This document contains overall and specific condition of the Partnership for the Delaware Estuary from the National Estuary Program Coastal Condition Report. The entire report can be downloaded from
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National Estuary Program Coastal Condition Report

Chapter 3: Northeast National Estuary Program Coastal Condition, Partnership for the Delaware Estuary

June 2007

Partnership for the Delaware Estuary

PARTNERSHIP FOR THE DELAWARE ESTUARY INC.

www.delawareestuary.org

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.

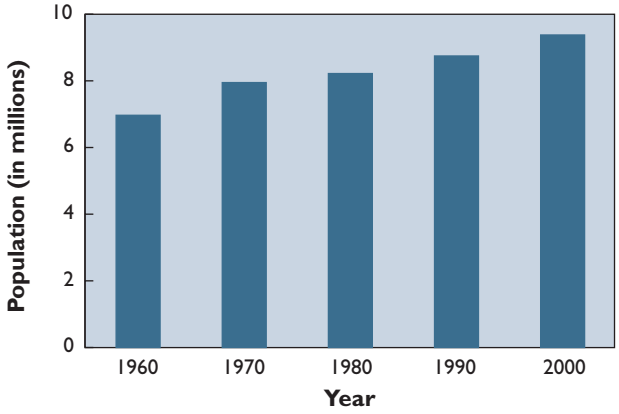

Figure 3-83. Population of NOAA-designated coastal counties of the PDE study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

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.

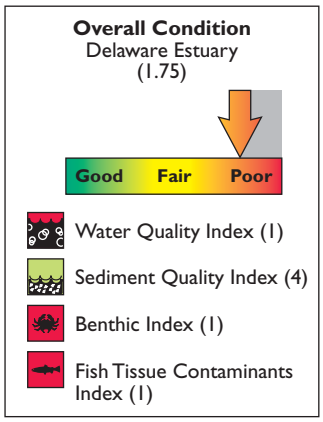

Figure 3-84. The overall condition of the PDE estuarine area is poor (U.S. EPA/NCA).

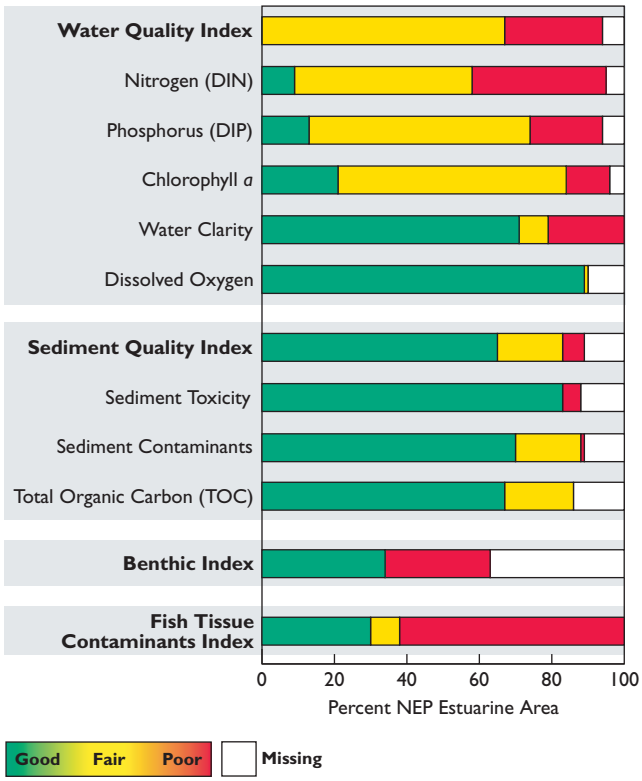

Figure 3-85. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Delaware Estuary (U.S. EPA/NCA).

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.

