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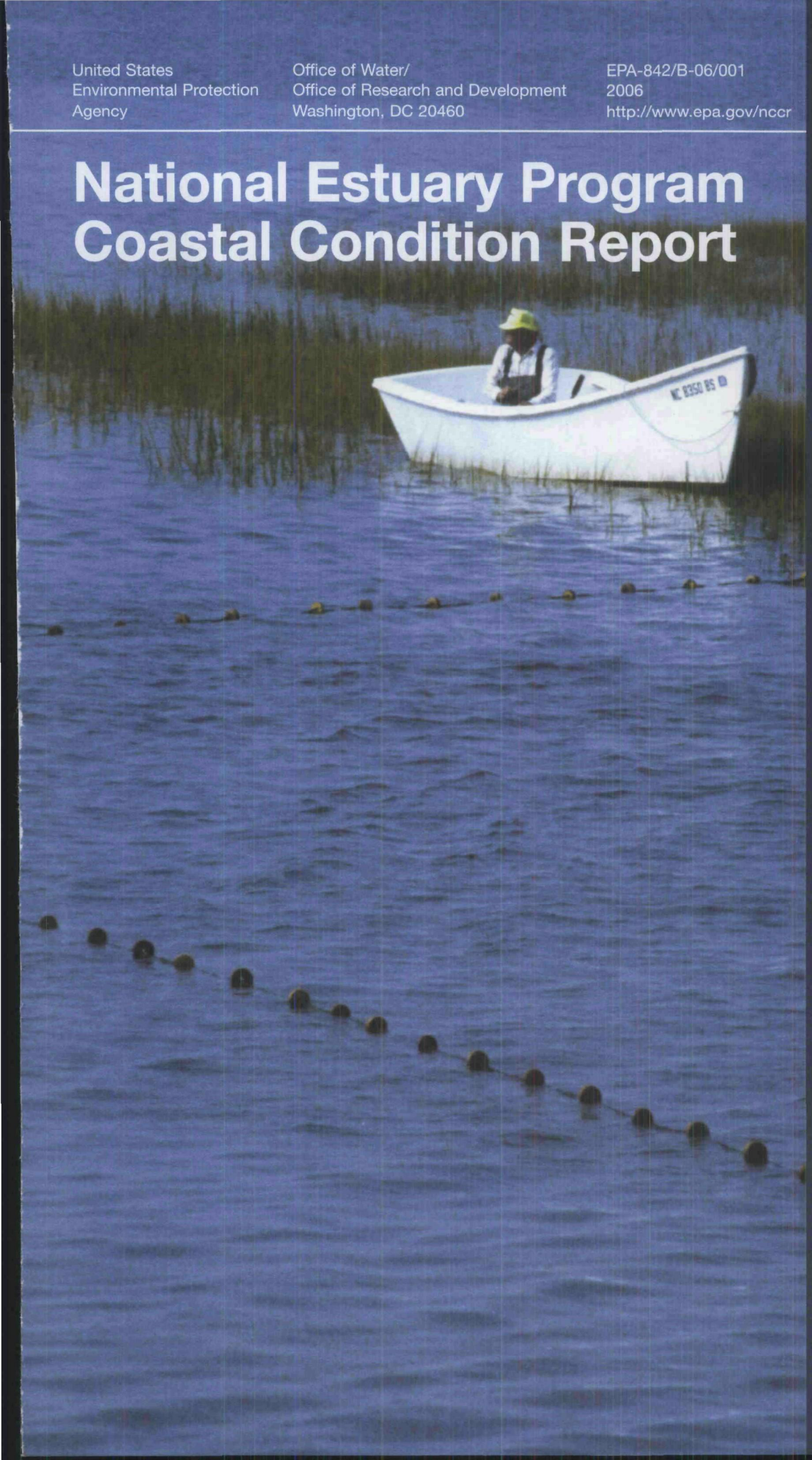

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Appendix A

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Acronyms

ADEM	Alabama Department of Environmental Management
AET	Apparent Effects Threshold
ALAMAP	Alabama Monitoring and Assessment Program
AMRAT	Alabama-Mississippi Rapid Assessment Team
APNEP	Albemarle-Pamlico National Estuary Program
BB NEP	Buzzards Bay National Estuary Program
BBNEP	Barnegat Bay National Estuary Program
BMP	best management practice
BOD	biological oxygen demand
BTNEP	Barataria-Terrebonne National Estuary Program
BYPP	Backyard Planting Program
CAFOs	confined animal feeding operations
CBB	Coalition for Buzzards Bay
CBBEP	Coastal Bend Bays and Estuaries Program
CBEP	Casco Bay Estuary Partnership
CCMP	Comprehensive Conservation and Management Plan
CCRWQCB	Central Coast Regional Water Quality Control Board
CDS	continuous deflective separation
CHNEP	Charlotte Harbor National Estuary Program
CIB	Center for the Inland Bays
CISNet	Coastal Intensive Sites Network
CLPS	Critical Lands Protection Strategy
CPF	Community Preservation Fund
CPUE	catch per unit effort
CRSSA	Center for Remote Sensing and Spatial Analysis
CSO	combined sewer overflow
CT DEP	Connecticut Department of Environmental Protection
CTR	California Toxic Rule
CZM	Coastal Zone Management
DDD	p,p'-dichlorodiphenyldichloroethane
DDE	p,p'-dichlorodiphenyldichloroethylene
DDT	p,p'-dichlorodiphenyltrichloroethane
DEP	Department of Environmental Protection
DIN	dissolved inorganic nitrogen
DIP	dissolved inorganic phosphorus
DMF	Division of Marine Fisheries
DNA	deoxyribonucleic acid

DNR	Department of Natural Resources
DNREC	Department of Natural Resources and Environmental Control
DoD	U.S. Department of Defense
DOI	U.S. Department of the Interior
DRBC	Delaware River Basin Commission
DSHS	Department of State Health Services
DWQ	Division of Water Quality
EMAP	Environmental Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
EQB	Environmental Quality Board
ERDG	Ecological Research & Development Group
ERL	effects range low
ERM	effects range median
FDA	U.S. Food and Drug Administration
FDEP	Florida Department of Environmental Protection
FIPS	Federal Information Processing Standards
FWS	U.S. Fish and Wildlife Service
FYN	Florida Yards and Neighborhoods
GAO	U.S. Government Accountability Office
GBEP	Galveston Bay Estuary Program
GCRL	Gulf Coast Research Laboratory
GIS	geographic information systems
GLO	General Land Office
GPS	Global Positioning System
HAB	harmful algal bloom
HCDOP	Hood Canal Dissolved Oxygen Program
HEP	Harbor Estuary Program
HRI	Habitat Restoration Initiative
IEC	Interstate Environmental Commission
IEP	Interagency Ecological Project
IRLNEP	Indian River Lagoon National Estuary Program
kg/yr	kilograms per year
LCREP	Lower Columbia River Estuary Partnership
LDNR	Louisiana Department of Natural Resources
LDWF	Louisiana Department of Wildlife and Fisheries
LIDAR	LIght Detection And Ranging
LISS	Long Island Sound Study
LTEIP	Long-Term Environmental Indicator Program

MAC	Manatee Awareness Coalition
MAIA	Mid-Atlantic Integrated Assessment
MAR	multiple antibiotic resistance
Massachusetts CZM	Massachusetts Office of Coastal Zone Management
MassWildlife	Massachusetts Division of Fisheries and Wildlife
MBP	Massachusetts Bays Program
MCBP	Maryland Coastal Bays Program
MCL	maximum contaminant level
MDE	Maryland Department of the Environment
MDPH	Massachusetts Department of Public Health
MFRMR	Maritime Forest Ridge and Marsh Restoration
mg/kg	milligram per kilogram
mg/L	milligram per liter
mi^2	square miles
mL	milliliter
Mobile Bay NEP	Mobile Bay National Estuary Program
Morro Bay NEP	Morro Bay National Estuary Program
MWRA	Massachusetts Water Resources Authority
NASA	National Aeronautics and Space Administration
NBEP	Narragansett Bay Estuary Program
NCA	National Coastal Assessment
NCCR I	National Coastal Condition Report
NCCR II	National Coastal Condition Report II
NCDENR	North Carolina Department of Environment and Natural Resources
NCDOT	North Carolina Department of Transportation
NEP	National Estuary Program
NEP CCR	National Estuary Program Coastal Condition Report
NERR	National Estuarine Research Reserve
NFWF	National Fish and Wildlife Foundation
NHCP	New Hampshire Coastal Program
NHEP	New Hampshire Estuaries Project
NJDEP	New Jersey Department of Environmental Protection
NJHDG	New Jersey Harbor Discharges Group
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NPS	National Park Service
NRCS	U.S. Natural Resource Conservation Service

NRDA	Natural Resource Damage Assessment
NS&T	National Status and Trends
NWI	National Wetland Inventory
NYCDEP	New York City Department of Environmental Protection
NYC DOHMH	New York City Department of Health and Mental Hygiene
NYSDEC	New York State Department of Environmental Conservation
ODEQ	Oregon Department of Environmental Quality
OEHHA	California Office of Environmental Health Hazard Assessment
ORD	Office of Research and Development
OWOW	Office of Wetlands, Oceans and Watersheds
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PDE	Partnership for the Delaware Estuary
PEP	Peconic Estuary Program
PIVOT	Performance Indicators Visualization and Outreach Tool
POTWs	publicly owned treatment works
ppm	parts per million
ppt	parts per thousand
PSAT	Puget Sound Action Team
PVSC	Passaic Valley Sewerage Commissioners
RAM	Rapid Assessment Method
RIDEM	Rhode Island Department of Environmental Management
RMP	Regional Monitoring Program for Trace Substances
SAV	submerged aquatic vegetation
SBEP	Sarasota Bay Estuary Program
SCCWRP	Southern California Coastal Water Research Project
SCDHS	Suffolk County Department of Health Services
SCWRRP	Southern California Water Resources Research Project
SET	surface elevation table
SFEI	San Francisco Estuary Institute
SFEP	San Francisco Estuary Project
SFRWQCB	San Francisco Regional Water Quality Control Board
SFWMD	South Florida Water Management District
SJBEP	San Juan Bay Estuary Partnership
SJRWMD	St. Johns River Water Management District
SMBRC	Santa Monica Bay Restoration Commission
SMBRP	Santa Monica Bay Restoration Project
SPMD	semipermeable membrane device

STAC	Scientific and Technical Advisory Committee
STOP	Stop Throwing Out Pollutants Program
STP	sewage treatment plant
SWFWMD	Southwest Florida Water Management District
SWIM	Surface Water Improvement and Management
TAC	Technical Advisory Committee
TAT	Tributary Action Team
TBBI	Tampa Bay Benthic Index
TBEP	Tampa Bay Estuary Program
TBI	The Bay Institute
TBT	tributyltin
TCEQ	Texas Commission on Environmental Quality
TEP	Tillamook Estuaries Partnership
TMDL	Total Maximum Daily Load
TOC	total organic carbon
TPWD	Texas Parks and Wildlife Department
ug/kg	microgram per kilogram
ug/L	microgram per liter
uM	micromolar
UNH	University of New Hampshire
URI	University of Rhode Island
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VIMS	Virginia Institute of Marine Studies
VMP	Volunteer Monitoring Program
VOC	volatile organic compound
WCI	Water Clarity Index
WDNR	Washington Department of Natural Resources
WDOH	Washington Department of Health
WHAT	Wetland Health Assessment Toolbox
WQI	Water Quality Index
WRP	Wetlands Restoration Program
WSDE	Washington State Department of Ecology
WWTP	wastewater treatment plant

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

Estuaries are bodies of water that provide transition zones between the fresh water from rivers and the saline environment of the ocean. The various interactions that occur between fresh water and salt water in estuaries result from the specific physical and hydrological characteristics of these waterbodies. These characteristics produce unique environments that support wildlife and fisheries and contribute substantially to the economy of the United States.

The nation's estuaries are a subset of U.S. coastal waters and encompass a wide variety of coastal habitats, including wetlands, salt marshes, coral reefs, mangrove and kelp forests, seagrass meadows, tidal mudflats, and upwelling areas. These estuarine habitats provide spawning grounds, nurseries, shelter, and food for fish, shellfish, and other wildlife species, as well as nesting, resting, feeding, and breeding habitat for 75% of waterfowl and other migratory birds.

As part of the 1987 amendments to the Clean Water Act, the Section 320 National Estuary Program (NEP) promotes comprehensive planning efforts to help protect nationally significant estuaries in the United States that are deemed to be threatened by pollution, development, or overuse. Since the inception of the program, 28 estuaries have been nominated by their respective state Governors and officially designated as NEP estuaries, and in 2007, the NEP will celebrate 20 years of restoring and protecting these nationally significant estuaries. As one of the U.S. Environmental Protection Agency's (EPA's) most successful watershed programs, the NEP demonstrates the effectiveness of a stakeholder-driven, collaborative process to address water quality problems and to target habitat restoration.

Individual NEPs are required to monitor the effectiveness of their management activities to address estuary-specific priority actions. The Clean Water Act also requires that EPA report periodically on the condition of the nation's estuarine waters. Coastal states provide EPA with valuable information about the condition of their estuarine resources; however, because the individual states and the NEPs and their partners use different approaches for data collection and the evaluation of estuarine condition, it has been difficult to compare this information among states, NEPs, or on a regional or national basis.

To better address questions about the condition of the nation's estuaries, EPA, the National Oceanic and Atmospheric Administration (NOAA), the U.S. Geological Survey (USGS), the U.S. Department of the Interior (DOI), and the U.S. Department of Agriculture (USDA) agreed to participate in a multi-agency effort to assess the condition of all U.S. estuaries, including the NEP estuaries. To minimize the problems created by compiling data collected using different sampling methods, the collaborating agencies chose to assess estuarine condition using nationally consistent monitoring surveys, the results of which are compiled periodically into a series of reports called the *National Coastal Condition Reports.*

Published in 2001, the first *National Coastal Condition Report* (NCCR I) reported that the nation's collective estuarine resources were in fair condition. This assessment was based on available data, collected from 1990 through 1996, that were used to characterize about 70% of the nation's estuarine resources. Agencies contributing data to the NCCR I included EPA, NOAA, DOI, and USDA. The second *National Coastal Condition Report* (NCCR II), published in 2004, was based on available data from 1997 to 2000 that were representative of 100% of the estuarine area of the conterminous 48 states and Puerto Rico. These data show that the nation's estuaries continue to be rated in fair condition. Agencies contributing to the NCCR II included EPA, NOAA, the U.S. Fish and Wildlife Service (FWS), and USGS, as well as several state, regional, and local organizations that provided information on the current condition of the nation's coastal waters.

The objective of this *National Estuary Program Coastal Condition Report* (NEP CCR) is to report on the condition of the nation's 28 NEP estuaries. The NEP CCR presents two major types of monitoring data for each NEP estuary: (1) data collected as part of EPA's National Coastal Assessment (NCA) and (2) data collected by the individual NEPs or by the NEPs in partnership with interested stakeholders, including state environmental agencies, universities, or volunteer monitoring groups. Together, these data paint a picture of the overall condition of the coastal resources of the nation's NEP estuaries.

The ratings developed in this report are based solely on NCA monitoring data and not the data collected by the individual NEPs. The NCA data—the most comprehensive and nationally consistent data available related to estuarine condition—were collected from 1997 through 2003 for four primary indices of estuarine condition (water quality index, sediment quality index, benthic index, and fish tissue contaminants index). These indices were assigned a good, fair, or poor rating for each NEP estuary according to the rating criteria presented in Table ES-1. These ratings were then used to create overall condition ratings for the collective NEP estuaries of each coastal region (Northeast Coast, Southeast Coast, Gulf Coast, West Coast, and Puerto Rico) and the nation (Figure ES-1). The overall condition rating for the nation's collective NEP estuaries is based on a weighted average of the regional index scores. More detailed information on the component indicators for water quality and sediment quality, when available, is also presented throughout this report.

In addition to the NCA-based assessments, this report provides individual profiles of the 28 NEP estuaries that describe the indicators each NEP uses to address specific environmental concerns, including water and sediment quality, habitat quality, living resources, and environmental stressors, as appropriate. Each profile includes background information on the NEP estuary discussed, maps of the NEP study area, and data on the population pressures that affect the study area, including the total population (2000), population density (2000), and population growth rate (1960–2000) in NOAA-designated coastal counties that are within or transect the boundaries of the study area (i.e., NEP-coincident coastal counties). A short discussion of an individual NEP's current projects, accomplishments, and future goals is also provided in each profile, as well as a Highlight article, developed by the individual NEP, that describes a representative species, program, or activity for the NEP. These profiles are not meant to be exhaustive or comprehensive reports, but are included to provide the reader with a perspective about the variety of habitats and species that each NEP estuary shelters, the salient or unique aspects about the nature of the estuary, the problems of most concern to local stakeholders, and the ongoing and planned initiatives to continue monitoring and managing the environmental health of the estuary. The monitoring data derived from the NEPs will be used to develop an effective management plan for protecting and improving the condition of the nation's NEP resources.

Estuaries are critical for the survival of a number of species, including the Brown Pelican, which nests and breeds along the nation's coasts (John Theilgard).

Describing Estuarine Condition

This report presents two types of monitoring data to provide a perspective on the condition of the nation's NEP estuaries: data collected by the NCA and data collected by the individual NEPs and their partners.

National Coastal Assessment (NCA) Monitoring Data

The monitoring data derived from EPA's NCA are used exclusively in this report to develop indices of estuarine condition for the 28 NEP estuaries and to calculate regional and national ratings of NEP estuarine condition. The NCA survey was designed to assess the percentage of the nation's estuaries and coastal waters exhibiting poor, fair, or good condition using consistent and comparable environmental indicators, and data from this survey was used for the NCCR series, which includes this NEP CCR. The probability survey design, indices, and component indicators of the NCA survey are appropriate to assess estuarine condition at state, regional (e.g., Gulf Coast), or national scales. When probability survey designs incorporate geographic areas smaller than a state, as in the case of the NEPs, assessments can be made of the condition of each strata, provided a sufficient number of samples were taken to achieve the desired confidence level.

