004b).

Currently, the MBP is working with EPA and the Massachusetts Watershed Initiative to develop a Wetlands Restoration Atlas for tidally restricted coastal wetlands from Winthrop to Quincy, which will be used to aid in the assessment of anadromous fish runs. The MBP is also pursuing No-Discharge Zone designations and is developing guidelines for personal watercraft use on Cape Cod (MBP, 2000).

Conclusion

Some of the most significant environmental challenges facing the Massachusetts Bays are wetlands loss and degradation, increased stormwater runoff in developing areas, contamination of Bay sediments with toxic contaminants, contamination of shellfish beds and recreational waters with bacteria, declines in fisheries stocks, and the impact of invasive species on the estuary. The actions of EPA and the MBP, with support from the MWRA and Massachusetts CZM, have been successful in addressing many of the priority environmental concerns facing the Massachusetts Bays. One of the notable successes in the region has been the restoration of 450 acres of wetlands. In addition, eelgrass populations have stabilized since the 1990s, partly due to improvements in water quality. Wastewater impacts in the Bays, specifically in Boston Harbor, are much less than historic levels. Total nitrogen levels have decreased, and dissolved oxygen levels in bottom waters have increased since 2000. Remediation of contaminated sediments in Boston Harbor is still a work in progress because the inner harbor area has had some of the highest concentrations of sediment contaminants compared to other sites in the Bays. For the Massachusetts Bays, the NCA estuarine survey rates water quality as good, fish tissue contamination as fair, and sediment quality and benthic condition as poor.

Humpback whales are found in the MBP study area (Robin Hunter, FWS).

Buzzards Bay National Estuary Program


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Background

Buzzards Bay is a moderately large estuary located between the western part of Cape Cod and the Elizabeth Islands in Massachusetts. The Bay is approximately 269 mi^2 in size and 28 miles long, averages about 8 miles wide, and has an average depth of 36 feet (NOAA, 1985; BB NEP, 2005). The coastline stretches over 280 miles and includes inner harbors, the bayward-facing portions of the Elizabeth Islands, the portions of the Cape Cod Canal that are in the watershed, and 11 miles of public beaches that lure thousands of tourists from Massachusetts and neighboring states (BB NEP, 1992). In addition, the world-renowned Woods Hole Oceanographic Institution and the Marine Biological Laboratory are located near a passage to Buzzards Bay.

Buzzards Bay exchanges water with Rhode Island Sound to the southwest, with Vineyard Sound through the Elizabeth Islands, and with Cape Cod Bay via the Cape Cod Canal at the northern end. A number of tributaries provide freshwater flows to the Bay, including the Agawam, Wankinco, Wewantic, Mattapoisett, Acushnet, Paskamanset, and Westport rivers. Buzzards Bay is rich in shellfish resources and has a $4 million annual shellfish industry, representing 25% of Massachusetts' annual fisheries total. Shellfish species harvested in Buzzards Bay include soft shell clams, quahogs, scallops, oysters, and lobster. Shellfish-harvesting is a popular pastime for many tourists, and more than 500 commercial permits and 12,800 recreational permits are sold annually (BB NEP, 2005).

The Buzzards Bay coastline features a wealth of habitats, including salt marshes, tidal flats, barrier beaches, eelgrass beds, and subtidal zones. The Buzzards Bay National Estuary Program (BB NEP) is an advisory and planning unit of the Massachusetts CZM and receives funding from EPA as part of the NEP.

Environmental Concerns

The most significant threats to Buzzards Bay and its watershed include toxic contamination of the ecosystem, closures of shellfish beds due to bacterial contamination, non-point source pollution, habitat loss, and nitrogen loading and resulting coastal eutrophication. In general, environmental degradation from pollutant inputs is localized in the more than 30 embayments along the periphery of Buzzards Bay, whereas water and habitat quality in the central Bay are very good (CBB, 2003).

Population Pressures

The population of the 4 NOAA-designated coastal counties (Barnstable, Bristol, Dukes, and Plymouth) coincident with the BB NEP study area increased by 72% during a 40-year period, from 0.72 million people in 1960 to about 1.24 million people in 2000 (Figure 3-34) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the BB NEP study area is almost three times the population growth rate of 24% for the collective NEP-coincident coastal counties of the Northeast Coast region. In 2000, the population density of the BB NEP's 4 coastal counties was 726 persons/mi^2, slightly lower than the population density of 1,055 persons/mi^2 for the collective NEP-coincident coastal counties of the Northeast Coast region (U.S. Census Bureau, 2001).

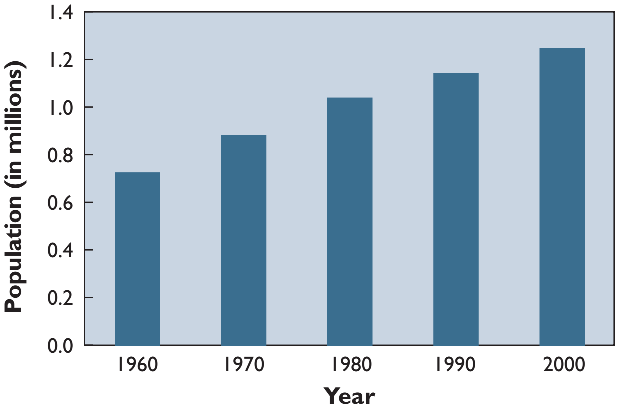


Figure 3-34. Population of NOAA-designated coastal counties of the BB NEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Buzzards Bay

The overall condition of Buzzards Bay is rated fair based on the four indices of estuarine condition used by the NCA (Figure 3-35). The water quality index for Buzzards Bay is rated good, the sediment quality index is rated fair, the benthic index is rated good to fair, and the fish tissue contaminants index is rated poor. Figure 3-36 provides a summary of the percentage of estuarine area rated good, fair, poor, or missing for each parameter considered. This assessment is based on data from 30 NCA sites sampled in the BB NEP estuarine area in 2000 and 2001. Please refer to Tables 1-24, 1-25, and 1-26 (Chapter 1) for a summary of the criteria used to develop the rating for each index and component indicator.

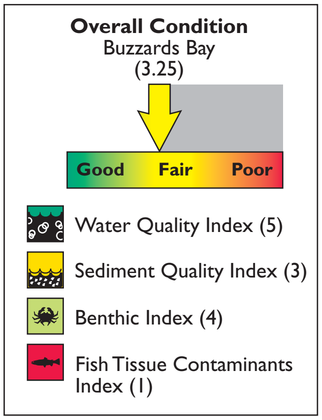


Figure 3-35. The overall condition of the BB NEP estuarine area is fair (U.S. EPA/NCA).

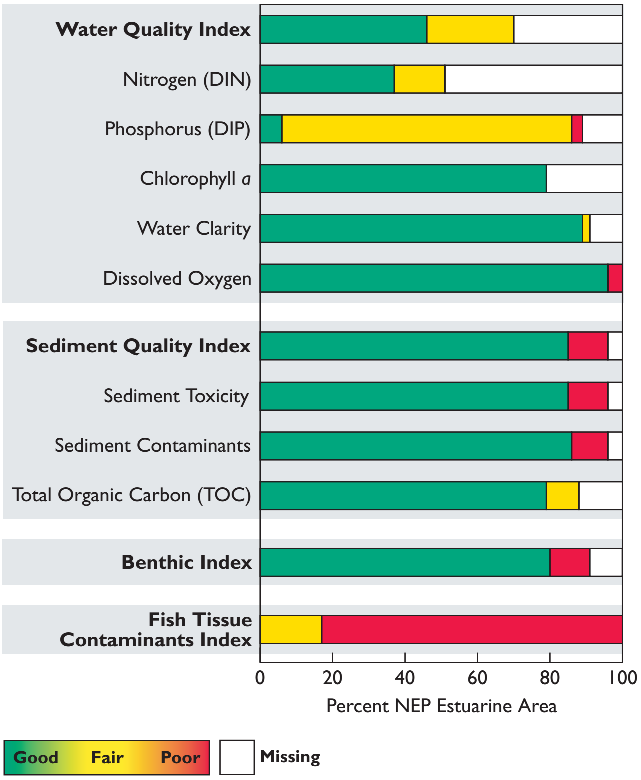


Figure 3-36. Percentage of estuarine area achieving each rating for all indices and component indicators — Buzzards Bay (U.S. EPA/NCA).

Water Quality Index

Based on the NCA survey results, the water quality index for Buzzards Bay is rated good, although water quality data were unavailable for nearly a third of the estuary (Figure 3-37). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Fourteen percent of Buzzards Bay had moderate DIN values, but DIN measurements were not available for almost half of the Bay. Nearly the entire Bay displayed moderately high DIP levels—not an unusual finding in Northeast Coast estuarine waters. Chlorophyll *a* concentrations were uniformly low for Buzzards Bay. Water clarity was satisfactory everywhere in Buzzards Bay, and there was only one incidence of oxygen depletion.

Dissolved Nitrogen and Phosphorus | The DIN concentrations rating for Buzzards Bay is good, with 37% of the estuarine area rated good and 14% of the area rated fair for this component indicator. None of the estuarine area was rated poor for DIN; however, DIN concentrations were not assessed in 49% of the BB NEP estuarine area. DIP concentrations in Buzzards Bay were rated fair, with 6% of the estuarine area rated good for DIP and 80% of the area rated fair. Three percent of the estuarine area was rated poor for this component indicator, and NCA data on DIP concentrations were unavailable for 11% of the BB NEP estuarine area.

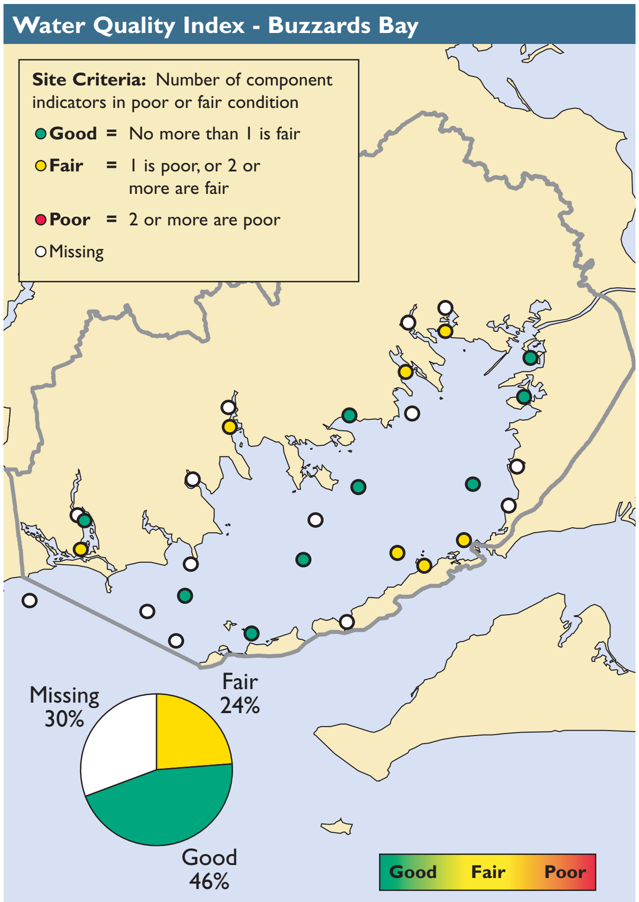


Figure 3-37. Water quality index data for Buzzards Bay, 2000–2001 (U.S. EPA/NCA).

Chlorophyll a | Buzzards Bay is rated good for chlorophyll *a* concentrations. Seventy-nine percent of the estuarine area was rated good for chlorophyll *a* concentrations, and none of the area was rated poor or fair; however, NCA data on chlorophyll *a* concentrations were unavailable for 21% of the BB NEP estuarine area.

Water Clarity | Buzzards Bay is rated good for water clarity. Water clarity was rated poor at a sampling station if light penetration at 1 meter was less than 10% of surface illumination. Eighty-nine percent of the Buzzards Bay estuarine area was rated good for water clarity, 2% was rated fair, and none of the area was rated poor. NCA data on water clarity were unavailable for 9% of the BB NEP estuarine area.

Dissolved Oxygen | Buzzards Bay is rated good for dissolved oxygen concentrations. Ninety-six percent of the estuarine area was rated good for dissolved oxygen concentrations, and only 4% of the estuarine area was rated poor.

Sediment Quality Index

The sediment quality index for Buzzards Bay is rated fair, with 11% of the estuarine area rated poor and less than 1% of the area rated fair for sediment quality condition (Figure 3-38). There were relatively few indications of sediment contamination in Buzzards Bay. Sediments proved to be toxic to amphipods at four sites (11% by area), including one contaminated site, and there were no indications of high TOC concentrations.

Sediment Toxicity | Buzzards Bay is rated poor for sediment toxicity. Eleven percent of the Buzzards Bay estuarine area was rated poor for sediment toxicity, and NCA data on this component indicator were unavailable for 4% of the BB NEP estuarine area.

Sediment Contaminants | Buzzards Bay is rated fair for sediment contaminant concentrations. Approximately 10% of the estuarine area was rated poor for this component indicator, and 86% of the area was rated good.

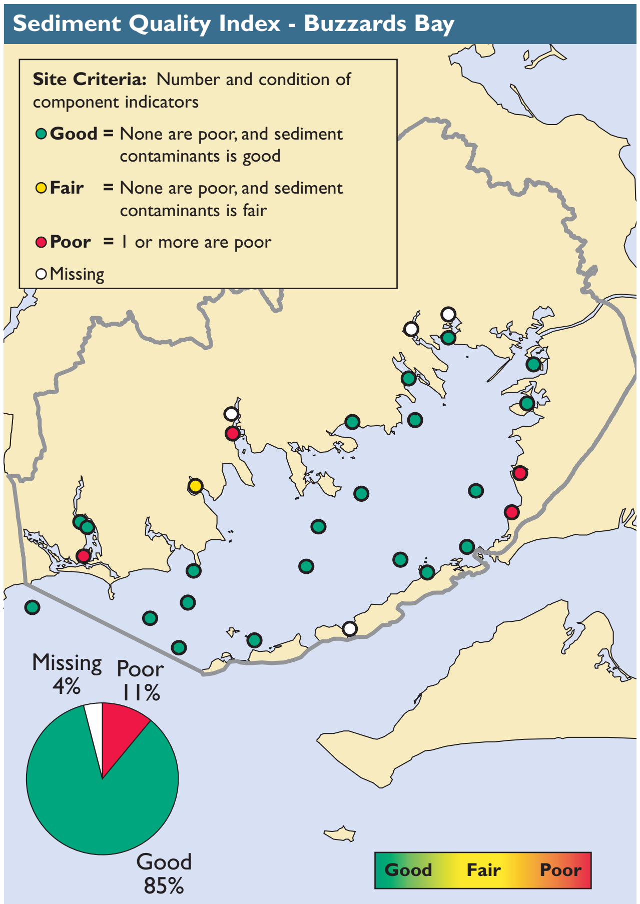


Figure 3-38. Sediment quality index data for Buzzards Bay, 2000–2001 (U.S. EPA/NCA).

Total Organic Carbon | Buzzards Bay is rated good for sediment TOC. Seventy-nine percent of the estuarine area was rated good for TOC concentrations, 9% of the area was rated fair, and none of the area was rated poor. NCA data on TOC concentrations were unavailable for 12% of the BB NEP estuarine area.

Benthic Index

The benthic condition rating for Buzzards Bay is good to fair, as evaluated by the Virginian Province Benthic Index (Figure 3-39). Eighty percent of the estuarine area was rated good for benthic condition, and 11% of the area was rated poor. Only one Buzzards Bay site designated as impaired for benthic condition also had an impaired rating for sediment contamination.

Fish Tissue Contaminants Index

Based on the NCA survey data collected in 2000–2001, the fish tissue contaminants index for Buzzards Bay is rated poor. Eighty-three percent of fish samples analyzed exceeded EPA Advisory Guidance values for at least one contaminant and were rated poor for this index (Figure 3-40).

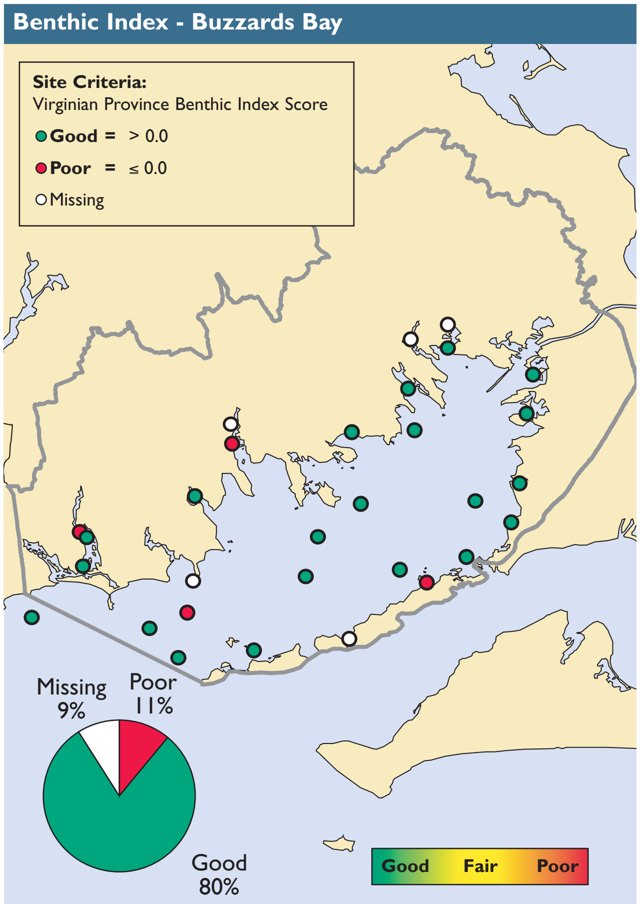


Figure 3-39. Benthic index data for Buzzards Bay, 2000–2001 (U.S. EPA/NCA).

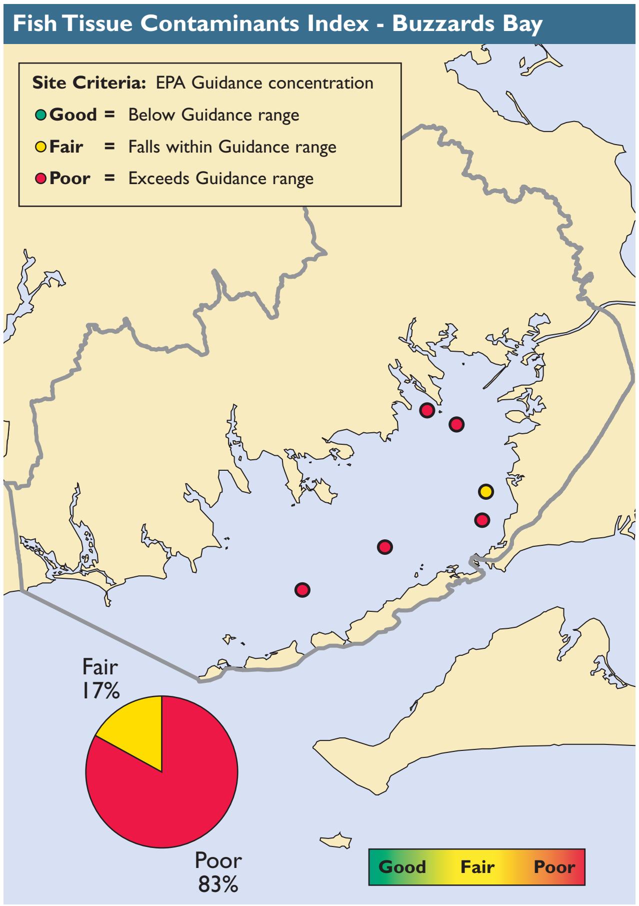


Figure 3-40. Fish tissue contaminants index data for Buzzards Bay, 2000–2001 (U.S. EPA/NCA).

Buzzards Bay National Estuary Program Indicators of Estuarine Condition

To assess environmental results for improving habitat, living resources, and water quality, the BB NEP relies on direct measures of water quality and acres of shellfish-harvesting closures. For other environmental assessments, the BB NEP relies on documentation of human behavioral impacts (e.g., number of gallons pumped at boat pump-out facilities). The following specific indicator measures are used by the BB NEP to evaluate environmental conditions in Buzzards Bay.

Water and Sediment Quality

In order to encompass the many different water quality measurements monitored by the BB NEP, the program created a eutrophication index, the Buzzards Bay Health Index, to score each cove and harbor on a scale of 0 to 100. The BB NEP uses this index as a compilation of five individual indicators: dissolved oxygen, DIN, total organic nitrogen, chlorophyll *a*, and Secchi disk depth. Dissolved oxygen measures used by the program are an average of the lowest 20% of readings collected by a citizens' water quality monitoring group, The Coalition for Buzzards Bay (CBB). Each embayment (harbors and coves) within the Buzzards Bay watershed has its own suite of nutrient sources and potential management solutions. Embayments with scores less than 35 are labeled eutrophic, whereas those with scores of 35 to 65 are designated as fair. Those embayments with scores greater than 65 are labeled good to excellent. Water quality measurements are collected by CBB, with roughly 10 to 15 samples collected at 2 to 4 sites at each of 30 different Buzzards Bay embayments (Costa et al., 1999). Central Buzzards Bay, which exhibits excellent water quality, has scored close to 100 on the Buzzards Bay Health Index, whereas the Nasketucket River, Agawam River, Eel Pond, and Westport River exhibited the lowest scores of any areas within the watershed between 1997 and 2003. In contrast, Quissett Harbor, Aucoot Cove, and Penikese Island received excellent scores (between 90 and 100) for their water quality (CBB, 2003).

The number of shellfish-harvesting closures is a good indicator of bacterial contamination problems in Buzzards Bay. Shellfish-harvesting closures reached their peak in 1990, when more than 16,500 acres were closed to harvesting due to bacteria contamination. In 2003, almost 41% (roughly 9,300 acres) of the 23,000 acres of Buzzards Bay's most productive nearshore shellfishing areas were closed to harvesting (CBB, 2003). The Massachusetts Division of Marine Fisheries (DMF) and the MDPH test surface waters or shellfish to track bacteria contamination, and the BB NEP creates a thumbnail sketch of the change in number of acres of shellfish beds closed over time, using data collected on July 1 of each year.

Habitat Quality

The widespread distribution of eelgrass in Buzzards Bay and its sensitivity to pollution make it an ideal indicator species for changes in water quality and for tracking overall ecosystem health. For these reasons, the BB NEP funded a study of eelgrass distribution in Buzzards Bay (Figure 3-41) that was based on historical aerial photographs, field surveys, and sediment cores. The ratio of existing eelgrass habitat area to potential eelgrass habitat area has been evaluated, and although there is considerable variability in response among the embayments, a clear trend overall of declining eelgrass coverage with increased nitrogen loadings was observed. Additionally, the decline in the catch of bay scallops in Waquoit Bay (Cape Cod Lagoon) has coincided with declines in eelgrass (BB NEP, 2005).

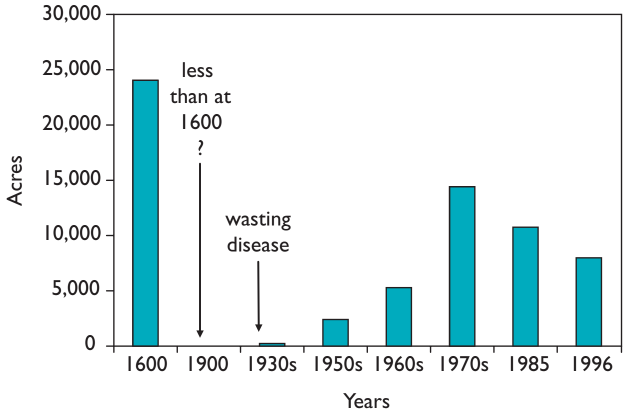


Figure 3-41. Eelgrass abundance measured by the BB NEP (BB NEP, 2005).

Buzzards Bay National Estuary Program

Protecting the Endangered Roseate Tern

Roseate terns (*Sterna dougallii*) are a federally endangered species recognized under the Migratory Bird Treaty Act. These birds breed in North America on the coasts and islands of the Atlantic Ocean, winter along the northern coast of South America, and nest in association with other tern species, such as the common tern. Although the population of roseate terns in northeastern North America has increased slowly since 1987, more than 90% of this species' population is concentrated in five predator-controlled sites in the United States. The largest North American colony of this species is found in Buzzards Bay, with half of North America's breeding pairs found on two of the Bay's tiny islands (Bird Island and Ram Island) (see bar graph). Roseate terns returned to Ram Island in the 1990s after a 20-year absence, and the island now hosts more breeding pairs than Bird Island.

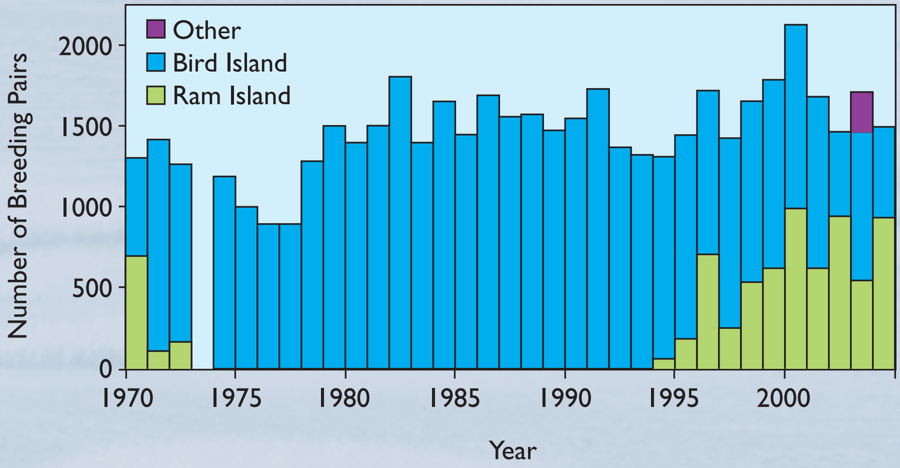
The Massachusetts Division of Fisheries and Wildlife (MassWildlife) reports on the numbers of roseate tern nests by individual island. The New Bedford Superfund trustees have awarded more than a million dollars to protect and preserve tern habitat on Bird Island through beach replenishment and restoration, while Penikese Island, located near the southern tip of the Elizabeth Island chain, is the focus of new efforts to expand roseate tern habitat onto additional islands in the estuary.

A century ago, roseate terns were a favorite target of hunters selling feathers to the millinery industry and egg collectors. Human exploitation (trapping for market) of the roseate tern on its South American wintering grounds, where no public protection is offered, is currently the main limiting factor for the species. Predation at breeding colonies by gulls, crows, marsh hawks, short-eared owls, and other wildlife poses a constant threat and seems to be the main reason for the selection of islands and inlets as nesting sites. Other concerns include competition for nest sites from other species (e.g., larger gulls) and the reproductive effects (e.g., thinning of eggshells, premature breakage of eggs, reduced reproductive success) of toxic chemicals that pass through the food chain. In addition, a shortage of males may limit the productivity of roseate terns at some colonies in northeastern North America, where 20% of breeding females do not find mates.

Roseate tern (Ted DEo n. http://www.geocities.com/teddeon509/gallery.html)

As a result of an oil spill in April 2003 that severely affected Ram Island, "hazing" operations using cannons and lights were put into effect to discourage the arrival and nesting of birds to the island until the oil was cleaned up. Some breeding pairs delayed nesting on Ram Island because of the cleanup activities, whereas other pairs nested on Penikese Island. One account of the impact included an estimate that at least 350 roseate tern chicks had been lost because of the delayed nesting; this number represents roughly 10% of annual chick production for the species. The impact to roseate terns and other species and habitat from the spill is being addressed through the Natural Resource Damage Assessment (NRDA) process. Separate from the NRDA process, a $10 million criminal settlement was finalized in November 2004.

Additional information about roseate terns in Buzzards Bay is available at http://www.buzzardsbay.org/roseates.htm.



Buzzards Bay roseate tern breeding pairs (Data courtesy of Brad Blodget and Carolyn Mostello, former and current State Ornithologist, MassWildlife).

Acres of forest cover serve as a useful indicator of the ability of the Buzzards Bay system to support healthy ecosystems. Forest growth along streambanks is critical for maintaining freshwater quality, filtering nitrogen and sediments, stabilizing erodible soils, and providing fish and wildlife habitat. A target threshold suggested for forest cover is approximately 70%, based on observations in similar coastal watersheds. Forest cover in the Bay watershed has increased since 1850 as pastures and farm fields were abandoned; however, about 23,000 acres (13%) of forests have been lost since 1973, primarily due to residential and commercial development. In 2003, more than half the Buzzards Bay watershed was covered by forests (CBB, 2003).

The BB NEP also uses the acreage of protected open space in the watershed as a useful indicator of potential habitat area. Open space areas that are critical for protection include coastal and freshwater wetlands, river and stream corridors, and watersheds to nitrogen-sensitive embayments and public drinking water supplies. More than 50,000 acres (or 20% of the total land area) in the Buzzards Bay watershed, from Fall River to Falmouth, is permanently protected open space (BB NEP, 2005).

Although it is not currently assessed, the number of anadromous (migratory) fish runs restored in the Bay will be used as an indicator by the BB NEP in the future. Populations of anadromous fish species such as the alewife and blueback herring have declined dramatically in Buzzards Bay during the past century. Not only are these two species part of an important commercial fishery, they are also an important forage food for other fish, whales, and coastal birds, such as the roseate tern (BBP NEP, 1999).

Living Resources

River herring populations are an important natural resource in Buzzards Bay, and their numbers have declined over time to a fraction of their historic levels. Currently, only the Mattapoisett and Sippican rivers are surveyed for river herring on a routine basis using electronic counters. In an effort to help restore the river herring population, the BB NEP has assisted with the removal of fish passage obstructions and the construction or repair of fish ladders (BB NEP, 2005). In addition, alewives and blueback herring populations have decreased dramatically in the Bay, whereas populations of shad, sturgeon, and Atlantic salmon have been eliminated (CBB, 2003).

The bay scallop population in Buzzards Bay is under close study by the Massachusetts DMF because pollution and declines in eelgrass bed coverage have hindered scallop colonization. Scallop populations in the Bay have declined dramatically during the past 30 years (CBB, 2003); therefore, the BB NEP is supporting physical restoration efforts to stimulate eelgrass and scallop recovery in areas of the Bay with good water clarity.

Environmental Stressors

Measurements of human activity (e.g., population growth rates, number of marine vessels in the Bay) can also be used as indicators of estuarine condition. Like most coastal areas, the Buzzards Bay watershed continues to lose open land to development. The 2000 U.S. Census confirmed that the Buzzards Bay watershed remains a fast-growing area. Although the City of New Bedford experienced a population decline, population growth averaged 8.8% during the last decade among other towns in the watershed (U.S. Census Bureau, 2001). More than 236,000 people live in the Buzzard Bay watershed, and nearly 20,000 marine vessels pass through the Bay annually (Martin et al., 1996).

Current Projects, Accomplishments, and Future Goals

Some of the major environmental accomplishments of the BB NEP include the following:

- The number of acres of shellfish beds closed because of bacterial contamination has declined nearly 25% since the *Buzzards Bay Comprehensive Conservation and Management Plan* was completed in 1991 (BB NEP, 1992; BBP NEP, 1999; CBB, 2003).
- The BB NEP assisted in the construction of a test center to evaluate and promote advanced septic treatment solutions for use in watersheds where limits have been established on the discharge of nitrogen, and the designation of Buzzards Bay as a No-Discharge Area has helped to reduce bacteria inputs to the Bay from vessel traffic.

- In 1989, the BB NEP gave $35,000 in grants to the City of New Bedford and the Barnstable County Health Department to upgrade their laboratories and to pay for the analysis of extra samples collected by the Massachusetts DMF. DMF staff also trained local officials to assist with the sanitary surveys in their communities (BBP NEP, 1999).
- CBB has created a nature trail for local schools, organized beach cleanups, and promoted bilingual stenciling of storm drains that discharge directly into Buzzards Bay.
- The BB NEP has developed two atlases to assist with wetland-restoration efforts. One atlas identifies 172 tidally restricted salt marshes and will be helpful in efforts to remove tidal restrictions and to improve and restore wetland health (Costa et al., 2002). The development of this atlas has already led to the restoration of 10 of these sites (Personal communication, Costa, 2006). The second atlas identifies filled and impaired wetlands on public and conservation lands and is used to identify wetland-restoration sites to meet mitigation requirements from other programs (Rockwell et al., 2004; Rockwell and Williams, 2005).
- The BB NEP recently completed an $85,000 grant entitled *Managing Nitrogen Sensitive Embayments through Land Conservation* for work in the Slocums River and Onset Bay (Wareham) watersheds. The Massachusetts Environmental Trust provided $29,000 in matching funds to this project.
- Nitrogen-analysis work begun in the mid-1990s by the BB NEP for West Falmouth Harbor led to the construction of a tertiary WWTP in 2005 that is designed to reduce nitrogen inputs to the harbor (BB NEP, 2005).
- New Bedford assessed its open space needs and incorporated a Greenway Plan for the city.
- Ongoing cleanup of New Bedford Harbor sediments represents one of the most promising restoration efforts in the Buzzards Bay watershed.
- The BB NEP Web site was used by state and federal agencies to disseminate information about the impacts of the 2003 oil spill in the Bay and about ongoing cleanup activities. The BB NEP also conducted an analysis of the volume of oil spilled during the accident, and this analysis contributed to the 98,000-gallon estimate adopted by state and federal agencies. The BB NEP continues to assist federal agencies in the NRDA efforts related to the 2003 oil spill and in the identification of potential restoration sites (BB NEP, 2005).
- In 2003, the BB NEP completed an atlas of stormwater discharges and stormwater drainage networks discharging to Buzzards Bay (Costa and Bissette, 2003). This atlas has helped municipalities achieve the mapping requirements for Phase II National Pollution Discharge Elimination System (NPDES) stormwater permits and identify problem discharges that contribute to shellfish bed closures. In partnership with a vocational high school and a non-profit composed of municipal officials, this effort expanded inland during 2005 to map all known discharges to wetlands located in the watershed. An updated stormwater atlas will be published in 2006 (BB NEP, 2005).
- Since 1992, the BB NEP has awarded millions of dollars in federal and state funds through their ongoing municipal mini-grant program to assist area municipalities and non-profits with the implementation of recommendations contained in the BB NEP CCMP. These mini-grants have helped leverage other funds. The BB NEP also assists municipalities in developing successful grant applications to other programs (BB NEP, 2005).

Conclusion

The Buzzards Bay estuarine area is rated fair for overall condition based on the NCA's four indices of estuarine condition. The BB NEP findings show that the four most significant environmental challenges facing the Buzzards Bay estuarine area are toxic contamination and oil spills, nitrogen loading and the effects of eutrophication, natural habitat loss, and bacterial contamination of Bay waters and shellfish-harvesting areas. The Buzzards Bay Health Index is used to evaluate water quality changes, with a scoring system based on oxygen depletion, excess nutrient levels, transparency, and algal blooms. Some of the key habitat indicators used to monitor environmental changes in Buzzards Bay include acres of eelgrass bed coverage, forest coverage, and the amount of protected open space. In addition, populations of several wildlife species are used as primary indicators of environmental quality, including the river herring and bay scallop. Populations of these species have decreased due to human activities in the watershed. New Bedford Harbor remains one area of special concern for the BB NEP, but substantial progress has been made in the remediation of contaminated sediments. Buzzards Bay has avoided many estuary-wide problems that plague other watersheds around the country, but land-use practices and the growing local population have impacted natural resources in the 32 small embayments in the Buzzards Bay area.

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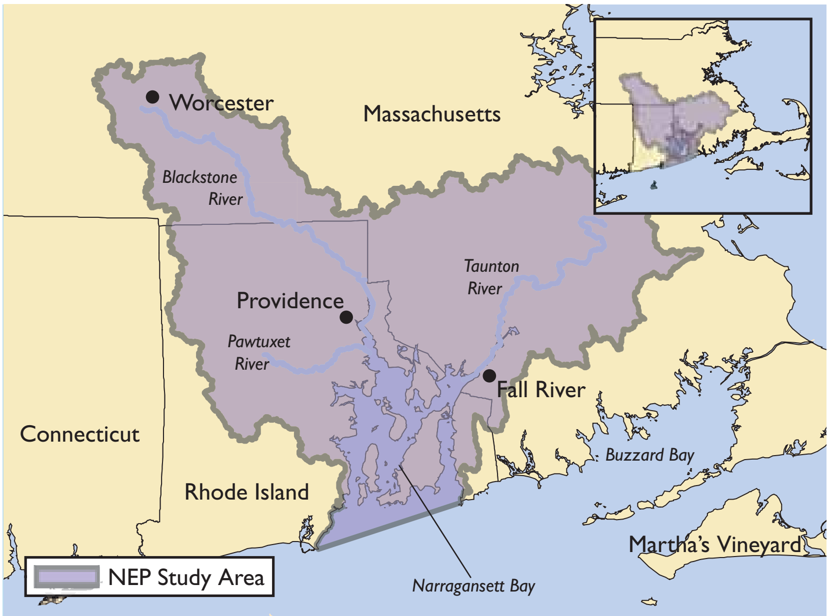


Background

Narragansett Bay is located primarily in Rhode Island; however, 60% of the Bay's watershed area is located in Massachusetts. The Narragansett Bay watershed area covers 1,650 mi^2 and is one of the most densely populated watersheds in the United States, with almost 1,000 people/mi^2 (RIDEM et al., 2000; U.S. Census Bureau, 2001). Worcester and Fall River, MA, and Providence, RI, are major cities within this watershed, and the Blackstone, Taunton, and Pawtuxet rivers provide the majority of fresh water that flows into the Bay. Narragansett Bay has approximately 147 mi^2 of surface water, with an average depth of 30 feet (NOAA, 1985). The Bay supports approximately 3,600 acres of various types of salt marshes and 570 acres of tidal flats (RIDEM et al., 2000) and contributes billions of dollars to Rhode Island's economy through fisheries, tourism, and marine industries. Quahog (hard clam), lobster, bluefish, striped bass, and flatfish are sought after as recreational and commercial fisheries species in Narragansett Bay (Martin et al., 1996).

Between 1985 and 1992, more than 100 people representing 45 federal, state, and local government agencies; non-profit organizations; universities; marine trade organizations; industry; communities; and citizens met under the direction of the Narragansett Bay Estuary Program (NBEP) to develop ways to preserve and restore Narragansett Bay. *The Narragansett Bay Conservation & Management Plan* (RIDEM, 1992) was completed in 1993 and is being implemented by the NBEP, which is now affiliated with the University of Rhode Island (URI) Coastal Institute. In addition, Rhode Island legislation created a Coordination Team in 2004 for the management of Narragansett Bay. This team formalizes the coordination among key state agencies with respect to the Bay and its watershed. Information on this and other Bay issues is available at http://www.ci.uri.edu/RIBayTeam/default.html.

Environmental Concerns

Eutrophication, nutrient loading, and pathogens are some of Narragansett Bay's major environmental concerns. Although relatively well mixed and less susceptible than other NEP estuaries to eutrophication, Narragansett Bay is exhibiting an increasing array of eutrophic-associated symptoms, including low dissolved oxygen levels, fish kills, eelgrass loss, macroalgae blooms, benthic community changes, and a shift in the Bay's dominant fish community from bottom-dwelling to water-column-dwelling species (RIDEM, 2003). These symptoms have led the NBEP to focus on nutrient inputs to the Bay, particularly nitrogen. Currently, secondary treatment at WWTPs does not reduce the high levels of nitrogen associated with sewage (RIDEM et al., 2000). Excess nitrogen appears to have caused episodes of oxygen depletion and fish kills in fairly wide areas of the upper Bay, especially during neap (very weak) summer tides, impairing habitat quality and function (RIDEM, 2003). As for pathogens, CSOs have been the major source of fecal coliforms to the Bay in recent years, contributing annual coliform loads nearly 4 orders of magnitude higher than those from WWTPs and approximately 200 times the estimated annual loading from separate storm drains (Governor's Narragansett Bay and Watershed Planning Commission, 2004a). Communities with older, failing septic systems also contribute significantly to bacterial and nutrient-loading. Together, these sources leave approximately 20% of Narragansett Bay permanently or conditionally closed to shellfish harvesting because of actual or suspected contamination from sewage-derived bacteria and viruses (RIDEM, 2002).

Population Pressures

The population of the 10 NOAA-designated coastal counties coincident with the NBEP study area increased by 28% during a 40-year period, from 3.8 million people in 1960 to almost 4.9 million people in 2000 (Figure 3-42) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the NBEP study area is equivalent to the population growth rate of 24% for the collective NEP-coincident coastal counties of the Northeast Coast region. In 2000, the population density of these 10 coastal counties was 984 persons/mi^2, slightly lower than the population density of 1,055 persons/mi^2 for the collective NEP-coincident coastal counties of the Northeast Coast region (U.S. Census Bureau, 2001). Population pressures for this NEP are likely high because this estuary serves as a major metropolitan area and a center of commerce and industrial development.

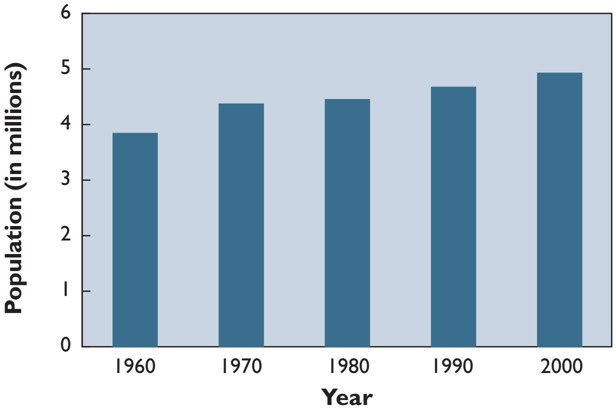


Figure 3-42. Population of NOAA-designated coastal counties of the NBEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Narragansett Bay

The overall condition of Narragansett Bay is rated poor based on the four NCA indices of estuarine condition (Figure 3-43). The water quality index for Narragansett Bay is rated fair, the benthic index is rated fair to poor, and the sediment quality and fish tissue contaminants indices are both rated poor. Figure 3-44 provides a summary of the percentage of estuarine area rated good, fair, poor, or missing for each parameter considered. Please refer to Table 1-24, 1-25, and 1-26 (Chapter 1) for a summary of the criteria used to develop the rating for each index and component indicator. By several measures, Narragansett Bay is a transitional estuary that is more similar to estuaries further south in the region. The Bay is distinct from estuaries in the Acadian Province (north of Cape Cod), which are characterized by higher tidal amplitude and tidal flushing rates. This environmental assessment is based on data from 56 NCA sites sampled in the NBEP estuarine area in 2000 and 2001.

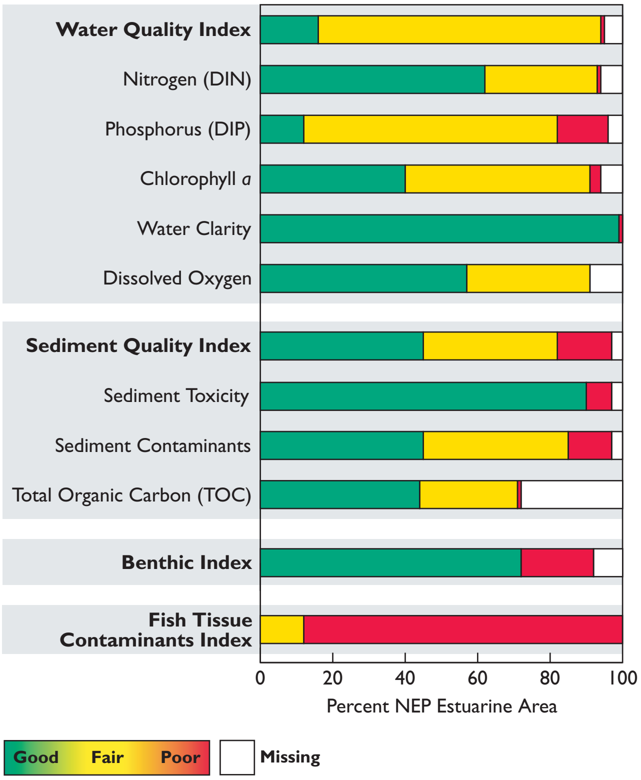


Figure 3-44. Percentage of estuarine area achieving each rating for all indices and component indicators — Narragansett Bay (U.S. EPA/NCA).

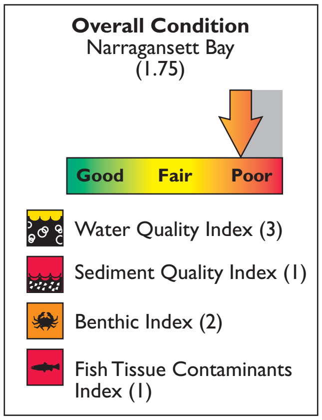


Figure 3-43. The overall condition of the NBEP estuarine area is poor (U.S. EPA/NCA).

Wickford Harbor on the west shore of Narragansett Bay (NBEP).

Water Quality Index

The water quality index for Narragansett Bay is rated fair (Figure 3-45), with 78% of the Narragansett Bay estuarine area rated fair for water quality condition. This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Relatively large areas of the Bay had elevated concentrations of nutrients and chlorophyll *a*—greater than neighboring bays to the north and similar to estuaries further south in the region. Narragansett Bay's pronounced signs of eutrophication are probably attributed in part to the confined nature of the estuary and the extensive urbanization in upper Narragansett Bay. Water clarity was satisfactory everywhere in the Bay, and low dissolved oxygen levels were identified in a third of the Bay, predominantly in the deeper portions of upper Narragansett Bay.

Dissolved Nitrogen and Phosphorus | Narragansett Bay is rated good for DIN concentrations, with 31% of the estuarine area rated fair and only 2% of the area rated poor. NCA data on DIN concentrations were unavailable for 5% of the NBEP estuarine area. DIP concentrations for Narragansett Bay are rated fair, with 69% of the estuarine area rated fair and 14% of the area rated poor. NCA data on DIP concentrations were unavailable for 5% of the NBEP estuarine area.

Chlorophyll a | Narragansett Bay is rated fair for chlorophyll *a* concentrations, with 51% of the estuarine area rated fair and 4% rated poor for this component indicator. NCA data on chlorophyll *a* concentrations were unavailable for 5% of the NBEP estuarine area.

Water Clarity | Narragansett Bay is rated good for water clarity. Water clarity was rated poor at a sampling site if light penetration at 1 meter was less than 10% of surface illumination. Only 1% of the Bay's estuarine area was rated poor for water clarity, and 99% of the area was rated good.