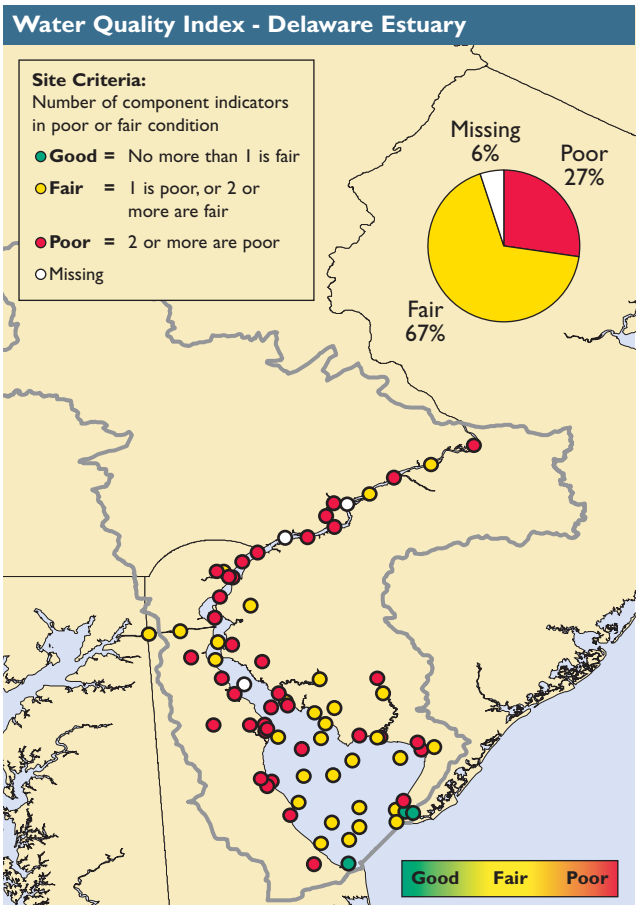

Figure 3-86. Water quality index data for the Delaware Estuary, 2000–2001 (U.S. EPA/NCA).

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.

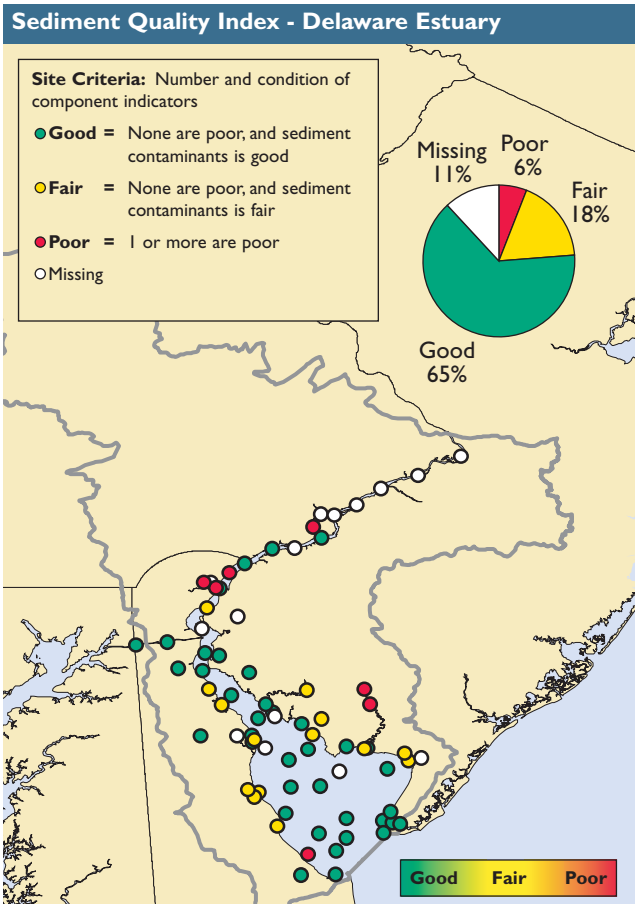

Figure 3-87. Sediment quality index data for the Delaware Estuary, 2000–2001 (U.S. EPA/NCA).

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).

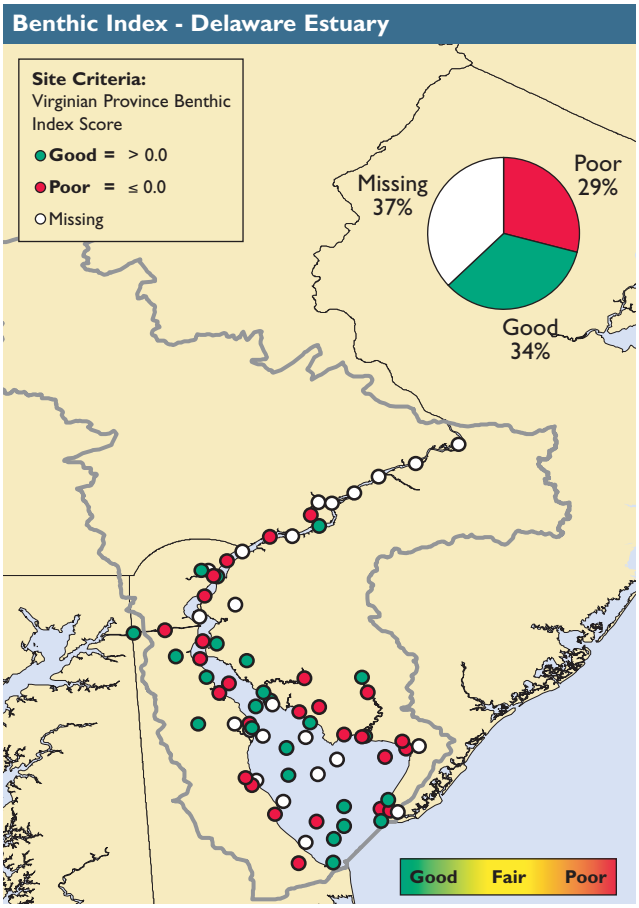

Figure 3-88. Benthic index data for the Delaware Estuary, 2000–2001 (U.S. EPA/NCA).

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.