The NCA sampled a minimum of 20 (typically 35–50) monitoring sites to assess the condition of each NEP estuary. Twelve hundred and thirty-nine NCA sites were sampled in the NEP estuarine areas. In addition, the NCA was designed to assess condition during the summer season, when estuaries are expected to be the most stressed (i.e., highest water temperature). These data are also used to determine reference conditions to assess ecological responses to stressors and to set state nutrient criteria.

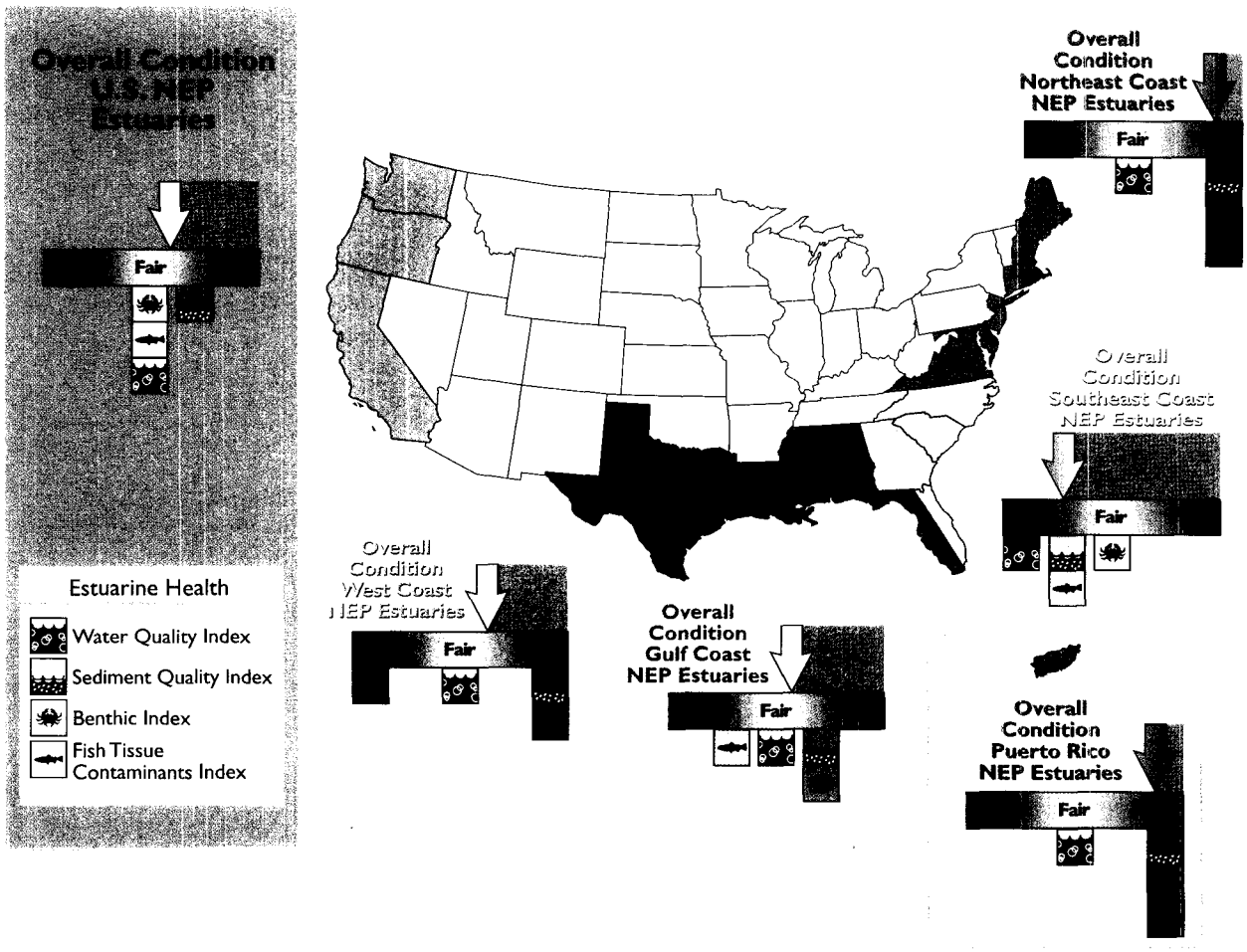
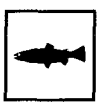


Figure ES-1. National and regional overall condition ratings for NEP estuaries based on NCA results (1997–2003).

Table ES-1. NCA Indices Used to Assess Estuarine Condition

Icon			
Water Quality Index	**Water Quality Index**—This index is based on five water quality component indicators (dissolved inorganic nitrogen [DIN], dissolved inorganic phosphorus [DIP], chlorophyll *a*, water clarity, and dissolved oxygen).		
	Ecological Condition by Site		**Ranking by NEP Estuary or Region**
	Good: No component indicators are rated poor, and a maximum of one component indicator is rated fair.		**Good:** Less than 10% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.
	Fair: One component indicator is rated poor, or two or more component indicators are rated fair.		**Fair:** 10% to 20% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.
	Poor: Two or more component indicators are rated poor.		**Poor:** More than 20% of the NEP estuarine area is in poor condition.
Sediment Quality Index	**Sediment Quality Index**—This index is based on three sediment quality component indicators (sediment toxicity, sediment contaminants, and sediment total organic carbon [TOC]).		
	Ecological Condition by Site		**Ranking by NEP Estuary or Region**
	Good: No component indicators are rated poor, and the sediment contaminants indicator is rated good.		**Good:** Less than 5% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.
	Fair: No component indicators are rated poor, and the sediment contaminants indicator is rated fair.		**Fair:** 5% to 15% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.
	Poor: One or more component indicators are rated poor.		**Poor:** More than 15% of the NEP estuarine area is in poor condition.
Benthic Index	**Benthic Index** (or a surrogate measure)—This index indicates the condition of the benthic community (organisms living in estuarine sediments) and can include measures of benthic community diversity, the presence and abundance of pollution-tolerant species, and the presence and abundance of pollution-sensitive species.		
	Ecological Condition by Site		**Ranking by NEP Estuary or Region**
	Good, fair, and **poor** were determined using regionally dependent benthic index scores.		**Good:** Less than 10% of the NEP estuarine area has a poor benthic index score, and more than 50% of the NEP estuarine area has a good benthic index score.
			Fair: 10% to 20% of the NEP estuarine area has a poor benthic index score, or more than 50% of the NEP estuarine area has a combined poor and fair benthic index score.
			Poor: More than 20% of the NEP estuarine area has a poor benthic index score.
 Fish Tissue Contaminants Index	**Fish Tissue Contaminants Index**—This index indicates the level of chemical contamination in target fish/shellfish species.		
	Ecological Condition by Site		**Ranking by NEP Estuary or Region**
	Good: For all chemical contaminants listed in Table 1-21 (Chapter 1), composite fish tissue contaminant concentrations are below the EPA Advisory Guidance* concentration range.		**Good:** Less than 10% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in poor condition, and more than 50% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in good condition.
	Fair: For at least one chemical contaminant listed in Table 1-21, composite fish tissue contaminant concentrations are within the EPA Advisory Guidance concentration range.		**Fair:** 10% to 20% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in poor condition, or more than 50% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in combined poor and fair condition.
	Poor: For at least one chemical contaminant listed in Table 1-21, composite fish tissue contaminant concentrations are above the EPA Advisory Guidance concentration range.		**Poor:** More than 20% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in poor condition.

*The EPA Advisory Guidance concentration is based on the non-cancer ranges for all contaminants except PAH (benzo(a)pyrene), which are based on a cancer range because a non-cancer range for PAHs does not exist (see Table 1-21, Chapter 1).

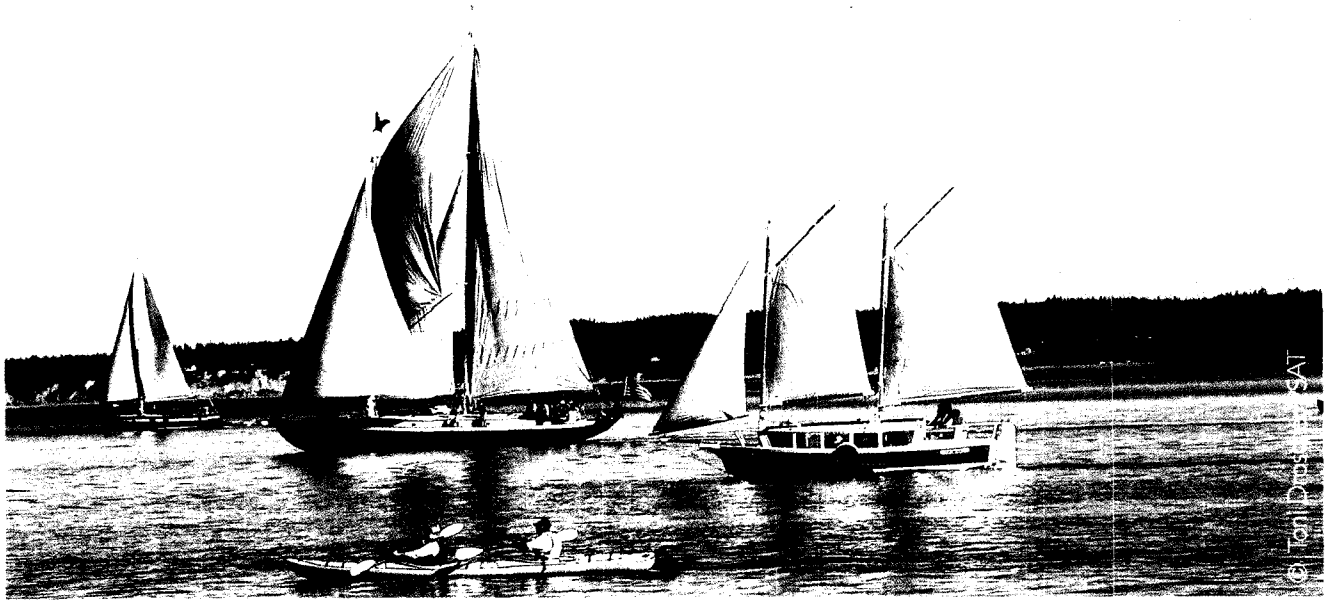
Given the parameters of the NCA methodology, the NEP CCR is not designed to assess the temporal variability or extent (i.e., how often within a summer these conditions exist or the area affected) of highly variable water quality parameters (e.g., nutrient, chlorophyll *a*, or dissolved oxygen concentrations). In addition, the report does not provide the specific location of poor, fair, or good conditions, but rather the proportion of a larger area that exhibits such conditions, nor does it answer local estuary-specific management questions regarding the location, temporal extent, or frequency of degraded conditions for rapidly changing parameters.

This report is appropriate for defining the percentage of the nation's NEP waters (nationally, regionally, and on an individual estuary basis) that exhibit poor, fair, or good conditions for fairly stable summer characteristics, such as sediment contaminant levels and benthic condition, which often reflect conditions integrated over months or even years. However, to maintain NCA monitoring at a reasonable cost, measurements were taken one time per sampling site during the summer over a modest number of sites; therefore, the resulting NCA survey data provide a less accurate view of the ephemeral conditions associated with an estuary's water column, where water quality conditions may change weekly, daily, or even hourly during a summer sampling period.

National Estuary Program (NEP) Monitoring Data

To assess the overall condition of each NEP estuary, the NCA data should be evaluated in addition to data collected locally by the NEPs over a longer time period and at more sampling locations. For example, degraded benthic condition may not necessarily be caused solely by the high sediment contaminant levels measured by the NCA, but may also be caused by short-term stresses, such as sporadic hypoxia or algal blooms. The NCA "snapshot" approach may not capture these stresses because they occur outside the summer diurnal sampling period; therefore, an assessment of NEP-specific data is necessary.

The NEP monitoring data are derived from the individual NEPs and are discussed in this report to provide information on NEP monitoring methods and indicators developed to address site-specific estuarine concerns. Because these data are collected using methods unique to each individual NEP, they generally cannot be used to make comparisons among estuaries at the regional or national level. A summary of the data is provided in the individual NEP profiles in the hope that information about the types of indicators that have been developed, implemented, and found to be effective in assessing spatial and temporal trends for one NEP estuary will also prove useful to other NEPs.



Boating, fishing, swimming, and bird watching are just a few of the numerous recreational activities that people enjoy in estuaries (Toni Droscher, PSAT).

To find out if there is an NEP in your coastal area and to obtain detailed environmental monitoring data for the 28 NEP estuaries, please visit www.epa.gov/owow/estuaries, www.nationalestuaries.org, or www.epa.gov/emap.

Summary of Findings

With this NEP CCR, the collaborating agencies and the individual NEPs strive to provide a benchmark of estuarine condition that paints a comprehensive picture of the nation's NEP estuaries. The report indices are based on the large amount of NCA monitoring data collected from 1997 through 2003 on the condition of the nation's NEP estuaries. NCA rating scores for estuarine condition are based on a 5-point system, where a score of less than 2.0 is rated poor; 2.0 to less than 2.3 is rated fair to poor; 2.3 to 3.7 is rated fair; greater than 3.7 to 4.0 is rated good to fair; and greater than 4.0 is rated good.

The major findings of this report are as follows:

- An assessment of the ecological monitoring data shows that the overall condition of the nation's NEP estuaries is generally fair (2.7), but that regionally, the Puerto Rico (1.5) and Northeast Coast (1.5) regions are rated poor, the Gulf Coast (2.75) and West Coast (2.5) regions are rated fair, and the Southeast Coast region is rated good to fair (4.0) for overall condition (Table ES-2). The overall condition ratings for the nation's NEP estuaries are based on four primary indices of estuarine condition—a water quality index, sediment quality index, benthic index, and fish tissue contaminants index.
- The **water quality index** for the nation's collective NEP estuaries is rated fair (3.6), with the Northeast Coast (3.0), Gulf Coast (3.0), West Coast (3.0), and Puerto Rico (3.0) regions rated fair and the Southeast Coast region (5.0) rated good for this index. Water quality data, including data on the five component indicators (DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen), were available for all NEP estuaries of the United States.
- The **sediment quality index** for the nation's collective NEP estuaries is rated fair to poor (2.1), with the Northeast Coast (1.0), West Coast (1.0), and Puerto Rico (1.0) regions rated poor; the Gulf Coast region (2.0) rated fair to poor; and the Southeast Coast region (4.0) rated good to fair for this index. Sediment quality index ratings were based on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC. For some NEPs, two of the three component indicators for assessing sediment quality were not monitored, and the sediment quality index was based solely on the measurement of one component indicator. Typically, sediment TOC

Table ES-2. Regional and National Rating Scores[a] for Indices of Estuarine Condition and Overall Condition for the Nation's NEP Estuaries

Index	Northeast Coast	Southeast Coast	Gulf Coast[b]	West Coast	Puerto Rico[c]	United States[d]
Water Quality Index	3	5	3	3	3	3.6
Sediment Quality Index	1	4	2	1	1	2.1
Benthic Index	1	3	2	5	1	2.7
Fish Tissue Contaminants Index	1	4	4	1	1	2.6
Overall Condition	**1.5**	**4.0**	**2.75**	**2.5**	**1.5**	**2.7**

[a] Rating scores are based on a 5-point system, where a score of less than 2.0 is rated poor; 2.0 to less than 2.3 is rated fair to poor; 2.3 to 3.7 is rated fair; greater than 3.7 to 4.0 is rated good to fair; and greater than 4.0 is rated good.

[b] This rating score does not include the impact of the hypoxic zone in offshore Gulf Coast waters.

[c] This rating score includes only San Juan Bay Estuary, Puerto Rico.

[d] The U.S. score is based on an areally weighted mean of the regional index scores.

was more consistently monitored among sites than sediment toxicity or sediment contaminant concentrations. The NCA did not evaluate the Peconic Estuary for sediment quality, and only sediment TOC data were available for the four NEP estuaries located in Florida (Indian River Lagoon, Charlotte Harbor, Sarasota Bay, and Tampa Bay).

- The **benthic index** for the nation's collective NEP estuaries is rated fair (2.7), with the Northeast Coast (1.0) and Puerto Rico (1.0) regions rated poor, the Gulf Coast region (2.0) rated fair to poor, the Southeast Coast region (3.0) rated fair, and the West Coast region (5.0) rated good for this index. Benthic indices were developed for the NEP estuaries of the Northeast Coast, Southeast Coast, and Gulf Coast regions, and benthic community diversity was used as a surrogate indicator of biological condition for the West Coast and Puerto Rico regions. No assessment was possible using the benthic community diversity indicator for three West Coast estuaries (Lower Columbia River Estuary, Morro Bay, and Santa Monica Bay).
- The **fish tissue contaminants index** for the nation's collective NEP estuaries is rated fair (2.6), with the Northeast Coast (1.0), West Coast (1.0), and Puerto Rico (1.0) regions rated poor, and the Southeast Coast (4.0) and Gulf Coast (4.0) regions rated good to fair for this index. NCA data for the fish tissue contaminants index were not available for several of the NEP estuaries, including Casco Bay, the Indian River Lagoon, Charlotte Harbor, Sarasota Bay, and Tampa Bay.
- Nationally, 37% of the NEP estuaries are in poor overall condition (Table ES-3, Figure ES-2). Regionally, roughly 100% of Puerto Rico's NEP estuary (San Juan Bay Estuary) is in poor overall condition, and 46% of the Northeast Coast, 46% of the Gulf Coast, 36% of the West Coast, and 23% of the Southeast Coast NEP estuaries are in poor overall condition.