Dissolved Oxygen | Narragansett Bay is rated good for dissolved oxygen concentrations. Fifty-seven percent of the estuarine area was rated good for dissolved oxygen concentrations, and 34% of area was rated fair. None of the NBEP estuarine area was rated poor for this component indicator, and NCA data on dissolved oxygen concentrations were unavailable for 9% of the area. Although no area of the Bay was rated poor on the NCA sample dates, transient episodes of dissolved oxygen at concentrations less than 2 mg/L are known to occur in upper Narragansett Bay, often following periods of minimal tidal mixing. Such events have been documented by programs other than the NCA surveys, using moored instrumentation and targeted sampling. Results of these targeted oxygen and chlorophyll *a* monitoring programs are available through the links at http://www.nbep.org.

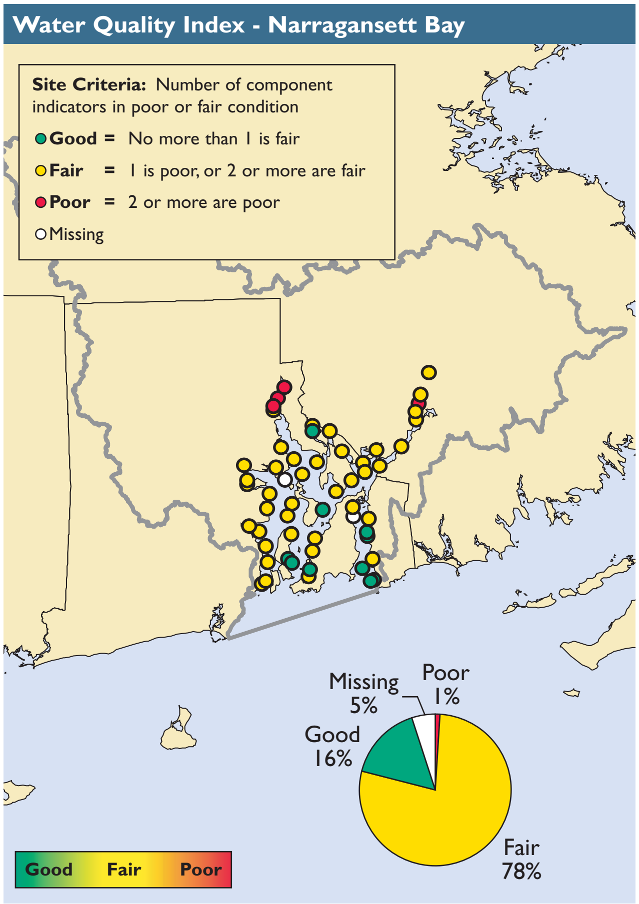


Figure 3-45. Water quality index data for Narragansett Bay, 2000–2001 (U.S. EPA/NCA).

Sediment Quality Index

The sediment quality index for Narragansett Bay is rated poor, with 15.3% of the estuarine area classified as poor, just slightly greater than the 15% threshold used to define this category (Figure 3-46). Sediment toxicity was observed at two sites in Narragansett Bay, both of which displayed sediment contamination. Moderate and high concentrations of metals and organochlorine chemicals, such as DDT and PCBs, were measured in about half the Bay's sediment samples, with the highest levels evident in the upper Bay tributaries (e.g., Taunton and Providence rivers) and Greenwich Bay. Moderate levels of TOC were also measured, again predominantly in upper Narragansett Bay.

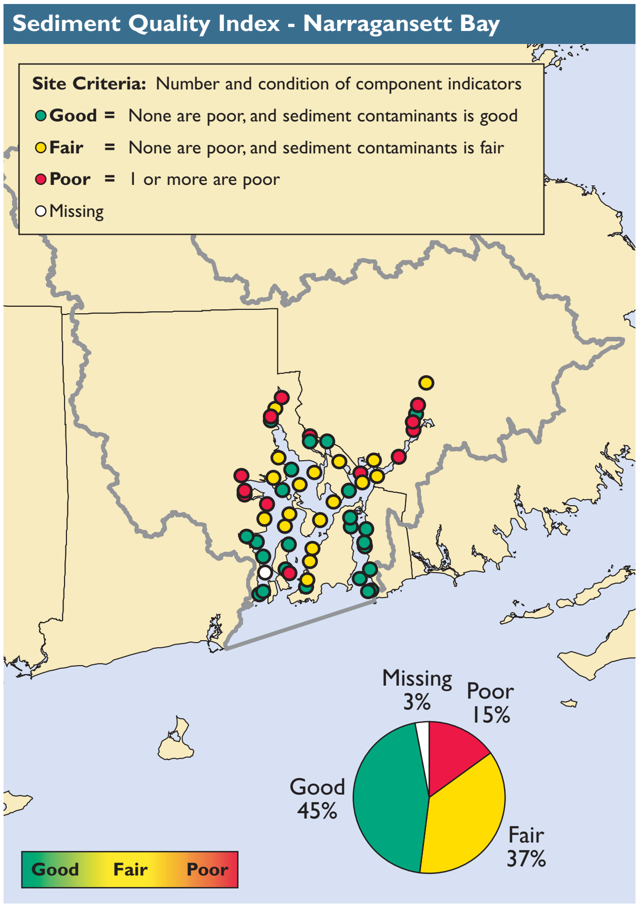


Figure 3-46. Sediment quality index data for Narragansett Bay, 2000–2001 (U.S. EPA/NCA).

Sediment Toxicity | The sediment toxicity rating for Narragansett Bay is poor. Seven percent of the Bay's estuarine area was rated poor for sediment toxicity, and NCA data were unavailable for 3% of the NBEP estuarine area.

Sediment Contaminants | Narragansett Bay is rated fair for sediment contaminant concentrations, with 45% of the estuarine area rated good for this component indicator and approximately 12% of the area rated poor.

Total Organic Carbon | Narragansett Bay is rated good for sediment TOC. Forty-four percent of the estuarine area was rated good for TOC concentrations, 27% of the area was rated fair, and only 1% of the area was rated poor. NCA data on TOC concentrations were unavailable for 28% of the NBEP estuarine area.

College students studying icthyology at a salt pond in Bristol, RI (NBEP).

Benthic Index

Benthic condition in Narragansett Bay is rated fair to poor, with 20% of the area receiving a poor designation using the Virginian Province Benthic Index (Figure 3-47). Similar to the results for the water quality and sediment quality indices, the impaired sites in the Bay were largely restricted to upper Narragansett Bay and the Bay's tributary rivers. Most of the sites designated as impaired also had elevated levels of contaminants in the sediments and can experience intermittent, but severe, hypoxic events.

Fish Tissue Contaminants Index

The fish tissue contaminants index for Narragansett Bay is rated poor because 91% of all fish tissue samples analyzed for this estuary were rated poor (Figure 3-48). All fish samples surveyed contained quantities of PCBs that exceeded or fell within EPA's Advisory Guidance values for fish consumption. High concentrations of PCBs are commonly observed in fish from estuaries in the Northeast Coast region.

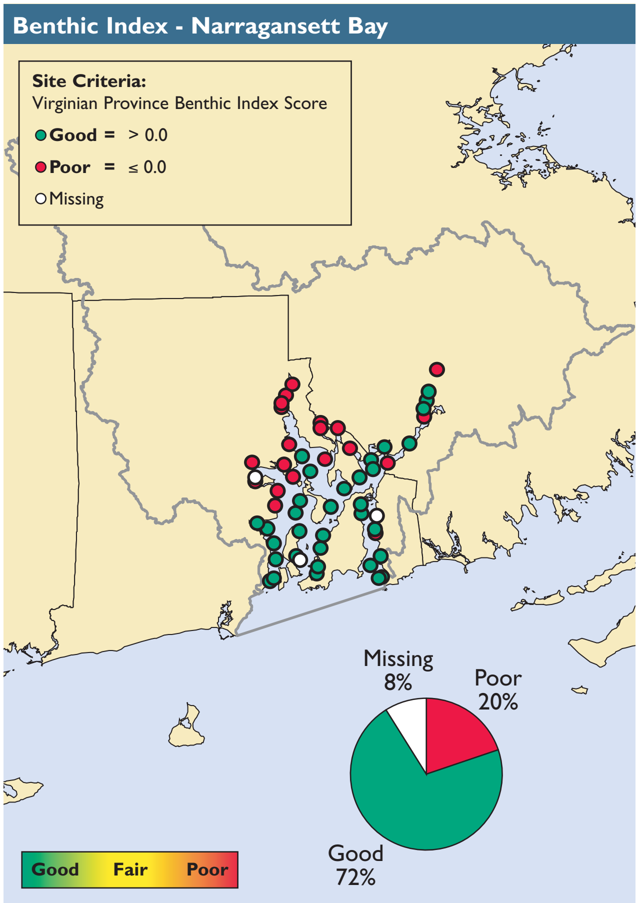


Figure 3-47. Benthic index data for Narragansett Bay, 2000–2001 (U.S. EPA/NCA).

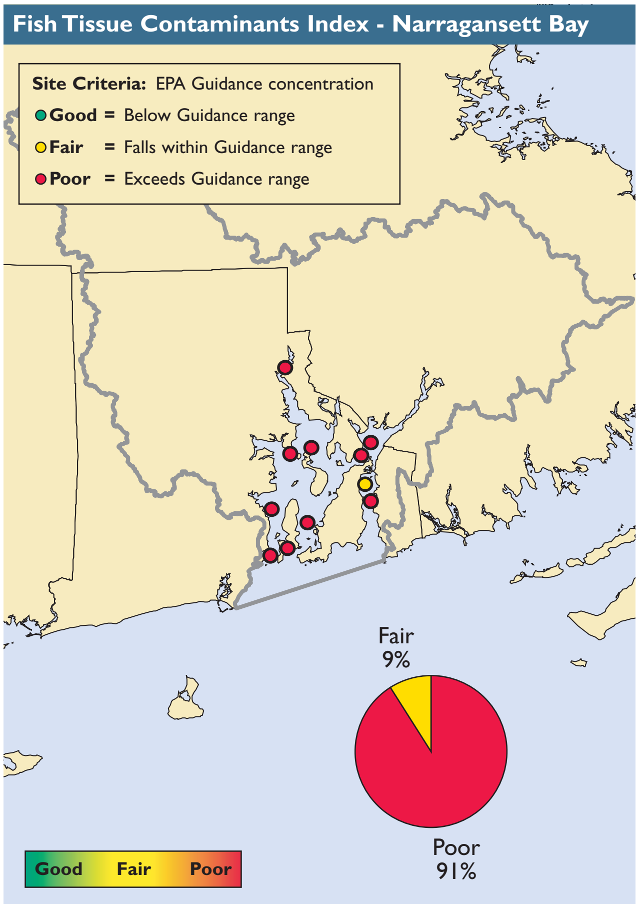


Figure 3-48. Fish tissue contaminants index data for Narragansett Bay, 2000–2001 (U.S. EPA/NCA).

Narragansett Bay Estuary Program Indicators of Estuarine Condition

Water and Sediment Quality

Few long-term, Bay-wide data sets exist for assessing water quality trends in Narragansett Bay. Until very recently, Rhode Island limited its environmental monitoring to fish population and bacterial surveys, such as those used to certify shellfish-harvesting waters. Although federal and university scientists have also engaged in research and monitoring, these efforts were for purposes other than management decision-making. This has resulted in a critical data gap in management-oriented, long-term water quality data for the Bay, especially with respect to excess nutrients, low dissolved oxygen levels, and shifts in phytoplankton blooms (RIDEM et al., 2000).

A more comprehensive monitoring network was initiated in 1999 and involves a collaborative effort among the Rhode Island Department of Environmental Management (RIDEM) Division of Fish and Wildlife, RIDEM Office of Water Resources, NBEP, Narragansett Bay Commission, NOAA's National Marine Fisheries Service (NMFS), EPA, National Estuarine Research Reserve (NERR) at Prudence Island, URI, Brown University, and Roger Williams University (RIDEM et al., 2000). Infrastructure development and data collection for this network include the following:

- Monthly neap-tide water-column surveys of dissolved oxygen levels, salinity, and temperature during the summer season are being coordinated by the NBEP and mapped using GIS by Brown University researchers.
- Continuous water quality monitoring stations at 10 sites have been strategically positioned around Narragansett Bay. These stations have two continuous monitoring probes: one set at a depth just off the bottom of the Bay and a second set just below the surface. Both probes measure salinity, temperature, dissolved oxygen concentrations, pH, and tidal amplitude. The near-surface probe also measures chlorophyll *a* to track phytoplankton blooms. Additional information on these stations is available at: http://www.dem.ri.gov/bart/stations.htm.
- Surface sediment samples have been collected from 43 sites in the Bay and analyzed for concentrations of heavy metals and organic contaminants (RIDEM et al., 2000). Bay-wide surveys of sediment contamination have been conducted by the NBEP in 1988 and 1989, as well as by URI in 1992, 1995, and 1998. Researchers have completed three major studies to determine the extent of sediment contamination in the Bay and the coastal salt ponds of Rhode Island's South Shore. Maps of sediment contamination and trend information have been developed for levels of copper, lead, and mercury in surface sediments and are available at http://www.narrbay.org/d_projects/rised/default.html.

An important step in enhancing Rhode Island's water quality information is the recent development of a statewide monitoring strategy. This strategy is being prepared under the review of a legislatively mandated environmental monitoring collaborative and a Science Advisory Committee, both of which have provided input to target monitoring priorities for new funding in the state's budget. Additional information on this environmental monitoring is available online at http://www.ci.uri.edu/Projects/RI-Monitoring/OnlineResources.html.

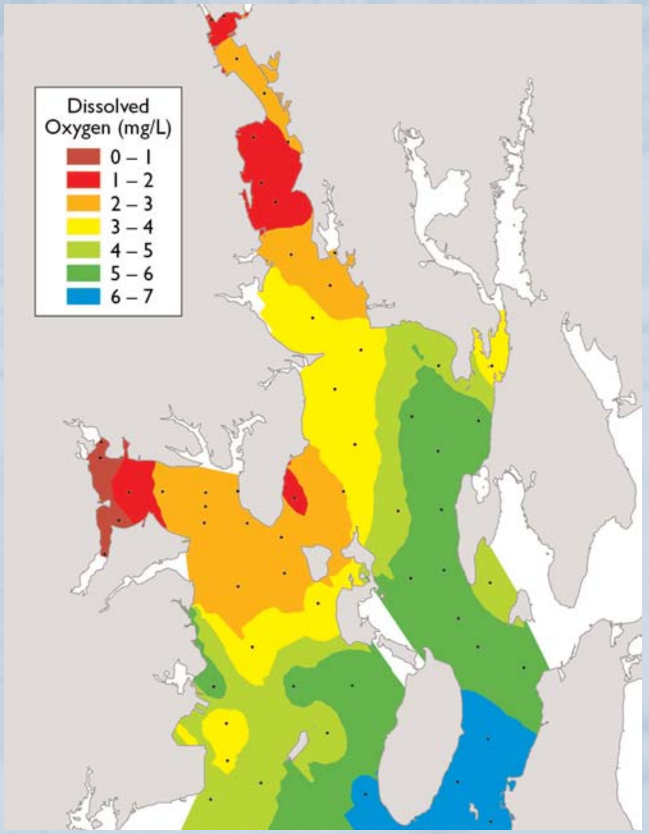
The current and historic concentrations of man-made pollutants (e.g., metals, nutrients, organic waste, and other constituents) in Narragansett Bay's water and sediments have demonstrated a clear north to south gradient, with levels in the main Bay channels decreasing towards the mouth of Bay. The highest pollutant levels are located in the urbanized Providence/Seekonk tidal rivers and the Fall River/Taunton River area, although poorly flushed coves and harbors sometimes experience localized impacts from pollutants. Since 1988, metals concentrations have decreased in surface sediment samples collected from the heavily urbanized portions of the study area and have remained constant or increased slightly in samples from the mid-Bay region (RIDEM et al., 2000).

Fact-Based Findings in Narragansett Bay

Rhode Island residents awoke on August 20, 2003, to reports of a mass die-off of more than one million fish in the state's Greenwich Bay. The stunning fish kill affected not only menhaden, but also other finfish, eels, crabs, and, in particular, soft shell clams. This kill—the worst in 50 years—was the result of prolonged oxygen depletion, and while it was unexpected, it was not a surprise. A report to the Governor prepared by RIDEM and the NBEP subsequently documented that the fish kill was not a simple or isolated event. Rather, it was part of a much larger event going on in Greenwich Bay and other parts of Narragansett Bay that year, as well as part of a continuing trend observed in many preceding years (RIDEM, 2003).

Hypoxia, or low dissolved oxygen levels, is often caused by blooms of phytoplankton. Rapid phytoplankton growth occurs in response to an increase in nutrients, especially nitrogen, in estuarine systems and can result in large algal blooms. Although heavy rainfall can lead to significant increases in nutrient loading via stormwater, WWTPs are typically the major nutrient source in densely populated areas. Other weather factors, such as water temperature and wind direction and strength, also play a roll, either by providing favorable conditions under which blooms can develop and persist, or by disrupting the process through the mixing and oxygenating of the water. Shallow bays and coves may have poor circulation and flushing rates. These waters are more vulnerable to nutrient loading, phytoplankton blooms, and hypoxic conditions (RIDEM, 2003).

Hypoxia can have a wide range of negative impacts on the biological community. Severe hypoxia is associated with fish kills and the mass mortality of benthic invertebrates and can have a structuring influence on depth-specific zones for benthic communities. Even moderate hypoxia can reduce growth rates of marine organisms, cause shifts in the bottom-dwelling and water-column-dwelling community structure, and alter predator-prey interactions. Where hypoxia is a recurrent problem, marine communities tend to shift dominance from large, long-lived species to more tolerant or opportunistic, short-lived species (Deacutis, 1999).



Bottom dissolved oxygen levels measured during an evening neap tide on July 31, 2001. Areas with dissolved oxygen concentrations less than 3 mg/L were exhibiting hypoxia (Emily Saarman, Brown University).

In the upper half of Narragansett Bay, low dissolved oxygen levels have occurred nearly every summer for at least the past 10 years. As early as 1998, scientists began systematically collecting evidence that suggested that low dissolved oxygen problems were more widespread than previously believed (RIDEM, 2003). This discovery went against conventional wisdom that tidal energies in the Bay were strong enough to preclude the development of hypoxic conditions beyond the confines of the Providence River in upper Narragansett Bay. For example, studies to predict the sensitivity of various U.S. estuaries to nutrient inputs had concluded that Narragansett Bay was only moderately susceptible to high levels of nitrogen inputs, with few demonstrated impacts, such as hypoxia and loss of SAV. These findings were due to a lack of any historical oxygen monitoring data or published evidence of loss of SAV. Recent work coordinated by the NBEP has now filled in this gap.

To test the hypothesis that significant portions of the Bay were experiencing summer hypoxic conditions, the NBEP organized a team of scientists and technically trained volunteers (the "Insomniacs") to conduct nighttime surveys of dissolved oxygen during the hours from midnight to 7 a.m. in the upper half of the Bay. Beginning in 1999 and extending through 2004, a flotilla of borrowed work boats and research vessels conducted the monitoring from the Providence hurricane barrier in the north to the northern tip of Conanicut (Jamestown) Island in the south. Survey dates were chosen to coincide with projected weak neap tides, when physical conditions were most conducive to the onset of hypoxia (e.g., warm water, stratified water column, evening hours). Station placement was determined based on bathymetry, and a mix of deep and shallow water stations were sampled.

The results of these evening oxygen surveys confirmed that broad areas of upper Narragansett Bay are subject to intermittent periods of hypoxia during summer months, with probable ecological consequences to benthic communities in these areas (RIDEM, 2003). It is now known that specific areas of the Bay are under temporary, but extreme stress from low-oxygen conditions. Although most of these events do not result in fish kills, such conditions can become harmful to the Bay's ecology, driving fish out of the upper Bay, stunting juvenile fish growth, and killing sensitive, bottom-dwelling organisms that cannot escape. Areas such as the Providence River, which experiences frequent low-oxygen events, end up with altered benthic communities where only the hardiest species survive (Deacutis, 2004).

The evidence provided by these surveys also indicated that although the contributing factors are numerous and complex, a primary cause of the problem is excess nutrient loading to the Bay. An analysis of the 2001–2002 data by the NBEP and Brown University scientists (see map) showed that high-runoff, low-salinity surface water was not required to produce very low dissolved oxygen values, only a low-energy situation (i.e., very weak neap tide and low winds) was required. Nutrients are the source of the problem; algae provide the organic "fuel" to the bacteria; and the weak neap tides maintain the layering (stratification) necessary to decrease oxygen in the lower water layers. This is why weak neap tides are the periods of maximum risk for hypoxic events in Narragansett Bay (RIDEM, 2003).

Although researchers cannot control the tides or the weather, they can use information documented through meticulous monitoring to better manage nutrient inputs and make hypoxic events less frequent. The fish kill was the wake-up call, but it was the data from the dissolved oxygen surveys that laid the foundation for unprecedented state legislation requiring nutrient reductions of least 40% to 50% from WWTPs discharging to upper Narragansett Bay (Governor's Narragansett Bay and Watershed Planning Commission, 2004b). Without another fish kill, the challenge now is to maintain this level of monitoring to document improvements in dissolved oxygen concentrations.

Habitat Quality

Using aerial photography and GIS applications, collaborative efforts are being undertaken to map and restore seagrass beds, salt marshes, shellfish beds, and other critical estuarine habitats. Eelgrass in the Bay has declined since the early 1950s as a result of water pollution, coastal development, harbor dredging, and other factors. In 1996, less than 100 acres of eelgrass remained in Narragansett Bay, and eelgrass has decreased 41% in coastal ponds due to increased nitrogen loads. No significant eelgrass beds occur north of Southern Prudence Island or in Greenwich Bay or the Palmer River (RIDEM et al., 2000). SAV in Narragansett Bay is currently being monitored by a partnership consisting of the NBEP, Save The Bay, the U.S. National Resource Conservation Service (NRCS), and URI. Links to maps of eelgrass, including NBEP maps of all significant beds in the Bay, can be found at http://www.nbep.org.

Living Resources

A variety of living resources are used as indicators of ecological condition in Narragansett Bay, including invertebrate assemblages; the abundance and health of finfish, oysters, scallops, colonial nesting birds, mammals, amphibians, and reptiles; fish kills; and the diversity of benthic organisms and macroinvertebrates (Kleinschmidt Energy and Water Resource Consultants, 2003).

Several different types of finfish and shellfish are monitored in Narragansett Bay. In recent years, the populations of the Bay's native bottom-dwelling fish, such as winter flounder and tautog, have demonstrated declining trends. Other water-column-dwelling species have shown population increases. Scup and striped bass stock have increased since the 1980s (Ardito, 2003b). Scallop landings in the Bay have decreased from 300,000 bushels per day to negligible levels due to eelgrass declines (Ardito, 2003a). After reaching record levels in the 1990s, lobster landings are also decreasing (Ardito, 2003b). Quahogs collected from the Providence River have exhibited a low meat-to-shell ratio, which may indicate that these shellfish are experiencing stress due to low dissolved oxygen levels (RIDEM et al., 2000).

Since data collection began, fish kills have been reported in Greenwich Bay every year, except for 2000. In August 2002, despite a severe drought, low oxygen levels covered almost half of the Bay, including the Providence River, East Passage, Upper Bay, and West Passage. Although Greenwich Bay was not directly measured, researchers working in the area at the time corroborate that a severe low oxygen event also occurred at this location in 2002. The severe hypoxia in the 2002 event was clearly not due to rainfall, but to baseline conditions driven by nutrients from the point sources (e.g., WWTPs) and groundwater entering the Bay due to low river flow (RIDEM, 2003).

Environmental Stressors

An estimated 160 private marinas, yacht clubs, boat yards, town docks, and launching ramps operated in the Bay in 1989, with more than 40,000 boats registered in Rhode Island (RIDEM, 1992; NBEP, 2002). Recognizing the need for additional pump-out facilities to maintain water quality standards, improve water quality, and protect open shellfish beds, NBEP staff developed the *Marina Pumpout Siting Plan for Narragansett Bay, RI* (NBEP, 1993). The result of this plan was the 1998 designation of Rhode Island's coastal waters as a No-Discharge Zone for boat sewage and the development of 30 additional pump-out facilities in the Bay for marine toilets (up from 14 in 1993), with several more under development (RIDEM et al., 2000).

Wetlands and yachts in Wickford Harbor (NBEP).

Current Projects, Accomplishments, and Future Goals

The upgrading of municipal WWTPs has reduced biochemical oxygen demand (RIDEM et al., 2000), and construction of a giant storage system (at a cost of more than $300 million) is underway and will eventually prevent the discharge of some 62 million gallons of untreated sewage to the Bay via CSOs during heavy rains (NBEP, 2005). Pretreatment requirements have radically reduced the amount of metals discharged in wastewater, as has the elimination of lead from gasoline (RIDEM et al., 2000). In addition, a law was passed in 2004 committing the State of Rhode Island to a 50% decrease in recorded 1995–1996 levels of nitrogen loads from major WWTPs to the Bay by 2008 (*An Act Relating to Waters and Navigation–Water Pollution*, H-8638). Finally, Rhode Island has committed to the initiation of a comprehensive monitoring program and adoption of a suite of indicators for the Bay and its watersheds that will track such ecosystem characteristics as land cover/use, demographics, water and sediment quality, hydrology, habitat quality and quantity, productivity, and species assemblages and relative abundance (RIDEM et al., 2000; Kleinschmidt Energy and Water Resource Consultants, 2003).

The NBEP will continue to serve as a coordinating entity for Bay actions and for organizing and creating collaborative efforts to meet common goals. The program will focus on expanding its partnership activities with municipalities, agencies, and non-profit organizations; securing the scientific data needed to support policy initiatives and develop effective management strategies; providing outreach on the Bay and watershed ecosystem through workshops, conferences, and educational events; securing additional funding for CCMP implementation; addressing priority water quality and living resource issues in the Bay; and identifying and analyzing emerging Bay issues (e.g., introduced species).

Conclusion

Based on the four indices of estuarine condition used by the NCA, the overall condition of Narragansett Bay is rated poor. Although relatively well mixed and less susceptible than other estuaries to eutrophication, Narragansett Bay is exhibiting an increasing array of eutrophic-associated symptoms, including low dissolved oxygen levels, fish kills, eelgrass loss, macroalgae blooms, benthic community changes, and a shift in the Bay's dominant fish community from bottom-dwelling to water-column-dwelling species. Workshops held in 2001 concluded that monitoring in Narragansett Bay remains under funded, that significant data gaps exist, and that there is a lack of coordination of monitoring efforts and a lack of integration and analysis of existing data. Since the workshops, the process of addressing these concerns is well underway, with a significant investment in both Bay monitoring and in the reduction of nutrients entering the Bay.

High school students having fun while cleaning up a beach at Conimicut Point on upper Narragansett Bay (NBEP).

Long Island Sound Study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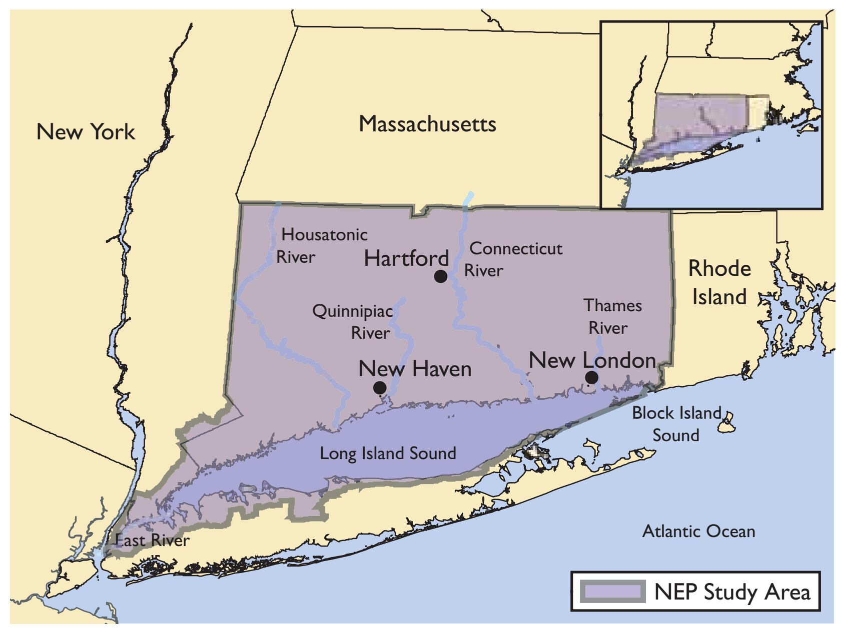
LONG ISLAND SOUND STUDY
A Partnership to Restore and Protect the Sound

www.longislandsoundstudy.net



Background

Long Island Sound is one of the most significant coastal areas in the nation, with a watershed that includes an area of more than 16,000 mi^2 and that traverses all of Connecticut and parts of New York, Massachusetts, New Hampshire, Rhode Island, and Vermont (LISS, 1994). Four major rivers (Connecticut, Housatonic, Quinnipiac, and Thames) deliver fresh water to the Sound, which is approximately 110 miles long and is bounded by Connecticut and New York's Westchester County to the north, by New York City to the west, and by Long Island to the south.

Research shows that at least $5 billion is generated annually in this region from boating, commercial and sport fishing, and beach tourism (LISS, 1994). More than 170 species of finfish can be found in the Sound, including at least 50 species that spawn in the Sound and 21 tropical species that stray into this region on a seasonal basis (LISS, 2006). Species such as winter flounder, tautog, bluefish, diamondback terrapins, and many others have been over-harvested to the point where resource management is critical to maintaining stocks (LISS, 2003c).

The Long Island Sound Study (LISS) began in 1985 as an innovative effort by EPA, New York, and Connecticut to restore and protect Long Island Sound. Two years later, under the newly established NEP, Congress designated Long Island Sound as an Estuary of National Significance. In its early years, the LISS Management Conference, composed of EPA scientists, representatives from other federal agencies, New York and Connecticut state partners, citizens, and local business representatives, worked together to draft a CCMP to guide efforts to manage the Sound. Completed in 1994, LISS's *The Comprehensive Conservation and Management Plan* (LISS, 1994) identified specific priority issues for the LISS, including low dissolved oxygen levels (hypoxia), pathogen contamination in swimming waters and shellfish-harvesting areas, declining populations of living resources, degradation of coastal habitats, contamination of bottom sediments by toxics, and increasing volumes of floatable trash and debris.

Environmental Concerns

Environmental concerns in Long Island Sound include hypoxia, toxic substances, and land-use changes. Low levels of dissolved oxygen have caused significant adverse ecological effects in the bottom-water habitats of Long Island Sound and affected the area's living resources (LISS, 1994). Since 1987, the areal extent and temporal duration of hypoxia in the Sound have exhibited improving trends, due in part to nitrogen-reduction efforts, such as sewage treatment plant (STP) upgrades. Toxic substances, including metals and organic chemicals, enter the Sound from manufacturing sources, stormwater runoff, household cleaning and pest-control products, and automobile and power plant emissions. Although releases of many contaminants in the watershed have declined since the late 1980s, contaminants continue to pose a threat to living resources in Long Island Sound (LISS, 2003c). The loss of wetlands, forests, farm areas, and other open spaces to increased population, development, and urban sprawl has increased pollution and stormwater runoff, altered land surfaces, decreased natural areas, and restricted access to the Sound (LISS, 1994; LISS, 2003c).

Population Pressures

The population of the 15 NOAA-designated coastal counties in New York and Connecticut coincident with the LISS study area increased by only 14% during a 40-year period, from 12.9 million people in 1960 to 14.6 million people in 2000 (Figure 3-49) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the LISS study area is roughly half the population growth rate of 24% for the collective NEP-coincident coastal counties of the Northeast Coast region. In 2000, the population density of these 15 coastal counties was 2,170 persons/mi^2, more than twice as high as the population density of 1,055 persons/mi^2 for the collective NEP-coincident coastal counties of the Northeast Coast region (U.S. Census Bureau, 2001) and second only to New York/New Jersey Harbor in population density (3,097 persons/mi^2). Population pressures for this study area are high because the Sound serves the population of New York City and its surrounding suburban communities—the largest center for commerce on the Northeast Coast.

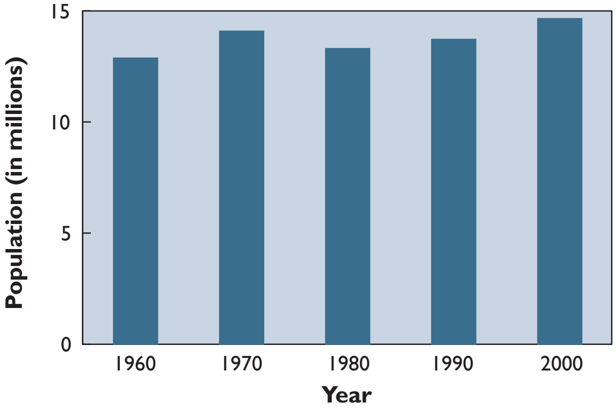


Figure 3-49. Population of NOAA-designated coastal counties of the LISS study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Long Island Sound

The overall condition of Long Island Sound is rated poor based on the four NCA indices of estuarine condition (Figure 3-50). The water quality index for Long Island Sound is rated fair, and the sediment quality, benthic, and fish tissue contaminants indices are each rated poor. Clear gradients in most parameters were evident in the Sound, with more degraded conditions noted in the western, more urbanized portion of the Sound. Figure 3-51 provides a summary of the percentage of estuarine area rated good, fair, poor, or missing for each parameter considered. This assessment is based on data from 86 NCA sites sampled in the LISS estuarine area in 2000 and 2001.

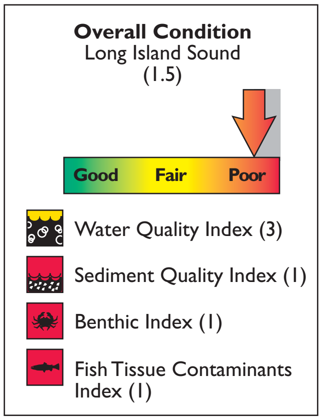


Figure 3-50. The overall condition of the LISS estuarine area is poor (U.S. EPA/NCA).

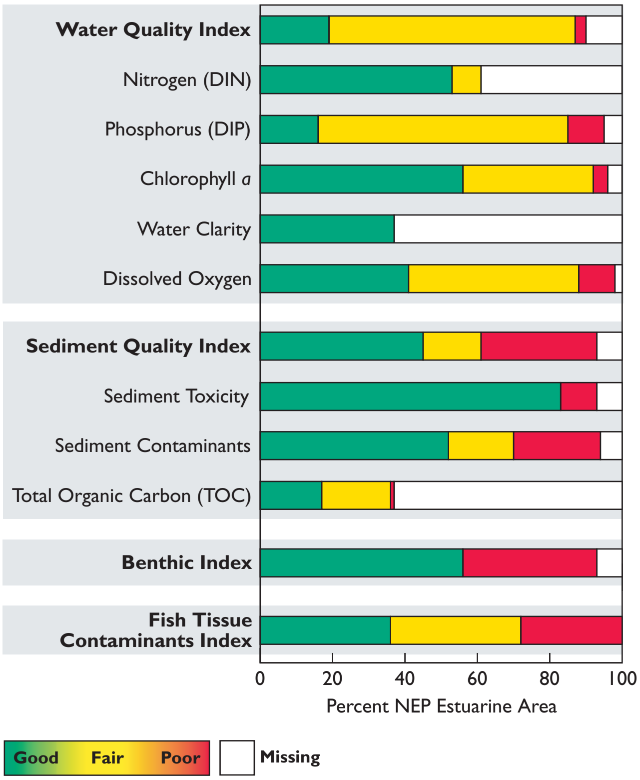


Figure 3-51. Percentage of estuarine area achieving each rating for all indices and component indicators — Long Island Sound (U.S. EPA/NCA).

The Nissequogue River flows north into Long Island Sound (Eileen Keenan, NY Sea Grant).

Water Quality Index

The water quality index for Long Island Sound is rated fair (Figure 3-52). This index was developed using data on five component indicators measured by the NCA: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen.

Dissolved Nitrogen and Phosphorus | Long Island Sound is rated good for DIN concentrations. Fifty-three percent of the estuarine area was rated good for DIN concentrations, and 9% of the area was rated fair. None of the estuarine area was rated poor for DIN, and NCA data on DIN concentrations were unavailable for 39% of the LISS estuarine area.

Water Quality Index - Long Island Sound

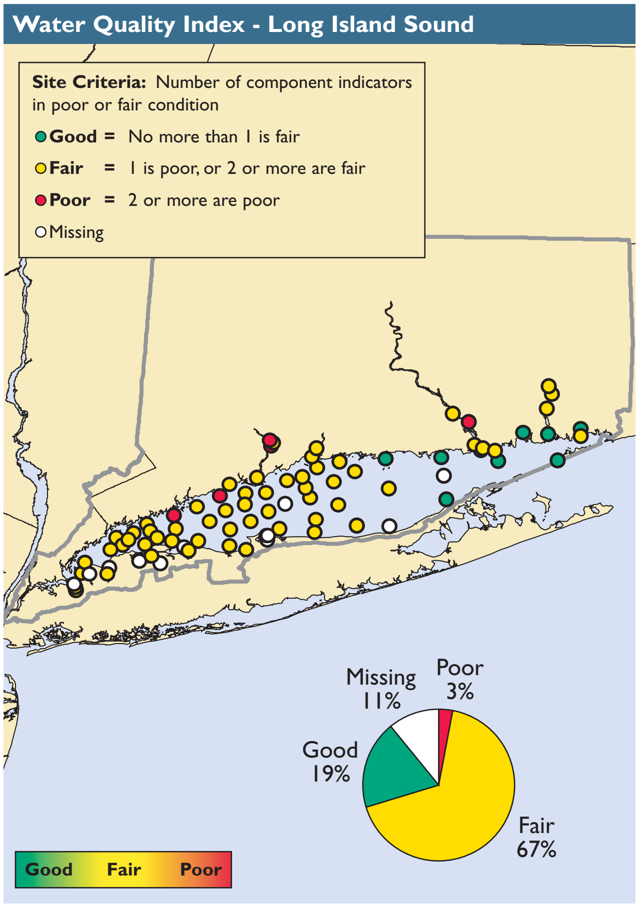


Figure 3-52. Water quality index data for Long Island Sound, 2000–2001 (U.S. EPA/NCA).

Long Island Sound is rated fair for DIP concentrations. High to moderate DIP concentrations were common throughout the Sound, particularly in the tributaries and offshore waters of Connecticut. DIP concentrations were rated good in only 16% of the estuarine area and fair in 69% of the area. Ten percent of the estuarine area was rated poor for this component indicator, and NCA data on DIP concentrations were unavailable for 5% of the LISS estuarine area.

Chlorophyll a | Long Island Sound is rated good for chlorophyll *a* concentrations. Relatively large areas of the Sound had moderately elevated concentrations of chlorophyll *a* that were distributed uniformly throughout the estuarine area. Fifty-six percent of the estuarine area was rated good for chlorophyll *a* concentrations, 36% was rated fair, 4% was rated poor, and NCA data were unavailable for 4% of the LISS estuarine area.

Water Clarity | Water clarity is rated good for Long Island Sound. Water clarity was rated poor at a sampling site if light penetration at 1 meter was less than 10% of surface illumination. No area of the Sound was rated poor or fair for water clarity; however, NCA data on water clarity were unavailable for 63% of the LISS estuarine area.

Dissolved Oxygen | Long Island Sound is rated fair for dissolved oxygen concentrations. A large area of the Sound had depleted levels of dissolved oxygen in bottom waters, with 47% of the estuarine area rated fair for this component indicator and 10% of the area rated poor. The oxygen-depleted waters were largely restricted to the western portions of the Sound. NCA data on dissolved oxygen concentrations were unavailable for 2% of the LISS estuarine area.

Sediment Quality Index

The sediment quality index for Long Island Sound is rated poor, with 32% of the estuarine area rated poor and 16% of the area rated fair for sediment quality condition (Figure 3-53). Ten percent (8 sites) of the Sound's estuarine area had sediments that were toxic to amphipods; however, there was little co-occurrence of toxicity and sediment contamination at the impaired sites, which were grouped in the western and far eastern ends of the Sound. A similar distribution was noted for sites contaminated by moderate and high concentrations of metals and DDT. TOC conditions were not well characterized for Long Island Sound because data were unavailable for two-thirds of the LISS estuarine area.

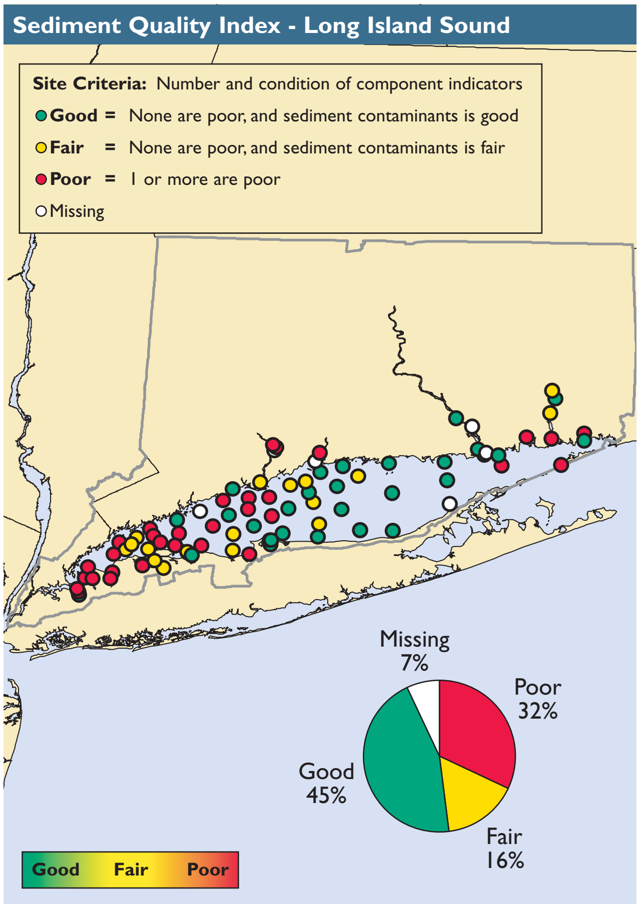


Figure 3-53. Sediment quality index data for Long Island Sound, 2000–2001 (U.S. EPA/NCA).

Sediment Toxicity | Long Island Sound is rated poor for sediment toxicity, with 10% of the estuarine area rated poor for this component indicator. NCA data on sediment toxicity were unavailable for 7% of the LISS estuarine area.

Sediment Contaminants | Long Island Sound is rated poor for sediment contaminant concentrations, with approximately 24% of the estuarine area rated poor for this component indicator and 18% of the area rated fair.

Total Organic Carbon | Long Island Sound is rated good for sediment TOC. Seventeen percent of the estuarine area was rated good for TOC concentrations, and 19% was rated fair. Only 1% of the estuarine area was rated poor for TOC concentrations; however, NCA data on TOC concentrations were unavailable for 63% of the LISS estuarine area.

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Benthic Index

Benthic community diversity in Long Island Sound is rated poor based on the Virginian Province Benthic Index (Figure 3-54). The east to west gradient that was noticeable in other parameters is absent in the results for the benthic index. Rather, the best results are clustered in the western and central portions of the Sound, and the poorest results are grouped in the nearshore waters and tributaries in New York and Connecticut. Consequently, there was a poor correlation between benthic condition and measures of sediment contaminant impairment.

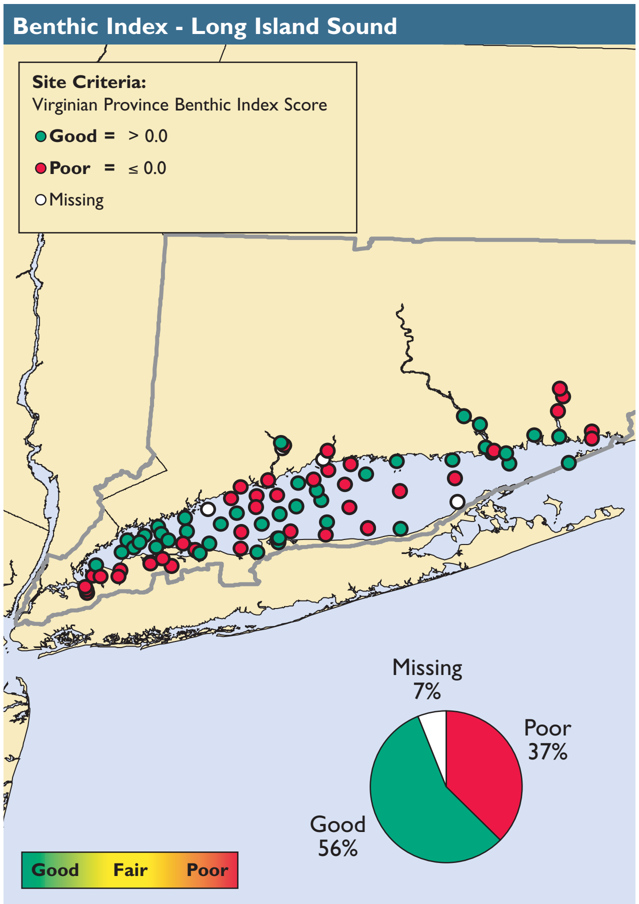

Benthic Index - Long Island Sound

Figure 3-54. Benthic index data for Long Island Sound, 2000–2001 (U.S. EPA/NCA).

Fish Tissue Contaminants Index

The fish tissue contaminants index for Long Island Sound is rated poor. Relatively few fish samples (13) from Long Island Sound were analyzed for contaminant concentrations; however, roughly a third fell into each of the good, fair, and poor categories (Figure 3-55). High levels of PCBs were responsible for nearly all of the samples rated poor, similar to conditions in other NEP estuaries of the Northeast Coast region.

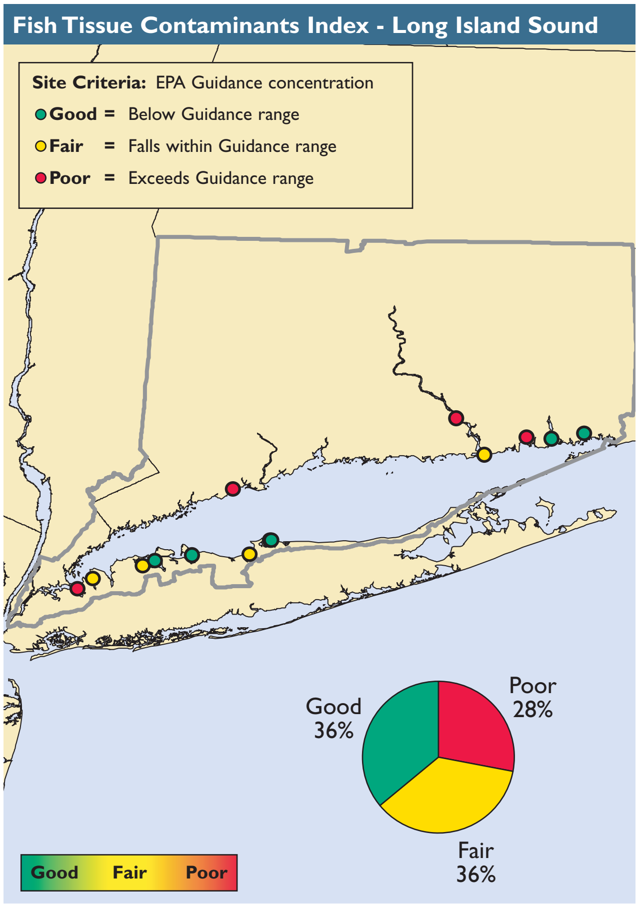

Fish Tissue Contaminants Index - Long Island Sound

Figure 3-55. Fish tissue contaminants index data for Long Island Sound, 2000–2001 (U.S. EPA/NCA).