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.

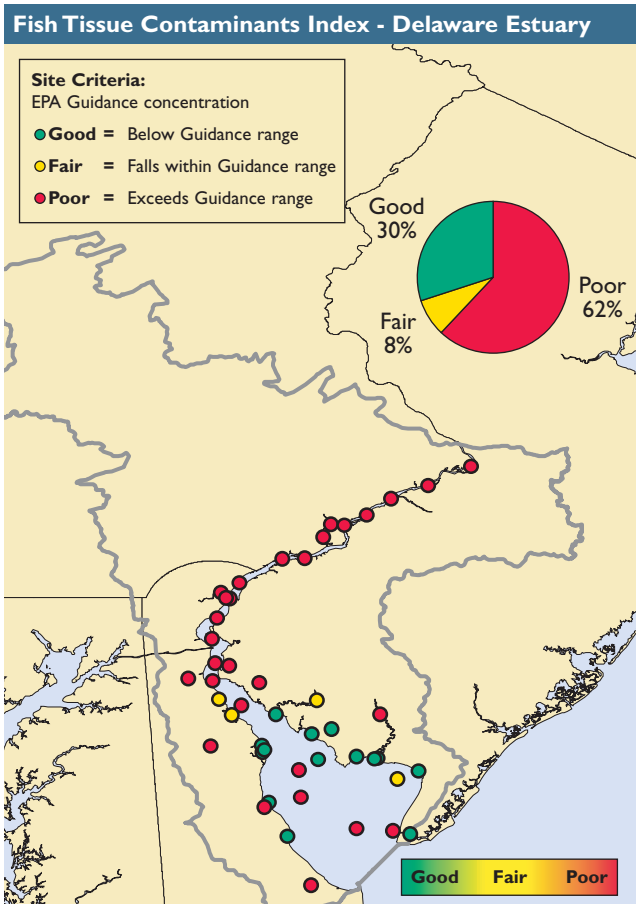

Figure 3-89. Fish tissue contaminants index data for the Delaware Estuary, 2000–2001 (U.S. EPA/NCA).

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).

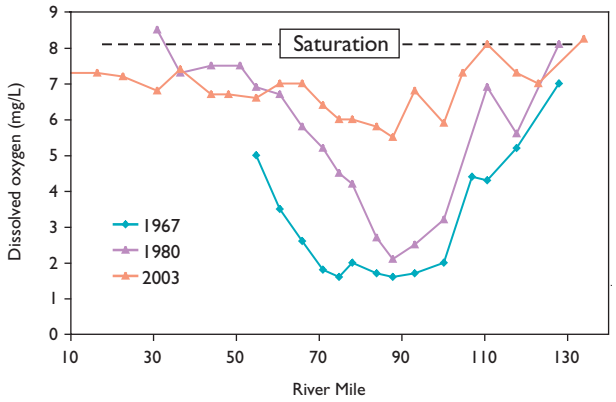

Figure 3-90. Annual dissolved oxygen levels for 1967, 1980, and 2003 along the main channel of the Delaware River from Trenton, NJ, to the mouth of the Delaware Bay (Santoro, 2004).

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).

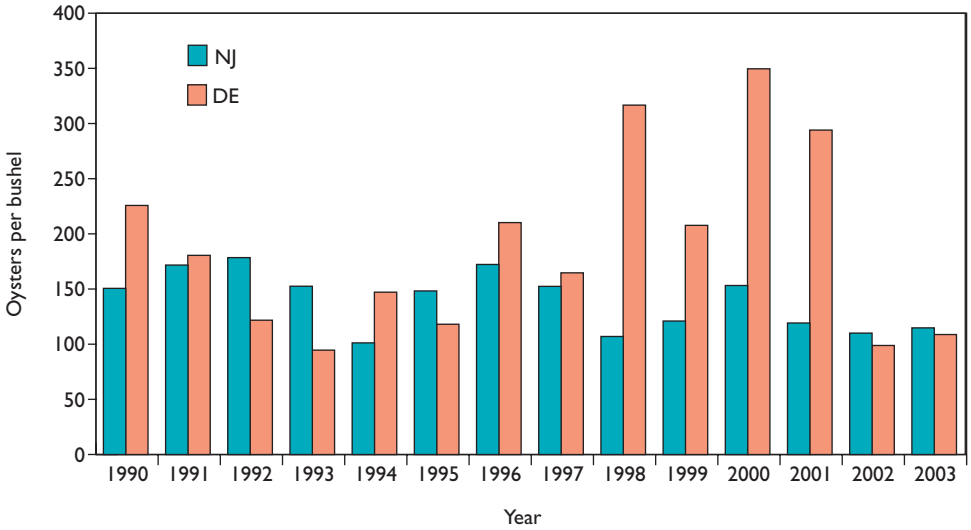

Figure 3-91. Fluctuations in oyster abundance in the Delaware Estuary (Santoro, 2004).

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).

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

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

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.