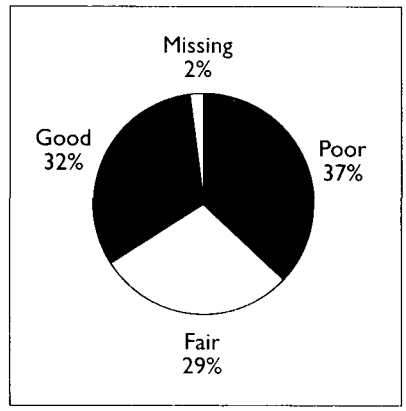


Figure ES-2. Overall condition data for U.S. NEP estuaries (U.S. EPA/NCA).

Comparison of NEP Estuaries with All U.S. Estuaries

A primary goal of the NCCR series is to provide a benchmark of estuarine condition to measure the success of estuarine programs over time. To achieve this goal, the conditions reported in the NCCR series and the NEP CCR need to be comparable. Comparing data between the NCCR II (inclusive of both NEP and non-NEP estuaries) and the NEP CCR is complicated because, in some cases, common indicators were not available for both reports. For example, the NCCR II used five environmental indices to determine coastal condition—water quality, sediment quality, benthic

Table ES-3. Percent of NEP Estuarine Area in Poor Condition by Index and Region

Index	Northeast Coast	Southeast Coast	Gulf Coast	West Coast	Puerto Rico	United States
Water Quality Index	9	4	13	4	8	8
Sediment Quality Index	21	6	15	17	33	15
Benthic Index	26	15	20	4	65	17
Fish Tissue Contaminants Index	38	10	12	32	40	23
Overall Condition	**46**	**23**	**46**	**36**	**100**	**37**

condition, fish tissue contaminant concentrations, and coastal habitat condition; however, information on coastal habitat condition was not available for the current NEP CCR. To facilitate a comparison between the two reports, the rating scores for the NCA indices reported in the NCCR II were recalculated, to the extent possible, using the methods followed in the NEP CCR. The coastal habitat index and its effect on regional and national ratings were excluded from the NCCR II scores presented in this report. Table ES-4 summarizes the rating scores by index and region, comparing the NCCR II and the NEP CCR results.

Table ES-4 shows that the overall condition score for the nation's collective NEP estuaries is 2.7 (rated fair); this score is comparable to the overall condition score of 2.6 (rated fair) for all U.S. estuaries (both NEP and non-NEP estuaries). On a national basis, it appears that the collective NEP estuaries score slightly higher for two of the four indices (water quality index and benthic index) than the scores for all U.S. estuaries, comparably for the fish tissue contaminants index, and slightly lower for the sediment quality index.

Regionally, the rating results are somewhat mixed when comparing NEP estuaries to all U.S. estuaries, although the regional overall condition scores are not appreciably different between the two groups (within 0.25 points or less of the corresponding score). For example, the regional overall condition scores for the NEP estuaries are higher for the Northeast Coast and West Coast regions, comparable for the Southeast Coast and Gulf Coast regions, and lower for Puerto Rico than the regional overall condition scores for all estuaries (both NEP and non-NEP).

It is noteworthy that the most complete data set collected in the NCA was for the water quality index, whereas data for the sediment quality index (predominately for the sediment toxicity and sediment contaminants component indicators), benthic index, and fish tissue contaminants index were missing for some NEPs.

EPA's *Clean Water State Revolving Fund Programs 2005 Annual Report* noted that significant improvements in wastewater treatment plants (WWTPs) since 1987 have resulted in expanded capacity for secondary and tertiary treatment of wastewater to remove nutrients, heavy metals, and organic contaminants. These strides, coupled with more stringent water quality standards for industrial dischargers, have resulted in water quality improvements in many areas; however, the legacy of contamination remains in the sediments of many estuaries as byproducts of the Industrial Revolution and years of discharging without the protective mandates of the Clean Water Act. This residual contamination may result in reduced benthic community health and in the bioaccumulation of chemical contaminants in fish and shellfish tissues.

Table ES-4. Regional and National Rating Scores* by Index for All U.S. Estuaries (NCCR) and for NEP Estuaries

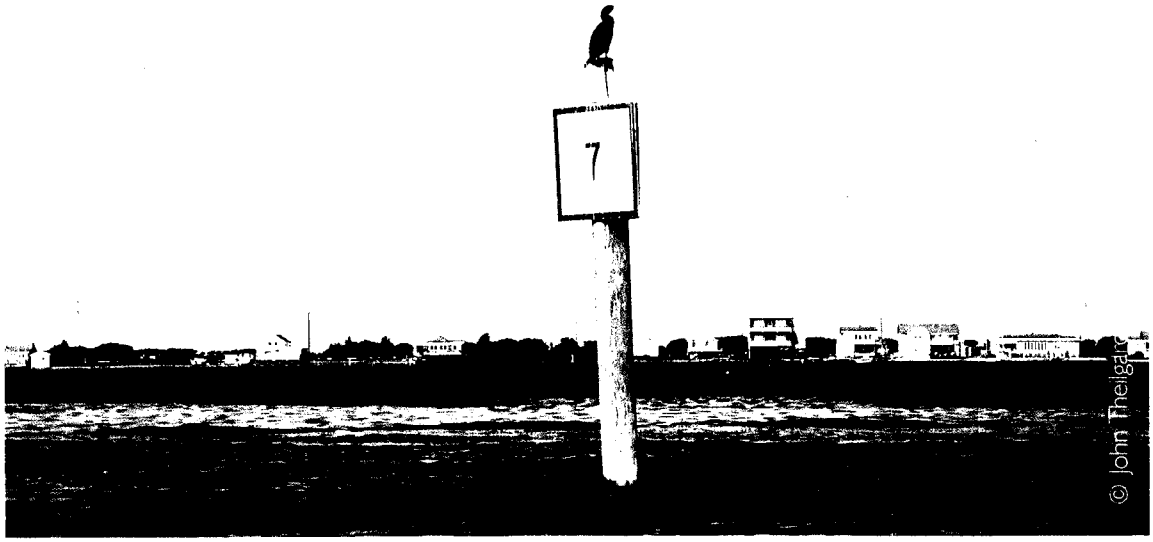
	Northeast Coast		Southeast Coast		Gulf Coast		West Coast		Puerto Rico		United States	
Index	**NCCR**	**NEP**	**NCCR**	**NEP**	**NCCR**	**NEP**	**NCCR**	**NEP**	**NCCR**	**NEP**	**NCCR**	**NEP**
Water Quality Index	2	3	4	5	3	3	3	3	3	3	3.0	3.6
Sediment Quality Index	1	1	4	4	3	2	2	1	1	1	2.6	2.1
Benthic Index	1	1	3	3	2	2	3	5	1	1	2.2	2.7
Fish Tissue Contaminants Index	1	1	5	4	3	4	1	1	NA	1	2.6	2.6
Overall Condition	1.25	1.50	4.0	4.0	2.75	2.75	2.25	2.50	1.67	1.50	2.6	2.7

* Rating scores are based on a 5-point system, where a score of less than 2.0 is rated poor; 2.0 to less than 2.3 is rated fair to poor; 2.3 to 3.7 is rated fair; greater than 3.7 to 4.0 is rated good to fair; and greater than 4.0 is rated good.

Population Pressures Affecting the NEPs

Population pressures on coastal counties coincident with the individual NEP study areas or collectively on NEP-coincident coastal counties within a specific region were evaluated with respect to both temporal and spatial perspectives using total population (2000), population density (2000), and percent population growth rate (1960–2000). Total population provides a perspective of the total number of individuals using the various resources within the NEP-coincident coastal counties at any point in time, and population density provides a measure of how saturated the associated NEP-coincident coastal counties are with respect to human development. The population growth rate over a specific time interval provides an indication of how quickly human development in an area occurs and the coinciding infrastructure development that would be needed to provide for the associated residential and commercial development and services. When assessed collectively, these population measures provide information about the pressures exerted by society on the NEP coastal ecosystems.

Regionally, the NEP-coincident coastal counties of the Northeast Coast region contained the highest total population in 2000 (38 million), followed by the West Coast (30 million), Gulf Coast (11 million), and Southeast Coast (3 million) regions. Population density values also showed that the NEP-coincident coastal counties of the Northeast Coast region have the highest regional density (1,055 persons/mi^2), followed by the West Coast (421 persons/mi^2), Gulf Coast (287 persons/mi^2), and Southeast Coast (168 persons/mi^2) regions. By comparison, Puerto Rico had the highest population density in 2000 of any NEP region (5,055 persons/mi^2). In contrast, population growth rates for these same regional areas show a different pattern, with the Gulf Coast region having the highest growth rate (133%), closely followed by the Southeast Coast (131%) and West Coast (100%) regions, and lastly by the Northeast Coast (24%) region.



Estuarine waters serve as habitat and breeding areas for hundred of species of birds and other wildlife (John Theilgard).

Correlation Between NEP CCR Index Scores and Population Pressures

Population data reveal some patterns for both total population and population density with respect to population pressures within the NEP-coincident coastal counties. As shown in Table ES-5, when the population in the coastal counties is greater than 2 million people, as it is for 11 NEPs, the overall condition scores for these NEPs range from 1.0 (rated poor) to 3.0 (rated fair), with a mean score of 2.26 (rated fair to poor). For the 8 NEPs with populations between 1 to 2 million people, the overall condition scores range from 1.5 (rated poor) to 5.0 (rated good), with a mean score of 3.30 (rated fair). For the 9 NEPs with populations less than 1 million people, the overall condition scores range from 1.75 (rated poor) to 5.0 (rated good), with a mean score of 3.45 (rated fair). Although it is clear that the NEPs with the highest populations (> 2 million) showed the lowest overall condition scores, as well as scores with the smallest range of values, the overall condition scores for the other two population groups varied widely; however, the mean overall condition scores tended to be slightly higher in the NEPs with the lowest total population.

The population density results (Table ES-6) are very similar to the total population results. For the 5 NEPs with population densities greater than 1,000 persons/mi^2 in NEP-coincident coastal counties, the overall condition scores range from 1.0 (rated poor) to 4.33 (rated good), with a mean score of 2.16 (rated fair to poor). For the 8 NEPs with population densities ranging from 500 to 1,000 persons/mi^2, the overall condition scores range from 1.75 (rated poor) to 3.5 (rated fair), with a mean score of 2.58 (rated fair). Finally, for the 15 NEPs with the lowest population densities (less than 500 persons/mi^2), the overall condition scores range from 1.75 (rated poor) to 5.0 (rated good), with a mean score of 3.39 (rated fair). A slight difference among the three population density groups shows an increase in the mean overall condition scores as the population density decreases.

Although the mean overall condition scores based on total population and population density within the NEP-coincident coastal counties appear to exhibit some patterns, it should be noted that within any of the total population groups (Table ES-5) or population density groups (Table ES-6), there is a high degree of variability in the overall condition scores for the individual NEPs that can be inconsistent with the patterns exhibited in the mean overall condition scores.

Table ES-5. Comparison of Total Population of NEP-Coincident Coastal Counties with the NCA Mean Overall Condition Scores for the NEP Estuaries

Total Population of NEP-Coincident Coastal Counties	Range in NCA Overall Condition Scores Observed	NCA Mean Overall Condition Score	Number of NEP Estuaries
> 2 million	1.0–3.0	2.26	11
1–2 million	1.5–5.0	3.30	8
< 1 million	1.75–5.0	3.45	9

Table ES-6. Comparison of Population Density of NEP-Coincident Coastal Counties with the NCA Mean Overall Condition Scores for the NEP Estuaries

Population Density of NEP-Coincident Coastal Counties	Range in NCA Overall Condition Scores Observed	NCA Mean Overall Condition Score	Number of NEP Estuaries
> 1,000 persons/mi^2	1.0–4.33	2.16	5
500–1,000 persons/mi^2	1.75–3.5	2.58	8
< 500 persons/mi^2	1.75–5.0	3.39	15

NEP Environmental Concerns

The NEP estuaries have been affected by a wide variety of environmental concerns, several of which have been adopted by the NEPs as priority management activities for their respective estuaries. For this report, more that two dozen major environmental concerns were identified by the NEPs, including the following:

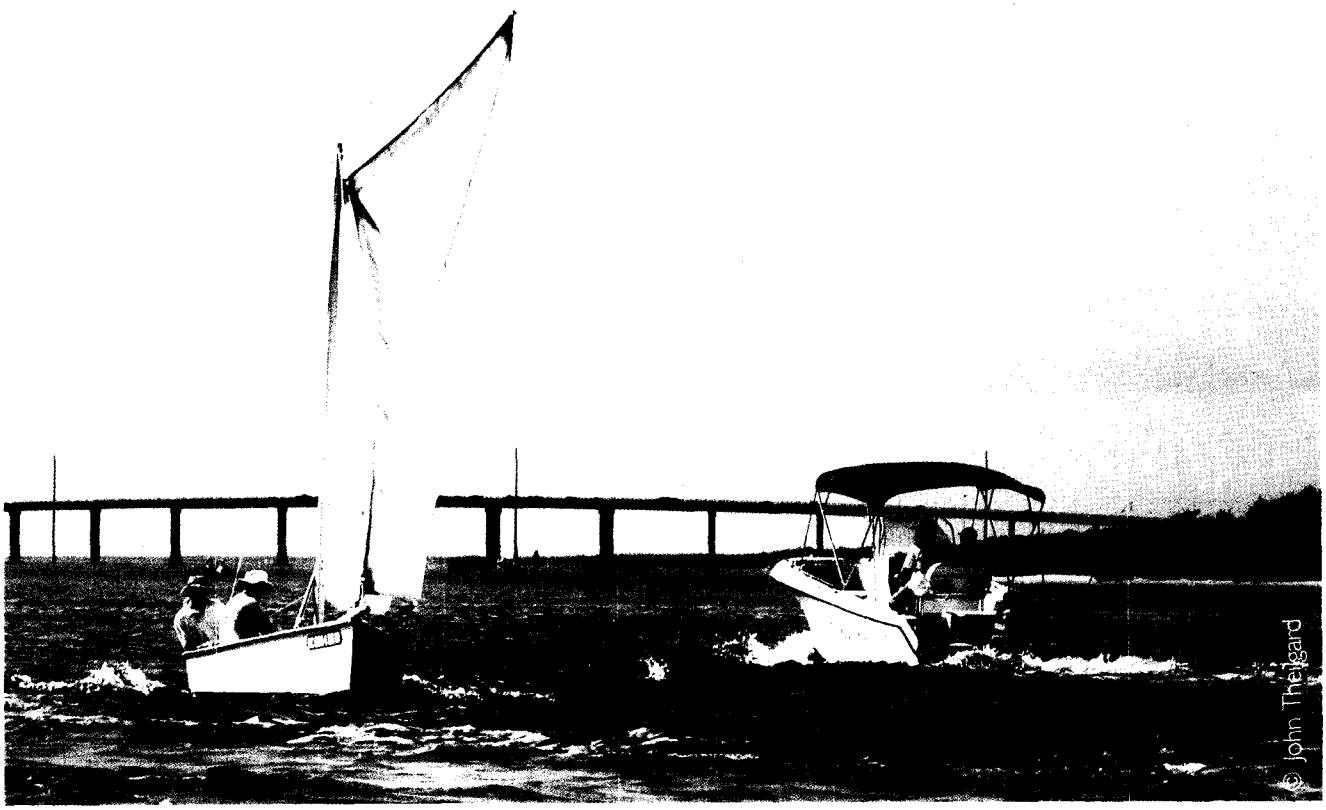
- Habitat loss/alteration
- Declines in fish and wildlife populations
- Excessive nutrients
- Toxic chemical contaminants
- Pathogens
- Alteration of freshwater flows
- Introduction of invasive species.

Some environmental concerns have commonality in many NEPs, whereas others are more NEP-specific because they relate to the unique climactic, hydrologic, geologic, or geomorphologic conditions associated with an individual estuary. Figure ES-3 shows a variety of environmental concerns identified by the 28 NEPs.

Shortcomings of Available Data

This NEP CCR provides estimates of estuarine condition on a national, regional, and individual scale for the 28 NEP estuaries. These estimates are based on nationally consistent and comparable NCA data on four primary indices of estuarine condition. For about one-third of the NEP estuaries, however, complete data on all four NCA indices were not available. As a result, an NEP estuary and its respective region may have received either a higher or a lower overall condition score and rating than would have been achieved if the missing data were available for use in the analysis of estuarine condition. This report makes the best use of the available NCA data to characterize and assess the condition of the nation's NEP estuaries; however, it cannot represent all individual NEP estuarine systems at all of the appropriate temporal and spatial scales necessary to assess the overall condition of the these estuaries.

In addition to the NCA data presented in this report, the individual NEPs have also been mandated the responsibility of monitoring environmental conditions in their individual estuaries to assess whether the



U.S. coastal areas are home to roughly 40% of the U.S. population (John Theilgard).