HIGHLIGHT

Tidal Marsh Loss in Long Island Sound

Throughout the Northeast, tidal marshes are turning into mudflats, resulting in the loss of important vegetated habitats for wading birds, juvenile fish, and invertebrates (LISS, 2004b). Tidal marsh loss—the loss of elevation relative to sea level and the conversion of vegetated marsh to mudflat— has been observed in Long Island Sound since the 1980s; however, recent studies indicate that the magnitude and distribution of these losses, which primarily occur in the western Sound, are far greater than previously realized (LISS, 2003b). At a 130-acre site on the Quinnipiac River, for example, nearly half of the brackish marshes have disappeared since 1974. The LISS is working to gain an understanding of and draw attention to this phenomenon (LISS, 2004b).

Significant areas of tidal wetland loss within Long Island Sound and of coastal wetlands elsewhere in New England have prompted scientists to investigate changes in these marshes with respect to relative sea-level rise. In 2001, Dr. Nels Barrett of the NRCS-Connecticut proposed establishing a long-term program to monitor the elevation dynamics of tidal marshes using surface elevation tables (SETs), a technique promoted by Dr. Don Cahoon of the U.S. Geological Survey (USGS) Pawtuxent Wildlife Research Center. SETs are tools for measuring changes in marsh surface elevation and sedimentation. With funding from the Long Island Sound Fund— a grant program administered by the Connecticut Department of Environmental Protection (CT DEP)— Dr. Barrett partnered with Dr. Cahoon and Dr. R. Scott Warren of Connecticut College to establish SET arrays at Barn Island in Stonington, CT. The nine SET benchmarks were constructed as a first step toward an envisioned network of SETs throughout the Sound. To help gather baseline information on marsh health, a network of 15 SETs is being established around the Sound. The CT DEP's Office of Long Island Sound Program, with funding from Connecticut's Coastal Zone Management Program, has purchased an additional 20 SET arrays that will be deployed in Connecticut marshes in 2005. The LISS has also provided support for the New York State Department of Environmental Conservation (NYSDEC), in partnership with the Marine Sciences Research Center at Stony Brook University, to install and monitor SETs in New York marshes (Barrett and Warren, 2005; LISS, 2005b).

In June 2003, the LISS and the NYSDEC held a workshop to share information regarding the possible causes of tidal marsh loss in the Sound. The participants highlighted the need to gather baseline information on the health and spatial distribution of the Sound's marshes and identified priority research topics. The LISS is helping to address these recommendations by supporting projects to examine coastal wetland trends in the Sound and to investigate potential causes of the observed subsidence (LISS, 2004b).

A researcher collects a sediment core at Sherwood Island in a patch of *Spartina alterniflora* surrounded by a mudflat (Suzy Allman).

A researcher takes SET elevation measures at Barn Island (Dr. R. Scott Warren).

The LISS is funding efforts by the CT DEP and NYSDEC to determine the rates of tidal marsh loss in the Sound. Through an agreement with the CT DEP, the FWS is interpreting wetland boundaries from archival aerial photographs taken between 1974 and 2000 of strategic coves and tidal rivers in the Connecticut portion of the western Sound. In New York, the NYSDEC will acquire aerial infrared photography of tidal marshes and will examine wetland trends by comparing these images with aerial photographs taken in 1930 (LISS, 2005b).

With support from an LISS research grant, Dr. Daniel Civco of the University of Connecticut and Dr. Martha Gilmore of Wesleyan University are collaborating on a project to identify and delineate coastal marshes and to distinguish various types of marsh vegetation. In addition, they are developing a cost-effective way to track changes in the condition of wetlands over time using remote-sensing satellite imagery coupled with in situ radiometry and other field data collection. These data sets and protocols can help provide coastal resource managers, municipal officials, and researchers with baseline information for current land management and long-term monitoring of habitat changes (LISS, 2004b).

One hypothesis formulated at the tidal wetlands-loss workshop was that excessive loading of nutrients, such as nitrogen and phosphorus, plays a role in causing marsh loss. In 2004, the LISS awarded a research grant to Dr. Shimon Anisfeld of Yale University to investigate the possible role of nutrients in contributing to marsh drowning. Dr. Anisfeld's research focuses on whether high levels of nitrogen, while increasing above-ground plant production, might actually decrease the growth of below-ground material, such as roots. Dr. Anisfeld is also testing a theory that, as nutrients increase in the marsh peat, bacteria increase and consume more organic matter. Dr. Anisfeld is assessing site conditions and factors, including nutrient levels, at three Connecticut marshes: a degraded marsh at Sherwood Island State Park in Westport, a stable marsh at Hoadley Creek in Guilford, and a restored marsh at Jarvis Creek in Branford (LISS, 2004b).

These efforts to monitor trends in the Long Island Sound's coastal habitats and investigate potential causes of tidal marsh loss are critical to understanding the changes occurring in the Sound's marshes. The partnerships fostered by the LISS provide a unique opportunity for the States of Connecticut and New York, local researchers, and federal agencies to work together to develop strategies to minimize tidal marsh loss and protect coastal habitats.

For more information, visit http://www.longislandsoundstudy.net.

Long Island Sound Study Indicators of Estuarine Condition

The LISS uses more than 40 specific environmental measures to assess the ecological condition of Long Island Sound (LISS, 2003c). These indicators are primarily associated with water and sediment quality, habitat restoration and protection, and fish and wildlife concerns.

Water and Sediment Quality

The following indicators have been formalized as measures used by the CT DEP and NYSDEC to evaluate water and sediment quality in the Long Island Sound estuarine area:

- Hypoxia (areal extent and duration of hypoxic zones, with dissolved oxygen levels less than 3 mg/L)
- Nitrogen concentrations in several constituent forms in tributaries and from both point and non-point sources
- Total phosphorus concentrations in tributaries
- Chlorophyll *a* concentrations
- Number of beach closure days (New York and Connecticut)
- Total fecal coliform counts in tributaries.

Hypoxia is most severe and prevalent in the western portion of Long Island Sound (NYSDEC, 2006). Since 1991, the CT DEP has conducted a comprehensive water quality monitoring program in the Sound that allows the LISS to track how hypoxia varies from year to year. Between October and May, water quality samples are collected once a month from 17 sites. Bi-weekly hypoxia surveys start in mid-June and end in September, with up to 36 sites being sampled in each survey (LISS, 2004b). The Interstate Environmental Commission (IEC) conducts additional monitoring of the western Sound for dissolved oxygen levels during the summer months. The area and duration of hypoxic occurences in the Sound have fluctuated from year to year, but appear to have improved since the late 1980s (NYSDEC, 2006) (Figure 3-56).

Trends in nitrogen concentrations in tributaries to the Sound have varied between 1971 and 1998. In general, total nitrogen increased from 1975 to 1988 and began to decline thereafter (Trench and Vecchia, 2002). In the Connecticut River, which discharges 70% of fresh water to the Sound, downward trends in total nitrogen since 1988 are most likely the result of improved nitrogen removal at municipal WWTPs, but could also relate to changes in land use (i.e., agricultural to residential or forest) (Mullaney, 2004). Reductions in nitrogen concentrations in the Connecticut River are likely not related to atmospheric sources because wet deposition of nitrogen oxides in precipitation has remained relatively unchanged since the 1980s (Driscoll et al., 2001). Figure 3-57 shows a decreasing trend in overall nitrogen loading to the Sound between 1991 and 2001. In general, Sound-wide nitrogen loads from point sources have also decreased (LISS, 2003a). For example, improvements to STPs in New York and Connecticut reduced the amount of nitrogen entering the Sound by 28% between 1994 and 2003 (LISS, 2003b).

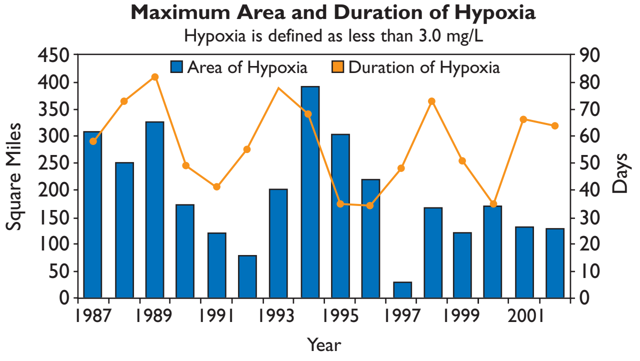
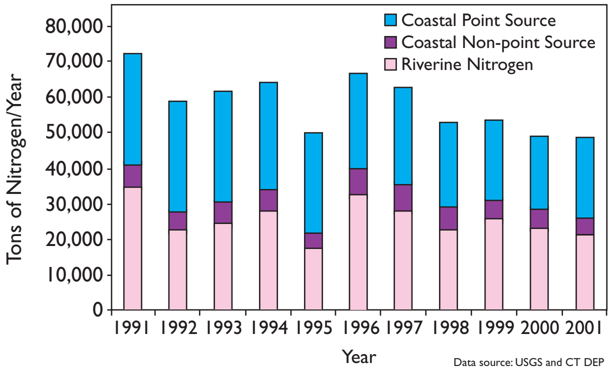


Figure 3-56. Hypoxia in Long Island Sound appears to have generally improved since 1987 (data obtained from CT DEP).



Data source: USGS and CT DEP

Figure 3-57. Trends in nitrogen loading to Long Island Sound (data obtained from USGS and CT DEP).

Total phosphorus concentrations are measured in the tributaries of Long Island Sound to assess the effect of total loading on overall nutrient balance and eutrophication. Phosphorus inputs are having far less impact than nitrogen inputs from point source and non-point sources in this system. Total phosphorus levels showed a declining trend in Long Island Sound tributaries between the years 1981 and 1988, most likely due to improvements at municipal STPs and the declining use of phosphate-based detergents (Trench and Korzendorfer, 1997).

Chlorophyll *a* levels are monitored closely to evaluate nutrient over-enrichment and to observe the effects of point and non-point source loadings of nitrogen to the Sound. In recent years, chlorophyll *a* measures have demonstrated erratic results, but high concentrations have coincided with large algal bloom events. These events have been detrimental to the growth of eelgrass and other SAV and have led to conditions of hypoxia in near-bottom waters. In 2003, chlorophyll *a* levels in western Long Island Sound were recorded as high as 25 µg/L, with average levels around 15 µg/L. Both peak and average chlorophyll *a* levels were higher between 2001 and 2003 than they were between 1998 and 2000 (LISS, 2003a).

One of the key indicators for pathogen contamination in Long Island Sound is the number of beach closure days associated with bacteria levels in water. New York, Connecticut, and EPA coordinate to test waters at 240 swimming beaches to determine whether water is safe from disease-causing pathogens. Sewage pump station overflows accounted for some beach closures, whereas all other closures were caused by rain or high bacteria levels. Beach closures during the past 10 years do not indicate any trend in pathogen contamination in Long Island Sound (Figure 3-58).

Total fecal coliform counts are also measured in Long Island Sound tributaries to help evaluate pathogen contamination from a variety of sources. Results of monitoring for fecal coliform have been highly variable in the past few years.

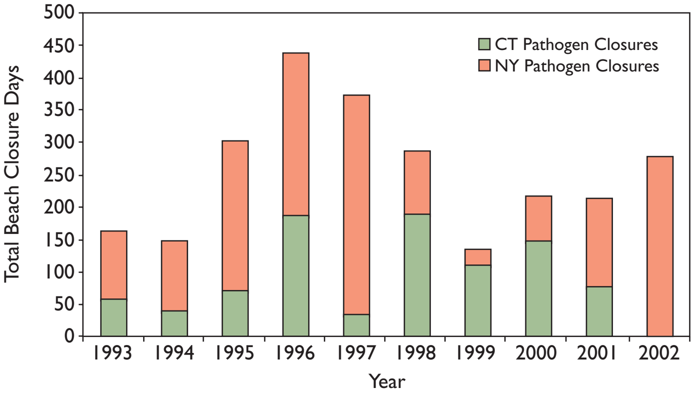


Figure 3-58. Trends in beach closures in Long Island Sound (1993–2002) (data obtained from CT DEP and NYSDEC).

Habitat Quality

The following two measures are used as indicators to determine the success or failure of habitat restoration and protection efforts implemented by state agencies and EPA in Long Island Sound:

- Acres of coastal habitat restored
- Number of river miles restored for anadromous (migratory) fish passage (LISS, 2005a).

In 1998, Connecticut, New York, and EPA created the LISS Habitat Restoration Initiative (HRI) and adopted goals to restore 2,000 acres of the Sound's coastal habitat by the year 2008. The majority of restoration projects in Long Island Sound have targeted tidal wetlands that were degraded by human development or tidal restrictions. Between 1998 and 2003, almost 500 acres of coastal habitat were restored through the HRI (LISS, 2003c).

The HRI also uses the number of river miles restored for anadromous (migratory) fish passage as a major indicator for the success of habitat restoration. In 1998, the LISS adopted a goal of restoring 100 miles of migratory river corridors for anadromous fish by 2008. As of 2003, 52 miles of stream had been restored for fish migration, and as a result, species such as striped bass, blueback herring, and American shad are now swimming into formerly inaccessible streams (LISS, 2003c; LISS, 2004a). Rebuilding riverine migratory corridors creates huge benefits for both recreational and commercial fisheries in this region.

Living Resources

Living resource indicators tracked by the LISS include finfish and shellfish abundance in Long Island Sound. In the late 1980s and early 1990s, several marine fish stocks were declining in the Sound, and as a result, management actions to limit exploitation and rebuild stocks were instituted. Scup and striped bass have responded well to management efforts, and populations of these species are rebounding; however, species that favor cold water temperatures, such as winter flounder, continue to experience declines. Traditionally, the most economically important shellfish harvested in the Sound have been oysters and lobsters. The harvesting of Long Island Sound oysters has declined significantly since the peak year of 1992 due to two deadly parasitic diseases, MSX and Dermo. The Sound's lobster harvests, which had developed into a $40 million a year industry by 1997, have also dropped dramatically as the result of a variety of infections and diseases (LISS, 2003c). The poor health of the Sound's lobsters and oysters has affected the Sound's marine economy, recreational fishers, and the ecosystem.

Bird populations around the Sound are threatened by habitat loss and by human and predator intrusion into nesting areas. The LISS bird population indicators focus on osprey, least terns, and piping plovers. As a result of efforts to build nesting platforms and to protect nests, the number of osprey and piping plover nesting adults is increasing around the Sound (LISS, 2003c); however, the number of nesting least tern adults has declined since the 1980s (LISS, 2003a).

Environmental Stressors

More than 8 million people live in the Long Island Sound watershed, and more than 20 million live within about an hour's drive of the Sound. Approximately 60% of total nitrogen inputs to the Sound come from STPs, and stormwater runoff carries contaminants from roads, parking lots, and construction sites to the Sound (LISS, 2003c).

The primary sources of bacterial pathogens in the Sound's waters are CSOs, malfunctioning STPs, illegal connections to storm sewers, malfunctioning septic systems, and discharges from marine vessels. Pathogen contamination has impacted the commercial economy of the region and has led to closings at many Long Island Sound beaches and shellfish-harvesting areas (LISS, 2003a). In New York alone, more than 48,000 acres of shellfish beds were completely closed or restricted from harvest in 1990 due to pathogen contamination (U.S. EPA, 2006c).

Progress continues to be made in reducing bacterial pathogens in Long Island Sound. In 2002, 134 marine vessel pump-out stations were servicing the Sound (compared to just 43 in 1995), and new stations continue to be built (LISS, 2003a). Fecal coliform counts in Long Island Sound tributaries displayed a recognizable downward trend over time between 1981 and 1988, possibly due to better agricultural practices and improvements at municipal STPs (Trench and Korzendorfer, 1997).

Current Projects, Accomplishments, and Future Goals

Some of the current projects and recent accomplishments of the LISS are summarized below:

- The total point-source nitrogen load to the Sound continued a 14-year declining trend through 2003. The total 2003 load from New York and Connecticut point sources is estimated at 159,969 lbs/day, a decrease of more than 50,500 lbs/day from the 1990s baseline (LISS, 2003a).
- As of December 2003, 30 municipal STPs in Connecticut have completed upgrades, including nitrogen removal, at a cost of more than $340 million (LISS, 2004a).
- Of the nine LISS-funded research projects awarded in 2000 and 2002, five have been completed and four are ongoing. Completed projects include studies of the causes and extent of lobster morbidity and mortality; isotope tracers of nitrates in the Sound to help distinguish sources of pollution; metal contaminant concentrations in Long Island Sound sediments over time; bottom water and sediments at critical sites in Long Island Sound; and the effects of trace metals, organic carbon, and inorganic nutrients in surface waters

on phytoplankton growth. Projects that are ongoing include studies of phytoplankton dynamics to determine shifts in primary productivity, water column oxygen production, and consumption; new approaches for assessing mutagenic risk of contaminants in Long Island Sound; and the status and productivity of salt marsh breeding sparrows.

Future goals outlined in the LISS CCMP include the following:

- **Low dissolved oxygen concentrations** – Reduce nitrogen from STPs and other point sources; reduce nitrogen loads from non-point sources; continue the management of hypoxia; fund implementation of hypoxia management plans; and monitor and assess hypoxic conditions in the Sound.
- **Pathogens** – Control pathogen contamination to Long Island Sound from CSOs, non-point sources, STPs, vessel discharges, and individual on-site systems/discharges; provide public education regarding causes of contamination; and improve monitoring and assessment methods.
- **Toxic substances** – Control and prevent toxic contamination from all sources; address sediment contamination; improve human health risk management; monitor and assess toxic contaminants; and conduct research to investigate toxic contamination.
- **Floatable debris** – Control floatable debris from CSOs and storm sewers and increase floatable debris cleanup efforts.
- **Habitats** – Restore and enhance aquatic and terrestrial habitats; protect and acquire habitat; develop inventories and management strategies for aquatic and terrestrial habitats; manage endangered and threatened species, harvested species, and exotic and nuisance species; educate the public; develop databases; conduct Sound-wide and site-specific research and monitoring; and conduct living resources and habitat research.

Conclusion

The overall condition of Long Island Sound is rated poor based on the four NCA indices of estuarine condition. Based on LISS findings, the most significant environmental priorities in Long Island Sound are low dissolved oxygen levels in bottom waters (hypoxia); pathogen contamination in swimming waters and shellfish-harvesting areas; declines in finfish and commercial shellfish populations; loss of coastal habitat; and increases in floatable debris. Since 1991, there has been a reduction in overall nitrogen loadings to the Sound, as well as in inputs from point sources. Upgrades to municipal STPs have had a major impact on reducing nitrogen discharges from coastal and tributary sources. Construction of pump-out stations has helped to reduce discharges of vessel sewage and the levels of pathogens in near-coastal areas of Long Island Sound. Protection of oyster beds and the lobster population is still an extremely critical priority for the economic viability of the fishing industry in Long Island Sound.

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Peconic Estuary Program

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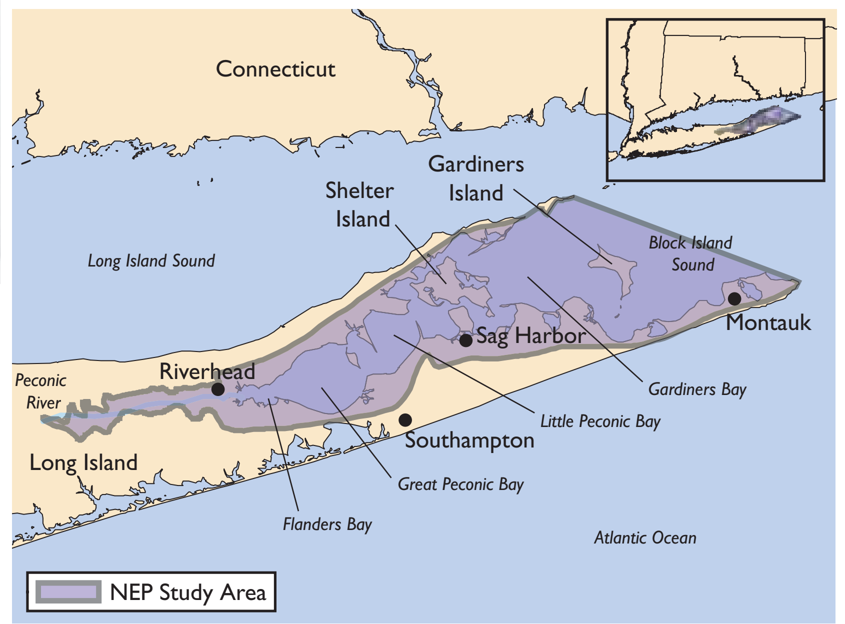


Peconic Estuary Program

www.peconicestuary.org

Background

The Peconic Estuary encompasses a series of connected bays between the north and south forks of eastern Long Island, NY. The Estuary's watershed spans more than 125,000 acres of land and 158,000 acres of surface water and features more than 100 distinct harbors, embayments, and tributaries (PEP, 2001; Balla et al., 2005). The Estuary provides important habitat and spawning and nursery grounds for a wide variety of marine organisms. The most notable species in the Estuary include shellfish, such as bay scallops and hard clams, and finfish, such as bay anchovy, Atlantic silverside, scup, summer flounder (also called fluke), winter flounder, windowpane flounder, weakfish, and blackfish. Eelgrass meadows are found in the eastern portion of the Estuary and provide food, shelter, and nursery grounds to many forms of marine life, including shrimp, bay scallops, crabs, and fish (Balla et al., 2005; SCDHS, 2006). The eelgrass beds also stabilize the Estuary bottom and are an important component of the nutrient cycle of this ecosystem.

The Peconic Estuary was declared an Estuary of National Significance in 1992, and the Peconic Estuary Program (PEP) is sponsored by EPA, the NYSDEC, and the Suffolk County Department of Health Services (SCDHS) (SCDHS, 2006). The PEP Management

Conference, established in 1993, is composed of numerous stakeholders, including citizens, businesses, non-profit groups, and local, state, and federal governmental agencies (PEP, 2006). Approved by EPA in November 2001, the *Peconic Estuary Program Comprehensive Conservation and Management Plan* (PEP, 2001) promotes a holistic approach to restoring and protecting the Estuary and its watershed.

Environmental Concerns

Land-use changes, SAV coverage, and phytoplankton and dinoflagellate blooms are some of the environmental concerns for the Peconic Estuary. The region's population growth and accompanying development pose substantial threats to the Estuary's water quality, nutrient balance, and habitat. Urbanization of the watershed continues, with approximately 600 acres per year converted from agriculture and vacant land to developed uses, mostly residential homes. The estimated 8,700 acres of eelgrass found throughout the Estuary in the 1930s (a conservative estimate) has dwindled to 1,550 acres of eelgrass today (119 beds). Blooms of the phytoplankton brown tide, *Aureococcus anophagefferens*, decimated the commercially significant fishery for Peconic Estuary scallops, particularly during the 1980s. Although brown tide blooms have not occurred since 1997, those species most affected (e.g., bay scallops and eelgrass) have not rebounded (Balla et al., 2005; PEP, 2006). In addition, blooms of the dinoflagellate *Cochlodinium polykrikoides* are of recent concern (Nuzzi, 2005). Other priority management issues are nutrient pollution, habitat and living resources, critical lands protection, pathogens, and toxic contaminants (PEP, 2001).

Population Pressures

The population of the NOAA-designated coastal county (Suffolk) coincident with the PEP study area increased by 113% during a 40-year period, from 0.67 million people in 1960 to almost 1.42 million people in 2000 (Figure 3-59) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the PEP study area is almost five times the population growth rate of 24% for the collective NEP-coincident coastal counties of the Northeast Coast region. A majority of this population growth has taken place in the western portion of Suffolk County, outside of the Peconic watershed. In 2000, the population density of this NEP-coincident coastal county (1,558 persons/mi^2) was the third-highest density calculated for any of the Northeast Coast NEPs and was about 50% higher than the population density of 1,055 persons/mi^2 for the collective NEP-coincident coastal counties of the Northeast Coast region (U.S. Census Bureau, 2001). Population pressures for this NEP study area are mounting, particularly for second homes and during the summer months, because the Peconic Estuary serves as a major center for recreational activities for the large urban population of New York City and Long Island.

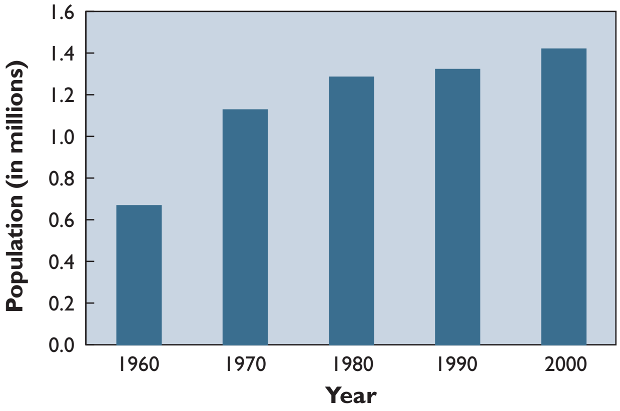


Figure 3-59. Population of NOAA-designated coastal county of the PEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Peconic Estuary

The overall condition of the Peconic Estuary is rated good based on three of the four NCA indices of estuarine condition (Figure 3-60). The water quality and fish tissue contaminants indices are both rated good,

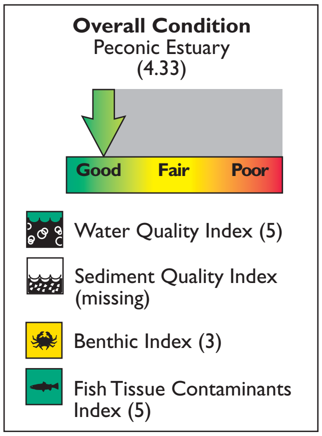


Figure 3-60. The overall condition of the PEP estuarine area is good (U.S. EPA/NCA).

and the benthic index is rated fair. No data were available to calculate a sediment quality index for the Peconic Estuary. Figure 3-61 provides a summary of the percentage of estuarine area rated good, fair, poor, or missing for each parameter considered. This assessment is based on data from 30 NCA sites sampled in the PEP estuarine area in 2000, 2001, and 2002. Please refer to Tables 1-24, 1-25, and 1-26 (Chapter 1) for a summary of the criteria used to develop the rating for each index and component indicator.

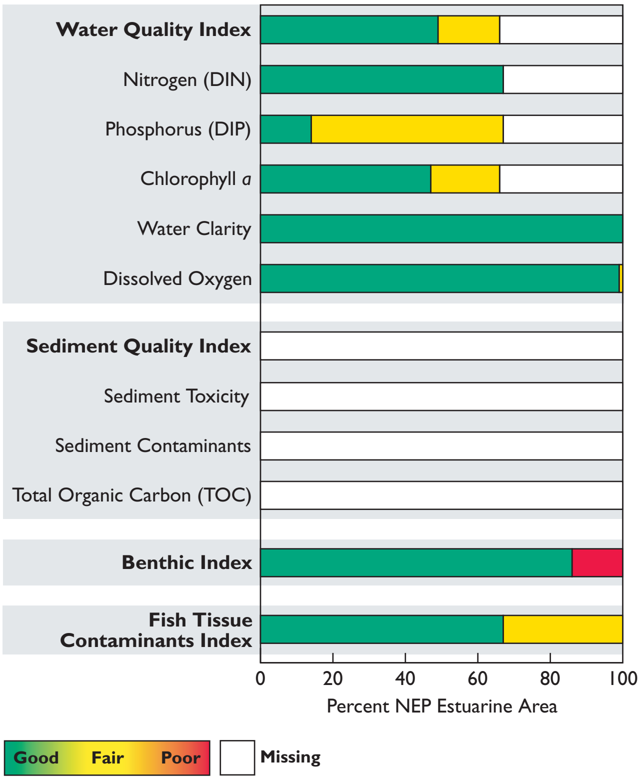


Figure 3-61. Percentage of estuarine area achieving each rating for all indices and component indicators — Peconic Estuary (U.S. EPA/NCA).

Water Quality Index

The water quality index for the Peconic Estuary is rated good; however, water quality data were unavailable for a third of the estuarine area (Figure 3-62). The water quality index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. DIN concentrations were uniformly low in the estuarine area, and moderate DIP concentrations were evident in most of the Estuary where data were available. Water clarity was satisfactory everywhere in the Estuary, and there was only one incidence of moderate oxygen concentrations. In all respects, water quality condition in the Peconic Estuary is similar to that observed in eastern Long Island Sound.

Dissolved Nitrogen and Phosphorus | The Peconic Estuary is rated good for DIN concentrations, with 67% of the estuarine area rated good for DIN concentrations and none of the area rated poor. NCA

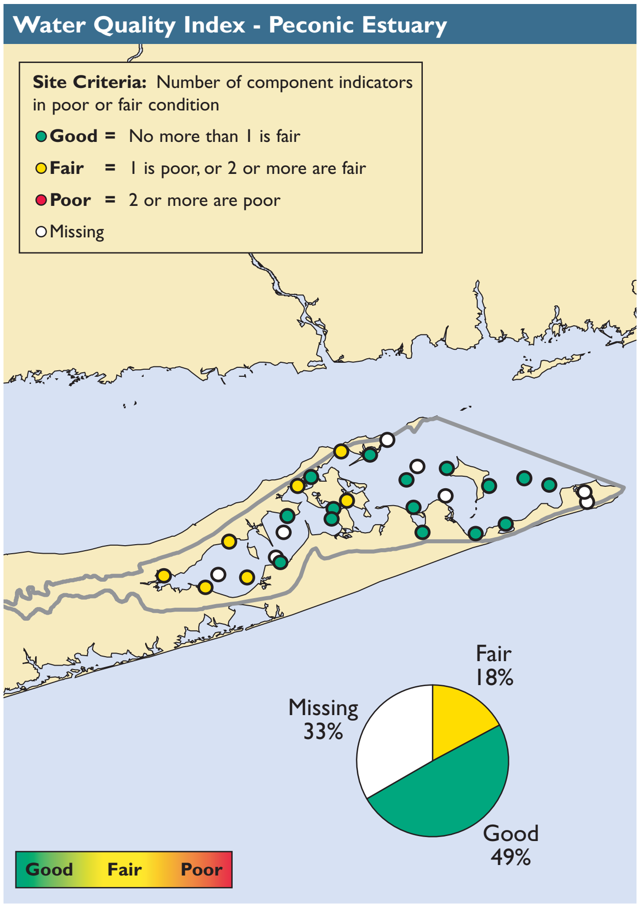


Figure 3-62. Water quality index data for the Peconic Estuary, 2000–2002 (U.S. EPA/NCA).

data on DIN concentrations were unavailable for 33% of the PEP estuarine area.

The Peconic Estuary is rated fair for DIP concentrations, with 14% of the estuarine area rated good for DIP concentrations and 53% of the area rated fair. None of the PEP estuarine area was rated poor for DIP concentrations, although NCA data on this component indicator were unavailable for 33% of the area. A more important measure for the evaluation of eutrophic condition for the Peconic Estuary may be the overall nitrogen load to the system.

Chlorophyll a | The Peconic Estuary is rated good for chlorophyll *a* concentrations. Forty-eight percent of the estuarine area was rated good, 19% was rated fair, and none of the area was rated poor for chlorophyll *a* concentrations; however, NCA data on this component indicator were unavailable for 33% of the PEP estuarine area.

Water Clarity | Water clarity in the Peconic Estuary is rated good, with 100% of the estuarine area rated good for this component indicator. Water clarity was rated poor at a sampling site if light penetration at 1 meter was less than 10% of surface illumination.

Dissolved Oxygen | The Peconic Estuary is rated good for dissolved oxygen concentrations, with 99% of the estuarine area rated good for dissolved oxygen concentrations and 1% of the area rated fair. None of the estuarine area was rated poor for this component indicator; however, the PEP has identified numerous areas of the Estuary that experience periods of low dissolved oxygen levels, particularly during the summer months.

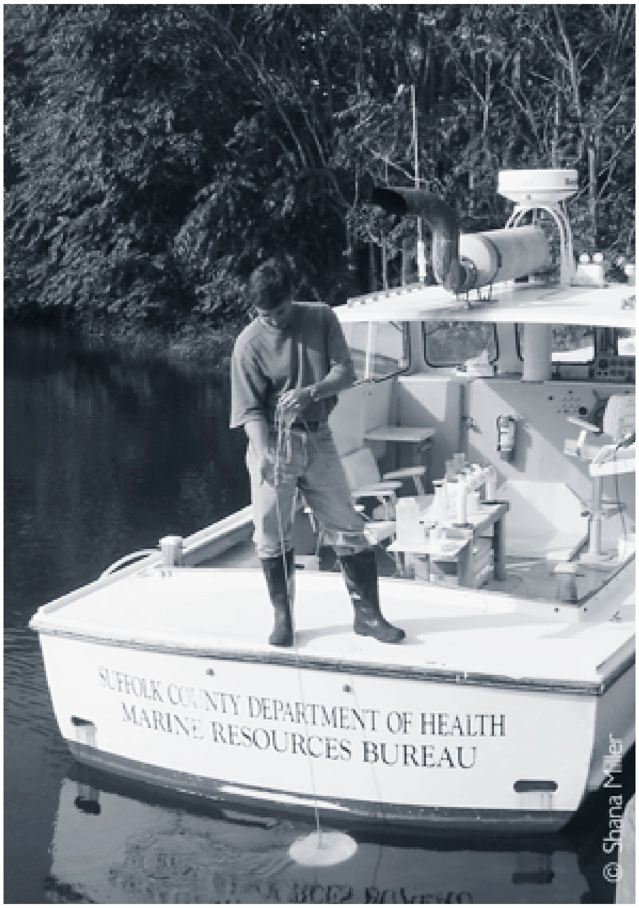
Sediment Quality Index

The NCA survey did not collect sediment quality data for the Peconic Estuary for any of the sediment component indicators in 2000–2002; therefore, a sediment quality index was not developed for this report.

Sediment Toxicity | The NCA 2000–2002 surveys did not collect sediment toxicity data for the Peconic Estuary; therefore, sediment toxicity in the Estuary has not been rated for this report.

Sediment Contaminants | The NCA 2000–2002 surveys did not collect sediment contaminants data for the Peconic Estuary; therefore, sediment contaminant concentrations in the Estuary have not been rated for this report.

Total Organic Carbon | The NCA 2000–2002 surveys did not collect sediment TOC data for the Peconic Estuary; therefore, sediment TOC has not been rated for this report.



An SCDHS sanitarian uses a Secchi disk to measure water clarity (Shana Miller).

Benthic Index

The Peconic Estuary has one of the best measures of benthic community diversity in the Northeast Coast region, with 86% of the estuarine area rated good by the Virginian Province Benthic Index (Figure 3-63); however, the benthic index for the Peconic Estuary is rated fair overall because 14% of the estuarine area was rated poor for benthic condition.

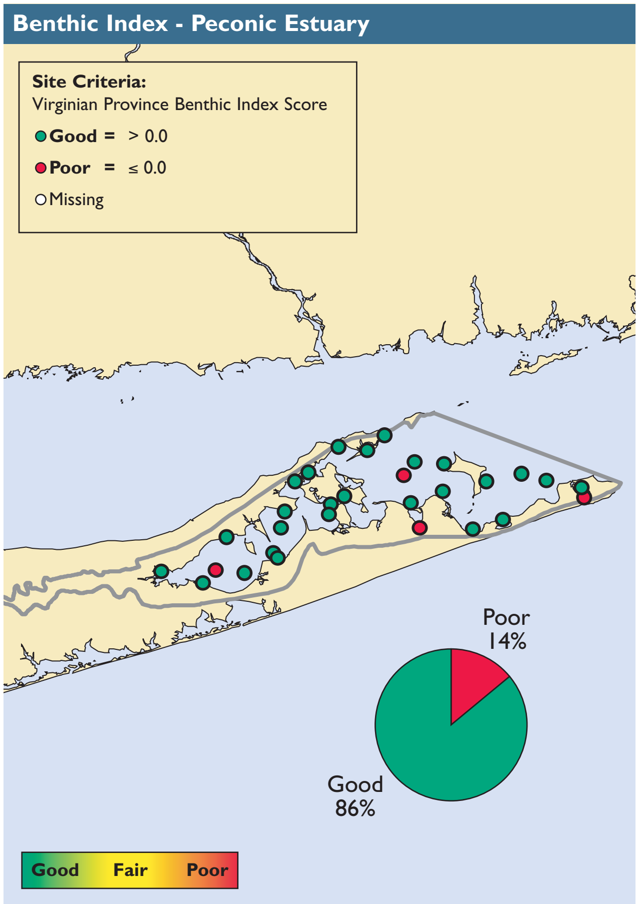


Figure 3-63. Benthic index data for the Peconic Estuary, 2000–2002 (U.S. EPA/NCA).

Fish Tissue Contaminants Index

The fish tissue contaminants index is rated good for the Peconic Estuary. Only three fish samples from the Peconic Estuary were analyzed for fish tissue contaminant concentrations, with two samples rated good and one sample rated fair (Figure 3-64). More data are needed to make an adequate assessment of fish tissue contaminant levels for the Estuary. Unfortunately, relatively few fish were analyzed in neighboring Long Island Sound waters, so it is difficult to determine an accurate assessment of fish tissue contaminant levels in this portion of the Northeast Coast region. EPA, in cooperation with the PEP, has completed a significant study of toxic contamination in shellfish and finfish tissue; however, the results of this study are not yet available.

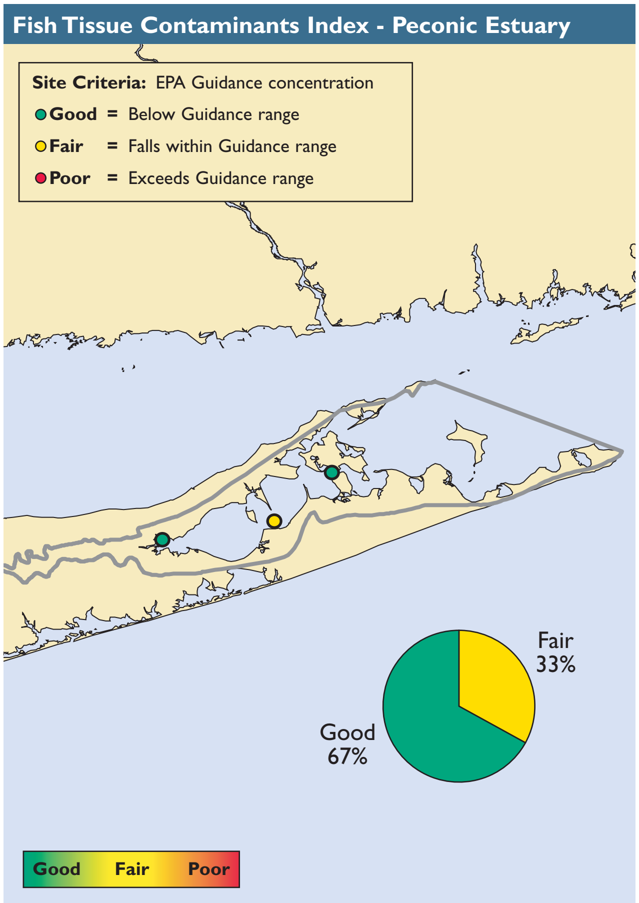


Figure 3-64. Fish tissue contaminants index data for the Peconic Estuary, 2000–2002 (U.S. EPA/NCA).

Peconic Estuary Program Indicators of Estuarine Condition

Compared to other estuaries nationwide, the Peconic Estuary is considered a relatively healthy system (PEP, 2001). For example, more than a third of the Peconic watershed is protected open space, protecting natural habitats, groundwater-recharge areas, and surface water quality. On the other hand, the Peconic Estuary shows signs of environmental stress, particularly in the more densely developed areas and tidal creeks. According to the PEP, low dissolved oxygen conditions occur in approximately 3% of the Estuary; numerous pesticides have been detected in groundwater and surface waters; and some local fisheries, most notably bay scallops and winter flounder, no longer support commercial harvests (Balla et al., 2005).

The PEP developed a list of 18 formal indicators and published a comprehensive environmental status report for the Peconic Estuary in March 2005 (Balla et al., 2005). All the PEP's environmental indicators are listed in the report, and a subset is discussed below.

Water and Sediment Quality

The following indicator measures are used to evaluate environmental changes and stressors affecting water and sediment quality in the Peconic Estuary:

- Number of bathing beach closures
- Acreage of shellfish bed closures
- Onset and duration of brown tide events
- Dissolved oxygen levels
- Total nitrogen levels
- Water clarity
- Pesticides in ground and surface waters.

The number of bathing beach and shellfish bed closures are used as indicators of excess pathogens in estuarine waters. From 1980 through 2004, there were a total of 43 beach closure days at four different bathing beaches within the Peconic Estuary; however, these were mostly precautionary closures. As of January 2004, 3,419 acres were closed and 1,803 acres were seasonally open to shellfishing (Balla et al., 2005) (Figure 3-65), although almost 96% of the Peconic Estuary was available for shellfish harvesting at some point in 2004.

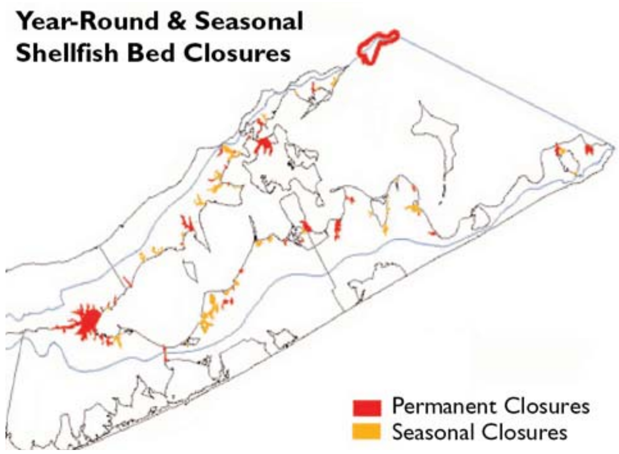


Figure 3-65. Permanent and seasonal shellfish closures in Peconic Bay on January 1, 2004 (PEP).

Some shellfish beds, such as those around Plum Island, were closed in 2004 due to administrative reasons rather than because of poor water quality (PEP, 2006). Stormwater runoff is the largest non-point source contributor of pathogens to the Peconic Estuary. Other contributions may come from wildlife, failing septic systems, improperly treated effluent from WWTPs, and illegally discharged wastes from boats (Balla et al., 2005).

Another measurable impairment of Peconic Estuary water quality is the occurrence of the harmful algal bloom (HAB) dubbed "brown tide," and it is unknown whether onset, duration, and cessation of these blooms are naturally occurring or related to human impacts on the watershed. Brown tide blooms persisted in high concentrations for extended periods in all or part of the Estuary from 1985 through 1988, 1990 through 1992, 1995, and 1997. Brown tides have not bloomed in high concentrations since 1997, but this issue continues to be an important management topic, particularly when efforts are mounted to restore shellfisheries and eelgrass meadows (Balla et al., 2005; PEP, 2006).

One of the most significant water quality concerns for the Peconic Estuary has been excess nitrogen loading, especially in the western portion of the Estuary. There seemed to be an overall decrease in total nitrogen in the Estuary's surface waters from 1994 to 2005; however, the specific cause (e.g., decreased loading, increased uptake in the food web, or a combination of other mechanisms) is not known. Nitrogen inputs to the Estuary originate from excessive agricultural and residential fertilizer use, on-site disposal systems, atmospheric deposition, nutrient-enriched bottom sediments, STPs, and stormwater runoff. Most of the nitrogen enters the Estuary from the atmosphere (rainfall) and groundwater, although STPs are an important factor in select localized areas (Balla et al., 2005).

The relationship between excessive nitrogen loading and low dissolved oxygen levels in estuaries is well documented. The Peconic Estuary has excellent water quality with regard to dissolved oxygen levels, with less than 3% of the estuarine area periodically failing to meet New York's dissolved oxygen standard of 5 mg/L. However, the PEP strives to maintain or improve both dissolved oxygen and total nitrogen levels in the westernmost portions of the Estuary (Balla et al., 2005). Monitoring of point sources, upgrades to sewage systems, and fertilizer-reduction programs are all important actions that could be used to control nitrogen loads, particularly given the fact that development and population increases are likely.

Continuous monitoring equipment has been deployed throughout the main stem of the Peconic Estuary. These devices download information every fifteen minutes and are set one meter off the Estuary bottom. Figure 3-66 depicts the dissolved oxygen concentrations experienced on July 15, 2004 (a typical summer day). The tidal Peconic River station, the most landward monitoring site of the three locations, experienced dissolved oxygen levels that were well below the New York State dissolved oxygen standard of 5 mg/L. Of the three sites, these waters have the least amount of ocean flushing and are most affected by land use and STP effluent discharges (Balla et al., 2005). Great Peconic Bay, the most seaward of the monitoring sites, did not experience any dissolved oxygen problems on July 15, 2004, most likely due to the mixing of the Bay's waters with more oxygenated waters from the seaward boundary (Balla et al., 2005; Personal communication, Bavaro, 2006). Flanders Bay, a station located between the tidal Peconic River and Great Peconic Bay, showed diurnal depressions in dissolved oxygen levels (Balla et al., 2005).

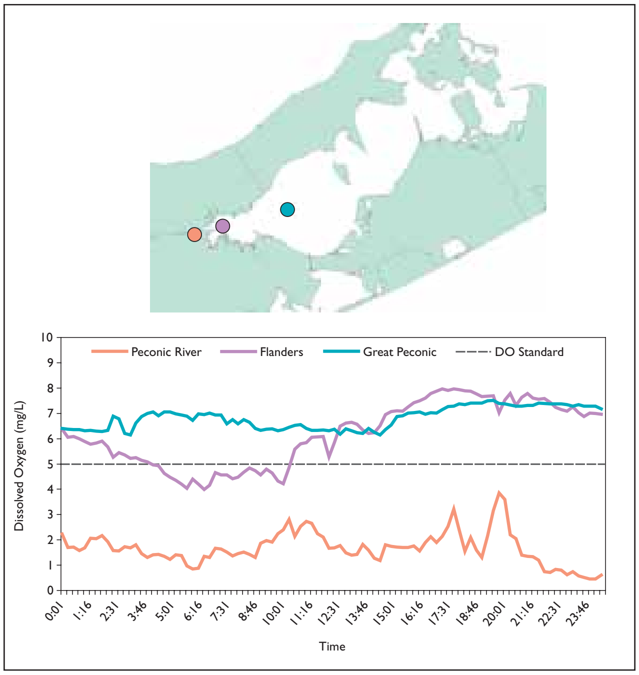


Figure 3-66. Dissolved oxygen concentrations at the three continuous monitoring locations on July 15, 2004 (Balla et al., 2005).

Habitat Quality

The indicators used by the PEP to evaluate habitat changes over time include the following:

- Extent of eelgrass beds (acres)
- Extent of tidal wetlands (acres)
- Area of habitat restoration (acres).

The extent of eelgrass beds in the Peconic Estuary continues to decline, with an areal decrease of at least 82% since the 1930s. Despite generally good water quality, eelgrass beds, measured at 1,550 acres in 2005, are not expanding. The most extensive Peconic wetlands losses occurred prior to 1972. The approximately 5,700 acres of estuarine wetlands in Peconic Estuary are constantly threatened by the degradation of surrounding buffer areas and the invasive common reed *Phragmites australis*. The wide variety of habitat-restoration efforts undertaken in the Estuary have included the replanting of eelgrass, restoration of intertidal marsh, control of common reed growth, and construction of fish passages. Most of these projects have been small, ranging in size from one-tenth of an acre to several acres, but there have been several open-marsh water management and grassland projects of about 50 acres in scope (Balla et al., 2005).

Living Resources

The PEP uses the following key indicator measures to study the overall health of the living resources in the Peconic Estuary system:

- Bay scallop commercial landings
- Winter flounder population abundance
- Piping plover nests and nesting productivity
- Osprey nests and nesting productivity
- Toxic substances in sediments, biota, and groundwater.

Peconic Estuary scallop landings are now a fraction of what was once a nationally significant fishery. In the 1970s and mid-1980s, the harvest of bay scallops ranged from 100,000 to 700,000 pounds of meat. Since 1996, commercial landings ranged from zero to just under 6,000 pounds. Although brown tides have had a large effect on the overall population of scallops, habitat loss, changes in predator-prey relationships, and overharvesting also play a role. Winter flounder are considered an overfished species and have declined throughout the northeastern United States. In the Peconic Estuary, the average catch/tow from 1987 to 1995 was 15.6 for winter flounder, whereas the mean winter flounder/tow was 0.4 and 1.4 in 2002 and 2003, respectively (Balla et al., 2005).

A variety of shorebirds are found nesting, feeding, and breeding along the shores of the Peconic Estuary and its islands. Some of these shorebirds are federally listed as threatened or endangered or are rare in New York, such as the piping plover, least tern, roseate tern, and common tern. The Peconic Estuary is also home to more than half of the ospreys on Long Island; the population of this species has burgeoned since the banning of DDT in 1972. Piping plover breeding pairs on Long Island have generally increased in numbers since the mid-1980s, when the total population was slightly more than 100 pairs. By 2002, the number of Long Island piping plover breeding pairs rose to 369, of which 57 were found in the PEP study area (Balla et al., 2005).

Environmental Stressors

The following indicators are used to assess the impact of human activities on the Peconic Estuary:

- Extent of shoreline hardening
- Extent of impervious surfaces
- Extent of land protection.

The largest threat to beaches and other shoreline habitat is shoreline hardening. Use of bulkheads, rip-rap, jetties, groins, and other hardened structures has been widely permitted to stabilize shoreline in front of waterfront property throughout the Estuary. These structures have replaced beaches with uplands, increased shoreline erosion, and altered sediment accretion patterns that may lead to loss of wetlands and beaches. More than 6% of the Peconic Estuary shoreline has hardened surfaces (Balla et al., 2005). Data on impervious surfaces has been collected, and analysis of these data is underway. Using GIS capabilities, the PEP has finalized its *Critical Lands Protection Plan* (PEP, 2004) to evaluate land available for development and to identify priorities for protection across the Estuary.

Scientists collect sediment samples in a tidal creek on the North Fork of Long Island to test for toxic contamination (Rick Balla).

Peconic Estuary Program

Critical Lands Protection in the Peconic Estuary Watershed

Increasing development in the Peconic Estuary watershed continues to result in the loss and fragmentation of open space and natural habitats, degraded groundwater quality, and declines in local plant and wildlife populations. As of 2001, almost half of the nearly 114,000 acres of land in the watershed's 5 eastern towns was developed, with more than 30% protected and more than 20% still available for development. More than 2,500 parcels of the developed area, comprising 3,500 acres, were developed between 1998 and 2001 (PEP, 2004).

The PEP's *Critical Lands Protection Plan* (PEP, 2004) identified and prioritized for protection the land available for development in the Peconic watershed. Using environmental criteria and GIS, each parcel was evaluated through the lens of habitat and water quality protection. The strategy and resulting plan were not meant to be the sole reference for land protection in the region, but rather a tool for state and local agencies that make land acquisition decisions based, in part, on estuarine considerations (PEP, 2004). Almost 70% of the 25,271 acres of remaining land available for development in the Peconic watershed have been designated as "Critical Lands Protection Strategy (CLPS) high-priority parcels" (Gringalunas et al., 2004).

The towns, county, state, and private land trusts have been instrumental in acquiring open space in the Peconic Estuary watershed. As of 2005, the most widely used land protection tool is full-fee acquisition from willing sellers. Although the Community Preservation Fund (CPF; 2% real estate transfer tax) is the most successful land protection program on Long Island, raising more than $245 million through January 2005, it does not sufficiently keep up with the rate of development and loss of critical landscapes. An estimated $1.375 billion would be needed to protect all of the vacant parcels in the Peconic watershed (approximately 17,000 acres) that meet at least one of the plan's environmental criteria (see map). Future CPF revenues could purchase less than 10% of these parcels. Given these findings, it is apparent that current land acquisition funding, including the additional funding from county, state, and federal sources, is not sufficient to keep pace with the current and anticipated rates of development.

Large amounts of land can be protected without having to expend large sums of money. Alternative protection tools include clearing restrictions, clustering requirements, rezoning, overlay districts, easements, purchase of development rights, and overall better land-use practices. It is estimated that the implementation of clearing restrictions would protect an additional

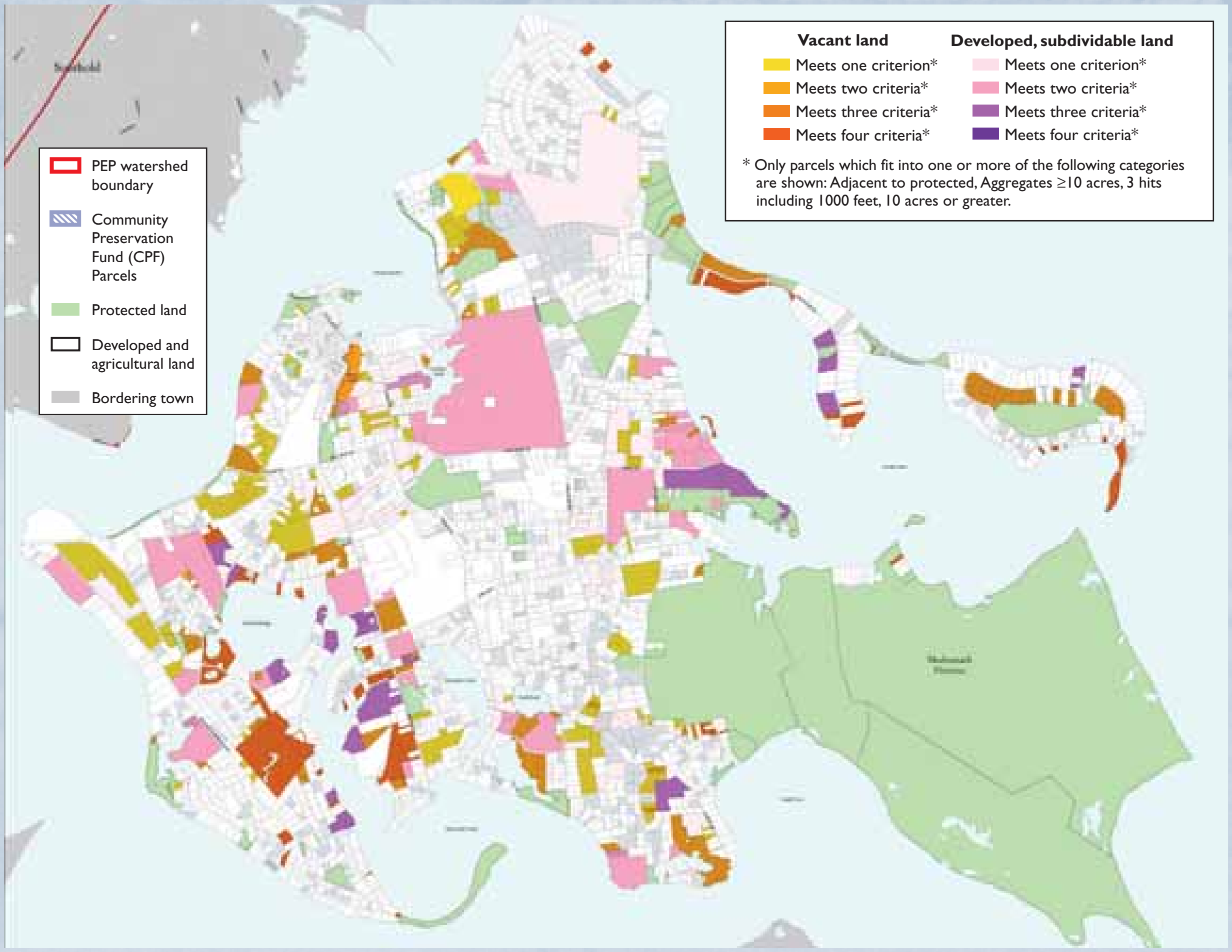
Non-market Benefits Associated with Open Space Acquisition in Riverhead, NY, Using a 3% Discount Rate (Gringalunas et al., 2004)

Non-market Benefit	Cost per Acre
On-site recreational use for bird watching and wildlife viewing	$209,362
Off-site water quality impacts on recreational swimming	$5,216
Localized amenity values to adjacent property owners	$18,300

3,183 acres in the five East End Towns and that acquiring an equivalent amount of land would cost approximately $355 million. If these same lands were developed with both clearing restrictions and clustering requirements, a total of 3,491 acres would be protected, and the estimated cost for acquiring an equivalent amount of land would be $382 million (PEP, 2004).

As part of a case study conducted in 2004, the costs and benefits of protecting 220 acres of open space in Riverhead, NY, through outright acquisition in perpetuity were examined. The cost of acquiring the open space was estimated to range from $22 million to $38 million. These costs were compared to estimated economic impact of three non-market benefits (see table). The estimated impact of these benefits ranged from $20.5 million to $51.4 million, depending on the discount rate selected. Although only three benefits were analyzed, the mid-point of the range of estimated benefit impact exceeds the mid-point of the estimated costs, thereby strengthening the argument for continued land protection (Gringalunas et al., 2004).

Much of the Peconic watershed will be built-out in the next decade. The PEP's efforts to highlight land-protection goals, funding gaps, and protection tools are critical in guiding the watershed's final landscape.



Map of prioritization of environmental criteria for Shelter Island (PEP).

Current Projects, Accomplishments, and Future Goals

Some of the major environmental accomplishments of the PEP include the following:

- **Restoration projects** – Between 1993 and 2005, more than 120 priority demonstration and implementation projects were funded using federal and state funds totaling more than $20.2 million. Projects include upgrades to STPs; restoration of wetlands, eelgrass beds, and fish passages; construction of artificial wetlands; and mitigation of stormwater runoff (Personal communication, Bavaro, 2006).
- **Nitrogen total maximum daily load (TMDL)** – A nitrogen TMDL for waters in the western Estuary will be submitted to EPA in 2006. Nitrogen loadings to these waters need to be reduced to alleviate dissolved oxygen impairments.
- **STP upgrades** – In 2001, the Riverhead and Sag Harbor STP upgraded to tertiary treatment with ultraviolet light disinfection.
- **Agricultural nitrogen reduction** – The PEP was responsible for bringing the region's agricultural community and other stakeholders together for the first time to develop a strategy to lower nutrient and pesticide inputs to the environment.
- **Promotion of best management practices (BMPs)** – The PEP promotes projects, such as the Stop Throwing Out Pollutants (STOP) Program, integrated pest management, and stormwater mitigation at marinas, golf courses, and other facilities, to reduce levels of toxics in the watershed.
- **Benthic mapping** – Underwater land maps are being created for the Peconic Estuary to document bathymetry and distribution of natural resources, identify potential sites for commercial aquaculture operations, assess biodiversity, and clarify Essential Fish Habitat designations.
- **Habitat restoration plan** – The PEP identified the need for 72 restoration projects encompassing 836 acres, with an estimated cost of more than $42 million (PEP, 2002).
- **Vessel Waste No-Discharge Zone** – In 2002, the entire Peconic Estuary was designated a Vessel Waste No-Discharge Zone, whereby the direct discharge of treated and untreated wastes from marine toilets is prohibited. In addition, the PEP aids municipalities in acquiring additional vessel waste pump-out boats.

Conclusion

Compared to other NEP estuaries, the Peconic Estuary is a relatively healthy system. For example, more than a third of the Peconic Estuary watershed is protected open space, preserving natural habitats, groundwater-recharge areas, and surface water quality. On the other hand, the Peconic Estuary shows signs of environmental stress, particularly in the more densely developed areas and in the tidal creeks. Monitoring data from Suffolk County show that water quality across the Peconic Estuary is in relatively good condition. This finding is consistent with EPA's overall condition rating of good based on three of the indices used by the NCA. The PEP feels that more scientific inquiry and monitoring of the Peconic Estuary and its watershed is needed to accurately understand the causes and effects of pollutants, and that additional funding is critical to develop indicators, monitor them over time, and report to the public about Estuary conditions.

Bay scallops were once a nationally significant fishery in Peconic Estuary (Shana Miller).

New York/New Jersey Harbor Estuary Program

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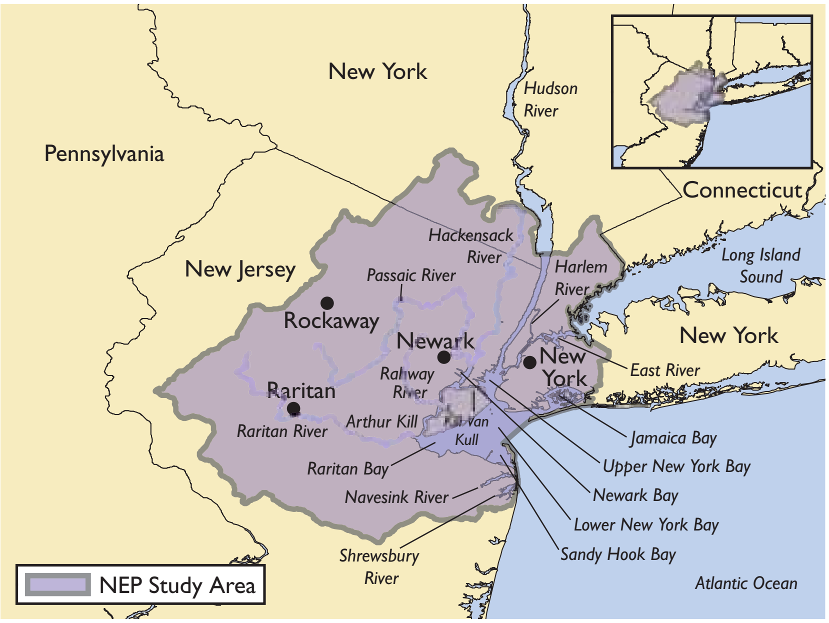

New York - New Jersey
Harbor Estuary Program
www.harborestuary.org

Background

The core area of the New York/New Jersey Harbor extends from the tidal waters of the Hudson-Raritan Estuary to Sandy Hook, NJ, and Rockaway Point, NY, at the mouth of the Harbor. This core area includes the Hudson River, Upper Bay, Lower Bay, Arthur Kill, Kill Van Kull, and Raritan Bay. The NEP study area also includes the East and Harlem rivers and Jamaica Bay in New York, and the Hackensack, Passaic, Raritan, Shrewsbury, Navesink, and Rahway rivers and Newark and Sandy Hook bays in New Jersey. The actual drainage basin or watershed of the Harbor encompasses about 16,300 mi^2, including much of eastern New York, northern New Jersey, and small parts of western Connecticut, Massachusetts, and Vermont. The quality of the estuary's water is affected not only by activities occurring directly in the Harbor and New York Bight (the ocean area that extends approximately 100 miles beyond Harbor waters), but also by industry, agriculture, and other individual practices throughout this larger watershed (NY/NJ HEP, 2006).

The New York/New Jersey Harbor Estuary Program (also known as the HEP) was designated an Estuary of National Significance in 1988 by EPA, in response to a request by the two states' Governors. The HEP was convened as an interstate partnership of federal, state, and local governments; scientists; civic and environmental advocates; the fishing community; business leaders; and educators. In 1987, Congress also required the preparation of a restoration plan for the New York Bight; however, because the Harbor and New York Bight are inextricably linked within the larger ecosystem, these two plans were later joined (NY/NJ HEP, 1996; 2006).

Environmental Concerns

Some of the primary environmental concerns in the New York/New Jersey Harbor system include toxic contamination, pathogens, and wetland loss. Levels of mercury are still above the ERM values for sediments in all basins of the estuary, and levels of contaminants in fish have resulted in the issuance of health advisories against fish consumption. In 1988, large improvements made at STPs helped end the discharge of roughly 210 million gallons of untreated sewage per day from Manhattan and Brooklyn and reduced fecal coliform levels in the estuary. CSOs still contribute raw sewage to the Harbor's waterways when it rains, and some shellfish beds have remained closed for decades. Compared to historic acreage levels, about 80% of the estuary's tidal wetlands and most of the 224,000 acres of the urban core's freshwater wetlands are gone. Despite these losses, Clean Water Act regulations have helped reduce wetland losses substantially in the past 10 to 15 years (Steinberg, 2004).

Population Pressures

The population of the 21 NOAA-designated coastal counties coincident with the HEP study area increased by 13% during a 40-year period, from 15 million people in 1960 to almost 16.9 million people in 2000 (Figure 3-67) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the HEP study area is about half the population growth rate of 24% for the collective NEP-coincident coastal counties of the Northeast Coast region. In 2000, the population density of these 21 NEP-coincident coastal counties (3,097 persons/mi^2) was the highest density calculated for any of the Northeast NEP study areas and was three times higher than the population density of 1,055 persons/mi^2 for the collective NEP-coincident coastal counties of the Northeast Coast region (U.S. Census Bureau, 2001). Population pressures for the HEP study area are extremely high because this estuary serves the major metropolitan area of New York City—one of the largest port facilities on the East Coast and a center for international commerce and banking.

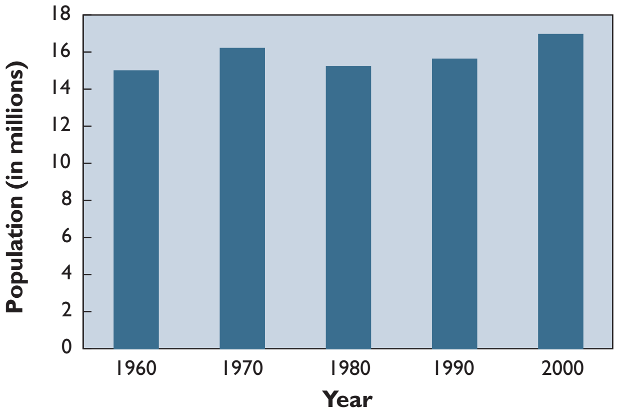

Figure 3-67. Population of NOAA-designated coastal counties of the HEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—New York/ New Jersey Harbor

The overall condition of the New York/New Jersey Harbor is rated poor based on the four indices of estuarine condition used by the NCA (Figure 3-68). All four indices—the water quality index, sediment quality index, benthic index, and fish tissue contaminants index—are also rated poor for the New York/

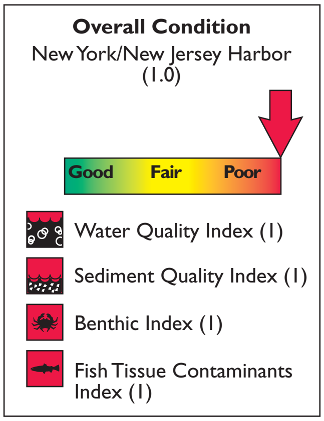

Figure 3-68. The overall condition of the HEP estuarine area is poor (U.S. EPA/NCA).

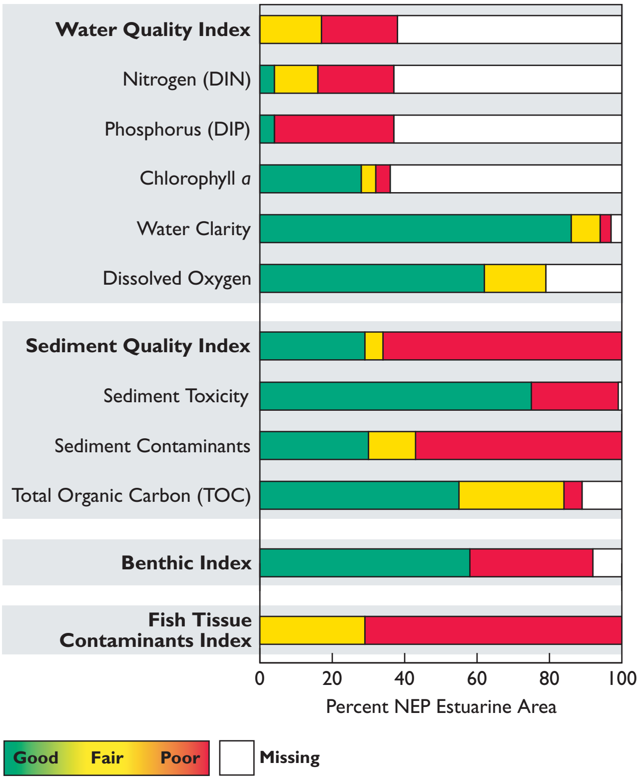

Figure 3-69. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — New York/New Jersey Harbor (U.S. EPA/NCA).

New Jersey Harbor. Figure 3-69 provides a summary of the percentage of estuarine area rated good, fair, poor, or missing for each parameter considered. This assessment is based on data from 32 NCA sites sampled in the HEP estuarine area in 2000 and 2001. Please refer to Tables 1-24, 1-25, and 1-26 (Chapter 1) for a summary of the criteria used to develop the rating for each index and component indicator.

Water Quality Index

The water quality index for the New York/New Jersey Harbor is rated poor. This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. None of the estuarine area was rated good for water quality, and 38% of the area was rated fair or poor (Figure 3-70). Water quality data were unavailable for 62% of the HEP estuarine area; therefore, this water quality index rating is only tentative. The available data show a wide occurrence of elevated concentrations of DIN and DIP and relatively few sites where chlorophyll *a* levels were elevated. Water clarity was largely satisfactory in the Harbor, with 11% of the estuarine area in fair or poor condition for this component indicator. This finding is a departure from the tendency for Northeast Coast NEP estuaries to have relatively clear water conditions, and the first indication of the degraded clarity that is usually found in estuaries in the southern part of the Northeast Coast region. Dissolved oxygen concentrations were satisfactory in 62% of the HEP estuarine area.

Dissolved Nitrogen and Phosphorus | The New York/New Jersey Harbor is rated fair for DIN concentrations. Four percent of the estuarine area was rated good for DIN concentrations, 12% of the area was rated fair, and 21% of the area was rated poor. NCA data on DIN concentrations were unavailable for

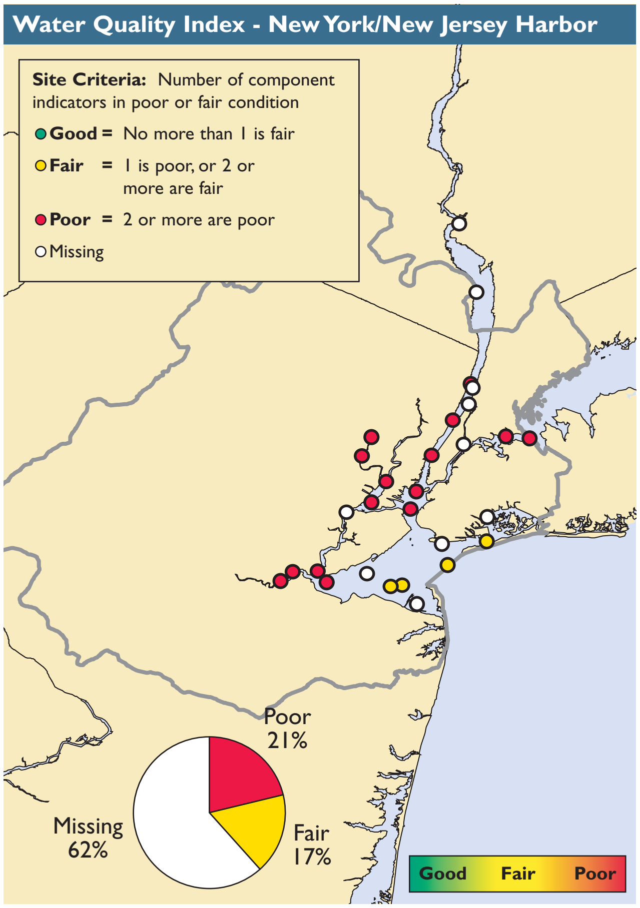

Figure 3-70. Water quality index data for New York/New Jersey Harbor, 2000–2001 (U.S. EPA/NCA).

63% of the HEP estuarine area. The New York/New Jersey Harbor is rated poor for DIP concentrations, with 4% of the estuarine area rated good for this component indicator and 33% of the area rated poor. NCA data on DIP concentrations were unavailable for 63% of the HEP estuarine area.

Chlorophyll a | The New York/New Jersey Harbor is rated good for chlorophyll *a* concentrations, with 28% of the estuarine area rated good for this component indicator, 4% of the area rated fair, and 4% of the area rated poor. NCA data for chlorophyll *a* concentrations were unavailable for 64% of the HEP estuarine area.

Water Clarity | Water clarity in the New York/New Jersey Harbor is rated good. Water clarity was rated poor at a sampling site if light penetration at 1 meter was less than 10% of surface illumination. Eighty-six percent of the estuarine area was rated good for water clarity, 8% was rated fair, and only 3% was rated poor. NCA data on water clarity were unavailable for 3% of the HEP estuarine area.

Dissolved Oxygen | The New York/New Jersey Harbor is rated good for dissolved oxygen concentrations, with 62% of the estuarine area rated good for this component indicator and none of the area rated poor. NCA data on dissolved oxygen concentrations were unavailable for 21% of the HEP estuarine area.

Sediment Quality Index

The sediment quality index for the New York/New Jersey Harbor is rated poor, with 65% of the estuarine area rated poor for sediment quality condition (Figure 3-71). This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC. Three survey sites (accounting for 25% of the HEP estuarine area) showed toxicity toward amphipods; metals and PCBs were most often responsible for contamination at impaired sites; and about a third of the estuarine area had elevated TOC levels in sediment.

Sediment Quality Index - New York/New Jersey Harbor

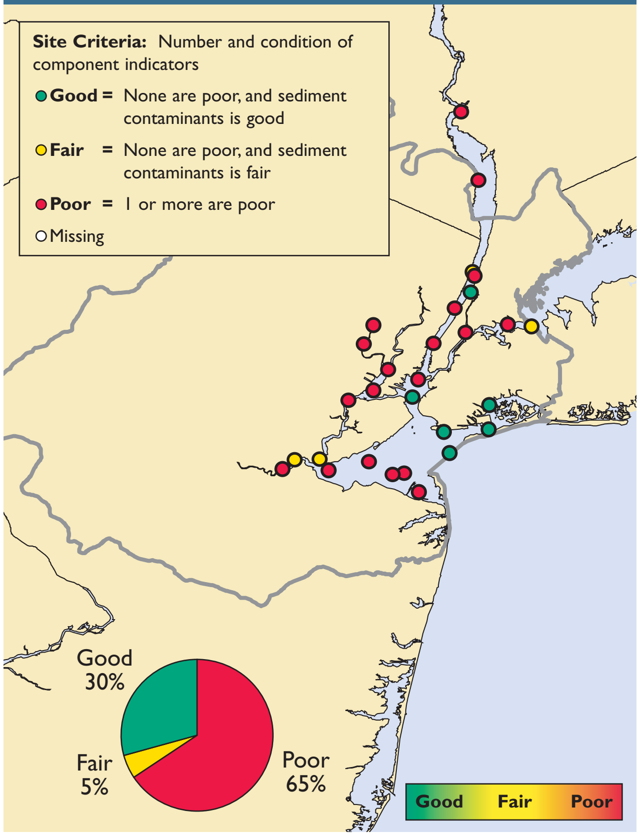

Figure 3-71. Sediment quality index data for New York/New Jersey Harbor, 2000–2001 (U.S. EPA/NCA).

Sediment Toxicity | The New York/New Jersey Harbor is rated poor for sediment toxicity, with 25% of the estuarine area rated poor for this component indicator. NCA data on sediment toxicity were unavailable for 1% of the HEP estuarine area.

Sediment Contaminants | The New York/New Jersey Harbor is rated poor for sediment contaminant concentrations, with more than half (57%) of the estuarine area rated poor for this component indicator and an additional 13% of the area rated fair.

Total Organic Carbon | The New York/New Jersey Harbor is rated good for sediment TOC, with 55% of the estuarine area rated good for this component indicator, 29% of the area rated fair, and only 5% of the area rated poor. NCA data on sediment TOC were unavailable for 11% of the HEP estuarine area.

Benthic Index

Based on NCA monitoring data, the benthic index for the New York/New Jersey Harbor is rated poor. A third of the Harbor's estaurine area had degraded benthic communities, whereas 58% of the area exhibited healthy benthic communities, as judged by the Virginian Province Benthic Index (Figure 3-72).

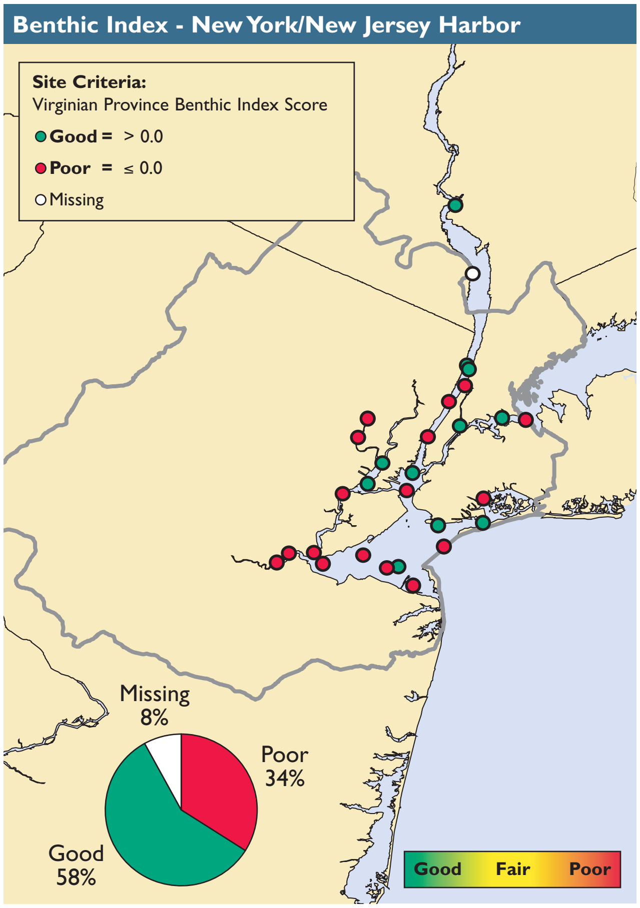
Benthic Index - New York/New Jersey Harbor

Figure 3-72. Benthic index data for New York/New Jersey Harbor, 2000–2001 (U.S. EPA/NCA).

Fish Tissue Contaminants Index

The fish tissue contaminants index for the New York/New Jersey Harbor is rated poor. Relatively few fish from the Harbor (14 fish samples) were analyzed for fish tissue contaminant concentrations (Figure 3-73). All of the fish analyzed either fell within the range of EPA Advisory Guidance values (29%) or exceeded EPA Advisory Guidance values (71%) for fish consumption, most commonly for PCBs and, occasionally, for DDT and mercury.

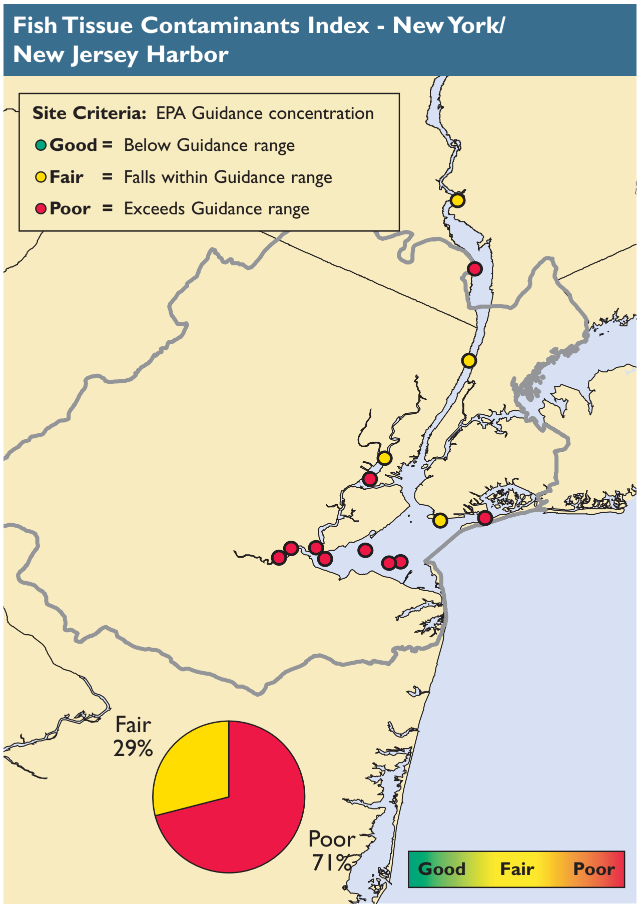
Fish Tissue Contaminants Index - New York/New Jersey Harbor

Figure 3-73. Fish tissue contaminants index data for New York/New Jersey Harbor, 2000–2001 (U.S. EPA/NCA).

New York/New Jersey Harbor Estuary Program

New York/New Jersey Harbor–Wide Water Quality Survey

The HEP reports that it has collaborated with numerous federal, state, and municipal agencies to initiate a long-term water quality monitoring program that covers all of the waters of the New York/New Jersey Harbor. New York City has monitored the New York side of the Harbor for nearly 100 years, but the HEP has recognized that a previous lack of monitoring data for the New Jersey waters of the Harbor is a significant concern.

To address this issue, the HEP formed an ad hoc monitoring group in 2002 to assess existing water quality monitoring efforts in the Harbor and to make recommendations to fill data gaps. This group included representatives from the New Jersey Harbor Discharges Group (NJHDG), New Jersey Department of Environmental Protection (NJDEP), New York City Department of Environmental Protection (NYCDEP), NYSDEC, National Park Service (NPS), IEC, EPA, and the New Jersey Sea Grant.

Although the collective monitoring group made recommendations about what needed to be done to fill data gaps, the NJHDG made the long-term commitment to the New Jersey data-collection program. The NJHDG is convinced that a robust water quality database is needed to allow the member agencies to make informed decisions about future needs and to allow the group to be confident that regulatory decisions are made based on high-quality environmental measurements.

The water quality surveys now conducted by the NJHDG and the NYCDEP are entirely complementary, and staff from all the participating agencies continue to collaborate on common issues. Parameters measured include dissolved oxygen, total suspended solids, fecal coliform bacteria, nitrogen, phosphorus, and salinity. Efforts are also underway to investigate adding real-time data collection to the monitoring effort.

Through these combined efforts, the data from the more than 60 stations in the HEP estuarine area can now be used to represent the water quality of the entire Harbor and will form the basis for documenting changes in water quality over time. Additional information on these programs is available from the HEP at www.harborestuary.org.

Passaic Valley Sewerage Commissioners (PVSC) vessel collecting water quality data as part of the Harbor-wide survey (PVSC).

New York/New Jersey Harbor Estuary Program Indicators of Estuarine Condition

Water and Sediment Quality

Table 3-1 presents trends in the main indicators used by the HEP. The NYCDEP collects water samples every two weeks at a series of stations around the Harbor to measure dissolved oxygen in surface and bottom waters to evaluate changes in water quality in the estuary. Historically, dissolved oxygen levels were routinely below 1.5 mg/L in summer months; however, since the 1970s, dissolved oxygen levels have been above the minimum EPA guideline of 2.3 mg/L at most sites, with mean Harbor-wide dissolved oxygen concentrations fluctuating between 5 and 7 mg/L in the surface and bottom waters of the HEP study area. When dissolved oxygen concentrations are above 4.8 mg/L, an area is considered to achieve objectives for the protection of marine life. Overall, dissolved oxygen levels in the Harbor improved considerably between 1990 and 2000 (Steinberg et al., 2004). The HEP's target is to increase water quality for the area so that dissolved oxygen levels never drop below 4.8 mg/L (30 mi^2 currently achieve this target) (NY/NJ HEP, 2004). Figure 3-74 illustrates changes in dissolved oxygen concentrations in the Harbor from 1946 to 2001.

Table 3-1. Trends in Water Quality Indicators Measured by the HEP (Steinberg et al., 2004)

Toxic Contamination	
Contaminant levels	Improving trend
Contaminant loadings	Improving trend
Sediment toxicity	No trend
Contaminants in fish tissue	Improving trend
Pathogens	
Acres of shellfish beds open	Improving trend
Disease linked to contaminated shellfish	Improving trend
Levels of coliform bacteria	Improving trend
Beach closures	No trend
Floatable Debris	
Floatable debris	No trend
Nutrients and Organic Enrichment	
Nutrient levels and loadings	Mixed trend
Dissolved oxygen	Improving trend
Chlorophyll *a*	No trend
Transparency	No trend
Harmful algal blooms	Improving trend

DIN and total nitrogen levels are monitored to evaluate water quality changes in the New York/New Jersey Harbor. For both nitrogen and phosphorus, loadings have decreased from most sources except STPs (nutrient loads were higher in 1994–1995 than they were in the same subbasins in 1988–1989). Although nutrient levels have fluctuated over time, they are not considered "limiting" elements for phytoplankton growth in this estuarine system. Total nitrogen levels in the mid-1990s were primarily driven by atmospheric sources, STPs, and tributary loadings. Ammonia and nitrate-nitrite concentrations were fairly stable between 1985 and 2000, averaging between 0.2 and 0.5 µg/L in the Inner Harbor, Lower New York Harbor, and Raritan Bay subbasins, with only slightly higher levels and fluctuations of ammonia nitrogen in Jamaica Bay (Steinberg et al., 2004).

Chlorophyll *a* is used as an index of phytoplankton biomass in this system by the NYCDEP and the NJDEP. Excessive phytoplankton conditions are defined based on the abundance and extent of HABs. A HAB index is used to quantify the severity and extent of blooms (5 rating levels) in the Harbor and to characterize the severity of the impact. These monitoring

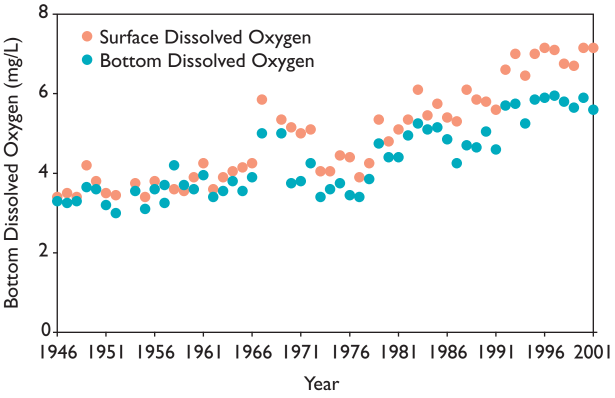

Figure 3-74. Trends in dissolved oxygen levels in surface and bottom waters of the New York/New Jersey Harbor (Steinberg et al., 2004).

agencies correlate water quality and a host of other environmental variables (e.g., temperature, salinity) with chlorophyll *a* levels in the estuary's waters (NY/NJ HEP, 2006). Since 2000, chlorophyll *a* levels have been highest in Jamaica Bay, with some levels measured at more than 50 µg/L (Steinberg et al., 2004). HABs are monitored closely, but are not a formal indicator of water quality in the Harbor. The NYCDEP, NJDEP, IEC, and NPS are all involved in recording HABs in the estuary (NY/NJ HEP, 2006). Most blooms in this system discolor the water and reduce water clarity, with only rare cases of blooms occurring that are severe enough to cause food poisoning in humans. Outbreaks of brown tides have not been observed in New York/New Jersey Harbor (HRF, 2002).

The number of beach closures is another primary indicator of water quality in the HEP study area. New York beaches are monitored by the state's county health departments. The New York City Department of Health and Mental Hygiene (NCY DOHMH) Sanitary Code requires that if there is a potential risk to human health, then bathing beaches should not be open for public use. The NYC DOHMH monitors public and private beaches once a week in Richmond, Kings, Queens, and Bronx counties; county health departments decide on the frequency of monitoring. All of the coastal counties in New York regularly test for total coliform, fecal coliform, and *Enterococci* bacteria and monitor ocean and bay beaches. New Jersey has one of the most comprehensive beach monitoring programs in the country, and some sampling stations are currently monitored for both fecal coliform and *Enterococci* bacteria. New Jersey not only monitors the recreational bathing beaches, but also samples environmental monitoring stations that are not bathing beaches. There were beach closures in the core area of the New York portion of the Harbor in 1988 and 1989 and in the core area of the New Jersey portion the between 1988 and 1991. In the New York portion of the core area, no beach closures occurred between 1990 and 1993. In the New Jersey portion, there were no beach closures due to high bacteria between 1992 and 1993 and no precautionary closures between 1989 and 1993 (Yuhas, 2002a). Figure 3-75 illustrates trends in beach closures over time in the New Jersey portion of the Harbor area.

Concentrations of toxics in New York/New Jersey Harbor sediments and fish tissue are the primary indicators used to evaluate water and sediment quality. An objective of the HEP is to complete characterization of sediment loadings by 2005 and to ensure that suitable reduction targets are achieved by 2009, including a specific goal to reduce sediment hot spots to the point that the levels of toxics in newly deposited sediments do not inhibit a thriving healthy ecosystem or threaten oyster reef habitats. The HEP has also set a guideline that all dredged materials from the estuary will have beneficial uses. By 2009, the HEP hopes to increase the areal extent of Harbor surface sediments below the

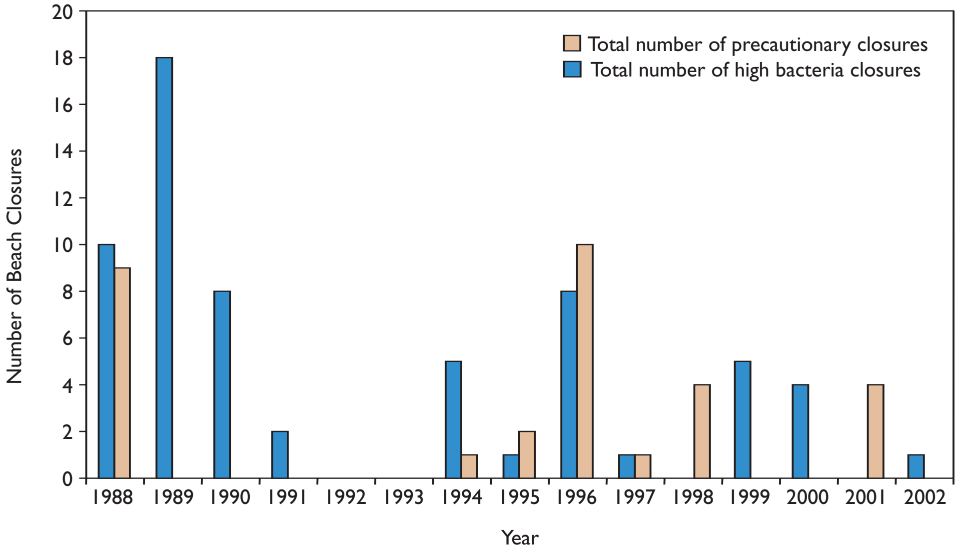

Figure 3-75. Number of beach closures by year at New Jersey beaches located in New York/ New Jersey Harbor (Yuhas, 2002a).

ERM values from the 1993–1994 baseline of 50% to target levels set in 2005 (NY/NJ HEP, 2004). Striped bass are a very popular catch for recreational anglers, and PCB tissue levels in striped bass are an indicator used by the HEP. The HEP has set a target that total PCBs levels in striped bass and other fish shall not exceed the FDA guideline of 2 ppm to protect human health (NY/NJ HEP, 2004). PCB levels recorded in the past have led to closure of the commercial fishery and issuance of fish consumption advisories for striped bass (Steinberg et al., 2004).

Habitat Quality

The acres of wetlands lost or acquired is used to evaluate environmental changes to natural habitat conditions and to track the health of estuary habitat in the New York/New Jersey Harbor. Trends in acreage of various habitat types are monitored over time using aerial photography and GIS technology. Approximately 20,000 acres of tidal wetlands now remain in the Harbor core area of both states (Steinberg et al., 2004). One of the specific targets for habitat improvement is to acquire 2,700 acres of land above the 2001 baseline level by 2009 (NY/NJ HEP, 2004). It is difficult to evaluate the overall function and health of different habitats, other than to study changes in the population sizes of the organisms these habitats support.

About 80% of the tidal wetlands and underwater lands in the Harbor area (300,000 acres) have been altered or destroyed over time, primarily due to filling, dredging, and other human activities. In 1990, an oil spill at Arthur Kill destroyed about 200 acres of salt marsh. New Jersey lost about 2.5% of its wetland acreage statewide between 1984 and 1995. Coastal wetland losses in Jamaica Bay (NY) and Arthur Kill (NJ) have been quite evident, and Little Neck Bay and coastal areas in the southeast Bronx have also suffered substantial losses. Loss of marsh grass islands in Jamaica Bay are some of the most alarming changes reported by the NYCDEP. If losses in this area continue at the present rate, all islands in this subbasin of New York/New Jersey Harbor will be gone by 2024. Habitat loss, dredging, and filling in the Hackensack Meadowlands has affected local populations of osprey, crabs, and juvenile fish, as well as the overall hydrology of this area. About 25% of tidal estuaries in the Hackensack Meadowlands disappeared between 1969 and 1995. In contrast, Newark Bay has exhibited minimal losses in wetland acres during the past 10 years (Steinberg et al., 2004). Table 3-2 shows some of the key trends in habitat loss and species changes over time in the New York/New Jersey Harbor estuarine system.