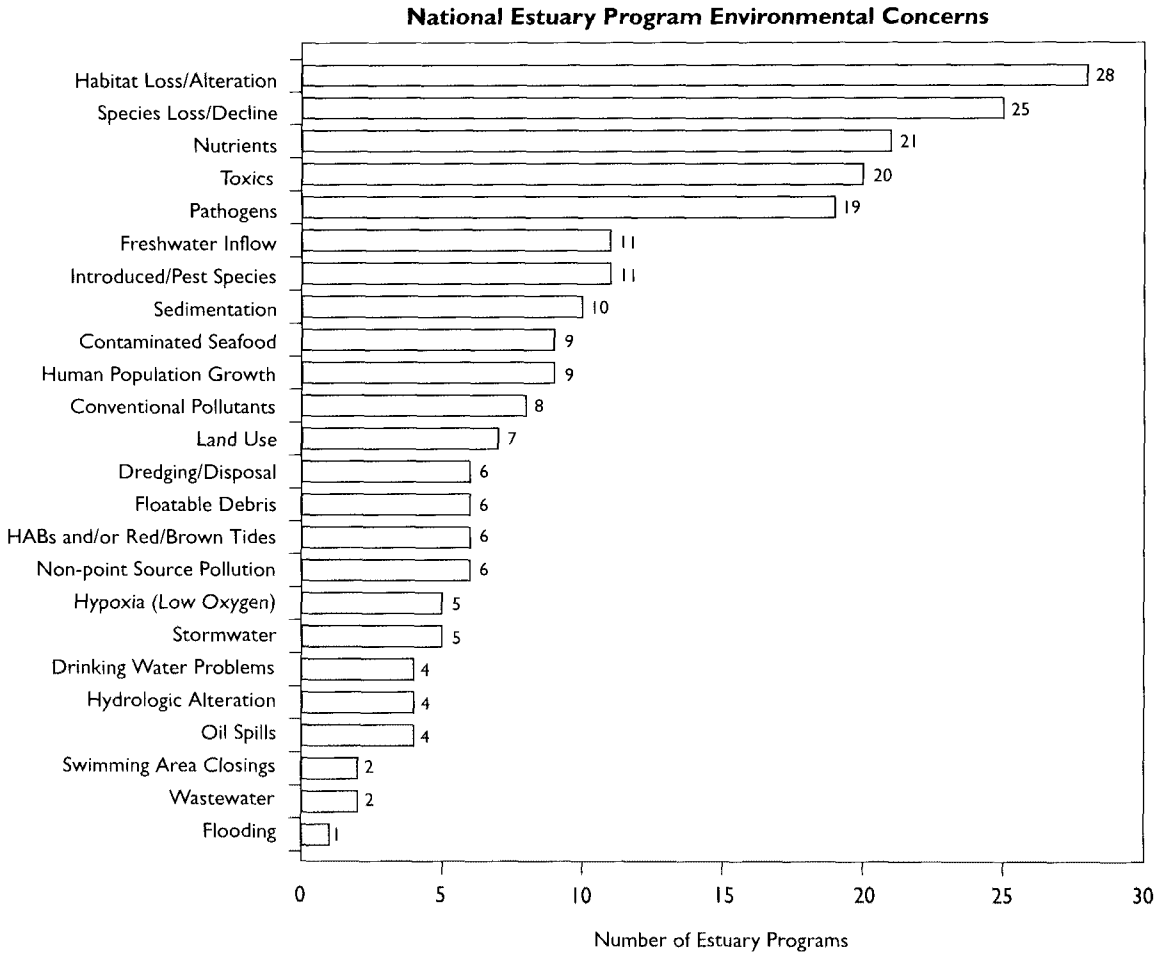


Figure ES-3. List of environmental concerns of the nation's 28 individual NEPs.

environmental health of the estuary is degrading and, if possible, to help restore ecological condition. Because each NEP estuary's suite of environmental concerns are site-specific, each state, NEP, and its stakeholders have often developed monitoring and assessment methods that are unique to their estuary. Individual NEP monitoring may not be randomized spatially (as was done for the NCA) because NEP monitoring may target specific areas to ascertain specific sources of contamination or to obtain more detailed information about a particular environmental concern relevant to the NEP estuary.

It is important that the users of this report realize the shortcomings and limitations of the data presented, both from the NCA and from the individual NEPs. Both of these data sources taken together can often show very different results for the same estuarine index or component indicator. For example, although the NCA survey data may indicate that dissolved oxygen concentrations in the water column are in good condition, this assessment is based on monitoring conducted in an estuary during daylight hours only for a one-day period in the summer season during a given year. In contrast, the individual NEP monitoring data may indicate that dissolved oxygen levels at the same site are poor based on hourly monitoring conducted over a 24-hour monitoring cycle, including hours after dark when oxygen concentrations often drop due to plant respiration. Both of these data collection methods are correct within the limitations of the conditions under which the monitoring was conducted and the analysis used to evaluate the data.

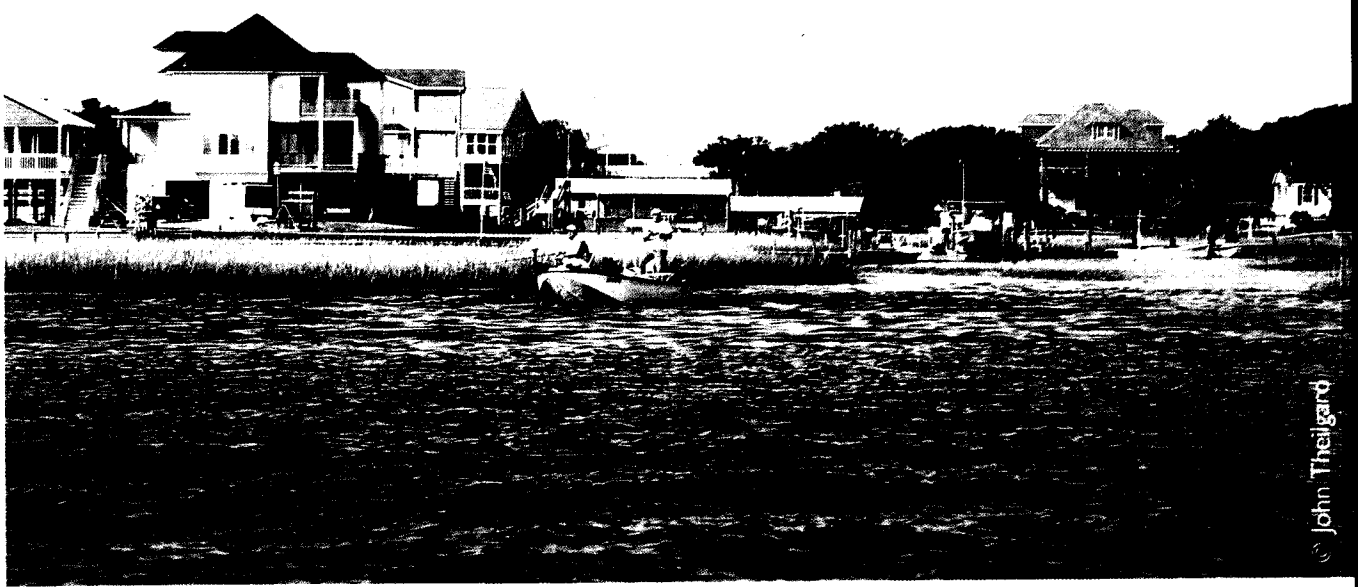
Conclusion

There was no consistent and comparable NCA estuarine survey at the inception of the NEP. However, based on the probabilistic sampling results collected by the NCA from 1997 through 2003, the NEP estuaries scored equal to or higher than all U.S. estuaries combined.

During the past 20 years, population pressures along the coasts have increased. By 2000, more than two-thirds of the coastal population lived in NEP-coincident counties, which comprise less than 6% of the coastal land area. Since 1987, as NEPs have attempted to address their individual environmental concerns, they have made many improvements to areas that are assessed by NCA. For example, work by the individual NEPs and their partners to make improvements in WWTPs, assist with the implementation of stormwater management plans, or identify primary sources of non-point source pollution may result in better ratings for water quality parameters in the NEP estuaries. The NEPs have also directed resources towards addressing some environmental concerns that are not directly assessed by the NCA. For example, habitat loss and alteration is listed as an environmental concern for all 28 NEP estuaries, and the individual NEPs have worked hard to monitor, conserve, protect, and restore important habitats (e.g., SAV, wetlands) in their study areas, including restoring and/or protecting more than one million acres of habitat between 2000 and 2006.

Tourism, fisheries, and other commercial activities thrive on the wealth of natural resources supplied by estuaries (John Theilgard).

CHAPTER 1 | INTRODUCTION



CHAPTER 1 | INTRODUCTION

The *National Estuary Program Coastal Condition Report* (NEP CCR), a comprehensive report on the condition of the nation's National Estuary Program (NEP) waters, is a collaborative effort among the individual NEPs and the U.S. Environmental Protection Agency's (EPA's) National Coastal Assessment (NCA), Office of Wetlands, Oceans and Watersheds (OWOW), and Office of Research and Development (ORD).

The first *National Coastal Condition Report* (NCCR I) (U.S. EPA, 2001) assessed the condition of the nation's coasts using data from 1990–1996 that were provided by several existing coastal programs, including EPA's Environmental Monitoring and Assessment Program (EMAP), the U.S. Fish and Wildlife Service's (FWS's) National Wetland Inventory (NWI), and the National Oceanic and Atmospheric Administration's (NOAA's) National Status and Trends (NS&T) Program. The second in this series of reports, the *National Coastal Condition Report II* (NCCR II) (U.S. EPA, 2004a), assessed coastal condition using data from 1997–2000 that were provided by the NCA and the NWI. The NEP CCR is similar to the NCCR series in structure, but instead of assessing national coastal condition, it focuses specifically on the condition of the 28 NEP estuaries using NCA data collected from 1997 through 2003. The NEP CCR also presents recent monitoring data collected and analyzed by the individual NEPs for a variety of estuarine indicators. Figure 1-1 shows the study areas assessed for all 28 NEP estuaries of the conterminous 48 states and Puerto Rico.

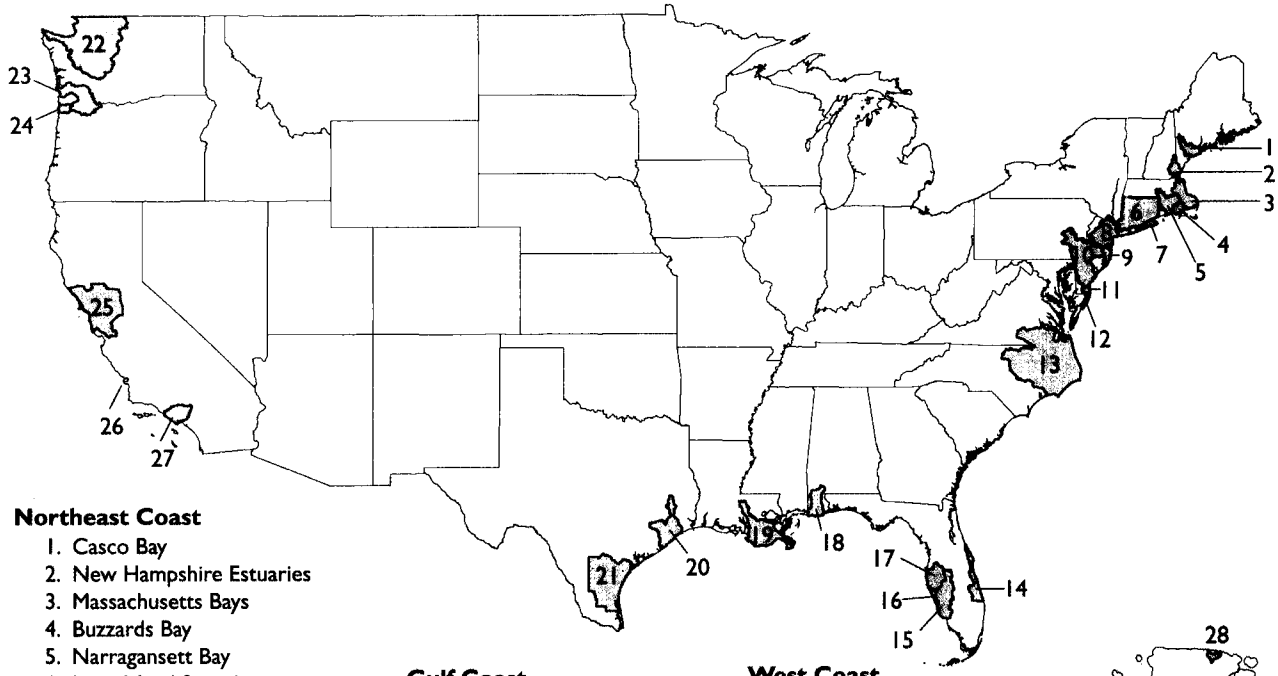
In addition to serving as important wildlife habitat, estuaries perform valuable services that benefit human communities (John Theilgard).

Why Are Estuaries Important?

Estuaries Are Valuable and Productive Natural Ecosystems

Estuaries are bodies of water that receive both fresh water and sediment influx from rivers and tidal influx from the ocean, thus providing transition zones between the fresh water of rivers and the saline environment of the sea. This interaction produces a unique environment that supports diverse habitats for a wide variety of living resources, such as fish and wildlife, and contributes substantially to the economy of coastal areas.

Estuaries are critical for the survival of a number of species. Many fish and shellfish species, including most commercially and recreationally important species, rely on the sheltered waters of estuaries as protected places to spawn and for their offspring to grow and develop (giving estuaries the nickname "nurseries of the sea"). Estuarine waters also serve as habitat and breeding areas for hundreds of species of birds and other wildlife, including marine mammals such as manatees, seals, sea lions, otters, porpoises, and whales.



Northeast Coast

1. Casco Bay
2. New Hampshire Estuaries
3. Massachusetts Bays
4. Buzzards Bay
5. Narragansett Bay
6. Long Island Sound
7. Peconic Estuary
8. New York/New Jersey Harbor
9. Barnegat Bay
10. Delaware Estuary
11. Delaware Inland Bays
12. Maryland Coastal Bays

Southeast Coast

13. Albemarle-Pamlico Estuarine Complex
14. Indian River Lagoon

Gulf Coast

15. Charlotte Harbor
16. Sarasota Bay
17. Tampa Bay
18. Mobile Bay
19. Barataria-Terrebonne Estuarine Complex
20. Galveston Bay
21. Coastal Bend Bays

West Coast

22. Puget Sound
23. Lower Columbia River Estuary
24. Tillamook Bay
25. San Francisco Estuary
26. Morro Bay
27. Santa Monica Bay

Puerto Rico

28. San Juan Bay Estuary

Figure 1-1. A map of the study areas for each of the 28 NEP estuaries.

Estuaries Have Many Human Uses

In addition to serving as important habitat for wildlife, estuaries perform valuable services that benefit human communities. Tourism, fisheries, and other commercial activities thrive on the wealth of natural resources supplied by estuaries. The many commercially important fish and shellfish that depend on estuaries include striped bass, shad, salmon, sturgeon, shrimp, crabs, lobster, clams, oysters, mussels, and bay scallops. Estuaries also supply water for industrial uses; lose water to freshwater diversions for drinking and irrigation uses; serve as the critical terminals for the nation's marine transportation system and the U.S. Navy; provide a point of discharge for municipalities and industries; and are the downstream end of non-point source runoff, serving as filters for pollutants and sediments carried in water flowing from upstream. Wetland plants along the edge of estuaries act as a natural buffer between the land and the ocean, absorbing flood waters, dissipating storm surges, and helping to prevent erosion by stabilizing the shoreline.

Estuaries also provide community benefits, such as recreation, scientific knowledge, education, and aesthetic values. They are often the cultural centers of coastal communities, serving as the focal point for local commerce, recreation, celebrations, customs, and traditions. Boating, fishing, swimming, surfing, and bird watching are just a few of the numerous recreational activities that people enjoy in estuaries.

Population Pressures Affecting the NEPs

The coastal areas surrounding estuaries are among the most populated areas in the nation. Although the nation's narrow fringe of coastal land represents only 13% of the total contiguous land area of the United States, it is home to roughly 43% of the U.S. population (Figure 1-2).

A comparison of U.S. population data (1960–2000) for the nation and various geographic areas (e.g., all non-coastal counties, all coastal counties, and all NEP-coincident coastal counties) reveals that the largest percentage of the U.S. population (57%) lived in non-coastal counties in 2000 (Figure 1-3). Of the 43% of the U.S. population living in NOAA-designated coastal counties in 2000, almost 69% lived in NEP-coincident coastal counties, which represent less than 6% of the coastal land area of the contiguous United States (Cuilliton et al., 1990; U.S. Census Bureau, 1991;

Certain aspects of the nation's economic activity depend on estuaries and other coastal waters:

- Estuaries provide habitat for more than 75% of U.S. commercial fish catch and for 80% to 90% of the recreational fish catch. Estuarine-dependent fisheries are among the most valuable within regions and across the nation.
- Commercial and recreational fishing, boating, tourism, and other coastal industries provide more than 28 million jobs nationwide and generate $54 billion in goods and services each year.
- There are 25,500 recreational facilities along the U.S. coasts and almost 44,000 mi^2 of outdoor public recreation areas. The average American spends 10 recreational days on the coast each year. More than 180 million Americans—nearly 70% of the U.S. population—visit ocean and bay beaches annually, and coastal recreation and tourism generate $8 to $12 billion in annual revenue.

Sources: NOAA, 1990; NRC, 2000.

Figure 1-2. Population distribution in the United States in 2000 (U.S. Census Bureau, 2001).

2001). It should be noted that these calculations include only marine NOAA-designated coastal counties for the lower 48 states. For the purposes of this report, the populations of the counties bordering the Great Lakes were processed as non-coastal counties. This topic, along with a discussion of NEP-coincident counties, can be found in Appendix A of this report.

Figure 1-4 shows the population densities for these same geographic areas during this same time period (1960–2000). Although the rate of increase in population density is relatively constant, there is clearly great variability (a 10-fold difference) between the population density of non-coastal counties versus NEP-coincident coastal counties. For example, the population density in the NEP-coincident coastal counties in 2000 was highest at almost 500 persons/mi^2, whereas the population density in the conterminous 48 states was about 100 persons/mi^2 and in non-coastal counties was a mere 60 persons/mi^2. The population density in all U.S. coastal counties in 2000 was about 300 persons/mi^2. As shown in Table 1-1, the population growth rate for all U.S. coastal counties from 1960 to 2000 was 70%, compared to 48% for non-coastal counties and 57% for the nation. The population growth rate for this same period within NEP-coincident coastal counties was 59%, slightly more than the national population growth rate (U.S. Census Bureau, 1991; 2001).