Table 3-2. Trends in Habitat Quality and Wildlife Indicators Measured by the HEP (Steinberg et al., 2004)

Changes in Habitat Acreage (overall)	**Improving trend**
Wetland acreage	Improving trend
Changes in Newark Bay	Improving trend
Wetlands in Jamaica Bay	Deteriorating trend
Habitat in the Hackensack Meadowlands	Improving trend
Abundance of Wading Birds	**Deteriorating trend**
Abundance of Fish and Crustaceans (overall)	**Mixed trend**
Striped bass	No trend
American shad	Deteriorating trend
Winter flounder	No trend
Summer flounder	No trend
White perch	Deteriorating trend
American eel	Deteriorating trend
Forage fish	No trend
Blue crab	No trend
Benthic Community Health	**Improving trend**
Sediment loading	**Improving trend**

Living Resources

One of the most remarkable characteristics of the New York/New Jersey Harbor is the diverse range of living resources that populate the estuary's waters and coastal wetlands. The HEP, along with the NYSDEC, NJDEP, and other local agencies, is heavily involved in monitoring and assessing the abundance and health of wading birds, fisheries, shellfish populations, and other wildlife. The HEP is currently establishing a list of key plant and animal species that are representative of the biodiversity of the Harbor, and the program is working to set targets for these populations (NY/NJ HEP, 2004).

The HEP study area is home to a variety of finfish and shellfish species, including striped bass, bluefish, freshwater sunfish, sturgeon, shad, winter and summer flounder, white perch, American eel, and a variety of forage fish. In total, more than 100 species live in the Harbor for some or all of their life cycle, and many are commercially important fish stocks. Generally, an index of abundance is used to evaluate population sizes over time. Overfishing, habitat destruction, and contamination by toxics are the major concerns that affect both fish and blue crab populations in the Harbor.

Many environmental groups and locals in the HEP study area consider the striped bass to be one of the enduring symbols of this system. The striped bass population has remained fairly constant during the past two decades, but abundance of other species such as white perch, American eel, and American shad has been declining. Catches of striped bass in Jamaica Bay have been better than in other subbasins of this estuary, but the reasons for this are not clear. The catch per unit effort (CPUE) of American shad has generally declined since the mid-1980s, and other species, such as the alewife and blueback herring, have exhibited similar declines over this same period. Relative abundance and catch of winter flounder has been a concern in some areas, but catch levels have stabilized in Jamaica Bay and Haverstraw Bay since the early 1990s. The abundance of white perch has been declining since the 1980s, which is likely due to water quality conditions in the Harbor because this ecologically important species spends the entire year in this estuary. Three important forage fish monitored in the HEP estuarine area—bay anchovy, Atlantic silverside, and killifish—are also likely affected by changes in salinity, temperature, river flow, and other factors in the Harbor. Blue crabs are harvested in both the New York and New Jersey waters of this estuary, but total landings are much lower than in the Chesapeake Bay system. The benthic community of the New York/New Jersey Harbor is considered impacted, or of degraded quality, as determined by using species index measures and toxicity tests to assess the health of benthic habitats (Steinberg et al., 2004).

Shellfish bed closures and shellfish landings are also monitored in the HEP study area. Shellfish beds are classified using the guidelines of the National Shellfish Sanitation Program. The direct harvesting of shellfish is only permitted in portions of the Navesink and Shrewsbury rivers between November and April. Although direct shellfish harvesting is prohibited in all other portions of the study area, several shellfish beds are designated as "special restricted." In these waters, shellfishers may harvest shellfish and transport them either to a purification plant in a process known as depuration harvesting, or to clean waters approved for shellfishing in a process known as relay harvesting. After purification at the depuration plant or in the clean waters, the shellfish are sent to market. In New York, hard clams are relay harvested in areas of the Great Kills Harbor and Raritan Bay between April and October, and more than 77,000 bushels of hard clams were produced in 2001. These shellfish beds were closed to relay harvest in 2002 due to an outbreak of the shellfish parasite QPX. A limited portion of the beds was reopened for relay harvest in 2005, and approximately 17,600 bushels of hard clams were produced that year (IEC, 2006; Personal communication, Hoffman, 2006). In New Jersey, both relay harvest and depuration programs are active year-round in parts of Raritan Bay, Sandy Hook Bay, Navesink River, and Shrewsburg River. In 2002, 5,425 acres of shellfish beds in the New Jersey portion of Raritan Bay were upgraded from "prohibited" to "special restricted" (Yuhas, 2002b). More than 38.8 million clams were collected through these harvesting programs from Raritan and Sandy Hook bays in 2004 (Personal communication, Celestino, 2006).

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Double-breasted cormorant populations have increased in the New York/New Jersey Harbor (Lee Karney, FWS).

Although there were virtually no wading birds in this estuary in the 1960s, populations of herons, egrets, ibises, and other birds can be seen in New York/New Jersey Harbor today. The abundance of herring gulls declined substantially between 1995 and 2001 (Steinberg et al., 2004). Double-breasted cormorants have increased in population numbers, expanding their nesting area on a number of Harbor islands (Bernick et al., 2005). Populations of black-crowned night heron, yellow-crowned night heron, glossy ibis, snowy egret, and great egret all showed significant population declines between 1997 and 2001; however, the resurgence of ospreys is a good indicator that some areas of the Harbor are cleaner and healthier than in the past (Steinberg et al., 2004).

Environmental Stressors

Floatable trash is another major indicator of water and near-coastal conditions in the HEP study area. The NJDEP's Clean Shores Program, which utilizes prison labor, collected 2,563 tons of floatables and wood in 2000. These efforts addressed about 115 miles of shoreline statewide, with the greatest efforts in the New York/New Jersey Harbor area (Yuhas, 2002a). The HEP has set a goal to decrease floatables discharged from CSOs in New York/New Jersey Harbor to an average of 679 cubic yards of trash by 2009 (NY/NJ HEP, 2004). In 1988, the *Short-term Action Plan for Addressing Floatable Debris in the New York Bight* (U.S. EPA, 1989) was developed by federal and state entities, and the USACE captured 543 tons of material that year, 90% of which was wood. For 2000, the estimated total captured was 5,399 tons of floatable debris. All floatables are transported out-of-state for disposal, and wood is transported to out-of-state recycling facilities. Daily helicopter surveillance fly-overs of the New York/New Jersey Harbor area, the south shore of Long Island, and the New Jersey coastline are conducted by state and federal agencies. The NYCDEP deploys a skimmer boat for daily floatables collection, commissioned via funding from an EPA Marine CSO Construction Grant. During 2000, 320 tons (81% wood) were collected by this vessel. In addition, area volunteer groups and organizations conduct beach and underwater debris cleanups during the spring and fall seasons (Yuhas, 2002a).

Current Projects, Accomplishments, and Future Goals

Some of the major environmental accomplishments of the HEP include the following:

- The successful restoration of habitat in the Arthur Kill area of the New York/New Jersey Harbor following the Exxon *Byway* oil spill in 1990.
- The Rahway River Association's restoration project (1996–2002) resulted in the creation of a new park in Rahway, NJ, the demolition of 11 unoccupied homes, and the restoration of 4 acres of urban land area (Barnes, 2002).
- Vast improvements in the study area's water quality due to the construction of and upgrades to publicly owned treatment works (POTWs) (Steinberg et al., 2004).

Conclusion

The overall condition of New York/New Jersey Harbor is rated poor based on the four indices of estuarine condition used by the NCA. The HEP has found that, although some measures of estuarine health in the study area have demonstrated improvements over time (including increases in dissolved oxygen levels and reductions in nutrient loadings), other trends, such as ongoing fish consumption advisories and declines in some fish and wading bird populations, have not been as positive. The inadequate availability of data is still a significant barrier to properly interpreting indicators in this estuary system. Some indicators that were once used are no longer monitored, and some data gaps and inconsistencies exist among available spatial and temporal monitoring data for this estuary. Comprehensive monitoring of water quality on the New York side of the Harbor has produced data for nearly 100 years. The NJDEP has an excellent system for reporting closures and beach conditions over time; however, the collection of comprehensive water quality data on the New Jersey side of the Harbor has occurred only recently. Citizens, regulators, and scientists must continue to work together to realize the HEP's vision to maintain a healthy and productive Harbor ecosystem with full beneficial uses.

Barnegat Bay National Estuary Program

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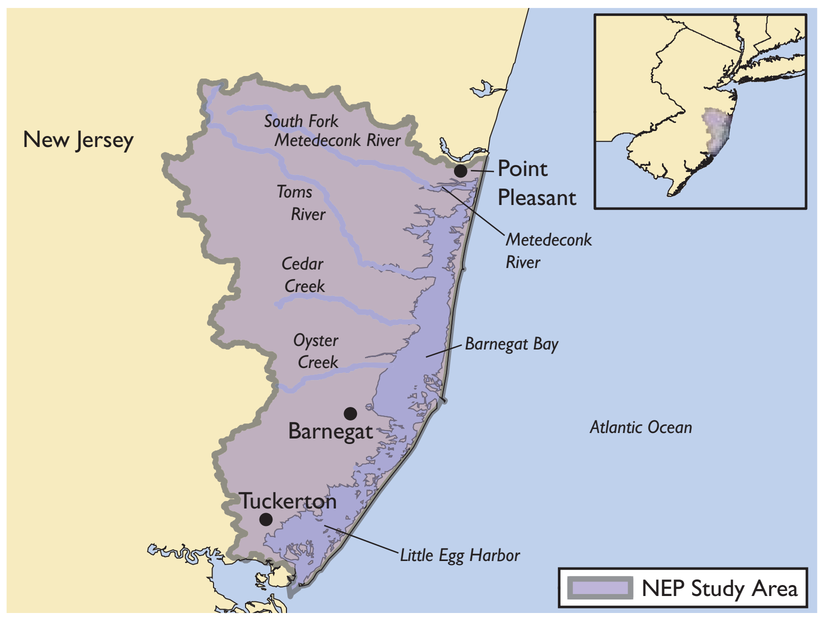


Barnegat Bay Estuary Program

www.bbep.org

Background

Barnegat Bay in New Jersey covers more than 42 miles of shoreline, from Point Pleasant Canal to Little Egg Harbor Inlet, and stretches over all of Ocean and parts of Monmouth counties (BBNEP, 2005a). Habitats found within the Barnegat Bay watershed vary from coastal dunes and marshes (much of these areas have been heavily developed) to the New Jersey pine barrens—a distinctive pine forest characterized by sandy soils and fire-adapted plant species, such as pitch pine, and protected from extensive development. Barnegat Bay is protected from the open ocean by a system of barrier island dunes. The Bay itself is very shallow, with a relatively small amount of fresh water flowing from tributaries and a limited connection to the ocean. Groundwater is the source of most of the freshwater input to the estuary (BBNEP, 2003), with additional freshwater input coming from several major tributary rivers, including the Metedeconk and Toms rivers, as well as the Cedar and Oyster creeks.

EPA designated Barnegat Bay an Estuary of National Significance on July 10, 1995 (BBNEP, 2002). Although long recognized for its great aesthetic, economic, and recreational value, the Bay is now affected by an array of human impacts that potentially threaten its ecological integrity. More than 500,000 people live within the 660-mi^2 area of the Barnegat Bay watershed, and the area's population more than doubles during the summer season. In the last half-century, the Barnegat Bay area has undergone dramatic development due to increasing population growth, with land uses changing from principally undeveloped and agricultural land to residential development (BBNEP, 2002). To help protect and preserve the ecological integrity of this estuary, the Barnegat Bay National Estuary Program (BBNEP) has instituted public participation efforts with citizens and other watershed stakeholders who live, work, and recreate in the Bay area.

Environmental Concerns

During the 1990s, the municipalities surrounding Barnegat Bay reported population growth that exceeded 20% per year on average (BBNEP, 2002). The development that accompanied this increased population growth has resulted in significant land-use changes. Boat traffic in Barnegat Bay has also grown, raising concerns about general use conflicts and impacts on the Bay's water quality. Since its inception in 1995, the BBNEP has focused on several of the area's environmental concerns, including the following:

- Non-point source pollution and water quality degradation
- Habitat loss and alteration
- Human activities and competing uses
- Water supply protection.

Population Pressures

The population of the 3 NOAA-designated coastal counties (Burlington, Monmouth, and Ocean) coincident with the BBNEP study area increased by 132% during a 40-year period, from 0.67 million people in 1960 to almost 1.55 million people in 2000 (Figure 3-76) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the BBNEP study area is more than five times the population growth rate of 24% for the collective NEP-coincident coastal counties of the Northeast Coast region. In 2000, the population density of the BBNEP's 3 coastal counties was 807 persons/mi^2, slightly lower than the population density of 1,055 persons/mi^2 for the collective NEP-coincident coastal counties of the Northeast Coast region (U.S. Census Bureau, 2001).

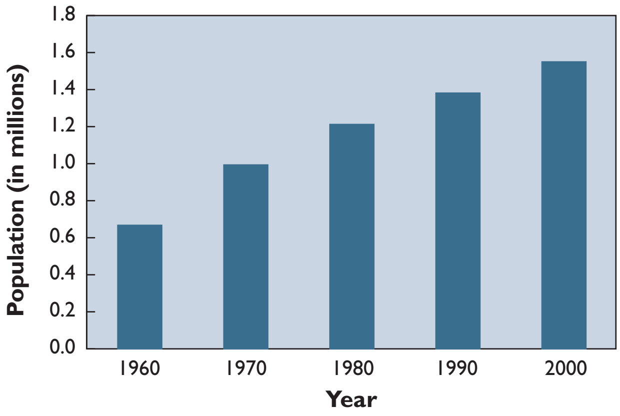


Figure 3-76. Population of NOAA-designated coastal counties of the BBNEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Barnegat Bay

The overall condition of Barnegat Bay is rated fair based on the four indices of estuarine condition used by the NCA (Figure 3-77). The water quality and sediment quality indices for Barnegat Bay are rated good to fair, and the benthic and fish tissue contaminants indices are rated fair. Figure 3-78 provides a summary of the percentage of estuarine area rated good, fair, poor, or missing for each parameter considered. This assessment is based on data from 30 NCA sites sampled in the BBNEP estuarine area in 2000 and 2001. Please refer to Tables 1-24, 1-25, and 1-26 (Chapter 1) for a summary of the criteria used to develop the rating for each index and component indicator.

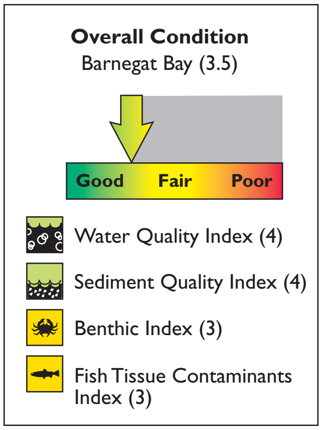


Figure 3-77. The overall condition of the BBNEP estuarine area is fair (U.S. EPA/NCA).

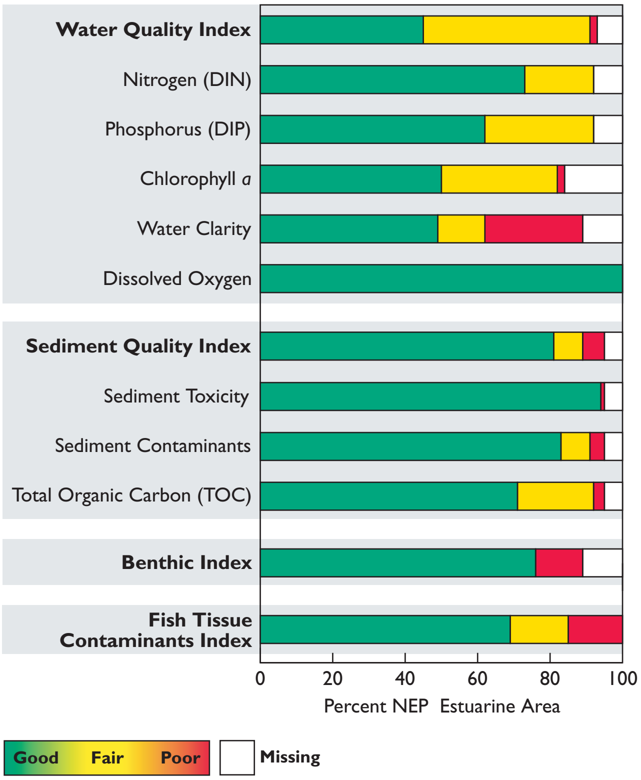


Figure 3-78. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Barnegat Bay (U.S. EPA/NCA).

Water Quality Index

The water quality index for Barnegat Bay is rated good to fair. This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen (Figure 3-79). Elevated DIN and DIP concentrations measured in Barnegat Bay covered one of the smallest extents of all Northeast NEP estuaries, and chlorophyll *a* concentrations were moderately high in about a third of the Bay. Water clarity was fair or poor in 40% of the Bay, in accordance with the observation that water in the southern estuaries of the Northeast Coast region is noticeably less clear than in estuaries farther north. All Barnegat Bay stations reported satisfactory dissolved oxygen levels.

Dissolved Nitrogen and Phosphorus | Barnegat Bay is rated good for DIN concentrations, with 73% of the estuarine area rated good for this component indicator, 19% of the area rated fair, and none of area rated poor. NCA data on DIN concentrations were unavailable for 8% of the BBNEP estuarine area.

Barnegat Bay is also rated good for DIP concentrations, with 62% of the area rated good, 30% of the area rated fair, and none of the estuarine area rated poor. NCA data on DIP concentrations were unavailable for 8% of the BBNEP estuarine area.

Chlorophyll a | Barnegat Bay is rated good for chlorophyll *a* concentrations. Fifty percent of the estuarine area was rated good for this component indicator, 32% of the area was rated fair, and 2% of the area was rated poor. NCA data on chlorophyll *a* concentrations were unavailable for 16% of the BBNEP estuarine area.

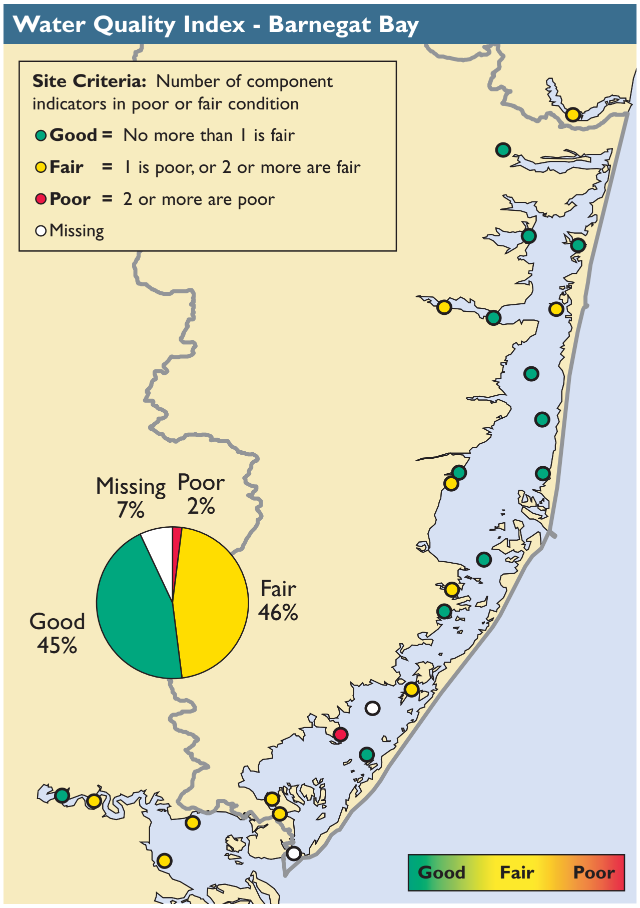


Figure 3-79. Water quality index data for Barnegat Bay, 2000–2001 (U.S. EPA/NCA).

Water Clarity | The water clarity rating for Barnegat Bay is poor. Water clarity was rated poor at a sampling site if light penetration at 1 meter was less than 10% of surface illumination. Twenty-seven percent of the estuarine area was rated poor for this component indicator, 49% of the area was rated good, and 13% of the area was rated fair. NCA data on water clarity were unavailable for 11% of the BBNEP estuarine area.

Dissolved Oxygen | Barnegat Bay is rated good for dissolved oxygen concentrations, with 100% of the estuarine area rated good for this component indicator.

Sediment Quality Index

The sediment quality index for Barnegat Bay is rated good to fair. Fourteen percent of the estuarine area was classified as having fair or poor sediment quality, primarily in the Bay's tributaries (Figure 3-80). Toxic sediments were detected at only one site in Barnegat Bay, and relatively little sediment contamination was noted (fair or poor in 12% of the Bay's estuarine area), a finding typical of the southernmost estuaries of the Northeast Coast region. TOC levels were elevated in about a quarter of the Bay's estuarine area.

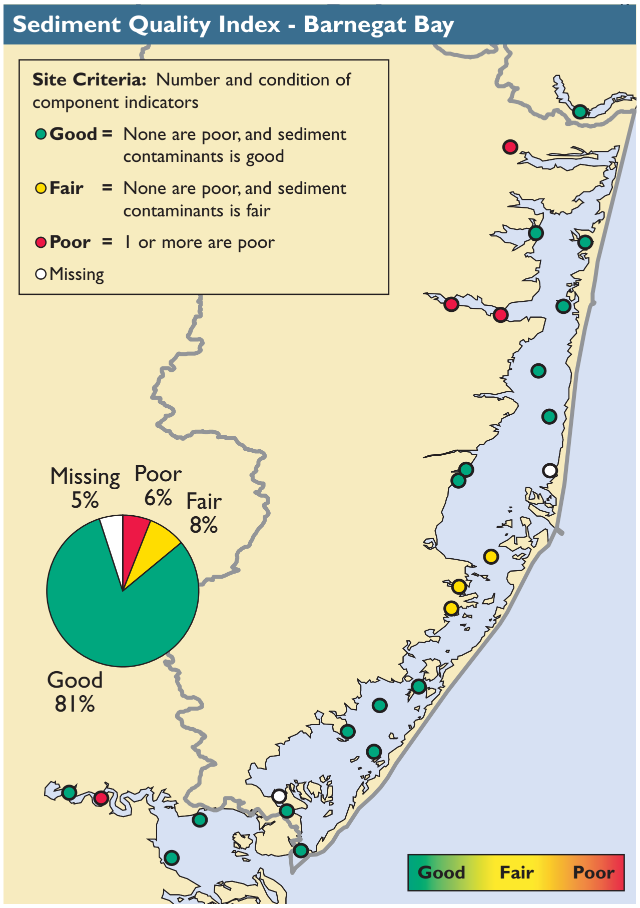

Sediment Quality Index - Barnegat Bay

Figure 3-80. Sediment quality index data for Barnegat Bay, 2000–2001 (U.S. EPA/NCA).

Sediment Toxicity | Barnegat Bay is rated good for sediment toxicity, with only 1% of the estuarine area rated poor for this component indicator. NCA data on sediment toxicity were unavailable for 5% of the BBNEP estuarine area.

Sediment Contaminants | Barnegat Bay is rated good for sediment contaminant concentrations. Only 4% of the estuarine area was rated poor for this component indicator, and an additional 8% of the area was rated fair.

Total Organic Carbon | Barnegat Bay is rated good for sediment TOC. Seventy-one percent of the estuarine area was rated good for TOC concentrations, and 21% of the area was rated fair. Only 3% of the estuarine area was rated poor for this component indicator, and NCA data on TOC concentrations were unavailable for 5% of the BBNEP estuarine area.

Headwaters of the Toms River (BBNEP).

Benthic Index

Benthic condition in Barnegat Bay is rated fair, as evaluated by the Virginian Province Benthic Index. Four sites (13%) in Barnegat Bay merited a poor rating for benthic condition; two of these sites also reported sediment contamination (Figure 3-81).

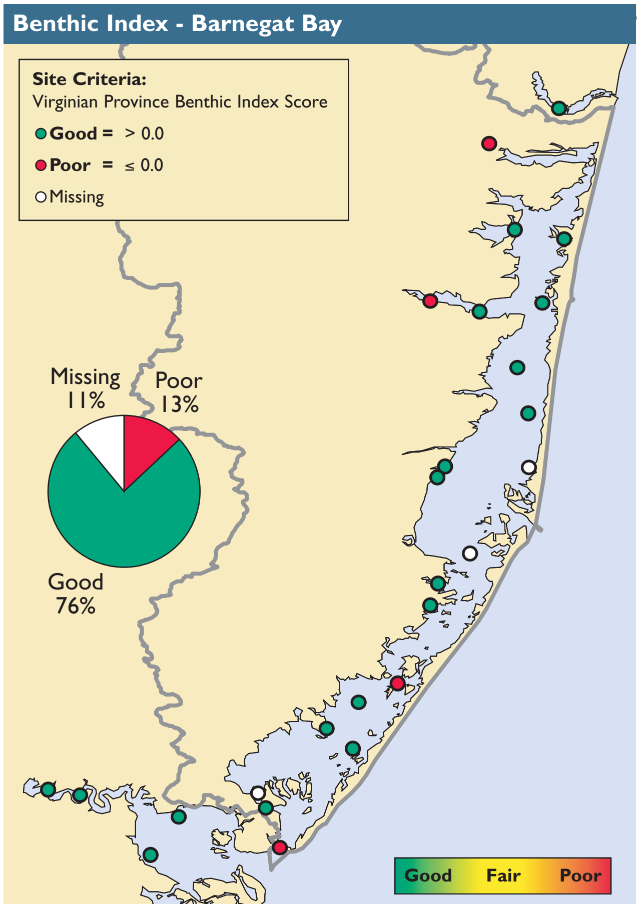


Figure 3-81. Benthic index data for Barnegat Bay, 2000–2001 (U.S. EPA/NCA).

Fish Tissue Contaminants Index

Thirteen fish samples were analyzed for chemical contaminants in Barnegat Bay, and 31% of samples were found to have elevated concentrations of mercury, the pesticide dieldrin, or PCBs (Figure 3-82); therefore, the fish tissue contaminants index for Barnegat Bay is rated fair.

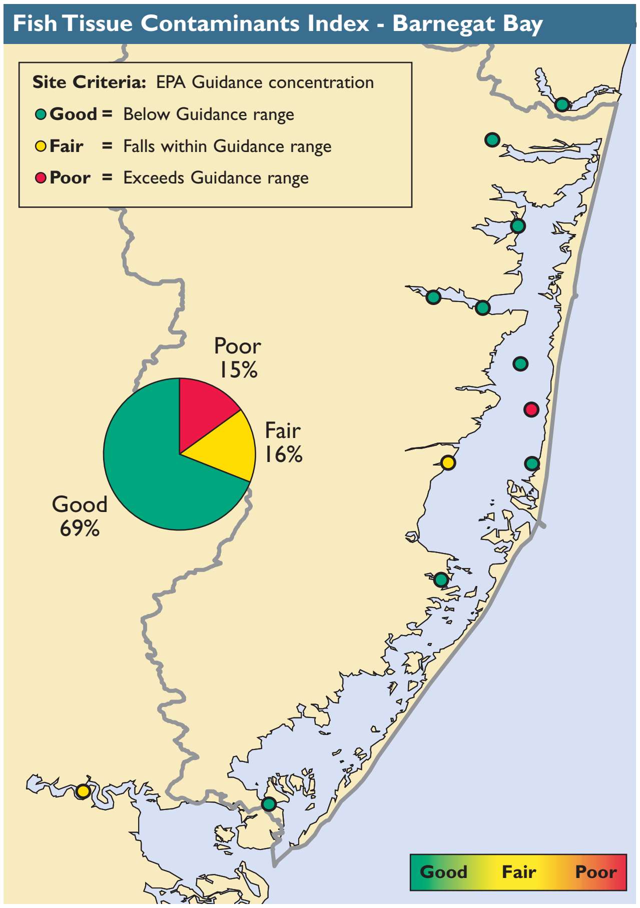


Figure 3-82. Fish tissue contaminants index data for Barnegat Bay, 2000–2001 (U.S. EPA/NCA).

Barnegat Bay National Estuary Program Indicators of Estuarine Condition

The BBNEP uses several primary indicators to evaluate environmental conditions and stressors in the Bay's estuarine area, including land-use changes; SAV distribution, abundance, and health; signature species; shellfish beds; and HABs. The BBNEP's indicators were selected based on their public acceptability, availability of historic data, and relevance to the goals set forth in the program's *Comprehensive Conservation and Management Plan* (BBNEP, 2002). Several additional indicators are used by the NJDEP, Rutgers University Institute of Marine Science, and USGS in the overall monitoring of this estuarine system (BBNEP, 2003). Based on all of these indicators, several waterbodies in the BBNEP estaurine area have been identified as impaired (Table 3-3).

More than 20 secondary indicators are also used internally by the BBNEP to help evaluate environmental changes in the Bay; however, most of these secondary indicators are considered less appropriate than the primary indicators for conveying environmental concerns to the public. A variety of secondary indicators are used for evaluating living resources; environmental stressors; and water, sediment, and habitat quality in the study area. For example, some of the secondary indicators used for water quality include dissolved oxygen, nutrient levels, salinity, turbidity, water temperature, pH, and saltwater intrusion. The program also uses measured levels of toxic contaminants in sediments to assess sediment quality in the Bay (BBNEP, 2003). Data gaps exist for many of these indicators regarding both spatial and temporal information (BBNEP, 2003). Secondary indicators for evaluating water quality, habitat, or living resources in the Bay have been approved for use by any of the BBNEP's state partners or other local agencies involved in managing the estuary system.

Table 3-3. Waterbodies Assessed as Impaired Based on the Indicators Used by the BBNEP and Partners (BBNEP, 2003)

Waterbody Name	Reach # / Location	Pollution/Impact: Water Quality Violation	Pollutant/ Biological Impact	Use Impairment
Metedeconk River Estuary		Fecal coliform		Shellfish consumption
Lake Carasaljo	Lakewood, Ocean County		Mercury in fish tissue	Fish consumption
Pohatcong/ Tukerton Lake	Ocean County	Elevated bacteria, phosphorus, sedimentation Current source: Non-point sources, including suspended solids from surrounding urban areas and bacteria and phosphorus from surrounding septic systems	Heavy macrophyte growth	Boating and fishing
Manahawkin Lake		Elevated bacteria, phosphorus Current source: Resident goose and gull populations. Former source: Surrounding septic systems, most of which have been eliminated through sewering	Localized heavy macrophyte growth	Primary contact: Recreation Some boating and fishing impairment
Toms River Estuary	02040301-018-022	Fecal coliform		Shellfish consumption
Toms River	02040301-018-080/ nr Toms River	pH, fecal coliform		Primary contact: Aquatic life support
Barnegat Bay	Portion adjacent to Toms River	Fecal coliform		Shellfish consumption

SAV Distribution, Abundance, and Health in Barnegat Bay

SAV, such as seagrass, is a key indicator of the environmental health of the Barnegat Bay-Little Egg Harbor Estuary. Seagrass beds are important in maintaining the energy flow and nutrients cycling of the estuary and serve as part of the estuarine food chain. For these reasons, seagrasses rank among the most sensitive indicators of long-term water quality and can be used as a sentinel of coastal ecosystem health (Dennison et al., 1993). Seagrass beds provide a critical structural component in an otherwise barren sandy bottom, serving as essential habitat for a host of organisms, including mollusks, crabs, worms, fish, and waterfowl.

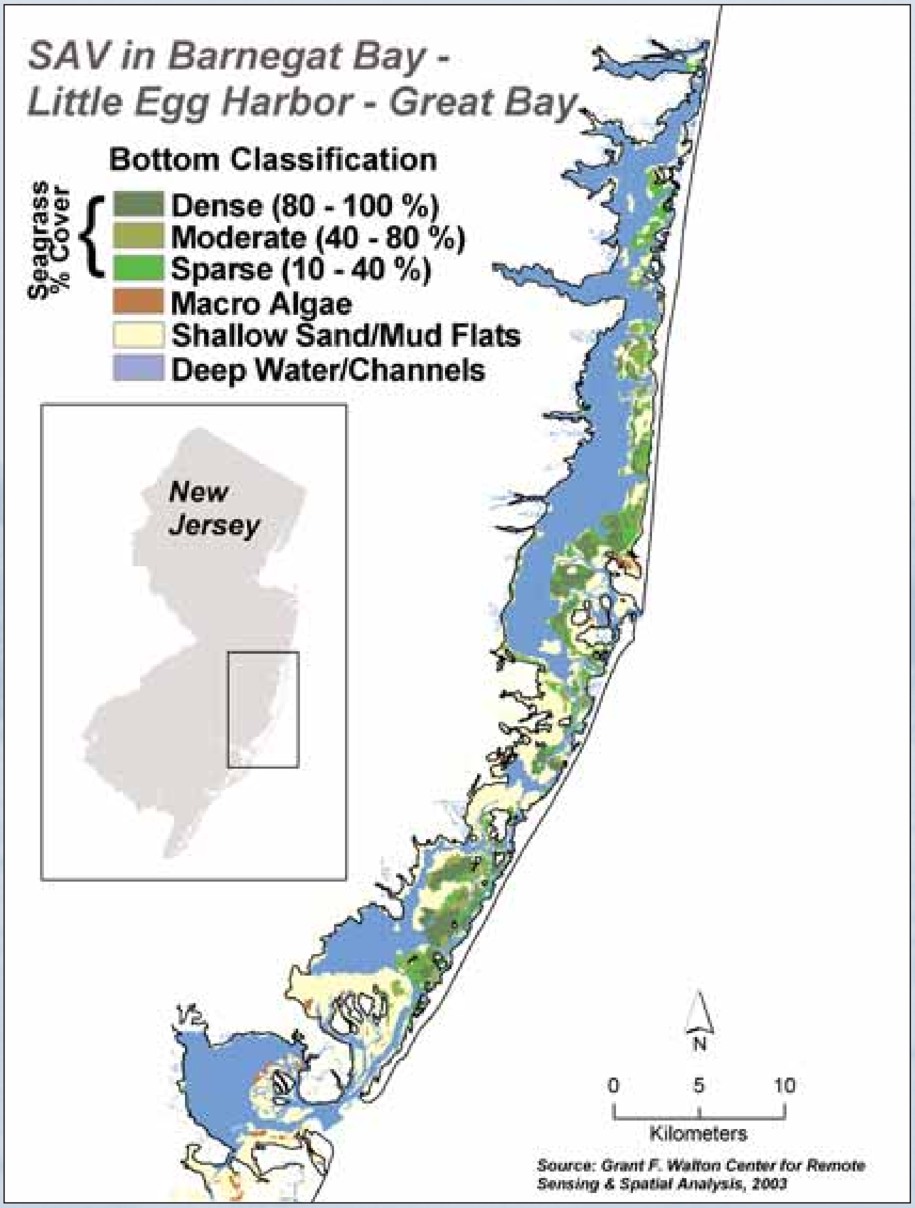
In recent years, seagrasses have suffered due to declining water quality; physical damage from dredging and resulting sedimentation; and the occurrence of brown tides, benthic algal infestations, boat scarring, and disease. To remain healthy, seagrasses are dependent on comparatively clear waters. As Barnegat Bay waters become more turbid due to HABs and suspended sediment, the light levels needed to sustain photosynthesis and seagrass productivity decrease. Nutrient enrichment of the Bay's waters, whether from runoff, atmospheric deposition, or boat wastes, promotes HABs and infestations of some types of algae that coat the seagrass blades and threaten the longevity of the seagrass beds.

During the past 30 years, significant declines in SAV have occurred in New Jersey estuaries (Lathrop and Bognar, 2001), resulting in the reduction of essential fish habitat and the potential loss of important commercial and recreational species. In addition, nutrient enrichment has caused blooms of phytoplankton and benthic macroalgae. Dinoflagellate and brown-tide blooms can reduce light availability; adversely affect SAV such as eelgrass (*Zostera marina*) (Dennison et al., 1989); and cause negative impacts on other living resources (Bricelj and Lonsdale, 1997). Brown-tide blooms are now a recurring phenomenon in the coastal bays of New Jersey, New York, and Maryland. In response to shading stress, it appears that eelgrass may also be susceptible to infection by "wasting disease" (*Labyrinthula zosterae*) (Bologna and Gastrich, unpublished data). This disease, which decimated eelgrass beds worldwide during the 1930s (den Hartog, 1987), may signal a significant decline in water quality. Aside from the impacts of wasting disease on eelgrass, large-scale losses of SAV habitat can occur due to the additional physiological stress associated with HABs.

Status and Trends

Investigators led by Dr. Richard G. Lathrop at the Grant F. Walton Center for Remote Sensing and Spatial Analysis (CRSSA) at Rutgers University and the Jacques Cousteau NERR are monitoring SAV beds in the Barnegat Bay-Little Egg Harbor Estuary. During 2003, these researchers conducted an extensive SAV mapping project to better understand the present status of the estuary's seagrass habitats. This project was conducted using advanced digital images shot from an aircraft-mounted camera flown along the entire length of the estuary. Color imagery was used in the spring (May 4 and 5, 2003), before Bay waters became too turbid, thereby enabling the researchers to visualize the Bay bottom and determine the location and extent of the seagrass beds. The aerial imaging was complemented by boat-based surveys in the Bay to determine species type (e.g., eelgrass, widgeon grass [*Ruppia maritima*]), percent coverage, blade height, and sediment type. Using these advanced computer-aided interpretation techniques, researchers were able to map precisely the location, areal extent, and percent coverage of the seagrass beds in great detail. The resulting maps documented 12,804 acres of seagrass beds in the Barnegat Bay-Little Egg Harbor Estuary (see map) (Lathrop, 2004).

SAV distribution in the Barnegat Bay-Little Egg Harbor Estuary appears to have remained reasonably stable when compared with the maps of the period from 1990–2000. This stability is a positive outcome considering the continued development of the watershed, as well as the severe brown-tide occurrences that were prevalent in the Bay during 2001 and 2002. However, the condition of the indicator appears to have changed substantially from previous years. Since 1968, for example, periodic mapping surveys in the Barnegat Bay-Little Egg Harbor Estuary indicated significant shifts in seagrass distribution. In particular, earlier surveys showed evidence of a decline in the seagrass extent between the late 1970s and the mid-1990s, especially in the northern areas of the Bay. Boat-based surveys conducted between 1996 and 1999 mapped 15,025 acres of seagrass. A decline of approximately 2,220 acres, or 15% of seagrass beds, appears to have occurred between the late 1990s and 2003 maps. Rather than representing a significant decline in seagrass, the difference in acreage is most likely due to a change in mapping techniques and the timing of the aerial imagery acquisition (Lathrop, 2004).


SAV in Barnegat Bay - Little Egg Harbor - Great Bay

Source: Grant F. Walton Center for Remote Sensing & Spatial Analysis, 2003

SAV coverage in Barnegat Bay and Little Egg Harbor (Grant F. Walton CRSSA).

Water and Sediment Quality

The following four primary indicators help the BBNEP measure water and sediment quality in Barnegat Bay:

- Number (and duration) of bathing beach closures
- Acres of shellfish beds open/closed
- Presence of HABs (e.g., acres of coverage)
- Freshwater inputs to the Bay (e.g., changes in stream flow, water allocation).

The number and duration of beach closures in the BBNEP study area is an indicator of water quality and is measured to help determine if bathing areas are safe for public use. The NJDEP helps report on levels of fecal coliform bacteria recorded in water samples and evaluates swimming conditions in the waters of Barnegat Bay. New Jersey's surface water quality standards in for recreational contact with estuarine waters specify that fecal coliform levels should be below a mean of 50/100 mL within 1,500 feet of the shoreline. From 1988 to 1998, 834 beach closings were registered in the estuary as a result of elevated fecal coliform counts in water samples (BBNEP, 2002). Fecal coliform bacteria data collected by the USGS/NJDEP water quality network have shown an improvement in the Toms River area between 1988 and 1992 (BBNEP, 2001).

The number of acres of shellfish beds that are open or closed for harvesting is also a good indicator of pathogen levels in the Bay. Bacterial standards for shellfish harvesting are set by the Interstate Shellfish Sanitation Conference. New Jersey uses fecal coliform measures to determine the areas of Barnegat Bay that are safe for shellfishing and the areas that are of potential risk to public health. The general trend in the BBNEP study area during the past 30 years has been toward fewer restrictions on shellfish harvesting. The largest areas of shellfish-harvesting restriction occur in the tributaries of Barnegat Bay, from Toms River northward, and along the barrier island in the same portion of the Bay. The harvesting of shellfish from all man-made lagoons and marinas is also prohibited (BBNEP, 2001).

The presence and growth of HABs is another indicator of water quality in the BBNEP system. Brown tides caused by a toxic dinoflagellate (*Aureococcus anaphagefferens*) have had severe effects on eelgrass beds, and the damage associated with these blooms has occurred with increasing frequency. Brown tides may also reduce local fishing, swimming, and boating activities in the estuary. HABs are monitored for frequency of occurrence, area/extent, and intensity, and the abundance and species composition of HABs provides information about changing water quality conditions (BBNEP, 2003). Educational information about the effects of these blooms has been made available to the public through local newspapers and outreach materials from the Rutgers University Cooperative Extension.

Freshwater inputs to Barnegat Bay are monitored closely as another primary indicator of water quality and environmental stress. The *New Jersey Statewide Water Supply Master Plan* (NJDEP, 1996) identifies the Barnegat Bay watershed as an area that will experience a significant water supply deficit by the year 2040. Despite this prediction, withdrawal of potable water for this area is almost completely consumptive because most wastewater is discharged to the ocean. These actions result in saltwater intrusion and reduced stream flow. Modifications to the Barnegat Bay landscape also change the natural hydrology by reducing recharge and increasing runoff. Monitoring surface water discharge is the most cost-effective means to monitor freshwater inputs (BBNEP, 2003). The USGS measures short- and long-term changes in base flow and water consumption in the northern part of the Bay, but continuous gauging is not available in the southern part of this system.

Osprey nest at Island Beach State Park, Seaside Park, NJ (BBNEP).

Habitat Quality

The following two measures are primary indicators used by BBNEP to evaluate habitat loss and/or changes in quality of land in the watershed:

- SAV distribution and abundance (acres)
- Land-use change (acres).

Land-use change in the Barnegat Bay watershed is a major indicator used to evaluate environmental changes to this ecosystem. The developed area of the Bay watershed increased from 18% in 1972 to 28% in 1995 (BBNEP, 2002). With more than 70% of the Barnegat Bay shoreline already developed, the remaining undeveloped shoreline areas are especially valuable as open space (BBNEP, 2003).

The BBNEP monitors shoreline habitats, island nesting habitats, and other sensitive areas as secondary indicators of habitat quality (BBNEP, 2003). Salt marshes are one of these sensitive habitats. Roughly 90% percent of Barnegat Bay's salt marshes are protected by some form of public conservation ownership (e.g., national wildlife refuge, state game management area, state/local park, or private conservation trust) (BBNEP, 2001). A variety of shorebirds and colonial nesting birds, such as common terns (*Sterna hirundo*), black skimmers (*Rhynchops niger*), and Forster's terns (*Sterna forsteri*), nest almost exclusively on salt marsh or dredge spoil islands for protection from mammalian predators. Sixty-one Barnegat Bay islands have been ranked for their importance as nesting habitat for common terns, black skimmers, and Forster's terns, based on data collected from the mid-1970s to the present (BBNEP, 2003). Other critical wildlife habitat areas that should receive special consideration are coastal dune scrub/shrub and large areas of cultivation/grassland. Dune grass and shrub vegetation serve a useful role in stabilizing dunes and protecting beaches against wind and wave erosion. Extensive remnants of these habitats exist at Island Beach State Park and at the Holgate section of Forsythe National Wildlife Refuge. The dune scrub/shrub and woodland communities of the barrier islands fronting Barnegat Bay have largely been destroyed or substantially altered (BBNEP, 2002).

Living Resources

The BBNEP uses several signature species as primary indicators of the living resources in the Bay. These species include the following:

- Hard clams
- Colonial nesting waterbirds
- Osprey.

The hard clam (*Mercenaria mercenaria*) is an important commercial and recreational fishery species that lives in the fine-grained sediments and SAV beds of the Bay. Hard clams are a good indicator of estuarine health because they are long-lived and have a wide distribution throughout the Bay (BBNEP, 2003). Hard clam populations have decreased over time (BBNEP, 2002), with the amount of hard clams harvested in Barnegat Bay falling from about 820,000 pounds to approximately 65,000 pounds between 1989 and 1997 (BBNEP, 2001).

Barnegat Bay provides nesting habitat for 20 species of colonial waterbirds, including 10 species of long-legged wading birds, 6 species of terns, 3 species of gulls, black skimmers, and piping plover. These birds are good indicators of the living resources in the Bay because they have high sensitivities to chemical contaminants, human disturbance, the availability of resources, and the overall quality of the available habitat. Since 1985, the NJDEP has conducted ground and aerial surveys to assess the abundance of these birds. These surveys have indicated that some species have experienced population decreases due to habitat loss, human disturbance, and predation (BBNEP, 2003).

The NJDEP conducts an annual census of the osprey population in the Bay to record the number of nesting pairs and fledglings success (BBNEP, 2003). Statewide, the number of ospreys increased between 1975 and 1998, from 50 to more than 250 nests. Although specific data for Barnegat Bay are unavailable, the Bay has historically been an important nesting area for this species. Osprey populations in the region are limited by available nesting habitat, predation, exposure to toxics, and human disturbance (BBNEP, 2001).

The BBNEP also uses several secondary indicators to assess living resources, including the abundance of shellfish and finfish, the composition and abundance of benthic communities, and the presence of rare plant and animal populations (BBNEP, 2003).

Environmental Stressors

Several of the BBNEP's secondary indicators can be used to evaluate the impact of human activities in the estuary. These indicators include the following:

- Amount and type of floatable debris
- Number of registered boats.

For example, boating is a popular activity in the study area. A variety of different watercraft support 182 marinas in the Barnegat Bay watershed (BBNEP, 2002). Between 1979 and 1988, the estimated number of boats in the Bay increased from 30,000 to 53,200 (BBNEP, 2001).

Current Projects, Accomplishments, and Future Goals

Some of the recent environmental success stories achieved in the Barnegat Bay system include the following:

- On June 6, 2003, EPA announced the establishment of a No-Discharge Zone in Barnegat Bay. This designation prohibits boats from releasing treated or untreated sewage into the Bay. Roughly 75 marinas in Ocean County maintain land-based pump-out stations to further reduce illegal discharges of sewage (Ocean County Department of Planning, 2006).
- In 2004, the BBNEP, in partnership with the Jacques Cousteau NERR, implemented a multi-tiered public education approach aligned with the NJDEP's Phase II Municipal Stormwater Permitting Program. A steering committee of interested county, academic, and local educational organizations was formed to provide outreach and assistance to the 37 municipalities within the Bay's watershed on new Phase II stormwater regulations. Examples of the committee's services include workshops, technical assistance, public outreach assistance, and stormwater resources. In addition, the BBNEP developed and implemented six Phase II Municipal Stormwater Roundtables in 2005 to help the municipalities achieve compliance with the new state regulations. The Ocean County Department of Planning also supplied matching funds to assist municipalities with the development of their EPA-required Stormwater Pollution Prevention Plans.
- The BBNEP and the Ocean County Department of Planning funded the purchase of dune grass for a restoration project on Island Beach State Park, where the BBNEP contributed more than 15,000 plants (Lynch, 2003).
- Between October 2003 and September 2005, more than 3,200 acres of habitat in the Bay's watershed were preserved by state, county, and municipal agencies (BBNEP, 2005b).
- The BBNEP and its partner, the Rutgers University Institute of Marine and Coastal Science, have recently completed a demographic investigation of SAV in Barnegat Bay. This investigation included an assessment of the potential impacts of benthic macroalgae and brown tides. The BBNEP has also partnered with Montclair State University to assess the effects of harmful macroalgal blooms on the Bay's SAV.
- The BBNEP, in partnership with Rutgers University, USGS, and the NJDEP, has established two

Mobile pump-out stations, such as the boat shown here, help reduce sewage discharges to Barnegat Bay (BBNEP).

water quality monitoring stations and data loggers in the Bay to record and deliver real-time data to an NJDEP Web site. These data loggers monitor some of the BBNEP's secondary indicators, such as turbidity, salinity, and dissolved oxygen (NJDEP, 2006). The BBNEP and other partner agencies plan to deploy several more data loggers at additional sites in the near future.