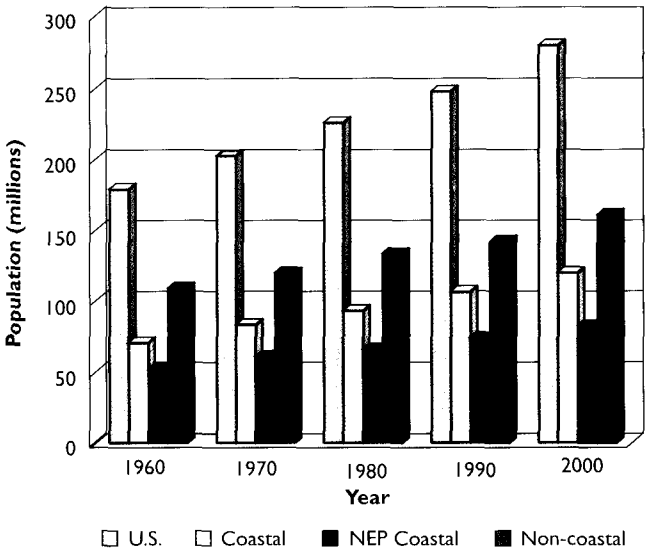


Figure 1-3. Total population data for the United States from 1960 to 2000 (U.S. Census Bureau, 1991; 2001).

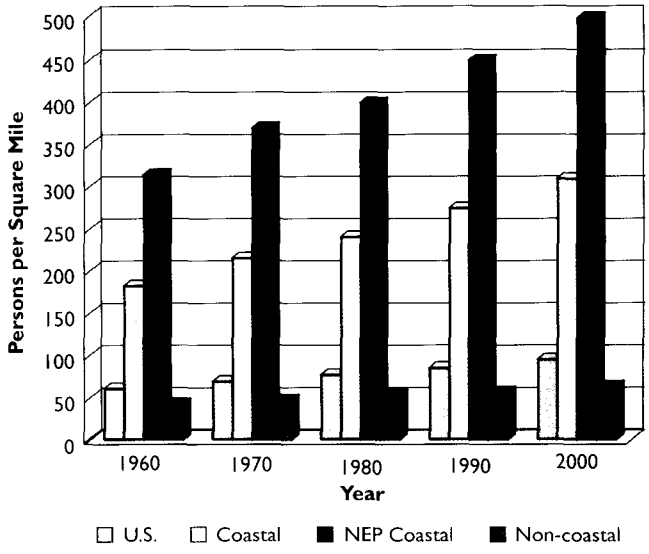


Figure 1-4. Population density data for the United States from 1960 to 2000 (U.S. Census Bureau, 1991; 2001).

Table 1-1. Comparison of U.S. Total Population, Population Density, and Population Growth Rate for the Nation, Coastal Counties, NEP-coincident Coastal Counties, and Non-coastal Counties* (U.S. Census Bureau, 1991; 2001)

	Total population, 2000 (millions)	Population density, 2000 (persons/mi^2)	Percent population growth rate, 1960–2000	Land area (mi^2)
United States	280	94	57	2,959,060
Coastal counties	119	308	70	387,470
NEP-coincident coastal counties	82	498	59	164,380
Non-coastal counties	160	62	48	2,571,590

*Excludes population and land area from Alaska, Hawaii, and U.S. Territories.

Why Be Concerned About the Health of Estuaries?

The economy of many coastal areas is based primarily on the natural beauty and bounty of estuaries, and the livelihoods of the people who live and work in these areas are affected when these estuaries are imperiled. Because a disproportionate percentage of the nation's population lives in coastal communities, the increased activities of municipalities, commerce, industry, and tourism in these areas have created environmental pressures that threaten coastal resources. These pressures include increased solid waste production; higher volumes of urban non-point source runoff; loss of green space and wildlife habitat; declines in ambient water and sediment quality; and increased demands for wastewater treatment, irrigation and potable water, and energy supplies. In addition, residential and commercial development continue to destroy estuarine wetlands and alter the quantity and timing of freshwater flow, which is critical to river and estuarine function. In effect, the same human uses that are desired of coastal waters also have the potential to lessen their value. This report not only discusses indices of estuarine condition that gauge the extent to which NEP habitats and resources have been altered, but it also addresses connections between estuarine condition and the ability of estuaries to meet human expectations for their use.

The National Estuary Program

As the U.S. population grows and the demands imposed on our nation's natural resources increase, so too does the importance of protecting these resources for their natural, economic, and aesthetic values. It is the mission of EPA's NEP to restore and protect America's nationally significant estuaries. Through its approach of inclusive, community-based planning and action on the watershed level, the NEP is an important initiative in conserving U.S. estuarine resources and an effective model for the protection and management of other coastal areas.

Established as part of the 1987 amendments to Section 320 of the Clean Water Act, the NEP promotes comprehensive planning efforts to help protect nationally significant estuaries judged to be threatened by pollution, development, or overuse. Section 320 requires the development of a Comprehensive Conservation and Management Plan (CCMP) for attaining or maintaining water quality in each NEP estuary. Aspects of water quality addressed by the CCMPs include the protection of public water supplies; the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife; and the maintenance of recreational opportunities, both in and on the water. The objective of each individual NEP is to create and implement a CCMP that addresses the entire range of environmental problems facing an NEP

The NEP promotes comprehensive planning efforts to help protect nationally significant estuaries judged to be threatened by pollution, development, or overuse (John Theilgard).

estuary, as well as to maintain the estuary's economic and social value; therefore, NEPs are required to monitor the effectiveness of their CCMPs to achieve measurable results. By providing grants and technical assistance, EPA helps state and local governments achieve these goals and share "lessons learned" among the individual NEPs and with other coastal communities.

Although EPA administers the national-level NEP, program decisions and activities for the 28 individual NEPs are carried out by committees of local government officials, private citizens, and representatives from other federal agencies, academic institutions, industry, and estuary user-groups. Estuaries are selected for inclusion in the NEP through a nomination process, with nominations submitted to EPA during designated nomination periods by the Governor of the state where the estuary is located. Table 1-2 provides a current list of the nation's NEP estuaries, as well as the year these estuaries received NEP designation.

Once selected for inclusion in the national program, each individual NEP must create decision-making committees comprised of relevant stakeholders to identify and prioritize the problems in their estuary. Most NEPs choose a management framework that includes a Management Committee to oversee the routine operation of the program; a Policy Committee comprised of high-level representatives from federal, state, and local government agencies; a Technical Advisory Committee to guide technical decisions; and a Citizens' Advisory Committee to represent the interests of estuary user-groups and the public. Together, these committees develop the CCMP to protect the NEP estuary and its resources.

The flexible and collaborative nature of the NEP has allowed the 28 individual NEPs to develop many innovative approaches to address local problems; approaches uniquely tailored to local environmental conditions and to the needs of local communities and stakeholders. At the same time, the national structure

Table 1-2. U.S. Estuaries in the National Estuary Program (U.S. EPA, 2006d)

Northeast Coast	Year of Entry
Casco Bay, ME	1990
New Hampshire Estuaries, NH	1995
Massachusetts Bays, MA	1990
Buzzards Bay, MA	1987
Narragansett Bay, RI and MA	1987
Long Island Sound, CT and NY	1987
Peconic Estuary, NY	1992
New York/New Jersey Harbor, NY and NJ	1988
Barnegat Bay, NJ	1995
Delaware Estuary, NJ, PA, and DE	1988
Delaware Inland Bays, DE	1988
Maryland Coastal Bays, MD	1995
Southeast Coast	
Albemarle-Pamlico Estuarine Complex, NC and VA	1987
Indian River Lagoon, FL	1990
Puerto Rico	
San Juan Bay Estuary, PR	1992
Gulf Coast	
Charlotte Harbor, FL	1995
Sarasota Bay, FL	1988
Tampa Bay, FL	1990
Mobile Bay, AL	1995
Barataria-Terrebonne Estuarine Complex, LA	1991
Galveston Bay, TX	1988
Coastal Bend Bays, TX	1992
West Coast	
Puget Sound, WA	1987
Lower Columbia River Estuary, WA and OR	1995
Tillamook Bay, OR	1994
San Francisco Estuary, CA	1987
Morro Bay, CA	1995
Santa Monica Bay, CA	1988

facilitates the sharing of successful management approaches, technologies, and ideas. Effective projects and innovative programs carried out by an individual NEP often serve as models for similar initiatives for other NEPs and coastal areas.

Although environmental results are often slow to be realized, positive signs of improving environmental conditions are already emerging from the activities of the individual NEPs. The NEPs have worked hard to monitor, conserve, protect, and restore important habitats (e.g., submerged aquatic vegetation [SAV], wetlands) in their study areas, including restoring and/or protecting more than one million acres of habitat since 2000 (U.S. EPA, 2006b). They are also demonstrating success in finding effective institutional arrangements from which to manage their estuaries, including securing and leveraging funds and improving public education and citizen participation through outreach efforts.

Purpose and Format of This Report

The purpose of this NEP CCR is to present a broad baseline picture of the condition of the nation's NEP estuaries from 1997 through 2003, as well as additional information about the specific conditions and challenges of each NEP estuary. This report uses currently available data to compare the condition of the nation's NEP estuaries to each other, as well as regionally and nationally; however, it is not intended to be a comprehensive literature review of estuarine information. Instead, this report uses NCA data on four primary indices of estuarine condition and data collected by individual NEPs on a variety of site-specific indicators to provide insight into current estuarine condition. This report also presents data gaps and other issues that environmental managers focus on to make more reliable assessments as to how the condition of the nation's NEP estuaries may be changing with time. This NEP CCR will serve as a continuing benchmark for analyzing the progress of the NEPs and is expected to be followed in subsequent years by reports on more specialized estuarine issues.

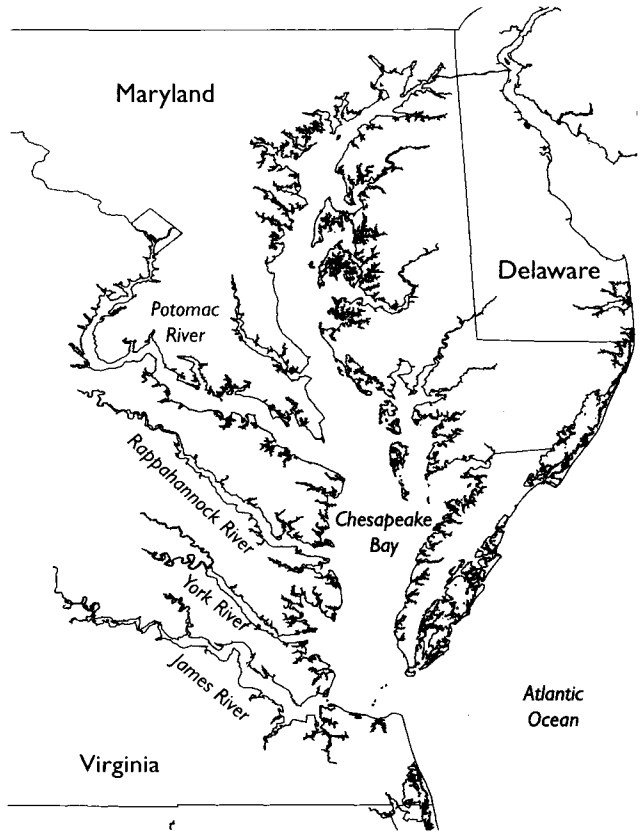
Chapter 2 of this report presents available NCA data on a national scale for the 28 NEP estuaries in the conterminous 48 states and Puerto Rico. These data are then broken down and analyzed for the NEP estuaries of five geographic regions: Northeast Coast (Chapter 3), Southeast Coast (Chapter 4), Gulf Coast (Chapter 5), West Coast (Chapter 6), and Puerto Rico (Chapter 7). These chapters include a regional overview of NEP estuarine condition and profiles of the individual NEPs in that region. Each NEP profile presents information on the specific indicators used by an NEP to evaluate water and sediment quality, habitat quality, living resources, and other environmental stressors in their estuary, as well as an overview of the current projects, accomplishments, and future goals of the individual program. The NEPs were also asked to provide a short Highlight article for each profile describing either a specific aspect of their estuary or an exemplary program developed at the local estuary level to address site-specific environmental concerns. These articles are intended to illustrate the unique living resources of the estuary, as well as innovative monitoring methods, successful restoration/remediation efforts, or novel decision-making and management efforts undertaken at the local level. The diversity of the subjects described in the Highlight articles speaks to the wide spectrum of programs and monitoring approaches that exist among the 28 NEP estuaries.

Chesapeake Bay Program

HIGHLIGHT

Why Isn't the Chesapeake Bay in the National Estuary Program?

The largest estuary in the United States, the Chesapeake Bay, is protected under its own federally mandated program that is separate from, but related to, the NEP. In fact, the approach and methods of the NEP were developed from the foundation laid by earlier efforts to protect Chesapeake Bay. Chesapeake Bay was the first estuary in the United States to be targeted for restoration and protection. In 1983, the Governors of Maryland, Virginia, and Pennsylvania; the Mayor of the District of Columbia; and the EPA Administrator signed the Chesapeake Bay Agreement, committing their states, the District of Columbia, and EPA to prepare plans for protecting and improving water quality and living resources in Chesapeake Bay. The Chesapeake Bay Program evolved as an institutional mechanism to restore the Bay and to meet the goals of the Chesapeake Bay Agreement. This program guides and coordinates multi-state and multi-agency activities.



The Chesapeake Bay Program raised awareness of the need to establish federal-state partnerships to protect estuaries threatened by pollution, development, and overuse. The NEP was established in response to the recognition of a need to protect not only the Chesapeake Bay but also the many other nationally significant estuaries throughout the country.

Approaches Used to Measure Estuarine Condition

There are two major approaches presented in each chapter of this report for evaluating estuarine condition. The first approach uses unbiased, quality-assured monitoring data collected nationally by the EPA NCA to make consistent comparison ratings of four primary indices of estuarine condition (water quality index, sediment quality index, benthic index, and fish tissue contaminants index) among the NEP estuaries. The resulting ratings for each index are then used to calculate an individual NEP rating, a regional NEP rating, and a national rating of NEP estuarine condition. Using the NCA approach, estuarine condition for the individual NEP estuaries and regions can be expressed in terms of the percent of estuarine area in good, fair, or poor condition and can be compared nationally. The overall condition and index ratings for the nation's collective NEP estuaries are based on an areally weighted mean of the regional overall condition and index scores. NCA sampling for each estuary is typically conducted at sites during a one-day period over the summer months for one to two years; therefore, the NCA data present only a "snapshot" of what is occurring in the estuary at that time.

The second approach presented in this report uses estuary-specific monitoring data collected by the individual NEPs and their partners in support of local problem-solving efforts. For some NEP estuaries, monitoring data have been collected continuously for more than a decade, and some estuarine indicators may be monitored on an hourly, daily, weekly, monthly, quarterly, or yearly basis. These monitoring data can provide a more detailed view of the various cyclic changes that may occur daily or seasonally in an estuary to evaluate long-term changes in an indicator; however, because the individual NEPs use a variety of approaches and methods for data collection and evaluation, it is often difficult to compare this information among estuaries or on a national basis. Table 1-3 compares some of the differences in temporal and spatial monitoring between the two monitoring approaches presented in this report.

Each of the two approaches has strengths and weakness, but the resulting information taken together paints a more precise picture of the overall condition of the resources of the NEP estuaries than can be gleaned from either program approach individually. The two monitoring approaches are described in the following sections.

National Coastal Assessment (NCA) Monitoring Data

EPA's NCA provides representative data on four indices of estuarine condition (water quality index, sediment quality index, benthic index, and fish tissue contaminants index) for the 28 NEP estuaries. These four primary indices were selected because of the availability

Table 1-3. Monitoring Approaches of the NCA and NEP

Parameter	NCA Approach	Individual NEP Approach
Indicators monitored	Water quality index Sediment quality index Benthic index Fish tissue contaminants index	Highly variable, but may include some or all of the four NCA indices, as well as a variety of other site-specific indicators
Selection of sampling sites	Randomized spatially throughout the estuary	Randomized spatially and/or targeted to monitor a specific area of the estuary that is known to be contaminated or degraded
Sampling frequency	One day during the summer sampling period (July–August), which is considered to be the most stressful period of the year; therefore, monitoring is able to capture evidence of degradation	Variable, but may be hourly, daily, weekly, monthly, quarterly, or annually, depending on the indicator being monitored
Sampling period	1997–2003 (The years of sampling differ slightly, depending on the specific NEP estuary, but fall within this time interval)	Historic data may be available for 20 years or more

of relatively consistent data for these indices for most of the nation's estuaries. The indices do not address all characteristics of estuaries that are valued by society, but they do provide information on both the ecological condition and the effects of human use on estuaries.

Characterizing the NEP estuaries using each of the four indices involves two steps. The first step is to assess condition at individual monitoring sites within an NEP estuarine area for each index and component indicator. The site-condition rating criteria for each index and component indicator are determined based on existing criteria, guidelines, or interpretation of scientific literature. For example, dissolved oxygen conditions (a component indicator of the water quality index) are considered poor if dissolved oxygen concentrations are less than 2 mg/L. This value is widely accepted as representative of hypoxic conditions; therefore, this benchmark for poor condition is strongly supported by scientific evidence (Diaz and Rosenberg, 1995; U.S. EPA, 2000a).

The second step is to assign index ratings for each NEP estuary and region based on the condition of the monitoring sites within an NEP estuary or region. For example, for an estuary or region to be rated poor with regard to dissolved oxygen concentrations, more than 15% of the NEP estuarine area must have concentrations measured at less than 2 mg/L. The criteria boundaries for the NEP estuary and the regional ratings (i.e., percentages used to rate each index of estuarine condition) were determined as a median of the responses provided through a survey of environmental managers, resource experts, and the knowledgeable public. The following sections provide detailed descriptions of each index and component indicator, as well as the criteria for determining the ratings for the four primary indices by site, NEP estuary, and region as good, fair, or poor.

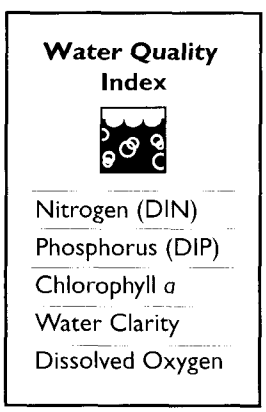


Figure 1-5. Component indicators of the water quality index.

Water Quality Index

The water quality index is made up of five component indicators: dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), chlorophyll *a*, water clarity, and dissolved oxygen (Figure 1-5). Some nutrient inputs to estuaries (such as DIN and DIP) are necessary for a healthy, functioning estuarine ecosystem; however, when nutrients from various sources, such as sewage and fertilizers, are introduced into an estuary, the concentration of available nutrients can increase beyond natural background levels. This increase in the rate of supply of organic matter is called eutrophication and may result in a host of undesirable water quality conditions (Figure 1-6). Excess nutrients can lead to excess plant production (phytoplankton or algae) and to increased chlorophyll *a* concentrations that can decrease water clarity and lower concentrations of dissolved oxygen.

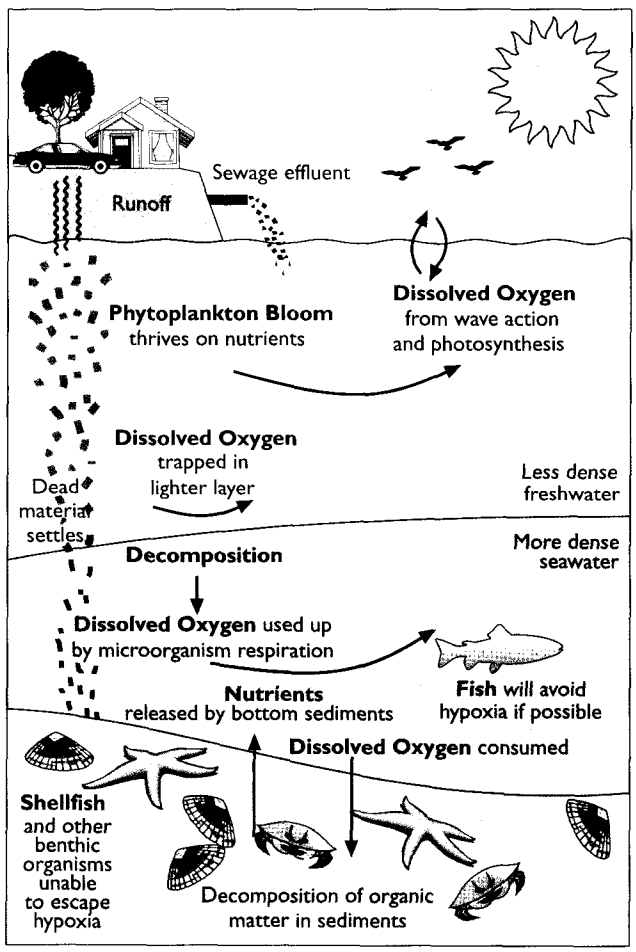


Figure 1-6. Eutrophication can occur when the concentration of available nutrients increases beyond normal levels.

The water quality index used in this report is intended to characterize acutely degraded water quality conditions and does not consistently identify sites experiencing occasional or infrequent hypoxia, nutrient enrichment, or decreased water clarity. As a result, a rating of poor for the water quality index means that the site is likely to have consistently poor condition during the monitoring period. If a site is designated as fair or good, the site did not experience poor condition on the date sampled, but could be characterized by poor condition for short time periods. In order to assess the level of variability in the index at a specific site over time, increased or supplemental sampling is needed.

Dissolved Nitrogen and Phosphorus | DIN and DIP are necessary and natural nutrients required for the growth of phytoplankton, the primary producers that form the base of an estuary's food chain; however, excessive DIN and DIP can result in large, undesirable phytoplankton blooms. For this report, DIN and DIP were determined chemically through the collection of filtered surface water at each site. NCA surveys were conducted in late summer—not the most likely period for maximal nutrient values in East Coast and Gulf Coast estuaries, but the period of expected peak concentrations for West Coast estuaries.

NCA monitoring sites were rated good, fair, or poor for DIN and DIP using the criteria shown in Tables 1-4 and 1-5. These ratings were then used to calculate DIN and DIP ratings for each NEP estuary and region.

Chlorophyll a | For this report, the surface concentrations of chlorophyll *a* were determined from a filtered portion of water collected at each site. Surface chlorophyll *a* concentrations at a site were rated good, fair, or poor using the criteria shown in Table 1-6. These ratings were then used to calculate chlorophyll *a* ratings for each NEP estuary and region.

Water Clarity | Clear waters are valued by society and contribute to the maintenance of healthy and productive ecosystems. Light penetration into estuarine waters is important for the healthy growth of SAV, which serves as food and habitat for the resident biota. The NCA estimates water clarity using specialized equipment that compares the amount and type of light reaching the water surface to the light at a depth of 1 meter, as well as by using a Secchi disk. Water clarity varies naturally among different parts of the nation; therefore, the water clarity index (WCI) is based on a ratio of observed clarity to regional reference conditions: WCI = (observed clarity at 1 meter/regional reference clarity at 1 meter). The reference conditions for the NEP estuaries and regions were determined by examining available data for each of the regions. Conditions

Table 1-4. Criteria for Assessing Dissolved Inorganic Nitrogen (DIN)

Area		Fair	
East/Gulf Coast sites	< 0.1 mg/L	0.1–0.5 mg/L	> 0.5 mg/L
West Coast sites	< 0.5 mg/L	0.5–1.0 mg/L	> 1 mg/L
Puerto Rico sites	< 0.05 mg/L	0.05–0.1 mg/L	> 0.1 mg/L
NEP Estuary or Region	Less than 10% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.	10% to 25% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.	More than 25% of the NEP estuarine area is in poor condition.

Table 1-5. Criteria for Assessing Dissolved Inorganic Phosphorus (DIP)

Area		Fair	
East/Gulf Coast sites	< 0.01 mg/L	0.01–0.05 mg/L	> 0.05 mg/L
West Coast sites	< 0.01 mg/L	0.01–0.1 mg/L	> 0.1 mg/L
Puerto Rico sites	< 0.005 mg/L	0.005–0.01 mg/L	> 0.01 mg/L
NEP Estuary or Region	Less than 10% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.	10% to 25% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.	More than 25% of the NEP estuarine area is in poor condition.

Table 1-6. Criteria for Assessing Chlorophyll *a*

Area		Fair	
East/Gulf/ West Coast sites	< 5 µg/L	5–20 µg/L	> 20 µg/L
Puerto Rico sites	< 0.5 µg/L	0.5–1 µg/L	> 1 µg/L
NEP Estuary or Region	Less than 10% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.	10% to 20% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.	More than 20% of the NEP estuarine area is in poor condition.

were set at 10% of incident light available at a depth of 1 meter for areas with normal turbidity (most of the United States), 5% for areas with naturally high turbidity (Alabama, Georgia, Louisiana, South Carolina, and parts of Delaware), and 20% for areas with significant SAV beds or active programs for SAV restoration (southern Laguna Madre, the Big Bend region of Florida, the region from Tampa Bay to Florida Bay, the Indian River Lagoon, and portions of the Chesapeake Bay). Table 1-7 summarizes the rating criteria for water clarity for each monitoring site and for the NEP estuaries and regions.

Table 1-7. Criteria for Assessing Water Clarity

Area		Fair	
Individual sampling sites	WCI ratio is greater than 2.	WCI ratio is between 1 and 2.	WCI ratio is less than 1.
NEP Estuary or Region	Less than 10% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.	10% to 20% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.	More than 25% of the NEP estuarine area is in poor condition.

Dissolved Oxygen | Dissolved oxygen is necessary for all estuarine life. Many states use a dissolved oxygen threshold average concentration of 4 to 5 mg/L to set their water quality standards, and concentrations below approximately 2 mg/L are thought to be stressful to many estuarine organisms (Diaz and Rosenberg, 1995; U.S. EPA, 2000a). Low oxygen levels (hypoxia) or a lack of oxygen (anoxia) most often occur in bottom waters and affect the organisms that live in the sediments. These conditions often accompany the onset of severe bacterial degradation, sometimes resulting in the presence of algal scums and noxious odors; however, in some estuaries, low oxygen levels occur periodically or may be a part of an estuary's natural ecology. Therefore, although it is easy to show a snapshot of the conditions of the nation's estuaries concerning oxygen concentrations, it is difficult to interpret whether this snapshot is representative of all summertime periods (such as representative of the variable daily conditions in Narragansett Bay) or the result of natural physical processes.

Unless otherwise noted, the dissolved oxygen data presented in this report were collected as part of the NCA survey. Table 1-8 summarizes the dissolved oxygen rating criteria for the individual monitoring sites and for the NEP estuaries and regions.

Table 1-8. Criteria for Assessing Dissolved Oxygen

Area		Fair	
Individual sampling sites	> 5 mg/L	2–5 mg/L	< 2 mg/L
NEP Estuary or Region	Less than 5% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.	10% to 20% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.	More than 15% of the NEP estuarine area is in poor condition.

Calculating the Water Quality Index

Once DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen were assessed for a given site, a water quality index rating was calculated for the site based on these five component indicators. Table 1-9 summarizes the rating criteria for developing a water quality index for an individual sampling site. The water quality index was then calculated for each NEP estuary and region using the criteria in Table 1–10.

Table 1-9. Criteria for Determining the Water Quality Index Rating by Site

Rating	Criteria
Good	A maximum of one component indicator is rated fair, and no component indicators are rated poor.
Fair	One of the component indicators is rated poor, or two or more component indicators are rated fair.
Poor	Two or more of the five component indicators are rated poor.
Missing	Two component indicators are missing, and the available component indicators do not suggest a poor or fair rating.

Table 1-10. Criteria for Determining the Water Quality Index Rating by NEP Estuary or Region

Rating	Criteria
Good	Less than 10% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.
Fair	10% to 20% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.
Poor	More than 20% of the NEP estuarine area is in poor condition.

Sediment Quality Index

Another issue of major environmental concern in estuaries is the contamination of sediments with toxic chemicals. A wide variety of metals and organic substances, such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides, are discharged into estuaries from urban, agricultural, and industrial sources in a watershed. These contaminants adsorb onto suspended particles and eventually accumulate in depositional basins, where they can disrupt the benthic community of invertebrates, shellfish, and crustaceans that live in or on the sediments. To the extent that the contaminants become concentrated in the organisms, they pose a risk to organisms throughout the food web—including humans.

Several factors influence the extent and severity of sediment contamination. Fine-grained, organic-rich sediments are efficient at scavenging pollutants and are likely to become resuspended and be transported to distant locations. Thus, silty sediments high in total organic carbon (TOC) are potential sources of contamination. Conversely, organic-rich particles bind some toxicants so strongly that the threat to organisms can be greatly reduced.

Physical and chemical characteristics of surface sediments are the result of interacting forces controlling chemical input and particle dynamics at any particular site. When assessing estuarine condition, researchers measure the potential for sediments to affect bottom-dwelling organisms. The sediment quality index is based on three component indicators of sediment condition: direct measures of sediment toxicity, sediment contaminant concentrations, and the sediment TOC concentration (Figure 1-7).

The NCA survey measured the concentrations of 91 chemical constituents in sediments to determine the sediment contaminants component of the index. Sediment toxicity was evaluated by measuring the survival of the marine amphipod *Ampelisca abdita* following 10-day exposure to the sediments under laboratory conditions. The sediment TOC concentration was measured on a dry-weight basis. The results of these evaluations may be used to identify the most polluted areas and may provide clues regarding the sources of contamination.

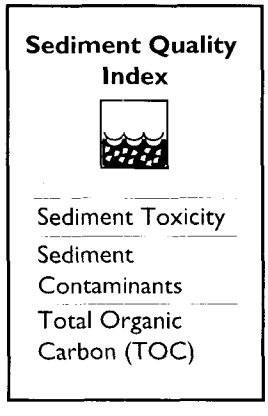


Figure 1-7. Component indicators of the sediment quality index.

Sediment Contaminant Criteria (Long et al., 1995)

ERM (Effects Range Median)—Determined for each chemical as the 50th percentile (median) in a database of ascending concentrations associated with adverse biological effects.

ERL (Effects Range Low)—Determined for each chemical as the 10th percentile in a database of ascending concentrations associated with adverse biological effects.

Some researchers and managers would prefer that the sediment triad (sediment contaminants, sediment toxicity, and benthic communities) be used to assess sediment condition (poor condition would require all three elements to be poor), or that poor sediment condition be determined at least based on the joint occurrence of elevated sediment contaminant concentrations and high sediment toxicity (see text box–*Alternative Views for a Sediment Quality Index*). However, benthic community attributes are included in this assessment of estuarine condition as an independent variable (see the *Benthic Index* section in this chapter), rather than as a component of sediment quality.

In this report, the focus of the sediment quality index is on sediment condition, not just sediment toxicity. Attributes of sediments other than toxicity can result in unacceptable changes in biotic communities. For example, organic enrichment through wastewater disposal can have an undesired effect on biota, and elevated contaminant levels can have undesirable ecological effects (e.g., changes in benthic community structure) that are not directly related to acute toxicity (as measured by the *Ampelisca* test). For these reasons, the sediment quality index used in this report combines sediment toxicity, sediment contaminants, and TOC to assess sediment condition. The condition of estuarine sediment is assessed as poor (high potential for exposure effects on biota) if any one of the component elements is rated poor; assessed as fair if the sediment contaminants indicator is rated fair; and assessed as good if all three component indicators are at levels that would be unlikely to result in adverse biological effects due to sediment quality.

When assessing estuarine condition, researchers measure the potential for sediments to affect bottom-dwelling organisms (Morro Bay NEP).

Alternative Views for a Sediment Quality Index

Some resource managers object to using ERM and ERL values to calculate the sediment quality index because the index is also based on actual measurements of toxicity. Because ERMs are acknowledged to be no greater than 50% predictive of toxicity, these managers believe that the same weight should not be given to a nontoxic sample with an ERM exceedance as is given to a sample that is actually toxic. O'Connor et al. (1998), using a 1,508-sample EPA and NOAA database, found that 38% of ERM exceedances coincided with amphipod toxicity (i.e., were toxic); 13% of the ERL exceedances (no ERM exceedance) were toxic; and only 5% of the samples that did not exceed ERL values were toxic. O'Connor and Paul (2000) expanded the 1,508-sample data set to 2,475 samples, and the results remained relatively unchanged (41% of the ERM exceedances were toxic, and only 5% of the nonexceedances were toxic). As a result, these researchers and managers believe that the sediment quality index used in this report should not result in a poor rating if sediment contaminant criteria are exceeded, but the sediment is not toxic.

Sediment Toxicity | Researchers applied a standard direct test of toxicity at thousands of sites to measure the survival of amphipods (commonly found, shrimp-like benthic crustaceans) exposed to sediments for 10 days under laboratory conditions. As in all tests of toxicity, survival was measured relative to that of amphipods exposed to uncontaminated reference sediment. The criteria for rating sediment toxicity based on amphipod survival for each sampling site are shown in Table 1-11, and Table 1-12 shows how these site data were used to evaluate sediment toxicity by NEP estuary or region. It should be noted that for this component indicator, unlike the others, only a good or poor rating is possible—there is no fair rating.

Table 1-11. Criteria for Assessing Sediment Toxicity by Site

Rating	Criteria
Good	The amphipod survival rate is greater than or equal to 80%.
Poor	The amphipod survival rate is less than 80%.

Table 1-12. Criteria for Assessing Sediment Toxicity by NEP Estuary or Region

Rating	Criteria
Good	Less than 5% of the NEP estuarine area is in poor condition.
Poor	5% or more of the NEP estuarine area is in poor condition.

Contaminants that absorb onto suspended particles can disrupt the benthic community of invertebrates, shellfish, and crustaceans that live in or on the sediments (Morro Bay NEP).

Sediment Contaminants | There are no absolute chemical concentrations that correspond to sediment toxicity, but ERL and ERM values are used as guidelines in assessing sediment contamination (Table 1-13). ERM is the median concentration (50th percentile) of a contaminant observed to have adverse biological effects in the literature studies examined. A more protective indicator of contaminant concentrations is the ERL

Table 1-13. ERM and ERL Guidance Values in Sediments (Long et al., 1995)

Metal[a]	ERL	ERM
Arsenic	8.2	70
Cadmium	1.2	9.6
Chromium	81	370
Copper	34	270
Lead	46.7	218
Mercury	0.15	0.71
Nickel	20.9	51.6
Silver	1	3.7
Zinc	150	410
Analyte[b]	**ERL**	**ERM**
Acenaphthene	16	500
Acenaphthylene	44	640
Anthracene	85.3	1,100
Fluorene	19	540
2-Methyl naphthalene	70	670
Naphthalene	160	2,100
Phenanthrene	240	1,500
Benz(a)anthracene	261	1,600
Benzo(a)pyrene	430	1,600
Chrysene	384	2,800
Dibenzo(a,h)anthracene	63.4	260
Fluoranthene	600	5,100
Pyrene	665	2,600
Low molecular-weight PAH	552	3,160
High molecular-weight PAH	1,700	9,600
Total PAHs	4,020	44,800
4,4'-DDE	2.2	27
Total DDT	1.6	46.1
Total PCBs	22.7	180

[a] units are µg/g dry sediment, equivalent to ppm

[b] units are ng/g dry sediment, equivalent to ppb

criterion, which is the 10th percentile concentration of a contaminant represented by studies demonstrating adverse biological effects in the literature. Ecological effects are not likely to occur at contaminant concentrations below the ERL criterion. The criteria for rating sediment contaminants at individual sampling sites are shown in Table 1-14, and Table 1-15 shows how these data were used to create ratings for the NEP estuaries and regions.