- The Ocean County Soil Conservation District is working in the Barnegat Bay watershed to increase groundwater recharge in developed areas by establishing Rain Garden Basins and repairing poorly constructed retention basins. In addition, the District is working to establish outdoor classrooms and rain gardens at schools throughout the watershed. Four outdoor classrooms were established in 2005, and the District has a goal to establish 50 classrooms in Ocean County by the year 2009 (BBNEP, 2005c).
- The Rutgers Cooperative Research and Extension of Ocean County has partnered with the BBNEP and Ocean County to educate citizens about the Bay, its watersheds, and human impacts on the estuary by using hard clams and oysters as living representatives of the Bay's ecosystem. The group is also working with volunteers to seed and grow hard clams in the Bay.

Conclusion

The overall condition of Barnegat Bay is rated fair based on the four indices of estuarine condition used by the NCA survey. Non-point source pollution/water quality degradation, habitat loss and alteration, human activities and competing uses, and water supply protection remain the most critical environmental concerns in Barnegat Bay. The apparent decline in SAV beds is a cause for concern and warrants further investigation. Some causes of habitat loss/fragmentation and the decline of fish and wildlife species in the BBNEP study area are not well understood. Similarly, although there is a clear indication that human development has led to declining water quality (associated with non-point source pollution), quantifying this impact on water quality and aquatic habitats in the estuary is more difficult. More research is warranted on the relationship between habitat loss and alteration in the estuary watershed and the impacts on nesting birds and other wildlife in the ecosystem.

Barnegat Lighthouse, Long Beach Island, NJ (BBNEP).

Partnership for the Delaware Estuary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Background

The Delaware Estuary stretches from the falls at Trenton, NJ, and Morrisville, PA, south to the mouth of the Delaware Bay between Cape May, NJ, and Cape Henlopen, DE. In addition to its remarkable natural habitats, the Delaware Estuary has one of the world's highest concentrations of heavy industry and maintains the world's largest freshwater port, which is also regarded as a strategic military port (DRBC, 2005; PDE, 2005). The port is home to the second-largest refining-petrochemical center in the United States, providing 70% of gasoline and heating oil for the entire East Coast (Martin et al., 1996). The NEP study area for the Estuary covers roughly 6,747 mi^2 of land that drains into 134 miles of the Delaware River and Bay. The study area is part of the larger Delaware River Basin, which is 13,539 mi^2 and drains parts of Pennsylvania (50.3%), New Jersey (23.3%), New York (18.5%), and Delaware (7.9%) (PDE, 2002b).

Primary freshwater inflows to the Delaware Estuary are from the Delaware and Schuylkill rivers (Sutton et al., 1996). The water budget for the basin includes numerous human uses, including public water supply, power generation, and other industrial needs. For example, the Delaware River Basin provides a source of drinking water for more than 15 million people (2000 estimate), and New York City uses up to 800 million gallons per day from the upper Delaware River for its drinking water (Martin et al., 1996; DRBC, 2005).

More than 200 migrant and resident finfish and shellfish species use the Delaware Estuary for feeding, spawning, or nursery grounds. These species include sharks, skates, blue crab, striped bass, shad, sturgeon, American eel, blueback herring, Atlantic menhaden, alewife, bluefish, weakfish, and flounder. Oysters and blue crabs represent important shellfish resources in this system. The Estuary is also home to the largest population of horseshoe crabs in the world and is an important link in the migratory path of a wide variety of shorebirds and waterfowl (Dove and Nyman, 1995). Natural habitats in this watershed include tidal salt marshes, tidal freshwater marshes, intertidal mudflats, oyster reefs, beaches, inland wetlands, and upland meadows and forests. Of particular note are the extensive tidal wetlands that fringe much of the margin of the Estuary. Historically, the Estuary's wetland habitats provided critical habitat for many of the region's threatened and endangered species. Today, these habitats are still believed to play a fundamental role in sustaining the ecology and helping to maintain water quality for the overall estuarine system (Kreeger et al., 2006).

The Partnership for the Delaware Estuary (PDE) oversees the NEP for the Delaware Estuary. The PDE was established in 1996 and is currently implementing its CCMP, *The Delaware Estuary–Discover its Secrets: A Management Plan for the Delaware Estuary* (Delaware Estuary Program, 1996). The PDE is the only tri-state NEP, and its principal partners include the States of Delaware and New Jersey; the Commonwealth of Pennsylvania; the Delaware River Basin Commission (DRBC); and the City of Philadelphia. Various key federal, state, and local agencies; non-profit organizations; the private sector; and citizens' groups also continue to play a critical role. Through the collective efforts and coordinated authorities of its participants, the PDE continues to strive for success in its role to implement the CCMP and address new and emerging issues that impact the Estuary. The role of the PDE is to act as a coordinator, information clearinghouse, facilitator, leader in providing a regional watershed focus, setter of environmental indicators and goals, and provider of incentives throughout the Delaware Estuary region to encourage actions toward the implementation of the CCMP.

Environmental Concerns

Changes in land use, the area's legacy of pollution, and declines in living resources are some of the top environmental concerns in the Delaware Estuary. Between 1970 and 1990, developed land within the watershed increased by 19.6%, and forecasts indicate that the amount of developed land in the region will increase by 36%, or roughly 275,000 acres, between 1990 and 2020 (PDE, 2002b). Residential and commercial development pressures impact the total acreage of natural lands, parklands, and farmlands in the watershed, reducing the amount of ecologically important wetland habitats, open areas for public recreation, and economically valuable farmland in the region. Such changes in land use have customarily been associated with increased stormwater runoff, which carries higher concentrations of nutrients, toxics, and heavy metals to the Estuary. The greater Philadelphia region was a former center for the Industrial Revolution in the New World and contains a legacy of pollution lasting more than 300 years. Much of the contaminant load in this area's present-day stormwater runoff can be attributed to the activities of past industry (Sharp, 2005). A TMDL process is currently underway to address the legacy of PCB contamination in the tidal river and Estuary, and mercury levels in fish tissue necessitate consumption advisories for many edible estuarine and freshwater fish species (Santoro, 2004; U.S. EPA, 2005a). In addition, the area's populations of finfish and shellfish decreased throughout the early 1900s due to overfishing, habitat loss, and water quality declines (Martin et al., 1996).

Population Pressures

The population of the 24 NOAA-designated coastal counties in Delaware, Maryland, New Jersey, and Pennsylvania coincident with the PDE study area increased by 35% during a 40-year period, from 7 million people in 1960 to almost 9.4 million people in 2000 (Figure 3-83) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the PDE study area is slightly higher than the population growth rate of 24% for the collective NEP-coincident coastal counties of the Northeast Coast region. In 2000, the population density of the Delaware Estuary's 24 coastal counties was 772 persons/mi^2, about 27% lower than the population density of 1,055 persons/mi^2 for the collective NEP-coincident coastal counties of the Northeast Coast region (U.S. Census Bureau, 2001). Population pressures for this study area are likely high because the Estuary serves a major metropolitan area that is a center for industry, commerce, and commercial and recreational fishing.

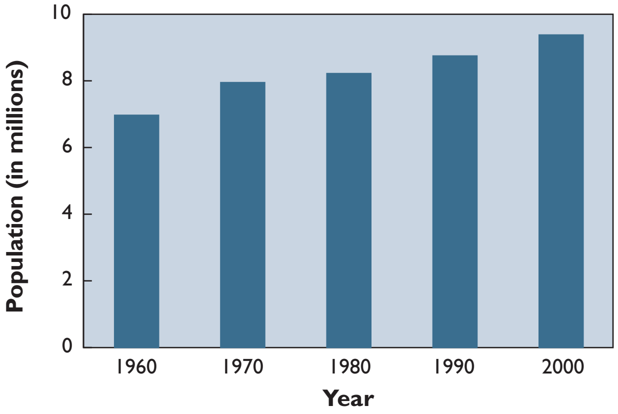


Figure 3-83. Population of NOAA-designated coastal counties of the PDE study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

The following sections of this report discuss two different approaches for characterizing estuarine condition. The Delaware Estuary is a complex system with many features that are distinctly different from other large estuaries. Ideally, a comprehensive assessment of conditions would consider as much physical, chemical, biological, and ecological information as possible, including data collected by both national and regional programs.

Approach 1 – The NCA provides unbiased, quality-assured data that can be used to make consistent "snapshot" comparisons among the nation's estuaries. These comparisons are expressed in terms of the percent of estuarine area in good, fair, or poor condition.

Approach 2 – Each individual NEP collects site-specific estuarine data in support of local problem-solving efforts. These data are difficult to compare among NEPs, within regions, or nationally because the sampling and evaluation procedures used by the NEPs are often unique to their individual estuaries; however, these evaluations are important because NEP-collected data can evaluate spatial and temporal changes in estuarine condition on a more in-depth scale than can be achieved by the NCA snapshot approach. As an example of the importance of considering information from both approaches, the water quality condition rating for the Delaware Estuary differs between the two approaches because it reflects different sampling metrics, approaches, and interpretations. Whereas the NCA survey places emphasis on nutrient conditions to understand eutrophication problems, regional NEP programs in the Delaware Estuary have found that eutrophication outcomes linked to high nutrient levels are not as problematic as other water quality stressors.

NCA Indices of Estuarine Condition—Delaware Estuary

The overall condition of the Delaware Estuary is rated poor based on the four indices of estuarine condition used by the NCA (Figure 3-84). The sediment quality index for the Delaware Estuary is rated good to fair, and the water quality, benthic, and fish tissue contaminants indices are each rated poor. Figure 3-85 provides a summary of the percentage of estuarine area rated good, fair, poor, or missing for each parameter considered. This assessment is based on data from 74 NCA stations sampled in the PDE estuarine area in 2000 and 2001. Please refer to Tables 1-24, 1-25, and 1-26 (Chapter 1) for a summary of the criteria used to develop the rating for each index and component indicator.

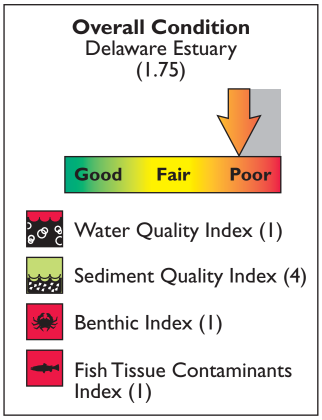


Figure 3-84. The overall condition of the PDE estuarine area is poor (U.S. EPA/NCA).

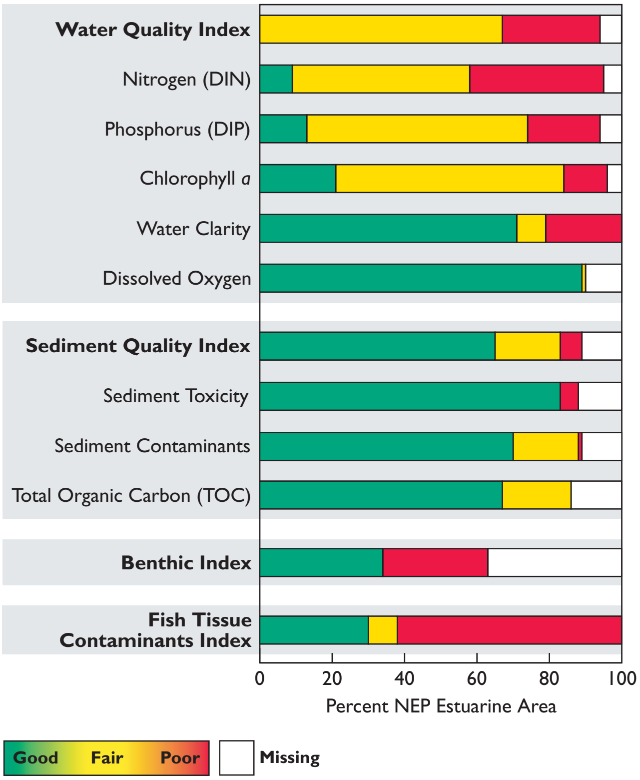


Figure 3-85. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Delaware Estuary (U.S. EPA/NCA).

Water Quality Index

The water quality index for the Delaware Estuary is rated poor. This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Sixty-seven percent of the estuarine area was rated fair for water quality, 27% of the area was rated poor, and less than 1% of the area was rated good. NCA data on water quality were unavailable for 6% of the PDE estuarine area (Figure 3-86). In general, the Delaware Estuary received better ratings for the component indicators of the water quality index than its rating for the index. The Estuary is rated good for dissolved oxygen; fair for DIP, chlorophyll *a*, and water clarity; and poor for DIN.

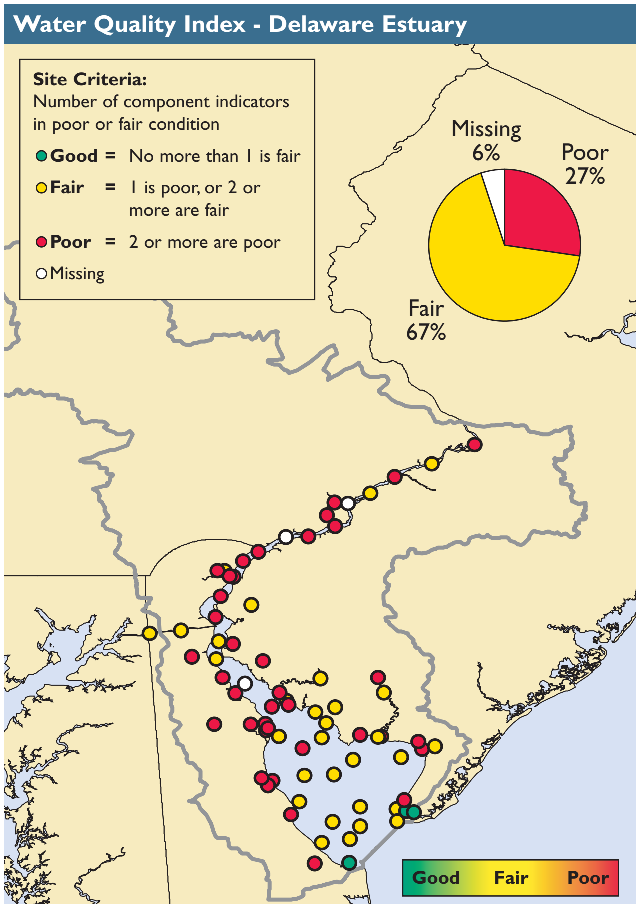


Figure 3-86. Water quality index data for the Delaware Estuary, 2000–2001 (U.S. EPA/NCA).

EPA has interpreted these ratings to indicate that the Delaware Estuary is a highly productive and relatively well-mixed system. The NCA data show that the Delaware Estuary has high nitrogen loadings and elevated levels of chlorophyll *a* relative to other NEP estuaries of the Northeast Coast. These elevated chlorophyll *a* levels indicate that an abundance of phytoplankton is present in the PDE estuarine waters. During the NCA evaluation period, all of the measured dissolved oxygen concentrations were greater than 2 mg/L, and 89% of the estuarine area was rated good for this component indicator. This finding may indicate that the well-mixed nature of the Estuary is decoupling, at least at times, the typical linkages between increased DIN, DIP, and chlorophyll *a* concentrations and the occurrence of hypoxic conditions; however, in 2000 and 2001, the NCA collected most of the dissolved oxygen data during the early fall (October). As a result, the degree to which this decoupling may be occurring is uncertain because of the minimal amount of dissolved oxygen data collected during the summer season (July 1 though September 30), which represents a more critical time period for water quality. The PDE has collected dissolved oxygen data during the summer (see Figure 3-90), and these findings are discussed later in this profile.

Dissolved Nitrogen and Phosphorus | The Delaware Estuary is rated poor for DIN concentrations. Nine percent of the estuarine area was rated good for DIN concentrations, 49% of the area was rated fair, and 37% of the area was rated poor. NCA data on DIN concentrations were unavailable for 5% of the PDE estuarine area.

The Delaware Estuary is rated fair for DIP concentrations. Thirteen percent of the estuarine area was rated good for DIP concentrations, 61% of the area was rated fair, and 20% of the area was rated poor. NCA data on DIP concentrations were unavailable for 6% of the PDE estuarine area.

Chlorophyll a | The Delaware Estuary is rated fair for chlorophyll *a* concentrations. Twenty percent of the estuarine area was rated good for this component indicator, 63% of the area was rated fair, and 12% of the area was rated poor. NCA data on chlorophyll *a* concentrations were unavailable for 5% of the PDE estuarine area.

Water Clarity | The water clarity rating for the Delaware Estuary is fair. Diminished water clarity is common in mid-Atlantic estuaries; therefore, the reference levels used to characterize water clarity were different for the more naturally turbid Delaware Estuary. Greater turbidity was required in the Delaware Estuary to merit a fair or poor rating than in neighboring estuaries. Water clarity was rated poor at a sampling site in if light penetration at 1 meter was less than 5% of surface illumination. Twenty-one percent of the estuarine area was rated poor for this component indicator, 71% of the area was rated good, and 8% of the area was rated fair.

Dissolved Oxygen | The Delaware Estuary is rated good for dissolved oxygen concentrations. Dissolved oxygen concentrations were rated good in 89% of the estuarine area and fair in 1% of the area. There were no areas where dissolved oxygen concentrations were rated poor. NCA data on dissolved oxygen concentrations were unavailable for 10% of the PDE estuarine area.

Sediment Quality Index

Based on the NCA data, the sediment quality index for the Delaware Estuary is rated good to fair. This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC. Sixty-five percent of the estuarine area was rated good for sediment quality, 18% was rated fair, and 6% was rated poor; NCA data on sediment quality were unavailable for 11% of the PDE estuarine area (Figure 3-87). Of the component indicators, sediment contaminant and sediment TOC concentrations in Delaware Estuary were rated good, but sediment toxicity was rated poor.

Sediment Toxicity | Based on NCA data, the Delaware Estuary is rated poor for sediment toxicity because 5% of the area was rated poor for this component indicator. It should be noted that this measurement of sediment toxicity is very close to a rating of good (less than 5% of the area rated poor) and that NCA data on sediment toxicity data were unavailable for 12% of the PDE estuarine area.

Sediment Quality Index - Delaware Estuary

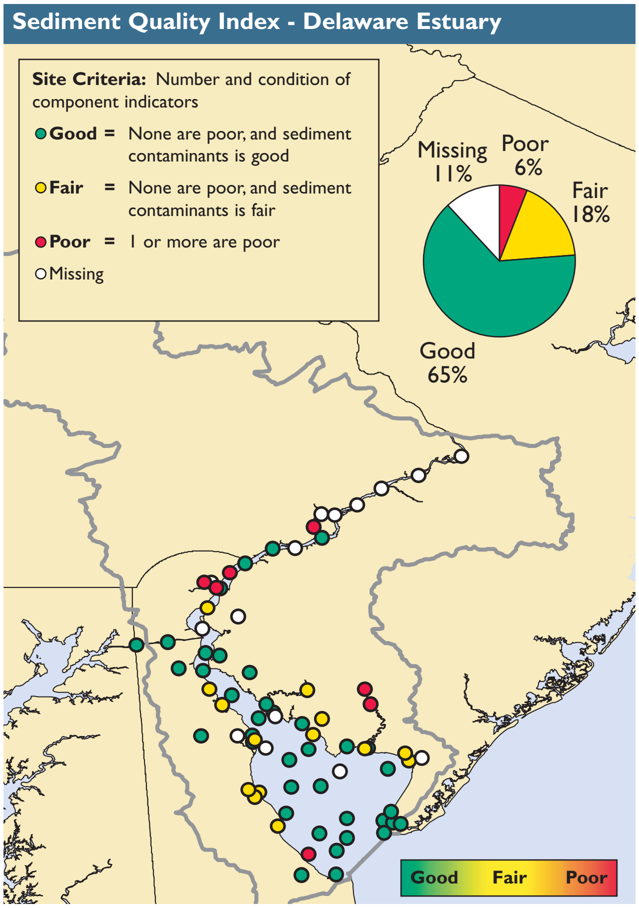


Figure 3-87. Sediment quality index data for the Delaware Estuary, 2000–2001 (U.S. EPA/NCA).

Sediment Contaminants | The Delaware Estuary is rated good for sediment contaminant concentrations. Only 1% of the estuarine area was rated poor for this component indicator, and 18% of the area was rated fair. The highest levels of sediment contaminants were measured in the vicinity of Philadelphia and the Maurice River.

Total Organic Carbon | The Delaware Estuary is rated good for sediment TOC. Sixty-seven percent of the estuarine area was rated good for this component indicator, and 19% of the area was rated fair. No portions of the Delaware Estuary were rated poor for this component indicator; however, NCA data were unavailable for 14% of the PDE estuarine area.

Benthic Index

The benthic condition rating for the Delaware Estuary is poor, as evaluated by the Virginian Province Benthic Index. The benthic index was rated good for 34% of the area and poor for 29% of the area. NCA data on benthic condition were unavailable for a significant portion (37%) of the PDE estuarine area (Figure 3-88).

Benthic Index - Delaware Estuary

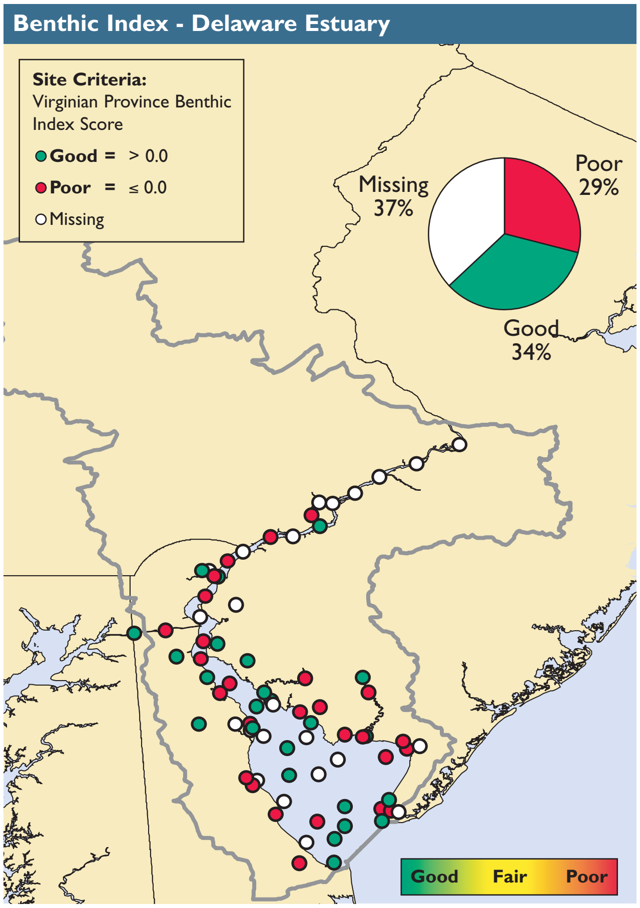


Figure 3-88. Benthic index data for the Delaware Estuary, 2000–2001 (U.S. EPA/NCA).

Fish Tissue Contaminants Index

The fish tissue contaminants index for the Delaware Estuary is rated poor (Figure 3-89). Thirty percent of fish tissues sampled were rated good for contaminant concentrations, and 8% were rated fair. Sixty-two percent of fish tissues sampled were rated poor for contaminant concentrations, with unsatisfactory concentrations of PCBs, DDT, PAHs, or the pesticide dieldrin exhibited in fish tissues.

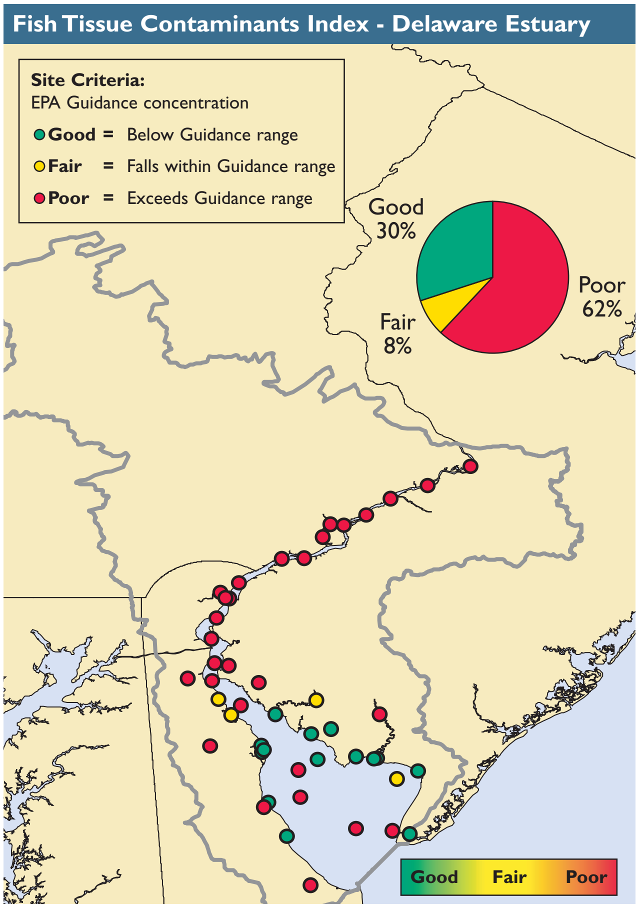


Figure 3-89. Fish tissue contaminants index data for the Delaware Estuary, 2000–2001 (U.S. EPA/NCA).

Partnership for the Delaware Estuary Indicators of Estuarine Condition

The PDE interpreted both the NEP's long-term monitoring data and the data collected by the NCA survey to form an integrated assessment of conditions in the Delaware Estuary. This analysis demonstrates the importance of considering information from both approaches because the water quality condition rating differs between the two data sets, reflecting different sampling metrics, approaches, and interpretations. Whereas the NCA survey places emphasis on nutrient conditions to understand eutrophication problems, regional NEP programs in the Delaware Estuary have found that the problems associated with eutrophication are dwarfed by problems from other water quality stressors. Based on the combined findings of the national and regional programs, and considering condition metrics in addition to water quality, the PDE rates the overall condition of the Delaware Estuary as fair (Personal communication, Kreeger, 2006).

The PDE has developed an initial suite of land and water indicators for water quality, habitat, and living resources, which are being used to assess progress in meeting program objectives to establish quantitative goals and to direct restoration efforts. Environmental conditions in the Estuary are currently monitored by numerous programs, as shown in Table 3-4. The PDE, EPA, DRBC, and a number of other partners are currently in the process of developing a conceptual framework that links science with management activities and integrates indicators, goals, restoration strategies, and monitoring efforts (Kreeger et al., 2006). The status of some of the PDE's indicators is discussed in this section. Additional information about the PDE's indicators and the Estuary's monitoring programs can be found at http://www.delawareestuary.org and http://www.state.nj.us/drbc.

Water and Sediment Quality

Water quality sampling is a collaborative effort between EPA and the state and regional partners managing the Delaware Estuary. Each year, water samples are routinely collected 12 times during the period from March to October. The following measures are key indicators used for evaluating water quality in the Delaware Estuary:

- Nutrients
- Dissolved oxygen
- Chlorophyll *a*
- Turbidity
- Toxics
- Bacteria.

Table 3-4. Examples of Monitoring Programs in the Tidal Delaware Estuary (Santoro, 2004)

Program	Purpose
Estuary boat run	Assess compliance with water quality standards for conventional pollutants, metals, and volatile organics; develop and calibrate water quality models for conventional and toxic pollutants
TMDLs	Collect, analyze, and assess air, ambient water, sediment, and tributary samples for contaminants of concern for TMDL efforts
Automated dissolved oxygen and specific conductance monitoring	Assess compliance with water quality standards; provide data to upgrade standards to fishable/swimmable levels; track salt fronts; and regulate reservoir releases
Groundwater and surface water flow monitoring	Provide data for regulating river flows and groundwater usage
Sediment surveys	Provide data on sediment concentrations of toxic pollutants for water quality models
Ambient toxicity surveys	Assess compliance with chronic whole-effluent water quality standards
Fish tissue analysis	Assess impairment of fish consumption use by bioaccumulative pollutants

The levels of most nutrients in the Delaware Estuary have generally been increasing since the early 1900s. Phosphorus levels are an exception and have changed little since the 1980s. The portion of the Delaware River between Burlington, NJ, and Wilmington, DE, has the highest nitrogen concentrations of any major estuary in the United States. Between 1998 and 2003, nutrient loadings to the Estuary continued to be elevated. Nutrient levels of nitrate-nitrogen, nitrite, ammonia nitrogen, total phosphorus, and orthophosphate are monitored in the Estuary, and in general, were higher in channel stations than in other portions of the Delaware Estuary (Santoro, 2004).

Since the late 1970s, dissolved oxygen levels have shown substantial improvements in the Camden-Philadelphia stretch of the Delaware Estuary. Historically, dissolved oxygen levels in the waters around this heavily industrialized area were significantly lower than in other reaches of the Delaware River, and seasonal declines in dissolved oxygen levels were dramatic. Figure 3-90 shows this drop in dissolved oxygen levels between river miles 75 and 95 in 1967 and 1980 (Santoro, 2004). The resulting hypoxic area discouraged or blocked the passage of many fish during their natural migration and resulted in population declines for certain fish species, such as the striped bass. Pollution-control measures and protective management have helped dissolved oxygen in estuarine waters rebound to acceptable levels (PDE, 2002b).

Chlorophyll *a* and turbidity are also monitored in the Delaware Estuary. Chlorophyll *a* is used as an indicator of algal biomass to assess the growth of the phytoplankton community in the Estuary. Mean chlorophyll *a* concentrations in the Delaware Estuary are similar to those measured in Chesapeake Bay, where eutrophication has been a major concern. Despite these levels of chlorophyll *a*, the Delaware Estuary has not yet experienced the negative signs typically associated with eutrophication (e.g., fish kills, algal blooms, and water discoloration) (Santoro, 2004). Several possible explanations for this lack of eutrophication exist, including the complex interrelationships between nutrient concentrations, turbidity, light penetration, and the degree of hydrodynamic mixing and flushing that occur in different areas of the Estuary. For example, high levels of turbidity and flushing typically observed near Reedy Island, DE, may be a natural feature of the system that could interfere with biological processes (Kreeger et al., 2006).

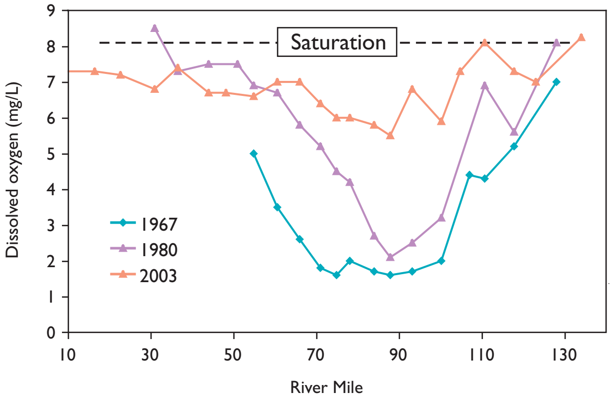


Figure 3-90. Annual dissolved oxygen levels for 1967, 1980, and 2003 along the main channel of the Delaware River from Trenton, NJ, to the mouth of the Delaware Bay (Santoro, 2004).

Toxic substances exist in the water and sediments of the Delaware Estuary, and contaminant issues are currently considered a top water quality concern for the PDE (Kreeger et al., 2006). High PCB concentrations are routinely measured in ambient water samples collected from the Philadelphia-Camden reach of the river during periods of low flow. When samples were obtained during periods of high river flow, PCB levels were lower and more evenly distributed throughout the Estuary (Santoro, 2004). The 1997 Mid-Atlantic Integrated Assessment (MAIA) study analyzed Delaware Estuary sediments for metals, PCBs, pesticides, and other organic contaminants. Metals, pesticides, PCBs, and organic contaminants were most frequently detected above their ERLs in sediments collected along the main stem of the Delaware River between Trenton, NJ, and the C&D Canal (just south of Wilmington, DE) (Santoro, 2000).

Habitat Quality

A diverse array of habitat types predominate the Delaware Estuary system, including tidal salt marshes, tidal freshwater marshes, non-tidal wetlands, mudflats, oyster reefs, open bays, upland meadows, forests, and beaches. Although seagrasses and SAV exist in the Delaware Estuary, they have not historically been reported as an abundant habitat type. As a result, SAV is not regarded as a key measure of estuarine condition (as it is in Chesapeake Bay). Instead, key habitat indicators identified by the PDE incorporate information about land-use changes, losses and gains of different wetland types, acreage of buffer habitats adjacent to tidal wetlands, miles of riparian buffers, changes in area of headwater streams and critical habitats, number of fish blockages removed in streams, and spawning areas for shad.

For example, between 21% to 24% of the Estuary's natural wetland habitats have been lost over time (PDE, 2002b). Freshwater tidal marshes have been disproportionately lost compared to salt marshes within the tidal portion of the Estuary (Kreeger et al., 2006), and invasive species, such as *Phragmites* (common reed), *Hydrilla*, and purple loosestrife, have out-competed many native plants and altered the quality and breadth of the Estuary's natural habitats (Kreeger et al., 2006). Efforts to remove fish blockages and dams are underway in many areas of the Delaware Estuary watershed, including the Schuylkill River.

Shell-planting operations help revitalize oyster populations in Delaware Estuary (PDE).

Living Resources

Changes in the population dynamics and health of key fish, shellfish, and bird species provide good indications of the overall health of the living resources in the Delaware Estuary. Some of these key indicator species include the horseshoe crab, Eastern oyster, American shad, shortnose sturgeon, striped bass, bald eagle, and red knot (Dove and Nyman, 1995; Kreeger et al., 2006).

Like other mid-Atlantic estuaries, the Delaware Estuary is home to the Eastern oyster (*Crassostrea virginica*). Oysters are valued for several important reasons. Similar to mussels, clams, and other bivalves, oysters help filter the surrounding water, enhance habitat for fish and wildlife, and act as a sentinel bioindicator of water quality and habitat conditions (Kreeger et al., 2006). Their importance as bioindicators follows the lessons learned from the International Mussel Watch Program; like mussels, suspension-feeding oysters bioaccumulate many contaminants more effectively than other types of consumers, and their sessile lifestyle is conducive to site-specific analyses. Recent estimates of oyster abundance in the Delaware Estuary suggest that the average population density of adults is declining, and especially worrisome is a precipitous drop in average spat (juvenile oyster) recruitment that could result in a point-of-no-return abundance for the overall population (Santoro, 2004; Powell, 2005). Figure 3-91 shows the long-term trends in oyster populations in the Delaware Estuary. Despite declines, oysters remain one of the most important commercial shellfish in the Delaware Estuary; however, the population has been victimized by the parasite Dermo since 1990. Researchers are working to develop a disease-resistant oyster and to better manage the Eastern oyster market (PDE, 2002b).

At one time, the population of American shad (*Alosa sapidissima*) in the Delaware River supported the largest shad fishery of any river on the Atlantic Coast. In the 1920s, this population declined due to water quality degradation, overfishing, and habitat destruction, such as damming of tributaries, entrainment and impingement at water intakes, and dredge-and-fill activities. As water quality improved in the 1970s, the American shad population in the Delaware Estuary began to increase (Brown, 2005). In recent years, population estimates have fluctuated greatly, but remain well below the species' pre-1900 abundance (PDE, 2001; Santoro, 2004). Researchers believe that the fluctuations observed between 1999 and 2003 were the result of natural variations in population (Santoro, 2004). The environmental stresses experienced by shad are important because they are shared by other anadromous (migratory) and semi-anadromous species, such as herring, striped bass, and sturgeon (Kreeger et al., 2006).

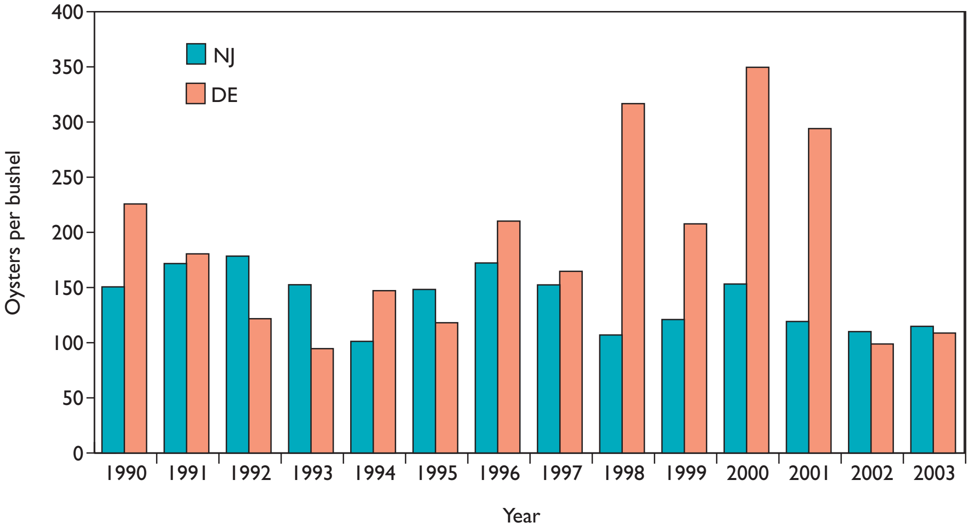


Figure 3-91. Fluctuations in oyster abundance in the Delaware Estuary (Santoro, 2004).

HIGHLIGHT

Horseshoe Crabs, Shorebirds, and People: The Many Facets of Delaware Estuary's Population Ecology

The Delaware Estuary is home to the world's largest population of horseshoe crabs (*Limulus polyphemus*). Horseshoe crabs are not true crabs, but are actually closer to spiders and scorpions. Their external appearance has remained relatively unchanged during the past 360 million years. Each spring, adult horseshoe crabs journey from the depths of the ocean to Delaware Estuary beaches to spawn. Once spawning is complete, the crabs return to the Estuary, and their eggs are left buried in the sand to develop and hatch. At the same time that the horseshoe crabs begin to lay their eggs, shorebirds are traveling northward from South America en route to their breeding grounds in the Arctic (PDE, 2002a). The Delaware Estuary is the largest stop-over for shorebirds in the Atlantic Flyway, and an estimated 425,000 to 1,000,000 migratory shorebirds converge on the Estuary to feed before continuing their migrations (PDE, 2002b). Buried eggs migrate to the surface through wave action and repeated "digging" by the crabs. Eggs on or near the surface are an easily accessible source of food for many shorebirds, including red knots, dulins, ruddy turnstones, sanderlings, and semi-palmated sandpipers. Each bird can eat thousands of eggs per day; for example, a sanderling that weighs 50 grams can eat one horseshoe crab egg every five seconds for 14 hours a day. These eggs provide the energy that shorebirds need for their flight to the Arctic (PDE, 2002b).

Over time, the number of horseshoe crabs in the Estuary has declined, and the current status of the crab population is the subject of considerable debate and regulatory attention in the region (Santoro, 2004; Kreeger et al., 2006). The decrease in the horseshoe crab population has corresponded with a decrease in the abundance of several species of shorebirds. For example, the red knot population, which depends on horseshoe crab eggs for the energy needed to complete migration, has shown significant declines in abundance and weight gain rates. Studies indicate that these declines are linked with decreases in the horseshoe crab population and the number of eggs available for foraging (Stiles and Mizrahi, 2005). The interrelationship of the shorebirds and horseshoe crabs can also be negatively affected by habitat loss, a loss of coastal wetlands due to increased development or erosion, a rise in sea level, and climate changes (PDE, 2002a).

Shorebirds feast on horseshoe crab eggs before migrating to their breeding grounds (PDE).

Many government agencies, fishermen, scientists, researchers, and local community groups are working to protect the shorebirds and horseshoe crabs in the Delaware Estuary region. This work has included the following:

- The Atlantic States Marine Fisheries Commission enacted horseshoe crab harvesting control measures for fishermen in Delaware, New Jersey, Maryland, and Virginia.
- The U.S. Department of Commerce designated a 1,500 mi^2 horseshoe crab preserve in federal waters to protect horseshoe crabs. This preserve extends 30 miles into the Atlantic Ocean, from Peck's Beach, NJ, to Ocean City, MD. This area was chosen as a preserve because it has the largest horseshoe crab population on the East Coast.
- The Ecological Research & Development Group (ERDG), which is a non-profit organization, and the Virginia Institute of Marine Studies (VIMS) conducted a study focused on devising alternative bait bags for fishermen. This study discovered that by using these alternative bait bags, commercial fishermen would need to use less bait, thus successfully reducing the number of horseshoe crabs being harvested. The ERDG has since produced and distributed more than 6,000 bait bags to fisherman in Maryland, Delaware, and New Jersey.
- Teams of researchers from both Delaware and New Jersey have been monitoring specific species of birds for weight gain, gender, molt, wing length, and bill length while the birds are in the Delaware Estuary. This monitoring of a subset of species allows for a better picture of the health of the population, as well as the determination of which habitat types are preferred for foraging and roosting.
- The NJDEP conducted a study to determine what effects a horseshoe crab egg decline might have on the survival of red knots. This work provided a baseline for establishing the viability of the red knot population. During the coming years, if a red knot population decline is detected, scientists will be able to distinguish effects and provide researchers and conservationists with an early warning sign (PDE, 2002a).

Additional information about horseshoe crabs and shorebirds in the Delaware Estuary can be found at http://www.delawareestuary.org.

Horseshoe crabs journey to the beaches of Delaware Estuary to spawn (PDE).

Current Projects, Accomplishments, and Future Goals

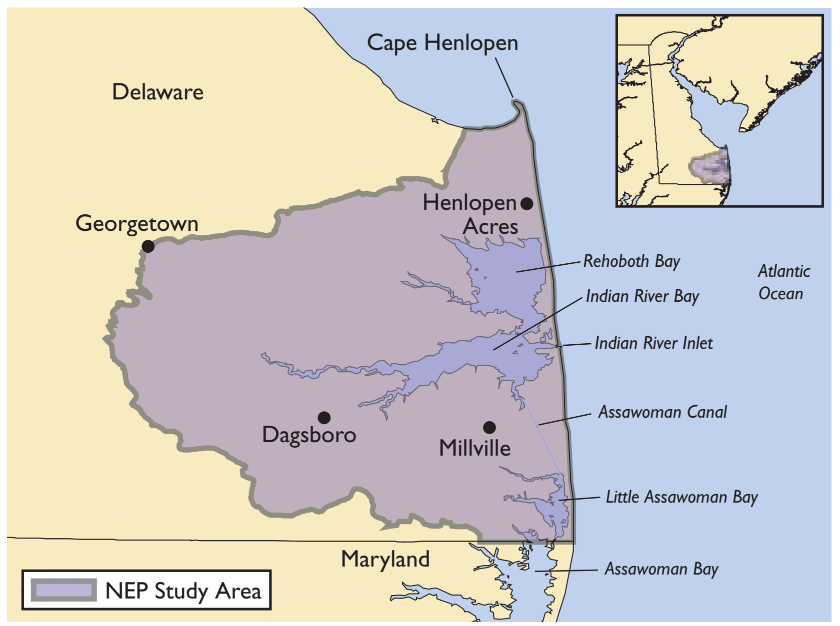
Examples of major water-quality-related accomplishments during the past several years for the PDE and its key partners in Delaware, New Jersey, and Pennsylvania are the following:

- In 2005, the PDE, DRBC, and several regional universities formed an alliance to begin to modernize indicators used to gauge status and trends of a comprehensive suite of environmental metrics related to water quality, living resources, and habitat.
- In July 2004, recognizing the continuing efforts of the Schuylkill Action Network, EPA awarded a $1.15 million grant to the Philadelphia Water Department and the PDE to improve water quality in the Schuylkill River watershed (U.S. EPA, 2004b). EPA announced in May 2003 that the Christina River Basin had been selected to receive a $1 million grant to preserve and protect this interstate subbasin of the Estuary (DRBC, 2005).
- The DBRC has implemented a comprehensive program to reduce PCBs and develop appropriate water quality criteria. As part of these efforts, the DBRC established a TMDL for PCBs for the tidal Delaware River (December 2003) and a rule to establish pollutant-minimization requirements for PCB discharges (May 2005). In addition, the DBRC has also set a goal to reduce PCB loadings to the Estuary by 50% over the next five years (DRBC, 2005).
- The oyster restoration program for the Delaware Estuary has set a specific goal for a five-fold increase in the oyster population by 2015 and has raised more than $2.7 million over the past two years to support this initiative. A shell-planting program was initiated in 2005 to help in this revitalization effort (PDE, 2005).
- The PDE continues to reach out to the smaller suburban and rural municipalities in the region to assist with the development of a stormwater management program for these communities. By implementing one or more outreach programs (e.g., Clean Water Partners, storm drain marking, dog waste collection program), communities are working to improve water quality throughout the region.
- In 2003, the National Fish and Wildlife Foundation (NFWF), in collaboration with the PDE, launched its Delaware Estuary Grants Program. In its first two years, the PDE made more than $1.1 million in public and private funds available to fund 58 projects. In addition, these projects leveraged more than $3.8 million in matching funds. Highlights of initial projects include support for stormwater retrofits; stream, wetland, and upland restorations; and outreach to reduce pollution associated with watershed marinas and boaters (NFWF, 2005).

Conclusion

The PDE's comprehensive assessment of the Delaware Estuary rates the Estuary's overall condition as fair based on the combined findings from both national and regional programs and reflecting a mix of the positive and negative findings and trends for different types of environmental measures. The Delaware Estuary is a large and complex system that requires consideration of its particular ecological features by local and regional NEP-sponsored programs for a complete assessment. The system is highly productive, relatively well mixed, and has high nitrogen loadings and elevated levels of chlorophyll *a* relative to the other NEP estuaries in the Northeast Coast region. Based on the four indices of estuarine condition used by the NCA, the overall condition of the Delaware Estuary is rated poor, partly because of high nutrient and chlorophyll *a* levels. Despite these levels of chlorophyll *a*, the Delaware Estuary has not experienced the negative signs typically associated with eutrophication (e.g., fish kills, HABs, and water discoloration). Although concerned about high nutrient concentrations and watchful for eutrophication problems, the PDE feels that toxic substances are a more pressing concern in the Delaware Estuary because of the more than 300-year contamination legacy of the Industrial Revolution and its impact on the Estuary's condition and resources.