Table 1-14. Criteria for Assessing Sediment Contaminants by Site

Rating	Criteria
Good	No ERM values are exceeded, and less than five ERL values are exceeded.
Fair	Five or more ERL values are exceeded.
Poor	An ERM value is exceeded for one or more contaminants.

Table 1-15. Criteria for Assessing Sediment Contaminants by NEP Estuary or Region

Rating	Criteria
Good	Less than 5% of the NEP estuarine area is in poor condition.
Fair	5% to 15% of the NEP estuarine area is in poor condition.
Poor	More than 15% of the NEP estuarine area is in poor condition.

Total Organic Carbon | Sediment contaminant availability or organic enrichment can be altered in areas where there is considerable deposition of organic matter. Sediment toxicity from organic matter is assessed by measuring the sediment TOC. The criteria for rating TOC concentrations at individual sampling sites are shown in Table 1-16, and Table 1-17 shows how these data were used to create ratings for the NEP estuaries and regions.

Table 1-16. Criteria for Assessing TOC by Site (concentrations on a dry-weight basis)

Rating	Criteria
Good	The TOC concentration is less than 2%.
Fair	The TOC concentration is between 2% and 5%.
Poor	The TOC concentration is greater than 5%.

Table 1-17. Criteria for Assessing TOC by NEP Estuary or Region

Rating	Criteria
Good	Less than 20% of the NEP estuarine area is in poor condition.
Fair	20% to 30% of the NEP estuarine area is in poor condition.
Poor	More than 30% of the NEP estuarine area is in poor condition.

Calculating the Sediment Quality Index

Once all three sediment quality component indicators (sediment toxicity, sediment contaminants, and sediment TOC) were assessed for a given site, a sediment quality index rating was calculated for the site. The sediment quality index was rated good, fair, or poor for each site using the criteria shown in Table 1-18. The sediment quality index was then calculated for each NEP estuary and region using the criteria shown in Table 1-19.

Table 1-18. Criteria for Determining the Sediment Quality Index by Site

Rating	Criteria
Good	None of the component indicators are rated poor, and the sediment contaminants indicator is rated good.
Fair	None of the component indicators are rated poor, and the sediment contaminants indicator is rated fair.
Poor	One or more of the component indicators are rated poor.

Table 1-19. Criteria for Determining the Sediment Quality Index by NEP Estuary or Region

Rating	Criteria
Good	Less than 5% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.
Fair	5% to 15% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in combined poor and fair condition.
Poor	More than 15% of the NEP estuarine area is in poor condition.

Benthic Index

The worms, clams, and crustaceans that inhabit the bottom substrates of estuaries are collectively called benthic macroinvertebrates, or benthos. These organisms play a vital role in maintaining sediment and water quality and are an important food source for bottom-feeding fish, shrimp, ducks, and marsh birds. Benthos are often used as indicators of disturbances in estuarine environments because they are not very mobile; thus, they cannot avoid environmental problems. Benthic population and community characteristics are sensitive indicators of chemical contaminant and dissolved-oxygen stress, salinity fluctuations, and sediment disturbance and serve as reliable indicators of estuarine environmental quality. To distinguish degraded benthic habitats from undegraded benthic habitats, EMAP and NCA have developed regional (Northeast, Southeast, and Gulf coasts) benthic indices of environmental condition for estuaries that reflect changes in the diversity and population size of indicator species (Engle et al., 1994; Weisberg et al., 1997; Engle and Summers, 1999; Van Dolah et al., 1999; Paul et at., 2001). These indices reflect changes in benthic community diversity and the abundance of pollution-tolerant and pollution-sensitive species. A high benthic index rating means that samples taken from an estuary's sediments contain a wide variety of species, a low proportion of pollution-tolerant species, and a high proportion of pollution-sensitive species. A low benthic index rating indicates that the benthic communities are less diverse than expected, are populated by more pollution-tolerant species than expected, and contain fewer pollution-sensitive species than expected. The benthic condition data presented throughout this report were collected by the NCA unless otherwise noted. Indices vary among the regions because species assemblages depend on prevailing temperatures, salinities, and the silt-clay content of sediments. A benthic index was rated poor when the index values for the Northeast, Southeast, and Gulf coasts' diversity or species richness, abundance of pollution-sensitive species, and abundance of pollution-tolerant species fell below a certain threshold. It should be noted that the benthic indices used in the Northeast are designed to discriminate between good and poor categories; a fair category does not exist.

Not all regions included in this report have developed benthic indices. Indices for the New England Coast north of Cape Cod (Acadian Province), the West Coast, and Puerto Rico are being developed and are not available for reporting at this time. The benthic index used in the Northeast region south of Cape Cod (Virginian Province) was developed by EMAP and NCA; however, EPA used the Shannon-Weiner Diversity Index to evaluate the benthic community for the NEP estuaries of the Acadian Province because the index used for the Virginian Province did not produce good results for these estuaries. In the West Coast and Puerto Rico regions, benthic community diversity was determined for each site as a surrogate for the benthic index. Values for benthic community diversity were examined regionally to determine if diversity varied directly with either salinity or sediment silt-clay content (the two natural variables most likely to influence

The abundant population growth in U.S. coastal areas increases the demands imposed on the natural, economic, and aesthetic value of estuaries (John Theilgard).

estuarine benthic diversity). If there was no significant relationship between diversity and these natural gradients in a region (as in Puerto Rico), then a surrogate benthic index was used based on the lower 95% confidence limit for the mean benthic diversity measures. If there was a significant relationship between diversity and either of these natural gradients in a region (as in the West Coast NEP estuaries), then a surrogate benthic index was used based on the ratio of observed to expected diversity. Expected diversity was determined based on the statistical relationship of site diversity to site salinity (or silt-clay content). Poor condition was defined as less than 75% of the expected benthic diversity at a particular salinity (expected diversity was determined by a regression between diversity and salinity). Table 1-20 shows the good, fair, and poor rating criteria for sites in the different regions of the country, which were used to calculate an overall rating for each NEP estuary and region.

The relationship between poor benthic condition (poor benthic index values) and environmental stressors (e.g., water quality and sediment quality indices and their component indicators) is examined using the co-occurrence of these factors in each region. In all regions, some sites with poor benthic community condition did not co-occur with high levels of environmental stressors measured by the NCA. The sites that do not co-occur with the poor water quality and sediment quality indices may be the result of physical habitat degradation (a parameter not measured by the NCA).

Fish Tissue Contaminants Index

Chemical contaminants may enter a marine organism in several ways: direct uptake from contaminated water, consumption of contaminated sediment, or consumption of previously contaminated organisms. Once these contaminants enter an organism, they tend

Table 1-20. Regional Criteria for Assessing Benthic Condition

Region		Fair	
Northeast Coast sites			
Acadian Province	Shannon-Weiner Diversity Index is greater than 0.63	NA*	Shannon-Weiner Diversity Index is less than or equal to 0.63
Virginian Province	Benthic index score is greater than 0.0	NA*	Benthic index score is less than 0.0
Southeast Coast sites	Benthic index score is greater than 2.5	Benthic index score is between 2.0 and 2.5	Benthic index score is less than 2.0
Gulf Coast sites	Benthic index score is greater than 5.0	Benthic index score is between 3.0 and 5.0	Benthic index score is less than 3.0
West Coast sites (compared to expected diversity)	Benthic index score is more than 90% of the lower limit (lower 95% confidence interval) of expected mean diversity for a specific salinity	Benthic index score is between 75% and 90% of the lower limit of expected mean diversity for a specific salinity	Less than 75% of observations had expected diversity
Puerto Rico sites (compared to upper 95% confidence interval for mean regional benthic diversity)	Benthic index score is more than 90% of the lower limit (lower 95% confidence interval) of mean diversity in unstressed habitats in Puerto Rico	Benthic index score is between 75% and 90% of the lower limit of mean diversity in unstressed habitats in Puerto Rico	Benthic index score is less than 75% of the lower limit of mean diversity for unstressed habitats in Puerto Rico
NEP Estuary or Region	Less than 10% of the NEP estuarine area has a poor benthic index score, and more than 50% of the NEP estuarine area has a good index score	10% to 20% of the NEP estuarine area has a poor benthic index score, or more than 50% of the NEP estuarine area has a combined fair and poor benthic index score	More than 20% of the NEP estuarine area has a poor benthic index score

* By design, these indices discriminate between good and poor conditions only.

to remain in the animal's tissues and may build up with subsequent feedings. When fish consume contaminated organisms, they may "inherit" the levels of contaminants in the organisms they consume. This same inheritance of contaminants occurs when humans consume fish with contaminated tissues. Contaminant residues can be examined in the fillets, whole-body portions, or specific organs of target fish and shellfish species and are compared with risk-based EPA Advisory Guidance criteria for fish contaminants (U.S. EPA, 2000b).

For the NCA surveys, target fish were collected from all stations where fish were available, and whole-body contaminant burdens were determined. No EPA Advisory Guidance criteria exist to assess the ecological risk of whole-body contaminants for fish, but EPA Advisory Guidance (U.S. EPA, 200b) can be used as a basis for estimating advisory determinations, even if the data are based on whole-fish or organ-specific body burdens (Table 1-21). The whole-fish contaminant information collected by the NCA for U.S. NEP estuaries was compared with risk-based thresholds based on the consumption of four 8-ounce meals per month for selected contaminants (approach used by many state advisory programs) and assessed for non-cancer and cancer health endpoints (U.S. EPA, 2000b). Table 1-22 shows the rating criteria for the fish tissue contaminants index for each site, and Table 1-23 shows how these data were used to create ratings for the NEP estuaries and the regions.

Table 1-21. Risk-based EPA Advisory Guidelines for Recreational Fishers (U.S. EPA, 2000b)

Contaminant	Concentration Range[a] (mg/L)	Health Endpoint
Arsenic (inorganic)[b]	3.5–7.0	non-cancer
Cadmium	0.35–0.70	non-cancer
Mercury	0.12–0.23	non-cancer
Selenium	5.9–12.0	non-cancer
Chlordane	0.59–1.2	non-cancer
DDT (total)	0.059–0.12	non-cancer
Dieldrin	0.059–0.12	non-cancer
Endosulfan	7.0–14.0	non-cancer
Endrin	0.35–0.70	non-cancer
Heptachlor epoxide	0.015–0.031	non-cancer
Hexachlorobenzene	0.94–1.9	non-cancer
Lindane	0.35–0.70	non-cancer
Mirex	0.23–0.47	non-cancer
Toxaphene	0.29–0.59	non-cancer
PAH (Benzo[a]pyrene)	0.0016–0.0032	cancer[c]
PCB (total)	0.023–0.047	non-cancer

[a] Range of concentrations associated with non-cancer and cancer health endpoint risk for consumption of four 8-ounce meals per month

[b] Inorganic arsenic estimated as 2% of total arsenic

[c] A non-cancer concentration range for PAHs does not exist

Table 1-22. Criteria for Determining the Fish Tissue Contaminants Index by Monitoring Station

Rating	Criteria
Good	For all chemical contaminants listed in Table 1-21, the measured concentrations fall below the range of the EPA Advisory Guidance* criteria for risk-based consumption associated with four 8-ounce meals per month.
Fair	For at least one chemical contaminant listed in Table 1-21, the measured concentration falls within the range of the EPA Advisory Guidance criteria for risk-based consumption associated with four 8-ounce meals per month.
Poor	For at least one chemical contaminant listed in Table 1-21, the measured concentration exceeds the maximum value in the range of the EPA Advisory Guidance criteria for risk-based consumption associated with four 8-ounce meals per month.

*The EPA Advisory Guidance concentration is based on the non-cancer ranges for all contaminants except PAH (benzo(a)pyrene), which are based on a cancer range because a non-cancer range for PAHs does not exist (see Table 1-21).

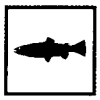
Table 1-23. Criteria for Determining the Fish Tissue Contaminants Index by NEP Estuary or Region

Rating	Criteria
Good	Less than 10% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in poor condition, and more than 50% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in good condition.
Fair	10% to 20% of the fish samples analyzed (Northeast Coast region) or monitoring stations where fish were caught (all other regions) are in poor condition, or more than 50% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in combined poor and fair condition.
Poor	More than 20% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in poor condition.

Summary of NCA Rating Criteria

The rating criteria for the NCA survey data used in this report are summarized in Table 1-24 (primary indices) and Tables 1-25 and 1-26 (component indicators).

Table 1-24. NCA Indices Used to Assess Estuarine Condition

Icon			
Water Quality Index	**Water Quality Index**—This index is based on five water quality component indicators (DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen).		
	Ecological Condition by Site		**Ranking by NEP Estuary or Region**
	Good:	No component indicators are rated poor, and a maximum of one component indicator is rated fair.	**Good:** Less than 10% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.
	Fair:	One component indicator is rated poor, or two or more component indicators are rated fair.	**Fair:** 10% to 20% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.
	Poor:	Two or more component indicators are rated poor.	**Poor:** More than 20% of the NEP estuarine area is in poor condition.
Sediment Quality Index	**Sediment Quality Index**—This index is based on three sediment quality component indicators (sediment toxicity, sediment contaminants, and sediment TOC).		
	Ecological Condition by Site		**Ranking by NEP Estuary or Region**
	Good:	No component indicators are rated poor, and the sediment contaminants indicator is rated good.	**Good:** Less than 5% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.
	Fair:	No component indicators are rated poor, and the sediment contaminants indicator is rated fair.	**Fair:** 5% to 15% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.
	Poor:	One or more component indicators are rated poor.	**Poor:** More than 15% of the NEP estuarine area is in poor condition.
Benthic Index	**Benthic Index** (or a surrogate measure)—This index indicates the condition of the benthic community (organisms living in estuarine sediments) and can include measures of benthic community diversity, the presence and abundance of pollution-tolerant species, and the presence and abundance of pollution-sensitive species.		
	Ecological Condition by Site		**Ranking by NEP Estuary or Region**
	Good, fair, and **poor** were determined using regionally dependent benthic index scores.		**Good:** Less than 10% of the NEP estuarine area has a poor benthic index score, and more than 50% of the NEP estuarine area has a good benthic index score. **Fair:** 10% to 20% of the NEP estuarine area has a poor benthic index score, or more than 50% of the NEP estuarine area has a combined poor and fair benthic index score. **Poor:** More than 20% of the NEP estuarine area has a poor benthic index score.
 Fish Tissue Contaminants Index	**Fish Tissue Contaminants Index**—This index indicates the level of chemical contamination in target fish/shellfish species.		
	Ecological Condition by Site		**Ranking by NEP Estuary or Region**
	Good:	For all chemical contaminants listed in Table 1-21, composite fish tissue contaminant concentrations are below the EPA Advisory Guidance* concentration range.	**Good:** Less than 10% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in poor condition, and more than 50% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in good condition.
	Fair:	For at least one chemical contaminant listed in Table 1-21, composite fish tissue contaminant concentrations are within the EPA Advisory Guidance concentration range.	**Fair:** 10% to 20% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in poor condition, or more than 50% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in combined poor and fair condition.
	Poor:	For at least one chemical contaminant listed in Table 1-21, composite fish tissue contaminant concentrations are above the EPA Advisory Guidance concentration range.	**Poor:** More than 20% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in poor condition.

*The EPA Advisory Guidance concentration is based on the non-cancer ranges for all contaminants except PAH (benzo(a)pyrene), which are based on a cancer range because a non-cancer range for PAHs does not exist (see Table 1-21).

Table 1-25. NCA Criteria for the Five Component Indicators Used in the Water Quality Index to Assess NEP Estuarine Condition

Dissolved Inorganic Nitrogen (DIN)

Ecological Condition by Site	Ranking by NEP Estuary or Region
Good: Surface concentrations are less than 0.1 mg/L (NE, SE, Gulf), 0.5 mg/L (West), or 0.05 mg/L (tropical)*.	**Good:** Less than 10% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.
Fair: Surface concentrations are 0.1–0.5 mg/L (NE, SE, Gulf), 0.5–1.0 mg/L (West), or 0.05–0.1 mg/L (tropical).	**Fair:** 10% to 25% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.
Poor: Surface concentrations are greater than 0.5 mg/L (NE, SE, Gulf), 1.0 mg/L (West), or 0.1 mg/L (tropical).	**Poor:** More than 25% of the NEP estuarine area is in poor condition.

Dissolved Inorganic Phosphorus (DIP)

Ecological Condition by Site	Ranking by NEP Estuary or Region
Good: Surface concentrations are less than 0.01 mg/L (NE, SE, Gulf), 0.01 mg/L (West), or 0.005 mg/L (tropical).	**Good:** Less than 10% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.
Fair: Surface concentrations are 0.01–0.05 mg/L (NE, SE, Gulf), 0.01–0.1 mg/L (West), or 0.005–0.01 mg/L (tropical).	**Fair:** 10% to 25% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.
Poor: Surface concentrations are greater than 0.05 mg/L (NE, SE, Gulf), 0.1 mg/L (West), or 0.01 mg/L (tropical).	**Poor:** More than 25% of the NEP estuarine area is in poor condition.