Center for the Inland Bays



www.inlandbays.org

Background

The Delaware Inland Bays are located in southeastern Sussex County, DE, and are composed of three estuaries: Rehoboth Bay, Indian River Bay, and Little Assawoman Bay, which combine to form the smallest of the 28 NEP estuarine systems (DNREC, 2000). Rehoboth Bay is the most northerly of the three bays and adjoins Indian River Bay, which discharges via Indian River Inlet into the Atlantic Ocean. Connected to Indian River Bay via the Assawoman Canal, Little Assawoman Bay is located further south and discharges into Assawoman Bay. The source of the majority of the freshwater input to the Bays is groundwater seepage. In the Rehoboth and Indian River bays, 80% of the freshwater inputs originate from groundwater discharging to the Bays directly or indirectly though the Bays' tributaries. The major tributaries to the Bays include Indian River, Pepper Creek, Herring Creek, Love Creek, and Dirickson Creek (DNREC, 2001).

The Center for the Inland Bays (CIB) was established as part of the NEP in 1994 under the auspices of the *Inland Bays Watershed Enhancement Act* (Title 7, Chapter 76). The mission of the CIB is to promote the wise use and enhancement of the Inland Bays, their tributaries, and the Inland Bays' watershed. The Bays have an average depth ranging from 3 to 8 feet and are poorly flushed by tidal movement; thus, they are especially sensitive to environmental changes (DNREC, 2001).

Fluctuations in water temperature, changes in salinity, and increases in pollutant levels can have dramatic effects on water quality and on the entire ecosystem of the Bays.

The Delaware Inland Bays are an important agricultural area and a popular tourist destination. In 2002, one-third of the watershed was devoted to agricultural uses (CIB, 2004). Approximately 70 million chickens are produced annually in the watershed, creating more than 90 tons of manure (DNREC, 2000; CIB, 2002). Recreation and tourism are also common in the Inland Bays and contribute approximately $250 million annually to the local economy. On summer weekends, the area's population can increase by more than 200% (DNREC, 2000). Boating is a popular activity, and it is estimated that 21,000 boaters use the Bays annually. The potential for illegal sewage discharge from these boats has led to the closure of some of the Bays' shellfish beds (DNREC, 2001).

Environmental Concerns

Water quality impairment and its effects on the estuarine ecosystem are a significant concern in the Delaware Inland Bays. Runoff from CAFOs, leaking or malfunctioning septic systems, and discharges from municipal treatment facilities can all lead to increases in nutrients and releases of fecal coliform bacteria to the Bays. Almost 70% of the streams entering the Bays are impaired, both from a water quality and habitat standpoint. Most of this impairment has occurred due to stream channelization and ditching to improve drainage. The ecology of the Bays has changed in the past 40 years, from a clear water system that supported seagrass, bay scallops, and a variety of other shellfish, finfish, and waterfowl to a murky water system that no longer supports a healthy ecology. Instead, this system enables HABs, nuisance seaweed blooms, and oxygen-depletion episodes, while suppressing bay grasses, bay scallops, and the variety and abundance of other shellfish, finfish, and waterfowl noted in earlier years (CIB, 2002).

Population Pressures

The population of the NOAA-designated coastal county (Sussex) coincident with the CIB study area increased by 114% during a 40-year period, from 0.07 million people in 1960 to almost 0.16 million people in 2000 (Figure 3-92) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the CIB study area is almost five times the population growth rate of 24% for the collective NEP-coincident coastal counties of the Northeast Coast region. In 2000, the population density of this one coastal county was 166 persons/mi^2, about six times lower than the density of 1,055 persons/mi^2 for the collective NEP-coincident coastal counties of the Northeast Coast region (U.S. Census Bureau, 2001). Population pressures for this study area are high, especially during the summer months, because this area and its beaches and bays serve as a major recreational center for the Washington, D.C., and Philadelphia metropolitan areas.

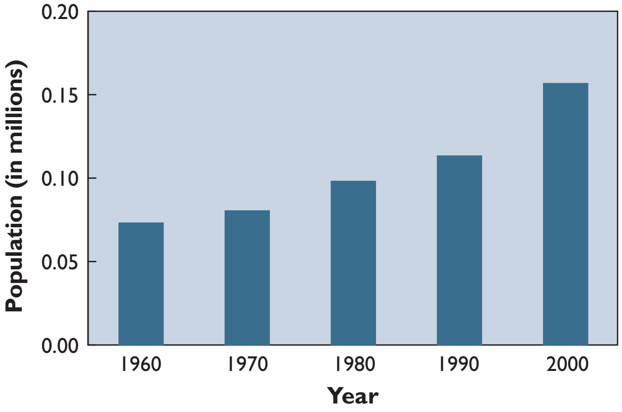


Figure 3-92. Population of NOAA-designated coastal county of the CIB study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Delaware Inland Bays

The overall condition of the Delaware Inland Bays is rated fair based on the four indices of estuarine condition used by the NCA (Figure 3-93). The water quality index for the Delaware Inland Bays is rated fair, the sediment quality and benthic indices are rated poor, and the fish tissue contaminants index is rated good. Figure 3-94 provides a summary of the percentage of estuarine area rated good, fair, poor, or missing for each parameter considered. This assessment is based on data from 30 NCA stations sampled in the CIB estuarine area in 2000 and 2001. Please refer to Tables 1-24, 1-25, and 1-26 (Chapter 1) for a summary of the criteria used to develop the rating for each index and component indicator.

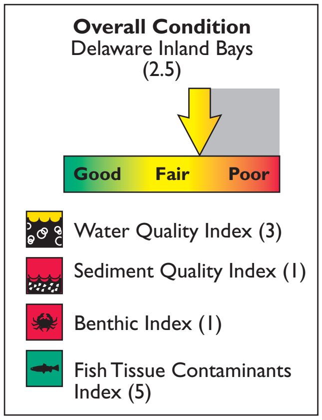


Figure 3-93. The overall condition of the CIB estuarine area is fair (U.S. EPA/NCA).

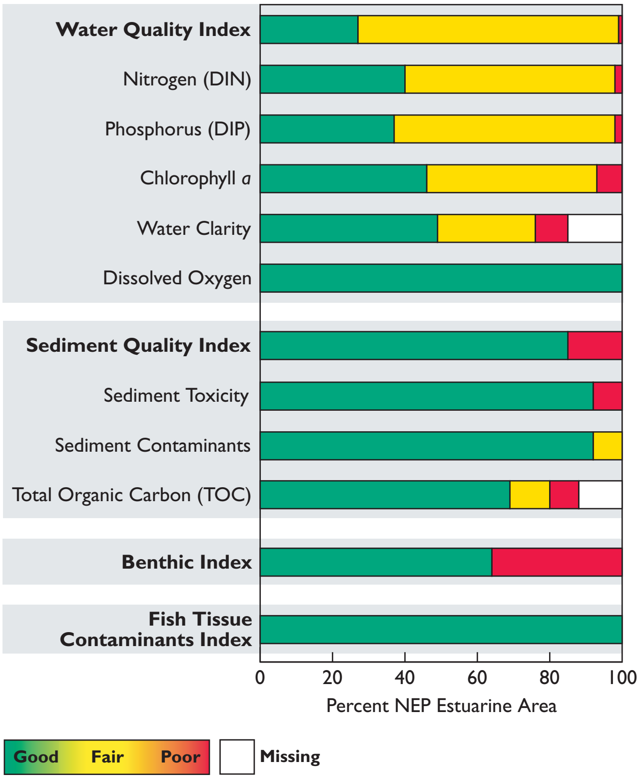


Figure 3-94. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Delaware Inland Bays (U.S. EPA/NCA).

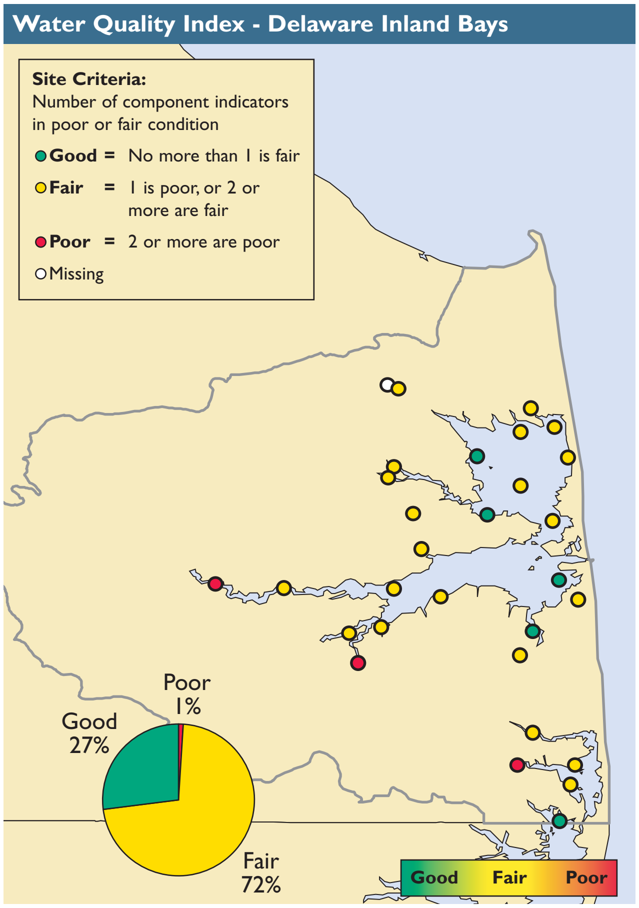


Figure 3-95. Water quality index data for the Delaware Inland Bays, 2000–2001 (U.S. EPA/NCA).

Water Quality Index

Based on the NCA survey results, the water quality index for the Delaware Inland Bays is rated fair, with 72% of the estuarine area rated fair for water quality (Figure 3-95). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Elevated concentrations of DIN, DIP, and chlorophyll *a* were measured in about 60% of the Bays. Diminished water clarity was evident in 36% of the Bays—a typical measurement for the southern estuaries of the Northeast Coast region. Dissolved oxygen concentrations in bottom waters were greater than 5 mg/L at all locations sampled during the study period.

Dissolved Nitrogen and Phosphorus | The Delaware Inland Bays are rated fair for DIN concentrations, with 40% of the estuarine area rated good, 58% of the area rated fair, and 2% of the area rated poor. The Delaware Inland Bays are also rated fair for DIP concentrations, with 37% of the estuarine area rated good for this component indicator, 61% of area rated fair, and 2% of the area rated poor.

Chlorophyll a | The Delaware Inland Bays are rated fair for chlorophyll *a* concentrations. Forty-six percent of the estuarine area was rated good for chlorophyll *a* concentrations, 47% was rated fair, and 6% of the area was rated poor.

Water Clarity | Water clarity in the Delaware Inland Bays is rated good. Forty-nine percent of the estuarine area was rated good for this component indicator, 27% of the area was rated fair, and 9% of the area was rated poor. NCA data on water clarity were unavailable for 15% of the CIB estuarine area.

For the purposes of this report, water clarity in the Delaware Inland Bays was rated poor at a sampling site if light penetration at 1 meter was less than 10% of surface illumination. These criteria are used for estuaries with normal turbidity and are applied to most U.S. estuaries. In some areas of the country, more stringent criteria are applied to support extensive SAV beds or active SAV restoration programs. Water clarity in these regions is rated poor at a sampling site if light penetration at 1 meter is less than 20% of surface illumination.

Although the more stringent water clarity criteria were not applied when rating the Delaware Inland Bays in this report, SAV restoration efforts are underway in this estuarine system; thus, these more stringent criteria could be applicable to the Bays. If these criteria had been applied, water clarity in the Bays would have been rated poor, with 36% of the estuarine area rated poor (see table below).

Rating	Current Criteria (% area)	More Stringent Criteria (% area)
Good	49	40
Fair	27	8
Poor	9	36
Missing	15	15

Dissolved Oxygen | The Delaware Inland Bays are rated good for dissolved oxygen concentrations, with 100% of the estuarine area rated good for this component indicator.

Sediment Quality Index

The sediment quality index for the Delaware Inland Bays is rated poor (Figure 3-96). Fifteen percent of the estuarine area was rated poor, and less than 1% of the area was rated fair. This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC. Sediments were toxic to amphipods at one NCA site; however, the extent of sediment contamination was relatively insignificant (8% rated fair). Moderate and high concentrations of TOC were measured in 19% of the Bays, largely in the tributaries.

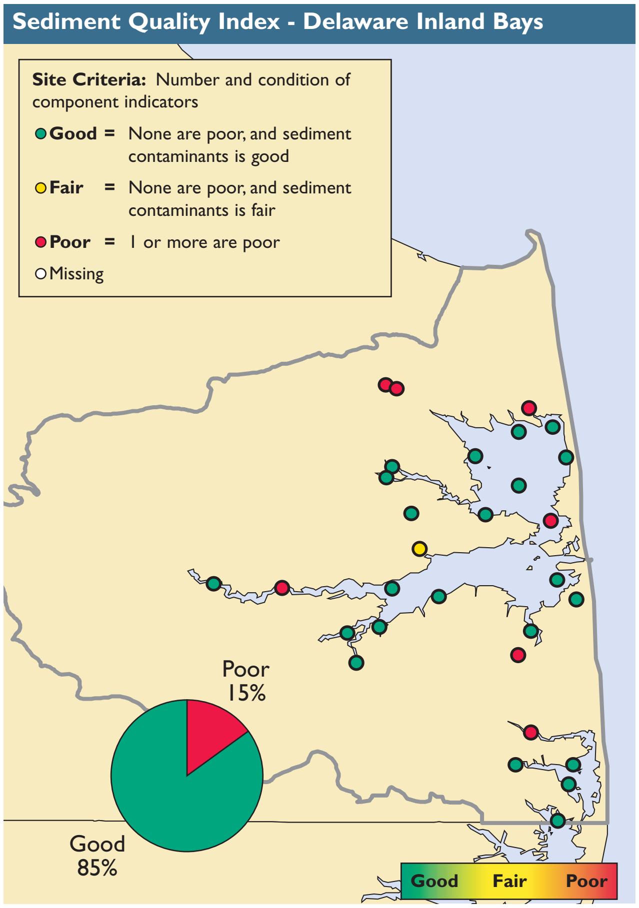

Sediment Quality Index - Delaware Inland Bays

Figure 3-96. Sediment quality index data for the Delaware Inlands Bays, 2000–2001 (U.S. EPA/NCA).

Sediment Toxicity | The Delaware Inland Bays are rated poor for sediment toxicity, with 7% of the estuarine area rated poor for this component indicator.

Sediment Contaminants | The Delaware Inland Bays are rated good for sediment contaminant concentrations. None of the estuarine area was rated poor for this component indicator, and 8% of the estuarine area was rated fair.

Total Organic Carbon | The Delaware Inland Bays are rated good for sediment TOC. Sixty-nine percent of the estuarine area was rated good for this component indicator, and 11% of the area was rated fair. Only 8% of the area was rated poor for sediment TOC, and NCA data on TOC concentrations were unavailable for 12% of the CIB estuarine area.

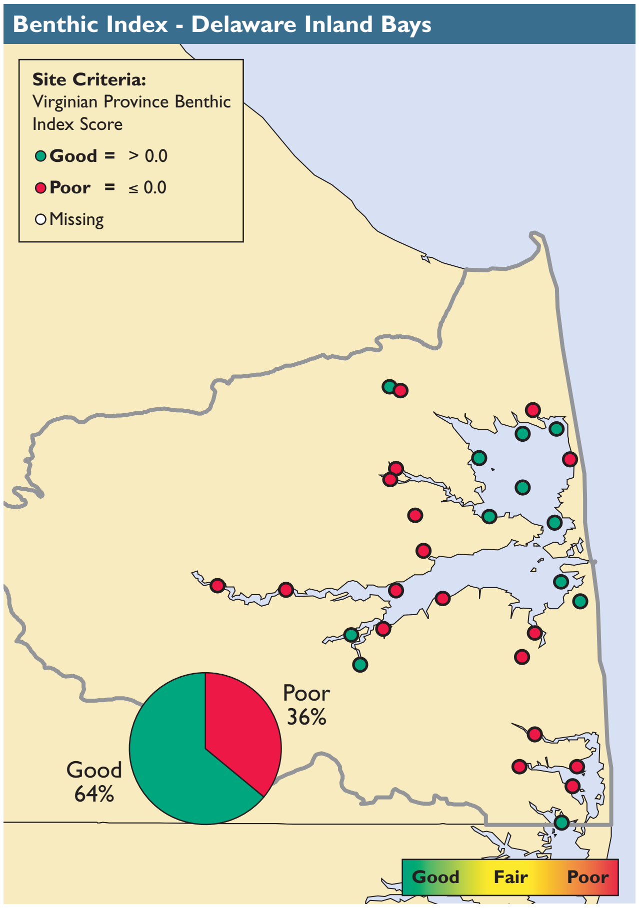


Figure 3-97. Benthic index data for the Delaware Inland Bays, 2000–2001 (U.S. EPA/NCA).

Benthic Index

The benthic condition rating for the Delaware Inland Bays is poor, as evaluated by the Virginian Province Benthic Index (Figure 3-97). More than a third of the estuarine area had index scores that indicated an unsatisfactory degree of benthic diversity, with most of the sites designated as impaired located in tributaries of the Bays.

Fish Tissue Contaminants Index

Based on NCA survey results, the fish tissue contaminants index for the Delaware Inland Bays is rated good. Only four fish samples were analyzed for chemical contaminants (Figure 3-98); however, none contained chemical contaminant concentrations that exceeded the EPA Advisory Guidance values for fish consumption.

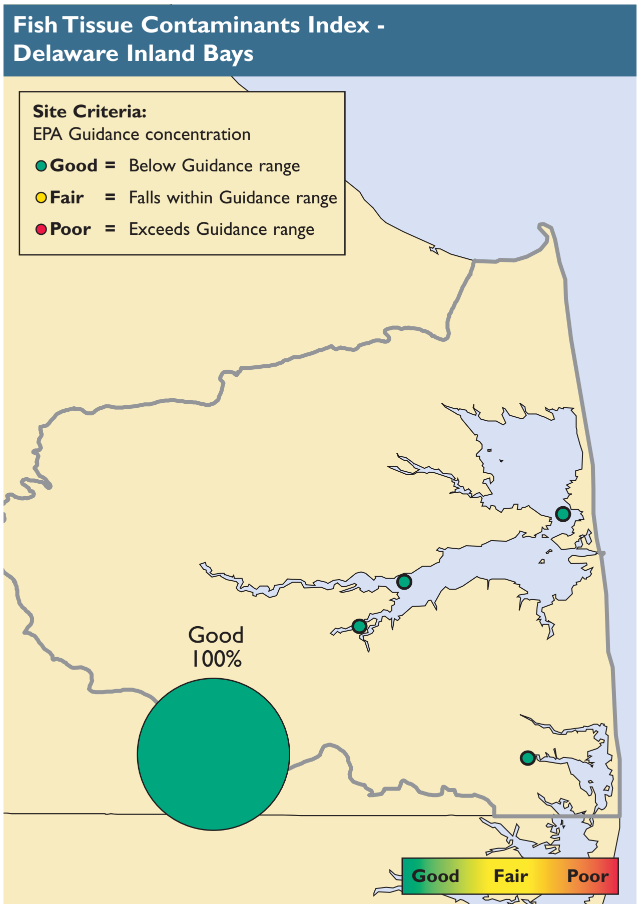


Figure 3-98. Fish tissue contaminants index data for the Delaware Inland Bays, 2000–2001 (U.S. EPA/NCA).

Delaware Inland Bays Tributary Action Team

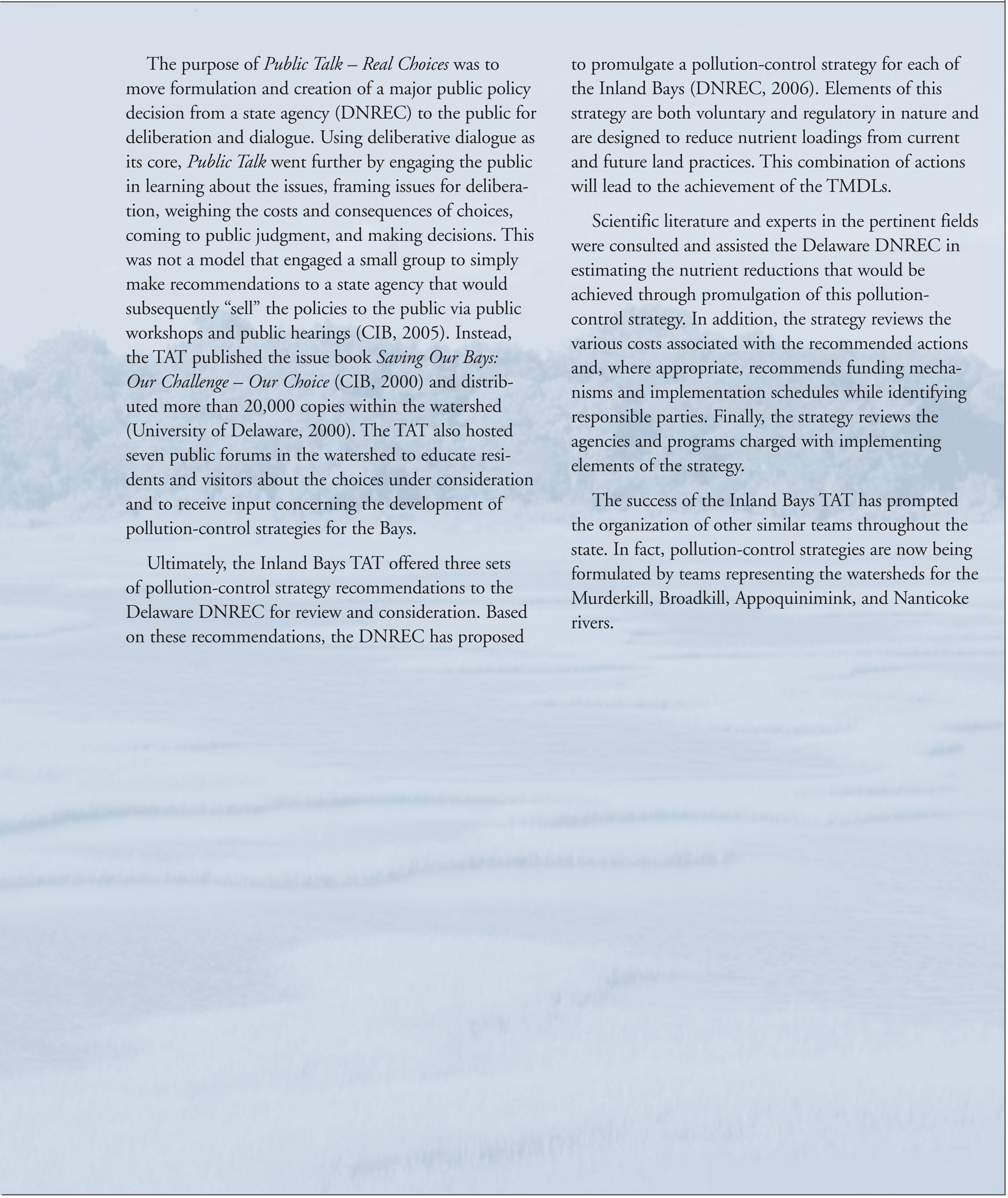
Eutrophication due to nutrient over-enrichment is a priority problem for Delaware's Inland Bays. Overall, the Inland Bays are highly eutrophic, with an increasing trend towards nutrient enrichment experienced during the past 40 years (CIB, 2002). These eutrophic conditions have led to nuisance algal blooms, fish kills, large variations in dissolved oxygen levels, loss of SAV, and an increase in HABs or harmful phytoplankton blooms. Some of these blooms have been composed of organisms, such as *Pfiesteria* and *Chattonella*, which are potentially toxic.

Because of degraded water quality conditions resulting primarily from eutrophication, the Inland Bays are identified as impaired waters on Delaware's 1996 303(d) list and require the application of TMDLs. In December 1998, the Delaware Department of Natural Resources and Environmental Control (DNREC) promulgated TMDLs for the Indian River, Indian River Bay, and Rehoboth Bay, which called for non-point source nutrient load reductions as high as 85% for nitrogen and 65% for phosphorus. The Delaware DNREC also called for the elimination of all point-source discharges to the Inland Bays (DNREC, 1998).

During the autumn of 1998, the CIB initiated a Tributary Strategy Program in which local stakeholders (e.g., industry, agriculture, municipalities, real estate businesses, golf courses, citizens) from each of the Inland Bays sub-watersheds (e.g., Rehoboth, Indian River, and Little Assawoman bays) were organized into an Inland Bays Tributary Action Team (TAT). The TAT created a body responsible for providing guidance and direction to the CIB in its mission to reduce nutrient contributions and restore habitat in the Delaware Inland Bays (CIB, 2005).

Since January 1999, the TAT has been involved in a coordinated effort with the Delaware DNREC to develop pollution-control strategies to meet the required TMDLs for nitrogen and phosphorus in the Bays. To accomplish this goal, a public engagement model, *Public Talk – Real Choices*, was developed and applied to this program by the University of Delaware's Cooperative Extension Agency, which co-facilitated the process with the university's Sea Grant Marine Advisory Service (CIB, 2005).

An Inland Bays' resident attempting to remove the nuisance macroalgae *Ulva* (sea lettuce) from shoreline property (James Alderman).



Center for the Inland Bays

The purpose of *Public Talk – Real Choices* was to move formulation and creation of a major public policy decision from a state agency (DNREC) to the public for deliberation and dialogue. Using deliberative dialogue as its core, *Public Talk* went further by engaging the public in learning about the issues, framing issues for deliberation, weighing the costs and consequences of choices, coming to public judgment, and making decisions. This was not a model that engaged a small group to simply make recommendations to a state agency that would subsequently "sell" the policies to the public via public workshops and public hearings (CIB, 2005). Instead, the TAT published the issue book *Saving Our Bays: Our Challenge – Our Choice* (CIB, 2000) and distributed more than 20,000 copies within the watershed (University of Delaware, 2000). The TAT also hosted seven public forums in the watershed to educate residents and visitors about the choices under consideration and to receive input concerning the development of pollution-control strategies for the Bays.

Ultimately, the Inland Bays TAT offered three sets of pollution-control strategy recommendations to the Delaware DNREC for review and consideration. Based on these recommendations, the DNREC has proposed to promulgate a pollution-control strategy for each of the Inland Bays (DNREC, 2006). Elements of this strategy are both voluntary and regulatory in nature and are designed to reduce nutrient loadings from current and future land practices. This combination of actions will lead to the achievement of the TMDLs.

Scientific literature and experts in the pertinent fields were consulted and assisted the Delaware DNREC in estimating the nutrient reductions that would be achieved through promulgation of this pollution-control strategy. In addition, the strategy reviews the various costs associated with the recommended actions and, where appropriate, recommends funding mechanisms and implementation schedules while identifying responsible parties. Finally, the strategy reviews the agencies and programs charged with implementing elements of the strategy.

The success of the Inland Bays TAT has prompted the organization of other similar teams throughout the state. In fact, pollution-control strategies are now being formulated by teams representing the watersheds for the Murderkill, Broadkill, Appoquinimink, and Nanticoke rivers.

Center for the Inland Bays Indicators of Estuarine Condition

The Inland Bays Scientific and Technical Advisory Committee (STAC) is a working group that formed the Inland Bays Indicators Subcommittee in 2001. This subcommittee developed a preliminary list of environmental indicators that were selected for several purposes, including the following:

- Communicating the health of the Delaware Inland Bays and its rivers to public audiences
- Evaluating progress in the CIB restoration effort
- Monitoring environmental conditions and responses to restoration efforts
- Providing information needed to establish restoration goals
- Regularly informing and involving the public in the achievement of restoration goals
- Making detailed information and reference data for these indicators available upon request so that others may participate in tracking indicator progress.

These indicators were characterized by their position in a hierarchy, ranging from Level 1 indicators, which are used to measure administrative actions such as issuing permits, to Level 6 indicators, which are indirect or direct measures of ecological or human health (Table 3-5). All of the information captured by this continuum has value for stakeholders and policymakers. Although the indicators toward the higher end of the continuum (Levels 4 through 6) portray a clearer, more direct image of the environmental condition of the Bays, indicators at the lower levels (Levels 1 through 3) are needed to establish a link between the actions taken and the effects observed (CIB, 2002).

Table 3-5. Indicators Recommended by the Scientific and Technical Advisory Committee (CIB, 2002)

Level 1. Actions by EPA/State/Local Regulatory Agencies

a. Septic tank conversions to central sewer system
b. Acquisition of land for parks and open spaces
c. Establishment of Nutrient Management Programs

Level 2. Responses of the Regulated and Non-regulated Community (To be developed later pending specific data collection)

a. Animal waste conversion projects
  1. Pelletized fertilizer
  2. Fuel

Level 3. Changes in Discharge/Emission Quantities

a. Removal of direct discharges or reductions in load to the Delaware Inland Bays

Level 4. Changes in Ambient Conditions

a. Nutrient pollution
  1. Nitrogen
  2. Phosphorus
  3. Chlorophyll *a*
  4. Water clarity
     a. Sneaker Index
     b. Secchi depth
  5. Dissolved oxygen

Level 5. Changes in Uptake and/or Assimilation

a. Shellfish-growing area closures

Level 6. Changes in Health, Ecology, or Other Effects

a. Bay grasses (SAV)
  1. Acres
  2. Density
  3. Changes
  4. Biofouling

b. Shellfish – Hard clam landings
c. Fish – Recreational fishing indicator
d. Habitat restoration efforts – SAV
e. Land-use issues
  1. Population growth
  2. Deforestation
  3. Nutrient loading by various land uses

Water and Sediment Quality

The CIB uses the measurements of several water quality parameters (nitrogen, phosphorus, chlorophyll *a*, water clarity, and dissolved oxygen) as indicators of the Bays' pollution levels and as a method for detecting changes in ambient conditions within the Bays. Figure 3-99 compares the Delaware DNREC's water quality goal and the mean value measured during the 1990s for several of these parameters. These data show that all four waterbodies did not achieve the desired goal for DIP concentrations during the 1990s and that the ability to meet other goals varied by waterbody. This analysis indicates that Little Assawoman and Indian River bays are more eutrophic than Rehoboth Bay (CIB, 2002).

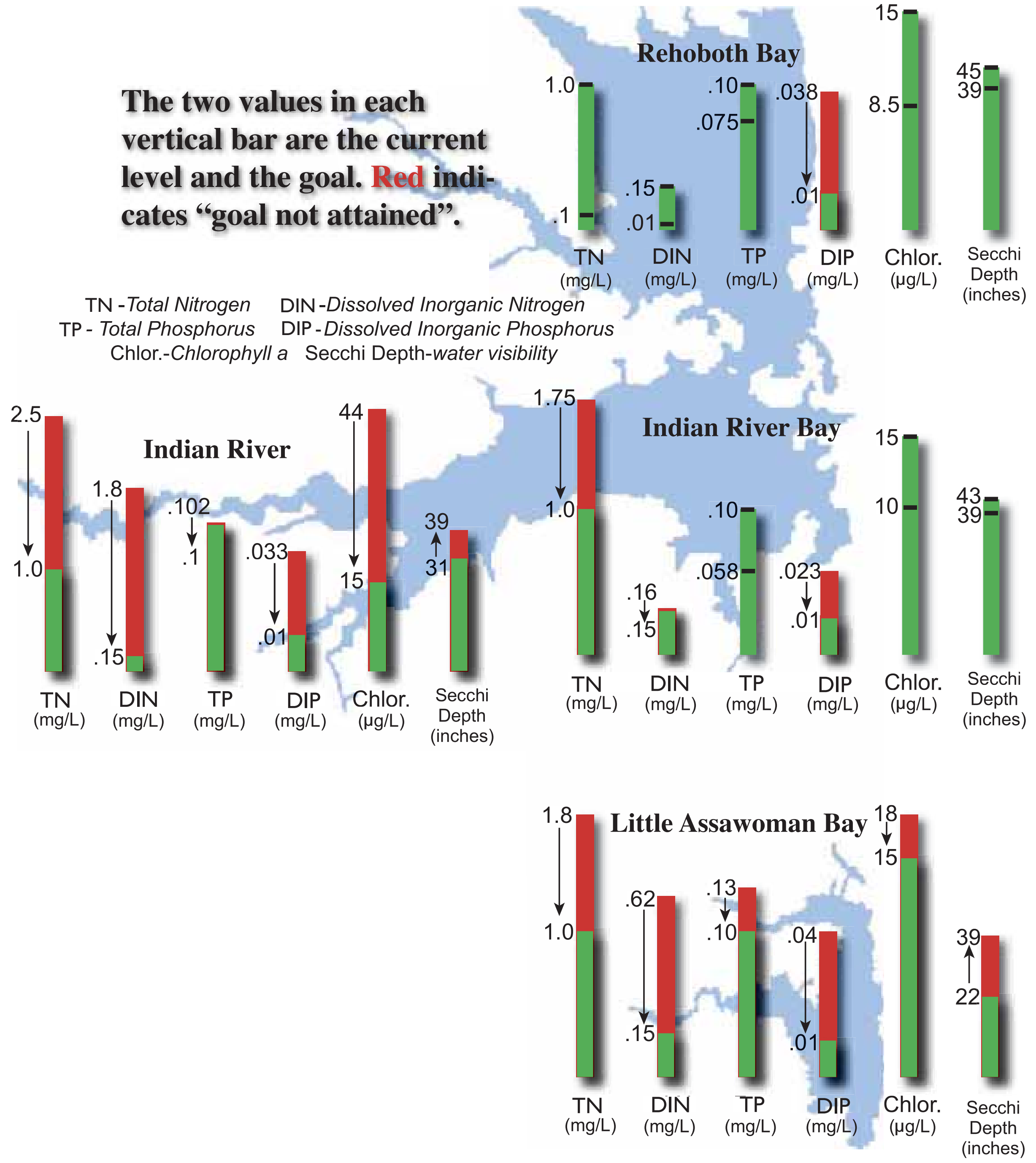


Figure 3-99. Water quality parameters as compared to water quality goals for the Delaware Inland Bays for the 1990s (CIB, 2004)

Nutrient loads entering the Delaware Inland Bays come from non-point, point, and atmospheric sources; however, the majority of the nutrient loadings to the Bays are derived from non-point sources. The Delaware DNREC estimated that almost 4,500 pounds of nitrogen and 163 pounds of phosphorus enter the Bays each day from non-point sources, such as septic systems, stormwater runoff, and agricultural activities (CIB, 2002). Direct discharges from point sources contribute less than 4% of the Bays' nitrogen loading (DNREC, 2000). Between 1990 and 2000, direct discharges of nitrogen increased by 32% to 710 pounds per day. Point-source releases of phosphorus also increased by 6% to 72 pounds per day (CIB, 2004). Nitrogen loading to the Bays from atmospheric deposition is estimated to range up to 25% of the total nitrogen load (DNREC, 2000).

The Sneaker Index has been collected in the Delaware Inland Bays since 2001. This surrogate measure for water clarity is calculated every year as the water depth at which Delaware's current governor can no longer see a pair of white tennis shoes while standing in the Bays. This method has proven to be a good way to raise public awareness about water clarity in the Bays. Submerged sneaker visibility has ranged from a maximum of 51 inches in 2001 to a minimum of 39 inches in 2002. In 2004, the Sneaker Index was 44 inches (CIB, 2004).

The CIB also measures levels of total coliform bacteria in the waters of Rehoboth Bay and Indian River Bay as an indicator of the potential for pathogen-contaminated shellfish to introduce illness to human populations. The DNREC uses coliform bacteria measurements to determine if local shellfish beds are safe for harvesting (CIB, 2004).

Habitat Quality

SAV is considered a good ecological indicator because ambient water quality conditions are generally considered to be good if healthy and reproducing SAV are abundant. The highest concentration and greatest diversity of SAV in the Bays is located in the Bay's freshwater tributaries (CIB, 2002). In the tidal portions of the Bays, eelgrass, a widely valued seagrass, is considered a particularly important indicator of water quality. Historically, the amount of eelgrass declined as nutrient loads to the Bays increased, and by the early 1970s, eelgrass and most of the other SAV species had almost completely died out in the tidal portions of the Bays (CIB, 2004). Currently, the majority of the Bays' estuarine area will not support eelgrass; however, restoration efforts have reintroduced eelgrass to the Indian River Inlet (DNREC, 2000; CIB, 2004). Where water quality is sufficient to support vigorous plant growth, the restored eelgrass beds are reproducing (DNREC, 2000).

The CIB uses changes in the region's land use to help characterize the changing landscape of the Bays. Aerial photography is used to determine the extent of each land-use category in the Inland Bays watershed. In 2002, agriculture, forest, urban, and wetlands were the top four land-use classes in the watershed (Figure 3-100), and overall, the watershed is becoming more urbanized. Between 1992 and 2002, urban lands increased by 8,940 acres, or 34%. During the same time period, forested, agricultural, and barren land acreage declined (CIB, 2004).

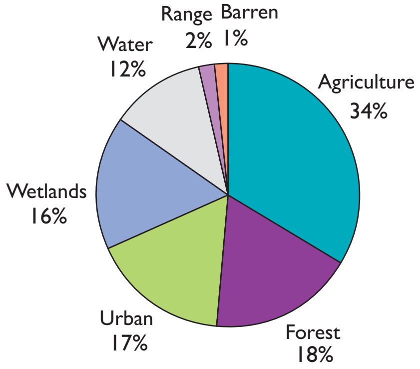


Figure 3-100. Delaware Inland Bays land use in 2002 (CIB, 2004).

Wetlands are an important type of habitat because they filter nutrients, trap sediments, control flooding, and support diverse plant and animal communities. Since 1780, Delaware has lost an estimated 54% of its wetlands (DNREC, 2000), and between 1982 and 1992, 92% of the 297 acres of wetlands lost in the Delaware Inland Bays area were freshwater vegetated wetlands. Agriculture, residential development, and pond construction were the primary causes for this loss (DNREC, 2001). In the Delaware Inland Bays watershed, the rate of wetlands loss has decreased in recent years, with wetlands acreage increasing slightly between 1992 and 2002 (DNREC, 2001; CIB, 2004).

Macroalgae (seaweeds) in the Delaware Inland Bays provide preferred habitat for blue crabs and a variety of fish. The monitoring of macroalgae (seaweeds) habitat in the Bays is important because macroalgae are a sensitive habitat type. As nutrient levels in the water increase, macroalgae density increases, which can result in diminished habitat quality, HABs, low dissolved oxygen levels, and the mortality of fish and benthic organisms. For example, thick mats of macroalgae formed in parts of Indian River Bay in 1998, impacting more than 8 acres and killing an estimated 100,000 clams. Rehoboth Bay has the greatest amount of macroalgae of the Delaware Inland Bays (DNREC, 2001).

Living Resources

Hard clams were chosen as a CIB indicator because they are the most important commercial fishery and one of the most abundant benthic species in the Delaware Inland Bays (CIB, 2004). Hard clams began to colonize extensive areas of Rehoboth and Indian River bays in the 1940s, and the majority of current habitat in the Bays is suitable for hard clams (DNREC, 2001). Hard clam landings peaked in the 1950s and 1960s and have been increasing in recent years, including increases from about 300,000 to more than 3.5 million clams between 1987 and 2003 (DNREC, 2001; CIB, 2004). Overall, the CPUE is stable, and the increase in clam landings is primarily due to a corresponding increase in the amount of effort expended to catch the clams. In recent years, a large percentage of each catch has been composed of clams that are in the smallest size category, which indicates the presence of more young clams in the Bays. The CIB suspects that improved water quality is the likely cause of the increased number of young clams (CIB, 2002; 2004).

Beach-nesting birds and the tiger beetle are considered to be good indicators of the ecological integrity of beach and dune communities in the Bays. The piping plover, least tern, common tern, black skimmer, and American oystercatcher are the five beach-nesting bird species that are tied to the Bays' beach and dune habitat. In the 1960s, these birds resided in the area in good numbers, and small numbers of least terns, common terns, and American oystercatchers continue to nest in the area, although common tern nesting efforts are sporadic. Piping plovers nest annually in the study area; however, the population has declined in recent years and nest productivity is low, primarily due to predation. Black skimmers have not nested in the Delaware Inland Bays since 1990, and the tiger beetle has only been recorded in Cape Henlopen State Park (DNREC, 2000; 2001).

Recreational fishing in the Delaware Inland Bays is a popular pastime, and sea trout, summer flounder, striped bass, and bluefish are commonly caught in the Bays. Recreational fishing trips and landings are seen as good indicators because the success of the recreational fisherman is linked to the ability of the Bays to support viable fish populations. Between 1988 and 2002, the number of fishing trips per year has followed an overall increasing trend. At the same time, the number of fish caught per trip has remained relatively constant. This indicates that the Bays are capable of sustaining the current level of recreational fishing (CIB, 2004).

Environmental Stressors

The centralization of sewers is used as an indicator of progress made by government action to decrease non-point source pollution to the Bays. The watershed's existing 16,000 septic systems discharge nutrients to the groundwater, which transports the nutrients to the Bays and tributaries. It is estimated that almost 1,000 pounds of nitrogen and up to 40 pounds of phosphorus are discharged on a daily basis to the Bays from existing and recently removed septic systems. Since 1993, more than 13,000 septic systems have been replaced with centralized public sewer systems (CIB, 2002; 2004)

The CIB uses population growth as a good indicator of overall environmental stress on the Bays and the watershed. Between 1990 and 2000, the population of Sussex County increased by more than 38%. The area of the county with the greatest population growth was located along the Atlantic Coast portion of the Delaware Inland Bays watershed, where the population increased by 59% (U.S. Census Bureau 1991; 2001). Population growth in this area is expected to continue. By 2020, the population of Sussex County as a whole is expected to reach 180,000 people, and much of this population will be concentrated in the watershed (CIB, 2004).

Current Projects, Accomplishments, and Future Goals

The establishment of the CIB was the culmination of more than 20 years of active public participation and investigation into the decline of the Delaware Inland Bays and remedies for the restoration and preservation of the watershed. The CIB was designed to accomplish several specific goals:

- Sponsor and support educational activities, restoration efforts, and land-acquisition programs that lead to the present and future preservation and enhancement of the watershed
- Build, maintain, and foster the partnership among the general public, private sector, and local, state, and federal governments; this partnership is essential for establishing and sustaining the policy, programs, and political will to preserve and restore the resources of the watershed
- Serve as a forum where Inland Bays watershed issues may be analyzed and considered for the purpose of providing responsible officials and the public with a basis for making informed decisions concerning the management of the resources of the watershed.

Some of the CIB's ongoing projects and major accomplishments in the Delaware Inland Bays' watershed include the following:

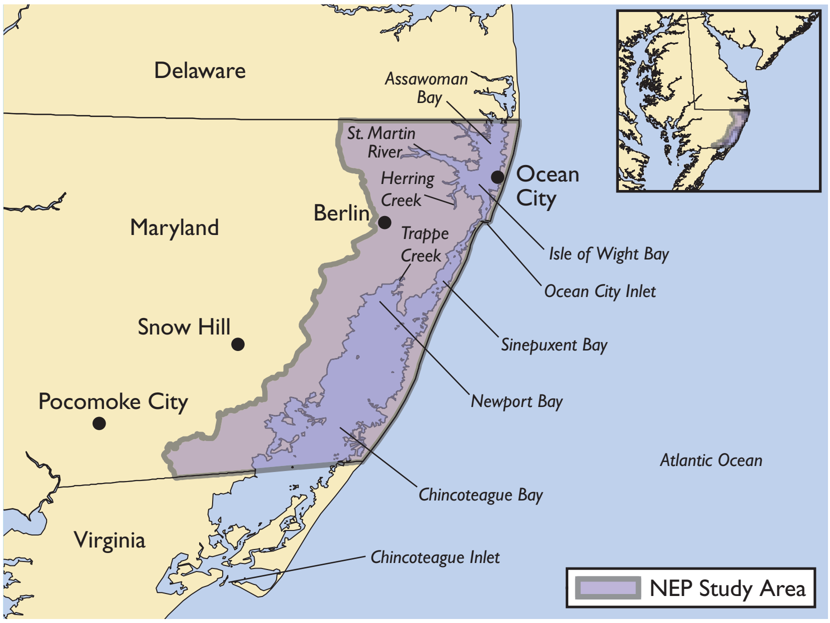
- In August of 2004, the CIB began a large-scale scientific research project to determine the ecological health of the area's freshwater wetlands.
- Since 1994, the CIB has awarded more than $1 million to support research, outreach, and demonstration projects. These projects have included evaluating HABs, enhancing the restoration of shellfish stocks, and raising water quality awareness in middle school students.
- More than 100,000 eastern oysters were raised during 2003 by volunteer oyster gardeners as part of the CIB's Shellfish Gardening Project, which was designed as a pilot program to restore oysters to the Inland Bays. These oysters were later planted on a constructed oyster reef in Indian River Bay. Since 2001, the CIB has planted more than 1.5 million oysters on this reef (CIB, 2005).

Conclusion

The Delaware Inland Bays combine to form the smallest of the 28 NEP estuarine systems. These Bays are shallow and poorly flushed by tidal movement, and as such, are especially sensitive to environmental changes. The overall condition of Delaware Inland Bays is rated fair based on the four indices of estuarine condition used by the NCA. The CIB has developed a suite of indicators used to measure a variety of elements—from administrative actions, such as issuing permits, to those elements that are indirect or direct measures of ecological or human health. These indicators should provide a comprehensive picture of the environmental and human components of the system over time.

Maryland Coastal Bays Program

www.mdcoastalbays.org



Background

The total watershed area of the Maryland Coastal Bays encompasses 175 mi^2 and includes more than 117,000 acres of land, 71,000 acres of water, and 280 miles of shoreline (ANEP, 2001b). To the east of Route 113, the watershed of the Coastal Bays includes Berlin and Ocean City, MD, as well as parts of Snow Hill and Pocomoke. The Maryland Coastal Bays make up one of the richest and most diverse estuaries on the Eastern Seaboard, with more than 115 species of finfish, 17 species of molluscs, 23 species of crustaceans, 360 species of birds, 44 species of mammals, and countless foraging/grazing organisms inhabiting these waterbodies (ANEP, 2001b; Maryland DNR, 2005a). The Maryland Coastal Bays are characterized as coastal lagoons with fairly uniform depths (< 10 feet) and relatively long water residence times (Wazniak et al., 2004; Wazniak and Hall, 2005). Circulation within the Bays is controlled by wind and tides, and flushing time is very slow across the system because tidal exchange is limited mainly to small channels separating the barrier islands. River inputs are fairly low due to the area's flat landscape and sandy soils, and groundwater is a major pathway for the introduction of fresh water and nutrients to the Bays. Salinity in the open Bays is similar to seawater, although portions of the upstream reaches of rivers and creeks remain fresh (Wazniak and Hall, 2005).

The Maryland Coastal Bays Program (MCBP) was established in 1996 as a partnership between the towns of Ocean City and Berlin, MD; EPA; the NPS; Worcester County, MD; and the Maryland Department of Natural Resources (DNR). The MCBP protects the land and waters of Assawoman Bay, Isle of Wight Bay, Sinepuxent Bay, Newport Bay, and Chincoteague Bay.

The Coastal Bays' multi-million dollar tourism industry is fueled by more than 11 million annual visitors who flock to the Bays to fish, boat, swim, or enjoy the atmosphere in their favorite bay-side restaurant (MCBP, 2005). Although more that 47,000 people lived in Worcester County in 2000, populations in the summer season have exceeded 300,000 people (Thompson and Wagenhals, 2002). Tourism-related activities generate $700 million in annual employee income in the Coastal Bays (Polhemus and Greeley, 2001). In 2002, commercial landings of fish and shellfish in Ocean City comprised 12.1 million pounds, valued at $8.1 million. In 2003, more than 700,000 people fished 7 million days in Maryland waters, and currently, recreational crabbing and fishing in the Bays generates at least $21 million annually (ANEP, 2001b; Wazniak and Hall, 2005). For more than a century, agriculture, forestry, fishing, farming, hunting, and tourism have sustained ways of life built on the land and water resources in these coastal communities. Worcester County's forests and 474 farms contribute hundreds of millions of dollars per year to the local economy and help provide the open space and natural land essential to the variety of wildlife species that call this area home (MCBP, 2005).

Environmental Concerns

A variety of environmental concerns in the Maryland Coastal Bays require the attention of environmental managers. The majority of these concerns are directly related to the area's growth and development. Projections indicate that there will be more than 60,000 residents living in the Coastal Bays' watershed by 2010 and more than 72,000 residents by 2020 (Wazniak and Hall, 2005). Pollution from agricultural and urban runoff, point-source discharges, septic tank system loadings, atmospheric deposition, and groundwater flow are all sources of nutrients in the Bays. With the right mixture of water quality conditions and nutrient loading levels, blooms of algae can form and block light infiltration to SAVs, foul boat propellers, and cause odor problems for homeowners along the Coastal Bays. Commercial development, the conversion of natural shorelines, the cumulative impacts of docks and boat traffic, and the invasion of exotic species have all degraded and/or eliminated tidal marsh and wetland habitats, and roughly 50% of the area's forest and wetlands have been lost during the past 300 years (ANEP, 2001b). Primary sources of pathogen contamination are runoff from livestock operations, urban areas with failing septic systems, and wildlife. Analysis of sediments has revealed higher than normal levels of DDT, arsenic, chlordane, and nickel, which have accumulated from agricultural sources, stormwater, and other sources (Wazniak and Hall, 2005). Dredging activities and boating in the Bays can easily resuspend contaminated sediments into the water column. Trash and debris that accumulate on estuary beaches of the Eastern Shore are a threat to local ecosystems and reduce the recreational value of popular sites along the coast. In 2002, approximately 50 volunteers scooped a ton and a half of garbage from the Bays and shoreline during a single-day event (MCBP, 2002).

Population Pressures

The population of the NOAA-designated coastal county (Worcester) coincident with the MCBP study area increased by 96% during a 40-year period, from about 0.02 million people in 1960 to almost 0.05 million people in 2000 (Figure 3-101) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the MCBP study area is four times the population growth rate of 24% for the collective NEP-coincident coastal counties of the Northeast Coast region. In 2000, the population density of this coastal county was 98 persons/mi^2, about one-tenth the population density of 1,055 persons/mi^2 for the collective

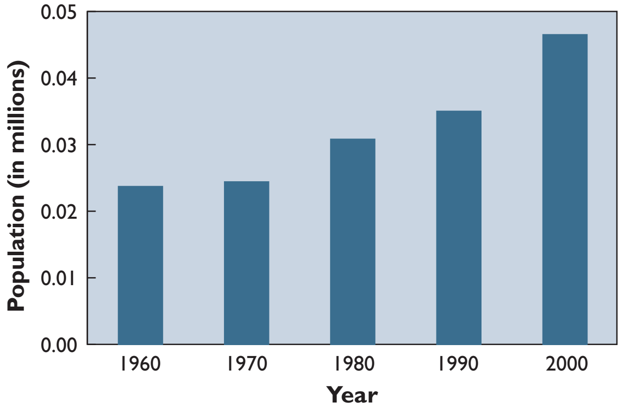


Figure 3-101. Population of NOAA-designated coastal county of the MCBP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NEP-coincident coastal counties of the Northeast Coast region (U.S. Census Bureau, 2001). Population pressures for the MCBP study area are especially high during the summer months because these beaches and bays serve as a major recreational center for the nearby metropolitan areas surrounding Washington, D.C.

NCA Indices of Estuarine Condition—Maryland Coastal Bays

The overall condition of the Maryland Coastal Bays is rated fair based on the four indices of estuarine condition used by the NCA (Figure 3-102). The water quality index for the Maryland Coastal Bays is rated poor, the sediment quality and fish tissue contaminants indices are rated good, and the benthic index is rated fair. Figure 3-103 provides a summary of the percentage of estuarine area rated good, fair, poor, or missing for each parameter considered. This assessment is based on data from 47 NCA sites sampled in the MCBP estuarine area in 2000 and 2001. Please refer to Tables 1-24, 1-25, and 1-26 (Chapter 1) for a summary of the criteria used to develop the rating for each index and component indicator.

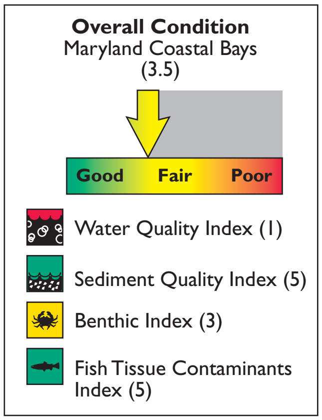


Figure 3-102. The overall condition of the MCBP estuarine area is fair (U.S. EPA/NCA).

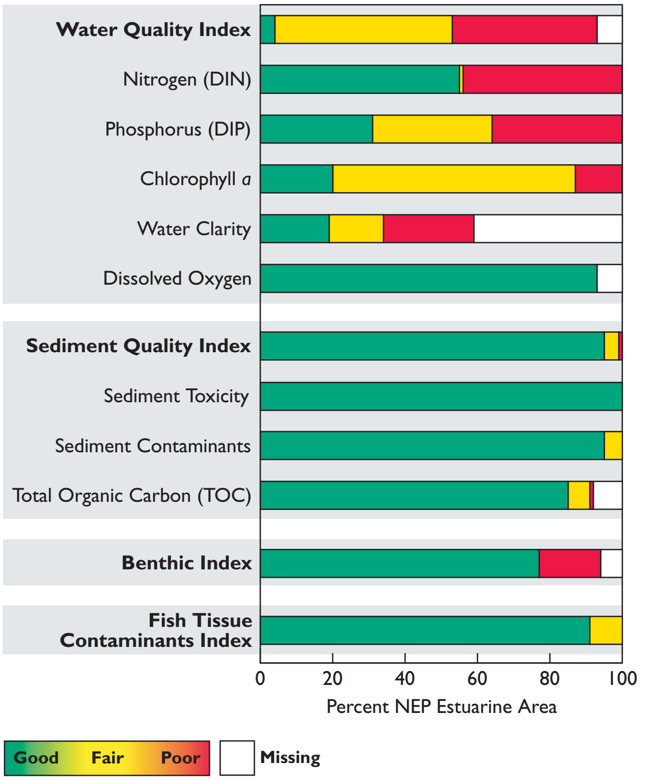


Figure 3-103. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Maryland Coastal Bays (U.S. EPA/NCA).

Water Quality Index

Based on NCA survey results, the water quality index for the Maryland Coastal Bays is rated poor (Figure 3-104). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen.

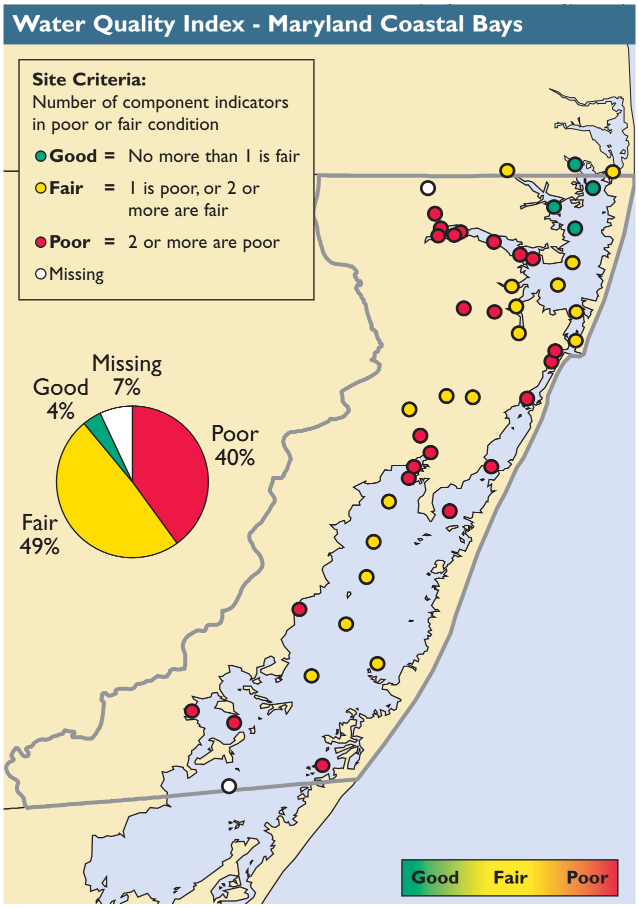


Figure 3-104. Water quality index data for the Maryland Coastal Bays, 2000–2001 (U.S. EPA/NCA).

Dissolved Nitrogen and Phosphorus | The Maryland Coastal Bays are rated poor for DIN concentrations, with 55% of the estuarine area rated good for this component indicator, 1% of the area rated fair, and 43% of area rated poor. DIP concentrations in the Maryland Coastal Bays are also rated poor, with 31% of the estuarine area rated good, 33% of the area rated fair, and 35% of the area rated poor.

Chlorophyll a | The Maryland Coastal Bays are rated fair for chlorophyll *a* concentrations. Twenty percent of the estuarine area was rated good for this component indicator, 67% of the area was rated fair, and 12% of the area was rated poor.

Water Clarity | The water clarity rating for the Maryland Coastal Bays is poor. If light penetration at a depth of 1 meter below the water's surface was less than 10% of the surface illumination, water clarity at the sampling site was rated poor. Twenty-five percent of the estuarine area was rated poor for water clarity, 19% of the area was rated good, and 15% of the area was rated fair. NCA data on water clarity were unavailable for 41% of the MCBP estuarine area.

Dissolved Oxygen | The Maryland Coastal Bays are rated good for dissolved oxygen concentrations, with 93% of the estuarine area rated good for this component indicator and none of the area rated poor. NCA data on dissolved oxygen concentrations were unavailable for 7% of the MCBP estuarine area.

Replanting marsh grass in an effort to protect and rebuild a beach (Mary Hollinger, NOAA).

Sediment Quality Index

The sediment quality index for the Maryland Coastal Bays is rated good (Figure 3-105). This index was developed using data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC. No sediments collected from the Bays were toxic to amphipods, and only three sites in the St. Martins River had low sediment quality ratings due to moderate concentrations of sediment contaminants and high concentrations of TOC.

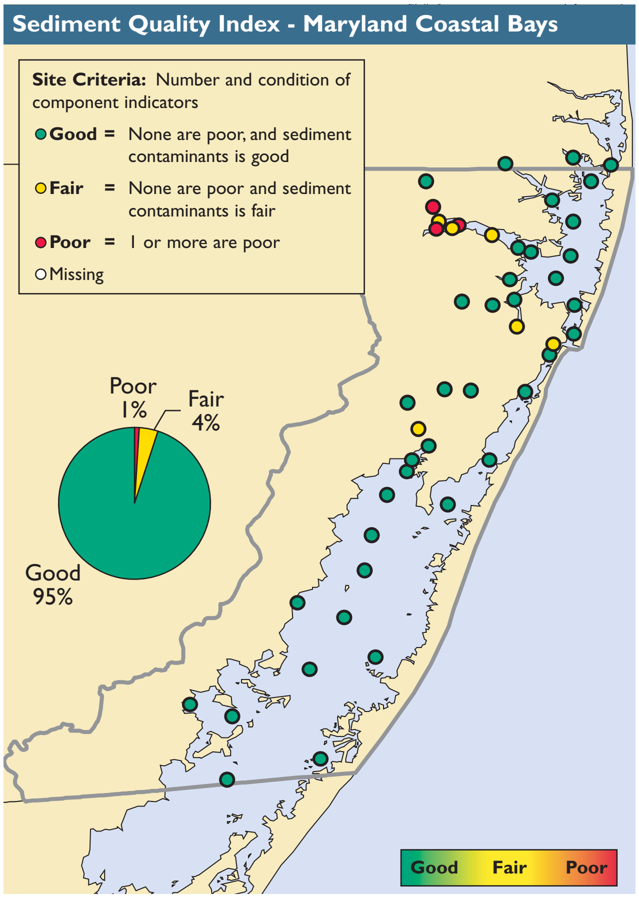


Figure 3-105. Sediment quality index data for the Maryland Coastal Bays, 2000–2001 (U.S. EPA/NCA).

Sediment Toxicity | The Maryland Coastal Bays are rated good for sediment toxicity because none of the estuarine area was rated poor.

Sediment Contaminants | The Maryland Coastal Bays are rated good for sediment contaminant concentrations, with 95% of the estuarine area rated good for this component indicator, 5% of the area rated fair, and none of the area rated poor.

Total Organic Carbon | The Maryland Coastal Bays are rated good for sediment TOC, with 85% of the estuarine area rated good and 6% of the area rated fair. Only 1% of the estuarine area was rated poor for this component indicator, and NCA data on sediment TOC concentrations were unavailable for 8% of the MCBP estuarine area.

Benthic Index

As evaluated by the Virginian Province Benthic Index, the benthic index for the Maryland Coastal Bays is rated fair, with 17% of the estuarine area rated poor for benthic condition (Figure 3-106). Seventy-seven percent of the estuarine area was rated good for benthic condition, and NCA data on benthic condition were unavailable for 6% of the MCBP estuarine area.

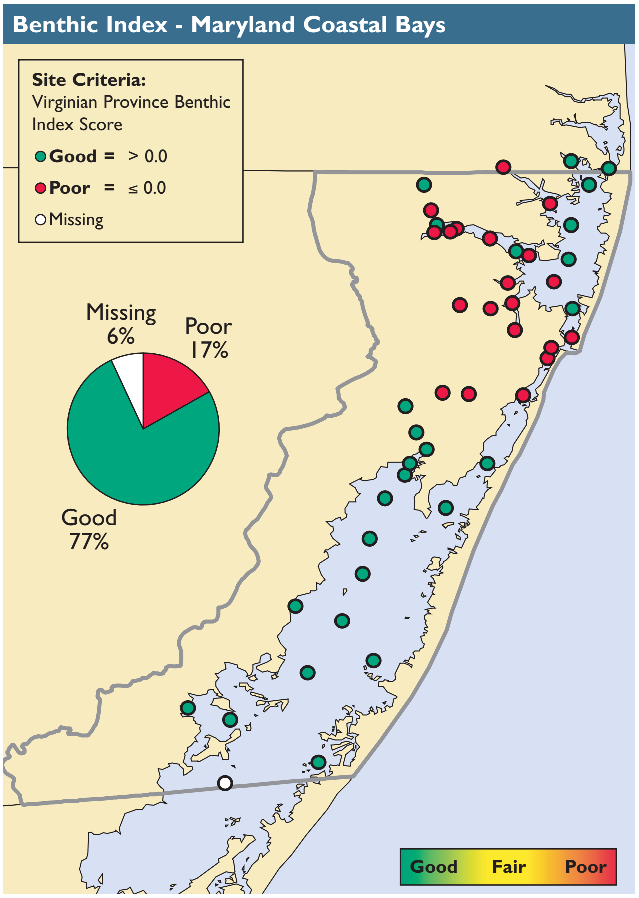


Figure 3-106. Benthic index data for the Maryland Coastal Bays, 2000–2001 (U.S. EPA/NCA).

Fish Tissue Contaminants Index

The fish tissue contaminants index for the Maryland Coastal Bays is rated good, with 91% of fish samples rated good for contaminant concentrations. Only two fish samples (9%) analyzed for chemical contaminants had contaminant concentrations that exceeded the EPA Advisory Guidance values for fish consumption (Figure 3-107). In both cases, the samples contained elevated concentrations of PCBs.

Fish Tissue Contaminants Index - Maryland Coastal Bays

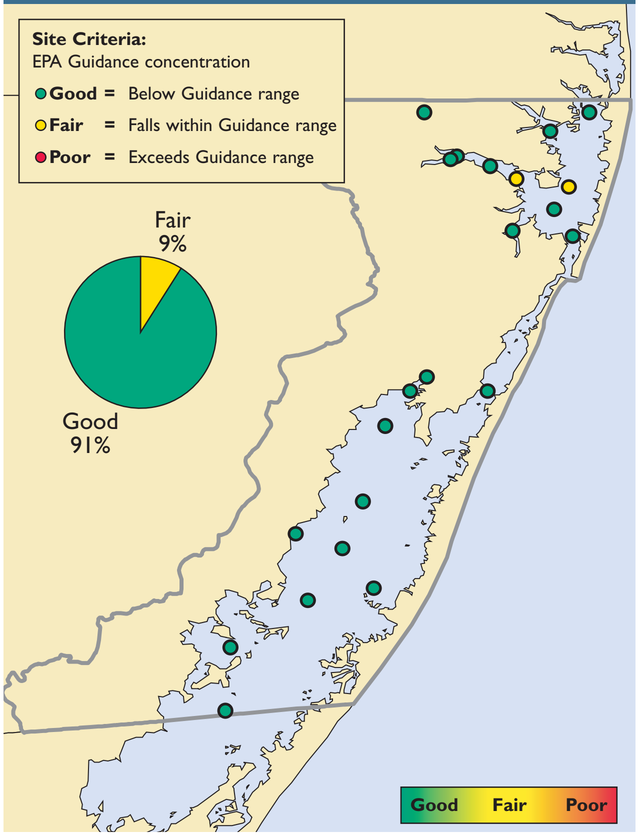


Figure 3-107. Fish tissue contaminants index data for the Maryland Coastal Bays, 2000–2001 (U.S. EPA/NCA).

Maryland Coastal Bays Program Indicators of Estuarine Condition

A variety of indicators are used to assess estuarine health in the Maryland Coastal Bays. The thresholds for each indicator were approved by the MCBP's STAC. Many local, state, and federal agencies participate in monitoring the Coastal Bays' ecosystem. Monitoring data are used to characterize water quality, habitat, and living resource conditions in the Coastal Bays, providing essential information for management actions. The STAC has developed a variety of indicators for assessing water quality, stream health, sediment quality, habitat, living resources, and harmful algae in the Maryland Coastal Bays. Table 3-6 presents these indicators, along with their thresholds and monitoring frequencies. The status and trends of some of these indicators are discussed below. Additional information about the Maryland Coastal Bays environmental indicators is available at http://www.dnr.state.md.us/coastalbays.

Water and Sediment Quality

The STAC's water quality indicators are monitored by several agencies, including the Maryland DNR, the NPS at Assateague Island, and MCBP volunteers. In addition, the University of Maryland Center for Environmental Science provides expertise in water quality mapping. The Maryland DNR also assesses stream health and monitors stream resources and sediment quality, whereas the USGS analyzes groundwater inputs to the estuary (Wazniak et al., 2004).

Four water quality indicators are assessed in the Maryland Coastal Bays— chlorophyll *a*, total nitrogen, total phosphorus, and dissolved oxygen. Overall, nutrient loading is showing measurable impacts on the area's ecosystem. Monitoring data collected between 2001 and 2003 demonstrated that the upper tributaries are severely enriched by nitrogen and that phosphorus enrichment is more widespread throughout the Coastal Bays. Although many of these upstream areas had nutrient concentrations above the MCBP's threshold levels, chlorophyll *a* concentrations were generally low in the open Bays. These results are significant because chlorophyll *a* measurements are often used to represent the amount of algae in the water column.

Table 3-6. Water Quality, Stream Health, and Sediment Quality Indicators, Thresholds, and Monitoring Frequencies for the Maryland Coastal Bays (Wazniak et al., 2004; Maryland DNR, 2005b)

Aquatic Ecosystem Monitoring	Indicator	Threshold	Monitoring Frequency
Water Quality	Total nitrogen	No more than 0.65 mg/L for seagrass growth No more than 1 mg/L as set by STAC	Monthly
	Total phosphorus	No more than 0.037 mg/L for seagrass growth No more than 0.01 mg/L as set by STAC	Monthly
	Chlorophyll *a*	No more than 15 µg/L to prevent low dissolved oxygen levels No more than 50 µg/L as set by STAC	Monthly, as well as continuous monitoring and water quality mapping (the latter two measure total chlorophyll)
	Dissolved oxygen	No less than 5 mg/L to prevent effects on aquatic life No less than 3 mg/L as set by STAC	Monthly, as well as continuous monitoring and water quality mapping
	Water quality index	Greater than 0.6	Calculated by combining values from all water quality indicators
Stream Health	Stream nitrate	Less than 1 mg/L	Variable
	Stream bottom-dwelling Animal Index 1	Less than or equal to 2.8	Annually
	Stream bottom-dwelling Animal Index 2	Less than or equal to 4	Every 5 years
	Freshwater fish index	Greater than or equal to 4	Every 5 years
Sediment Quality	Excess organic carbon	Less than or equal to 1%	Periodically
	Ambient toxicity	Significant difference from uncontaminated sediment	Annually (2000–2003)
	Mean Apparent Effects Threshold	None	Calculated from sediment contaminant data (2000–2003)
Habitat	Seagrass	18,951 acres	Annual survey
	Macroalgae	None	Not routinely monitored
	Wetlands	No net loss	Not monitored directly
Living Resources	Fish	No decreasing trend in forage fish index	Monthly trawl: April – October Seine: June and September
	Fish kills	None	As needed
	Blue crabs	None	Monthly with fish survey
	Shellfish (clams, scallops, oysters)	None	Clams – Annual survey
	Bottom-dwelling animals	MAIA benthic index value > 3	Annually (2000–2003)
	Phytoplankton	None	Monthly – Weekly
Harmful Algae	HABs	Species-specific thresholds	As needed, when water quality indicates algae are at high levels

Applied Monitoring: Incorporating Stable Isotope Analysis into a Water Quality Index

Environmental managers for the Maryland Coastal Bays have set several environmental objectives, including reducing sewage/septic inputs to the Bays and maintaining suitable habitat for seagrass and fisheries. Each objective can be linked to a water quality indicator. Managers have set reference values for each indicator to determine whether or not a particular waterbody is achieving an individual objective. During a pilot study in 2004, six water quality indicators (dissolved oxygen, Secchi depth, chlorophyll *a*, total phosphorus, total nitrogen, and isotopic ratios of nitrogen) were used to develop a water quality index for the Maryland Coastal Bays and tributaries (Jones et al., 2004). The table below shows the management objective and reference value for each water quality indicator.

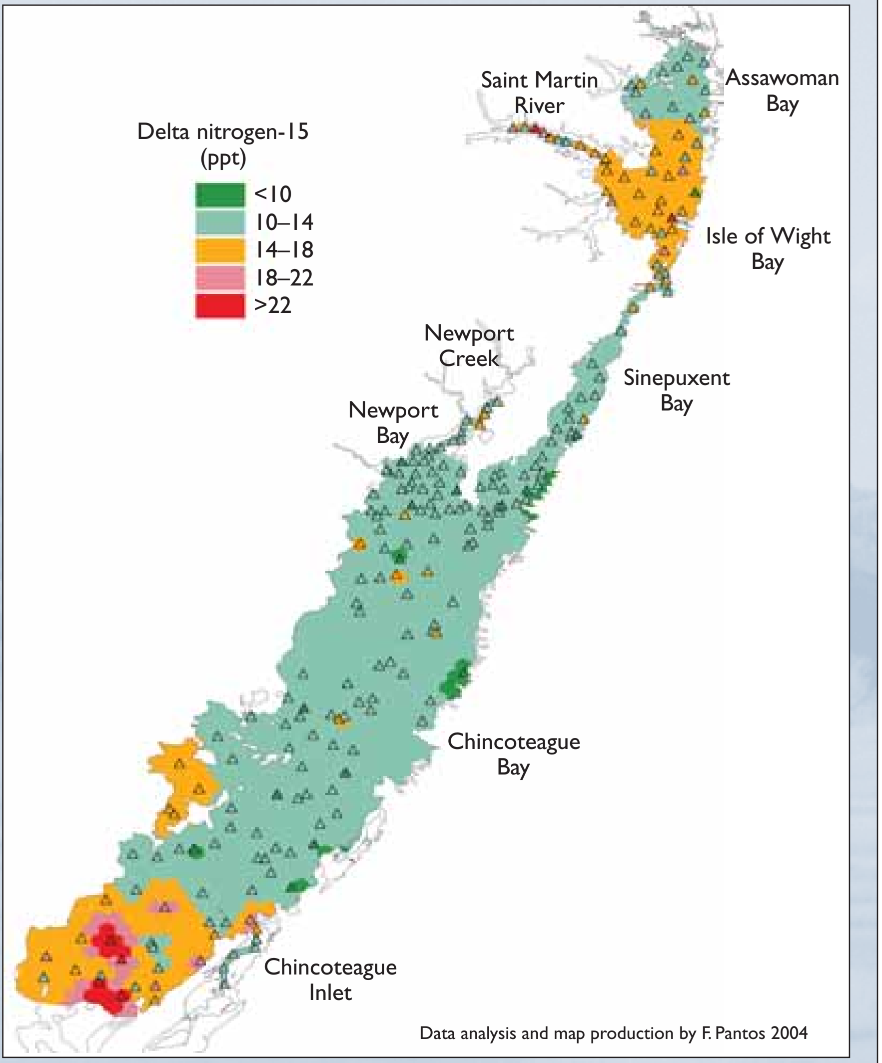
In June 2004, a field-sampling program was conducted to measure the 6 indicators at approximately 250 sites in the Maryland Coastal Bays. Secchi depths were determined, and water samples were analyzed for dissolved oxygen, chlorophyll *a*, total phosphorus, and total nitrogen concentrations. Isotopic ratios of nitrogen (delta nitrogen-15 values) were also measured. Measuring isotopic ratios of nitrogen is important because various sources of nitrogen to the Bays often have distinguishable isotopic ratios. For example, elevated delta nitrogen-15 ($\delta^{15}N$) values are associated with treated sewage effluent. The figure on the next page displays the sampling results for $\delta^{15}N$ in the Maryland Coastal Bays. Elevated $\delta^{15}N$ values were found in the St. Martin River, Isle of Wight Bay, and the southern portion of Chincoteague Bay (near the town of Chincoteague and Wallops Island). These elevated values indicate that sewage is a major source of nutrients in these portions of the Bays (Jones et al., 2004).

The sampling sites were divided into reporting regions by waterbody, and a water quality index for each region was calculated by comparing the measured values for each of the six indicators to the reference values for each management objective (see table below). The calculated water quality index is a number between zero

Indicators, Management Objectives, and Reference Values Used in the Calculation of the Water Quality Index for the Maryland Coastal Bays (Jones et al., 2004)

Indicator	Management Objective	Reference Value
Dissolved oxygen	Maintain suitable fisheries habitat	> 5 mg/L
Secchi depth	Clear water	> 1 meter
Chlorophyll *a*	Reduce phytoplankton	< 15 µg/L
Total phosphorus	Reduce phosphorus	< 0.037 mg/L (1.2 µM)
Total nitrogen	Reduce nitrogen	< 0.65 mg/L (46 µM)
Total ratio of nitrogen (delta nitrogen-15)	Reduce sewage/septic inputs	< 14%

and one. A score of 0.8 and above indicates that habitat conditions are considered good for fish and seagrass survival, whereas a score of 0.4 or below indicates unsuitable habitat for either fish or seagrass. Intermediate values indicate that the system is variable and that some ecosystem functions (e.g., seagrass beds or fish) may be expected to be present some of the time. The table below presents the water quality indices for several waterbodies in the Maryland Coastal Bays. The Isle of Wight Bay received a good water quality index rating, probably due to the relatively high flushing rate with the ocean at the southern end of the Bays. The areas with the lowest water quality index values were the St. Martin River and the western side of Chincoteague Bay (Newport Bay). Secchi, total phosphorus, and chlorophyll *a* were the main factors resulting in the poor overall water quality index rating for Chincoteague Bay (Jones et al., 2004).



Data analysis and map production by F. Pantos 2004

Distribution of isotopic ratios of nitrogen in the Maryland Coastal Bays (Jones et al., 2004).

Summary of Water Quality Index Ratings by Region (Jones et al., 2004)

Region	Sites	WQI	Health
Assawoman Bay	18	0.56	Fair
Chincoteague Bay	106	0.42	Fair
Isle of Wight Bay	20	0.69	Good
Newport Bay	31	0.33	Poor
Sinepuxent Bay	36	0.68	Good
Chincoteague Inlet	7	0.62	Good
St. Martin River	11	0.29	Poor
Newport Creek	10	0.36	Poor

Large algal blooms can limit the amount of light available to seagrasses or reduce dissolved oxygen levels in the water. Although shallow lagoons typically do not stratify, oxygen values in the Coastal Bays were frequently low in some areas. For example, continuous monitoring data collected during the summer seasons of 2002 through 2004 show that dissolved oxygen levels in the tributaries Bishopville Prong and Turville Creek were low (less than 5 mg/L) approximately 40% to 60% of the time (Table 3-7) (Wazniak and Hall, 2005).

The monitoring data on the four component indicators collected from around the Bays between 2001 and 2003 were compared to the threshold values listed in Table 3-6, which are known to maintain fisheries and seagrasses. The results of this comparison were then used to develop the water quality index for a given waterbody. This index ranks the Bays from best to worst as follows: Sinepuxent, Chincoteague, Isle of Wright, Newport, Assawoman, and St. Martin River (Wazniak and Hall, 2005).

The health of the streams in the MCBP study area is also assessed for the water quality index. Streams and small creeks often serve as the initial receptors for the nutrients, sediments, and chemicals that are later transported to the Bays, and fish and benthic communities are used as indicators of stream health. Most streams in the watershed are degraded with excess nutrients, and high stream nitrate levels have been observed in all segments of the Coastal Bays. These elevated stream nitrate levels indicate excess inputs from human activities, which can be transported to the stream via surface runoff or groundwater flow. Data on fish and benthic animals indicate that most streams in the Coastal Bays are degraded; however, long-term trend data indicate that conditions are improving. Most animals found in the streams were classified as pollution tolerant. Impacts to the biota of Coastal Bays streams are likely the result of physical habitat modification within the watershed due to the extensive ditching that has increased the number of creeks and tributaries in the region. Man-made ditched streams generally have less habitat diversity and lower flows than the minimally altered streams of the Coastal Plain, which retain a more natural wetland character. This ditching may also affect nutrient levels in the region's creeks, tributaries, and bays by allowing groundwater to enter streams more quickly, thereby decreasing the filtration that the groundwater would normally have encountered before entering the Bays (Wazniak and Hall, 2005).

Excess organic carbon, ambient toxicity, and the mean Apparent Effects Threshold (AET) are used to assess sediment quality in the Maryland Coastal Bays. Excess organic carbon is an important measure of sediment quality because it can be used as an indicator of an area's rate of eutrophication and degree of pollution. High excess carbon levels may be caused by frequent algal blooms, the deposition of excessive plant debris (e.g., from an eroding marsh), or human inputs. Elevated excess carbon may also be significant because metals and other pollutants tend to attach to organic carbon, concentrating these contaminants in the sediment. St. Martin River, Herring Creek, and Newport

Table 3-7. Percent of the Time that Dissolved Oxygen Concentrations Were Below Threshold Levels in Two Tributary Creeks Based on Continuous Monitoring Data Collected During the Summer Season (2002–2004) (Wazniak and Hall, 2005)

Site	Dissolved Oxygen Threshold Level (mg/L)	2002	2003	2004
Bishopville Prong	< 5	59%	66%	49%
	< 3	30%	47%	24%
Turville Creek	< 5	39%	39%	39%
	< 3	7%	11%	9%

Creek have excessively organic-rich sediments, which may have an impact on benthic communities. Sediments in the open-water areas of the Bays are not enriched in organic carbon (Wazniak et al., 2004; Wazniak and Hall, 2005). In 1999, the Maryland DNR conducted a pilot study of sediment toxicity in samples collected from five sites in the Coastal Bays, with subsequent toxicity studies conducted by the NCA. Overall, sediments in the study area show little evidence of toxicity (Wazniak and Hall, 2005).

Mean AET values are an evaluation criterion derived from a correlation of the weight of evidence from multiple matched chemical and biological effects data sets. AET values generally fall between the ERL and ERM values (Wazniak and Hall, 2005). The AET is used to assess the combined impact of multiple contaminants and is more sensitive to low contaminant concentrations. The AET results show a higher potential for chemical contaminants to impact living resources in the St. Martin River, Assawoman Bay, and Herring, Turville, and Newport creeks (Figure 3-108). Higher AET results can also indicate higher levels of contaminants in the sediment (Wazniak et al., 2004). Based on the AET and using NCA 2000 contaminant data, bottom sediments in the southern Maryland Coastal Bays (Sinepuxent, Newport, and Chincoteague bays) and the open water areas in Assawoman and Isle of Wight bays are not impaired by high levels of contaminants; concentrations for most metals are generally within background levels; and most organic contaminants are at trace levels or below detection limits.

Higher contaminant levels were restricted to localized areas in tributaries in the northern bays and in Newport Creek. These areas were also high in TOC (Wazniak and Hall, 2005).

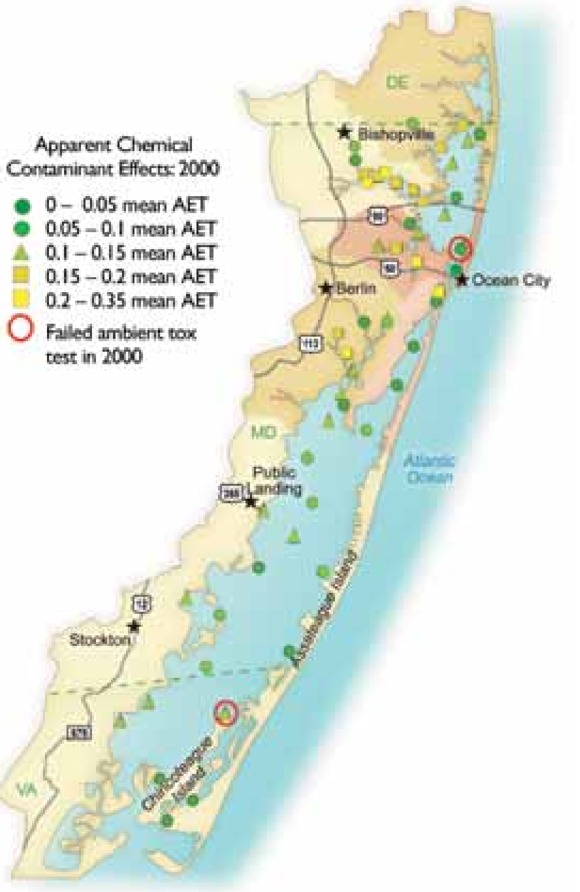


Figure 3-108. Map of mean Apparent Effects Threshold measurements for samples collected in 2000 by the Maryland Geological Survey (Wazniak et al., 2004).

Assateague Island National Seashore, Maryland (NPS).

Habitat Quality

The status and trends of seagrass, macroalgae, and wetlands habitat in the Maryland Coastal Bays have been assessed. Virginia Institute of Marine Science (VIMS) conducts an annual aerial survey of seagrass bed distribution, whereas the Maryland DNR monitors macroalgae abundance and distribution. In addition, the Maryland Department of the Environment (MDE) teams with the Maryland DNR to collect data on wetlands. Seagrasses have been increasing in the Coastal Bays and are estimated to cover 67% of the potential habitat in the Bays. The 2003 acreage of 17,942 acres represents the second-highest total documented in the Coastal Bays and an overall 320% increase since annual data collection began in 1986 (Wazniak et al., in press) (Figure 3-109). Macroalgae, also known as seaweeds, are abundant and distributed throughout the Bays (Wazniak and Hall, 2005). Some macroalgae species are occurring at harmful levels in some areas, causing such problems as blocking needed light from SAV, decreasing oxygen levels, and fouling boat propellers (Wazniak et al., 2004). Wetlands in the Coastal Bays have decreased substantially (up to 60%), especially in the northern Bays (Wazniak and Hall, 2005).

Living Resources

Fish, shellfish, and benthic communities are surveyed by the Maryland DNR and VERSAR, whereas fish kills are monitored by the MDE. There are species-specific thresholds that are used to determine if an HAB has occurred. Monitoring is also performed as needed when routine water quality indicates algae at high levels or a specific incidence occurs (e.g., fish kill, color complaint).

The Maryland Coastal Bays provide habitat for 140 species of finfish (Wazniak et al., 2004; Wazniak and Hall, 2005). Although finfish in the Bays are diverse, the forage fish index has been declining over time. This index is based on the abundance of the four most common forage species (e.g., bay anchovy, menhaden, spot, and Atlantic silverside). The decline in the forage fish index has been dominated by the decreasing abundance of spot; however, the populations of other species assessed by the index have also been slowly declining. Low dissolved oxygen levels in the Maryland Coastal Bays have caused two-thirds of fish kills (where the cause was determined), and sporadic fish kills due to low oxygen appear to be increasing in frequency (Wazniak and Hall, 2005).

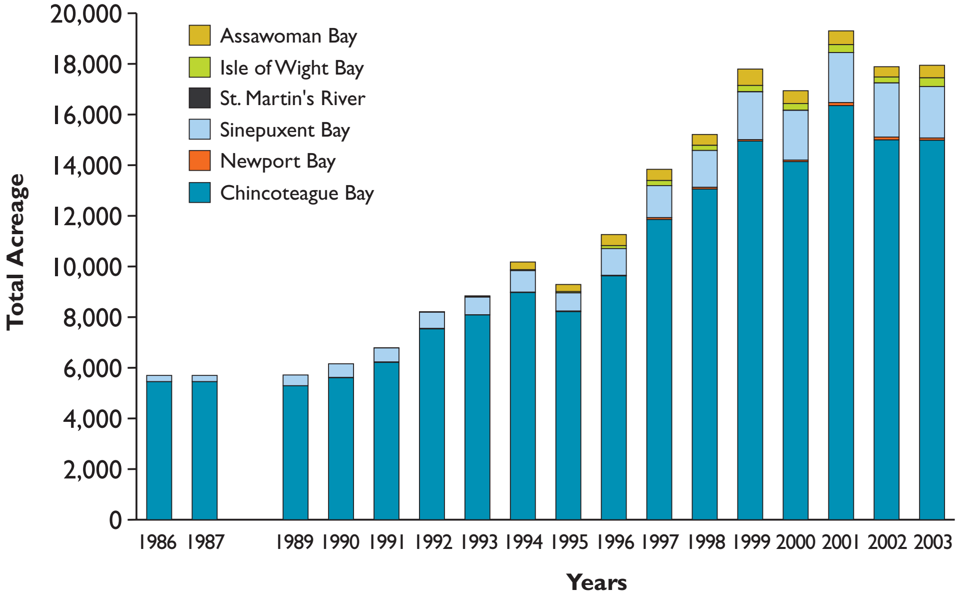


Figure 3-109. Seagrass abundance in the Maryland Coastal Bays (Wazniak and Hall, 2005).

Based on the MAIA benthic index, benthic communities are generally faring poorly in the creeks and better in the open Bays (Figure 3-110). Catches of hard clams have declined during the past three decades, but have been relatively stable for the past ten years. Bay scallops have recently returned to the area and have been found in most Bay segments, although in low numbers (Wazniak and Hall, 2005).

Between 2001 and 2003, the highest diversity of phytoplankton in the Maryland Coastal Bays occurred during the winter, with varied long-term phytoplankton trends at individual sampling sites. For example, phytoplankton abundance decreased in the St. Martin River, and phytoplankton density increased in the tributaries of the Isle of Wight Bay (Wazniak and Hall, 2005).

Certain types of algae may become harmful if they occur in large amounts as HABs or if they produce a toxin that can harm aquatic life or humans. Approximately 5% of the phytoplankton species identified in the Maryland Coastal Bays represent potential HAB species. The presence of these species is richest in the polluted tributaries of St. Martin River and Newport Bay. In recent years, brown tide (*Aureococcus anophagefferens*) has been the most widespread and prolific HAB species in the area, affecting the growth of juvenile clams in test studies and potentially impacting seagrass distribution and growth in the Bays. Although no evidence of toxic activity has been detected among the phytoplankton in Maryland Coastal Bays, some of the species found in the Bays have been responsible for positive toxic bioassays, detectable toxin levels, and/or fish kills in other areas along the eastern shore of the United States. Tracking the diversity, abundance, distribution, and toxic activity of potential HAB species over time provides important indicators of environmental change for the Coastal Bays (Wazniak and Hall, 2005).

Environmental Stressors

The Maryland DNR monitors shoreline change as an indicator of human impacts on habitat quality in the Maryland Coastal Bays. Evaluations of aerial photography taken in 1989 showed that approximately 10% of the Coastal Bays have artificially hardened shoreline (e.g., bulkheads or riprap). The percentage of hardened shoreline was higher in the northern Bays (Assawoman Bay, Isle of Wight Bay, and St. Martin River), where percentages ranged from 21% to 44% (Wazniak et al., 2004; Wazniak and Hall, 2005).

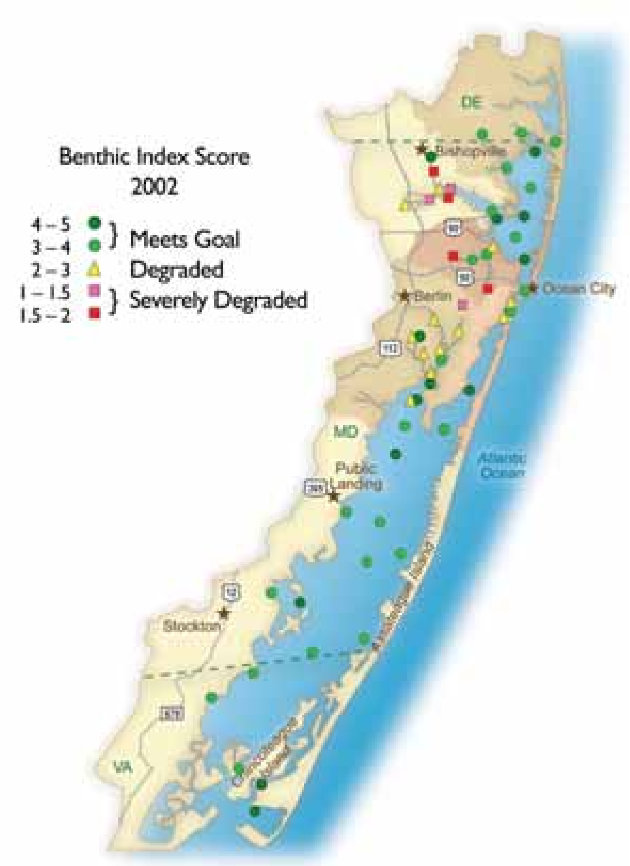


Figure 3-110. Map of 2002 MAIA benthic index results for the Maryland Coastal Bays (Wazniak et al., 2004).

Current Projects, Accomplishments, and Future Goals

Some of the recent environmental success stories and restoration efforts completed around the Coastal Bays include the following:

- The Maryland DNR's Fish Advisory Committee has completed fishery management plans for hard clams and blue crabs and has also obtained a $25,000 NOAA Coastal Services Center Grant for developing the concepts of water zoning and sanctuaries to manage resources.
- In April 2002, the Maryland Saltwater Sportfishermen's Association and local anglers coordinated a cooperative angler flounder survey to collect and assess data to promote better fishing techniques and legislation to benefit both fish and fishermen (Wazniak et al., 2004).
- Co-organized by the MCBP, the Delmarva Birding Weekend highlights the watershed's status as an internationally significant route on the Atlantic Flyway by featuring more than 27 kayaking, boating, and walking tours through the watershed and other parts of the Delmarva Peninsula. More than 500 people from 20 states attended this event in 2005 (MCBP, 2005).
- Recognizing shortcomings in state enforcement of wetland laws, Worcester County, the MCBP, planners, regulators, and wetland delineators formed the Wetland Planning Group to discuss projects, laws, and issues affecting area wetlands. The group has served as a coordinator among agencies and spawned a wetland White Paper on ways to better protect wetlands in the Coastal Bays' watershed.
- The Bishopville Restoration Project is funded under the Estuary Restoration Act of 2000 and focuses efforts to initiate restoration efforts in the upper St. Martin River, which is considered the most degraded waterbody in the Bays. The restoration project is a cooperative effort among the MCBP, Maryland DNR, USACE, State Highway Administration, and Worcester County to restore about 1,000 feet of stream and streamside vegetation and remove the existing dam at Bishopville to open the stream to fish passage (MCBP, 2005).
- Worcester County government has pursued local responsibility for achieving nutrient-reduction goals through sub-watershed planning by engaging stakeholders in each sub-watershed to develop strategies for meeting reduction goals. The new comprehensive development plan included strategies for TMDL implementation.
- The Maryland DNR has worked with the U.S. Department of Agriculture (USDA) Forest Service in programs such as Rural Legacy and Stream ReLeaf to improve forest character, develop educational outreach programs, and identify and promote programs that protect these areas (Wazniak et al., 2004).
- The MCBP has developed a homeowner's guide that provides more than 100 ways to protect the Maryland Coastal Bays.
- The MCBP has completed more than 500 news articles, 11 school projects, and 33 television spots to help educate the public about the Maryland Coastal Bays. In 2000, 11 radio shows highlighted the MCBP's efforts (ANEP, 2001b).

Conclusion

The overall condition of the Maryland Coastal Bays is rated fair based on the four indices of estuarine condition used by the NCA survey. Based on the findings of the MCBP, water and sediment quality are generally poorer in and near tributaries than in the open Bays, and, in general, most streams in the MCBP study area are degraded with excess nutrients. Higher contaminant and organic carbon levels in sediments were restricted to localized areas in tributaries in the northern Bays and in Newport Creek. Seagrass acreage has been increasing, and wetlands have been decreasing. Macroalgae communities are abundant and well distributed throughout the area; however, some macroalgae species occur at harmful levels. Although finfish in the Bays are diverse, the forage fish index has been declining over time. Overall, benthic communities are faring poorly in the creeks and better in the open Bays, and the presence of HAB species is richest in the polluted tributaries of St. Martin River and Newport Bay.