Chlorophyll *a*

Ecological Condition by Site	Ranking by NEP Estuary or Region
Good: Surface concentrations are less than 5 µg/L (less than 0.5 µg/L for tropical ecosystems).	**Good:** Less than 10% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.
Fair: Surface concentrations are between 5 µg/L and 20 µg/L (between 0.5 µg/L and 1 µg/L for tropical ecosystems).	**Fair:** 10% to 20% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.
Poor: Surface concentrations are greater than 20 µg/L (greater than 1 µg/L for tropical ecosystems).	**Poor:** More than 20% of the NEP estuarine area is in poor condition.

Water Clarity

Note: A water clarity index (WCI) is calculated by dividing observed clarity at 1 meter by a regional reference clarity at 1 meter. This regional reference is 10% for most of the United States, 5% for areas with naturally high turbidity, and 20% for areas with significant SAV beds or active SAV restoration programs.

Ecological Condition by Site	Ranking by NEP Estuary or Region
Good: WCI ratio is greater than 2.	**Good:** Less than 10% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.
Fair: WCI ratio is between 1 and 2.	**Fair:** 10% to 25% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.
Poor: WCI ratio is less than 1.	**Poor:** More than 25% of the NEP estuarine area is in poor condition.

*Tropical ecosystems in this NEP CCR include San Juan Bay Estuary, Puerto Rico.

Table 1-25. NCA Criteria for the Five Component Indicators Used in the Water Quality Index to Assess NEP Estuarine Condition (continued)

Dissolved Oxygen

Ecological Condition by Site	Ranking by NEP Estuary or Region
Good: Concentrations are greater than 5 mg/L.	**Good:** Less than 5% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition.
Fair: Concentrations are between 2 mg/L and 5 mg/L.	**Fair:** 5% to 15% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition.
Poor: Concentrations are less than 2 mg/L.	**Poor:** More than 15% of the NEP estuarine area is in poor condition.

Table 1-26. NCA Criteria for Measurements for the Three Component Indicators Used in the Sediment Quality Index to Assess NEP Estuarine Condition

Sediment Toxicity is evaluated as part of the sediment quality index using a 10-day static toxicity test with the amphipod *Ampelisca abdita*.

Ecological Condition by Site	Ranking by NEP Estuary or Region
Good: Mortality* is less than or equal to 20%.	**Good:** Less than 5% of the NEP estuarine area is in poor condition.
Poor: Mortality is greater than 20%.	**Poor:** 5% or more of the NEP estuarine area is in poor condition.

Sediment Contamination is evaluated as part of the sediment quality index using ERM and ERL guidelines.

Ecological Condition by Site	Ranking by NEP Estuary or Region
Good: No ERM values are exceeded, and fewer than five ERL values are exceeded.	**Good:** Less than 5% of the NEP estuarine area is in poor condition.
Fair: No ERM values are exceeded, and five or more ERL values are exceeded.	**Fair:** 5% to 15% of the NEP estuarine area is in poor condition.
Poor: One or more ERM values are exceeded.	**Poor:** More than 15% of the NEP estuarine area is in poor condition.

Sediment Total Organic Carbon (TOC) is measured as part of the sediment quality index.

Ecological Condition by Site	Ranking by NEP Estuary or Region
Good: The TOC concentration is less than 2%.	**Good:** Less than 20% of the NEP estuarine area is in poor condition.
Fair: The TOC concentration is between 2% and 5%.	**Fair:** 20% to 30% of the NEP estuarine area is in poor condition.
Poor: The TOC concentration is greater than 5%.	**Poor:** More than 30% of the NEP estuarine area is in poor condition.

*Test mortality is adjusted for control mortality.

How the NCA Indices Are Summarized

Overall condition for each region was calculated by summing the scores for the available regional indices and dividing by the number of available indices (i.e., equally weighted), where good = 5; fair = 4, 3, or 2 (based on position in percent range); and poor = 1.

The Southeast Coast, for example, received the following scores:

Index	Score
Water Quality Index	5
Sediment Quality Index	4
Benthic Index	3
Fish Tissue Contaminants Index	4
Total Score	**16**
Overall Condition	**16/4 = 4.0**

The national index scores and the overall condition score are calculated based on a weighted average of the regional scores for each index. The national ratings are assigned to each index score and overall condition score based on these regional scores, rather than on the percentage of area in good, fair, or poor condition. The indices were weighted based on the NEP estuarine area contributed by each geographic area, not the total estuarine area contributed by each region. For example, the weighted average for the water quality index was calculated by summing the products of the regional water quality index scores and the area contributed by the NEPs in each region (Figure 1-8). These weighting factors were used for all indices. The national overall condition score was then calculated by summing each national index score and dividing by four.

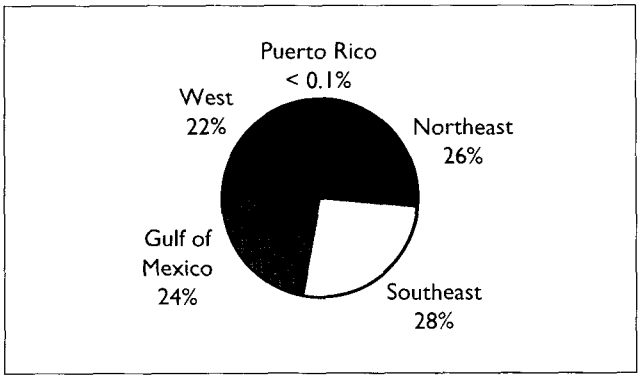


Figure 1-8. Percentage of NEP estuarine area contributed by each geographic region assessed in this report.

The NCA and the individual NEPs have the same goal of measuring estuarine condition, but these programs often use different monitoring methods and analysis procedures. Even when the indices used by these two programs seem to measure the same parameter, they may not be directly comparable because of differences in the methodology, time and spatial scales, and seasonality of the monitoring design. For instance, although the NCA may monitor chlorophyll *a* in an estuary over the course of a single week during the summer at randomly selected sites, an individual NEP may collect chlorophyll *a* samples every day, all year, but target the sampling to sites where nutrient inputs are anticipated to be high. Both types of information are important for learning about estuarine condition, but the information cannot be directly compared due to differences in methodology, time and spatial scales, and seasonality.

National Estuary Program (NEP) Monitoring Data

To measure the effectiveness of their CCMPs, each of the 28 individual NEPs develops a strategy for collecting and analyzing environmental monitoring data. Each program is also expected to develop indicators for measuring the change in estuarine conditions over time. In this report, indicator data have been collected from the individual NEPs to provide a specific picture of the conditions in each NEP estuary. Some of the more commonly assessed water quality indicators among the NEPs are nitrogen, chlorophyll *a*, and dissolved oxygen concentrations. Many NEPs are also concerned about habitat loss and have used a variety of methods, such as satellite imagery, geographic information systems (GIS) mapping, and aerial surveys, to track the changes in habitat coverage over time. Because the NEPs are able to choose the types of monitoring data and analytical methods that best fit their estuary's particular environmental conditions and concerns, the resulting data includes a variety of different measurements that are not readily comparable among the estuaries. This report takes advantage of region- and site-specific information from the individual NEPs to present a description of the condition of each NEP estuary, which is supplemented by the nationally consistent data provided by the NCA.

CHAPTER 2

U.S. NATIONAL ESTUARY PROGRAM COASTAL CONDITION—A NATIONAL SNAPSHOT

CHAPTER 2

U.S. NATIONAL ESTUARY PROGRAM COASTAL CONDITION—A NATIONAL SNAPSHOT

EPA summarizes environmental conditions in the 28 NEP estuaries to allow for statistical comparisons of coastal conditions nationwide. As discussed in Chapter 1, assessments of estuarine condition were developed for each individual NEP estuary and for the collective NEP estuaries on a regional and national basis. This chapter presents the national estuarine condition ratings for the collective NEP estuaries, as well as information on the regional estuarine condition ratings for the five U.S. regions discussed in this report. More in-depth information on the estuarine condition of these regions and the 28 individual NEP estuaries is provided in the regional summary sections and NEP profiles presented in Chapters 3 through 7.

The overall condition of the NEP estuaries of the United States is rated fair, with the water quality index, benthic index, and fish tissue contaminants index each rated fair and the sediment quality index rated fair to poor at the national level. Figure 2-1 shows the overall condition and estuarine index ratings for the nation and for the five regions discussed in this report. These ratings are based on monitoring data collected as part of the NCA, which sampled 1,239 sites within U.S. NEP estuaries from 1997 through 2003, with the majority of

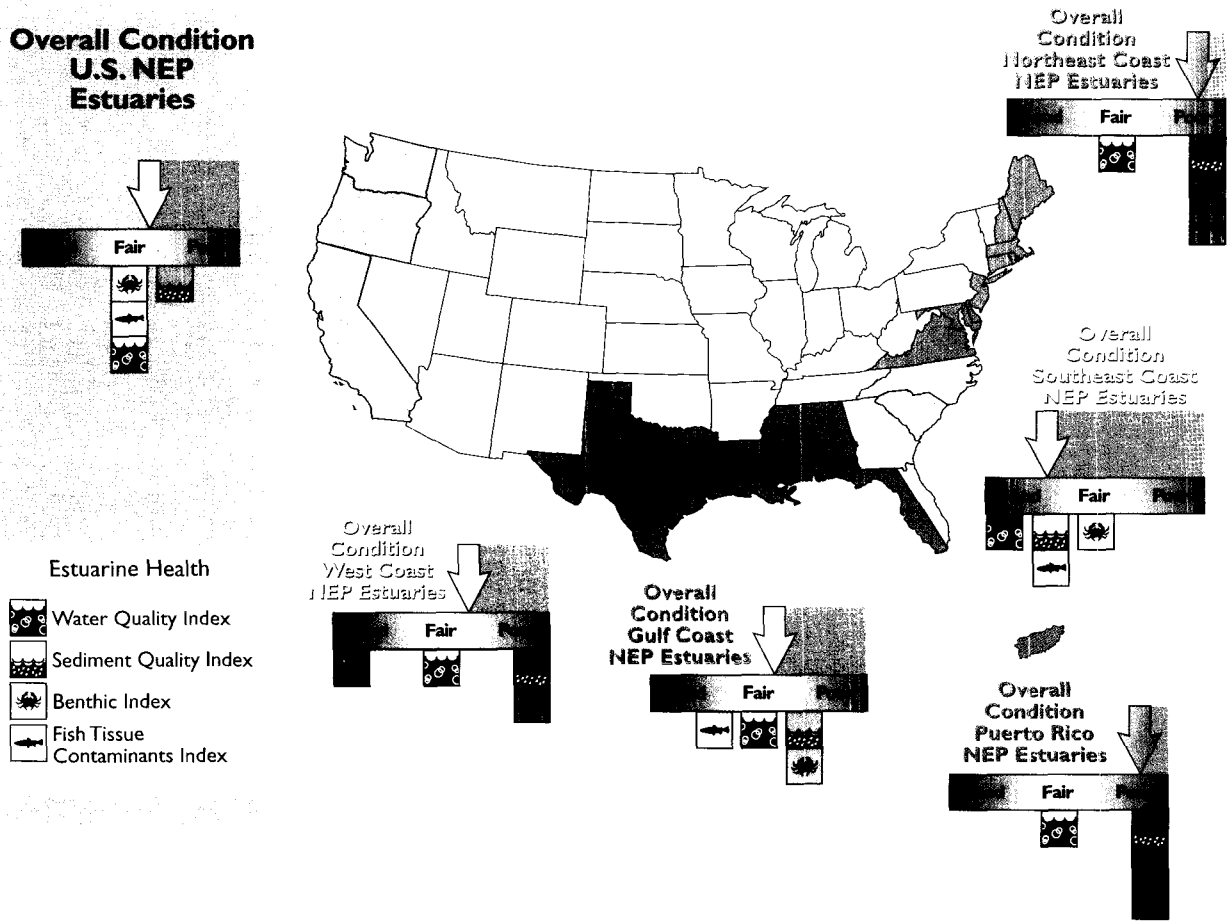


Figure 2-1. National and regional overall condition ratings for the nation's NEP estuaries (U.S. EPA/NCA).

the samples (95%) collected between 1999 and 2001. Of the four NCA indices rated for NEP estuaries nationwide, only the water quality index for the Southeast Coast region and the benthic index for the West Coast region were rated good.

The ratings for the individual NEP estuaries and the five geographic regions were based on the criteria outlined in Tables 1-24, 1-25, and 1-26 of this report, and overall condition ratings for each region were developed by averaging the four regional estuarine index ratings. Based on these calculations, the Northeast Coast region is rated fair for the water quality index; poor for the sediment quality, benthic, and fish tissue contaminants indices; and poor for overall condition. The Southeast Coast region is rated good for the water quality index; good to fair for the sediment quality index; fair for the benthic index; good to fair for the fish tissue contaminants index; and good to fair for overall condition. The Gulf Coast region is rated fair for the water quality index; fair to poor for the sediment quality and benthic indices; good to fair for the fish tissue contaminants index; and fair for overall condition. The West Coast region is rated fair for the water quality index; poor for the sediment quality index; good for the benthic index; poor for the fish tissue contaminants index; and fair for overall condition. Finally, the sole NEP estuary (San Juan Bay Estuary) in Puerto Rico is rated fair for the water quality index; poor for the sediment quality, benthic, and fish tissue contaminants indices; and poor for overall condition.

NCA Indices of Estuarine Condition—U.S. NEP Estuaries

This section presents EPA's NCA monitoring data, which were used to rate the four primary indices of estuarine condition discussed in this report. Based on NCA data, the overall condition of the nation's NEP estuaries is rated fair, with 37% of the nation's collective NEP estuarine area rated poor (Figure 2-2). The overall condition score was calculated by averaging the rating scores for the individual indices (water quality, sediment quality, benthic, and fish tissue contaminants). Figure 2-3 shows the percent of the nation's NEP estuarine area rated good, fair, poor, or missing for each of the parameters considered. Each NCA survey site was visited only once during the summer season; therefore, the results emerging from the NCA study form a "snapshot" of estuarine condition at a site, rather than a description of long-term conditions. This approach provides an accurate assessment of conditions in the relatively stable media of sediment and the associated benthic community, as well as of fish tissue contamination conditions that change relatively slowly over time; however, it provides a less accurate view of the ephemeral conditions associated with the water column, where water quality conditions may change weekly or even daily during a summer sampling period.

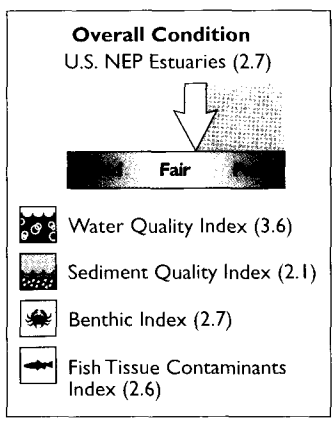


Figure 2-2. The overall condition of the nation's NEP estuarine area is fair (U.S. EPA/NCA).

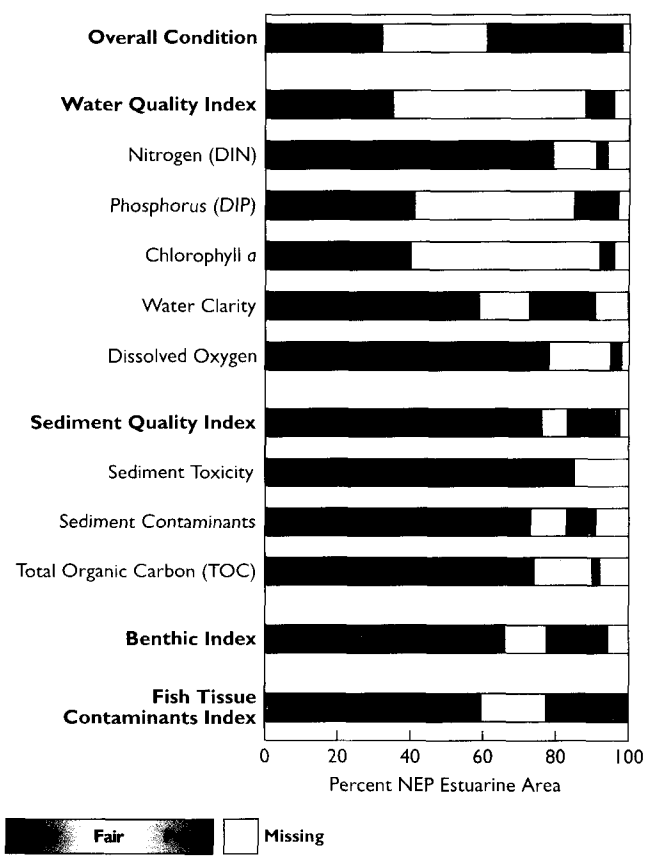


Figure 2-3. Percentage of estuarine area achieving each rating for all indices and component indicators – U.S. NEP estuaries (U.S. EPA/NCA).

Water Quality Index

Based on NCA data (representing five component indicators—DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen), the water quality index for the nation's collective NEP estuaries is rated fair. The index shows that 8% of the nation's NEP estuarine area is rated poor for water quality, and 54% of the area is rated fair (Figure 2-4). These categories combine to show that 62% ± 3% of the nation's NEP estuaries are experiencing a moderate to high degree of eutrophication. Poor water quality condition is generally characterized by degradation in the water quality variable (i.e., increased chlorophyll *a* concentrations and decreased dissolved oxygen concentrations). Moderate eutrophication shows some minor degradation in response variables, but poor water quality condition is more likely to be characterized by degradation due to environmental stressors, such as increased nutrient concentrations and reduced water clarity.

The Gulf Coast region shows the highest proportional area of NEP estuaries in poor condition (13%) for water quality, although the water quality index for this region is rated fair. NEP estuaries along the Northeast Coast, West Coast, and Puerto Rico also had water quality indices rated fair, with 9%, 4%, and 8% of NEP estuarine waters in these regions rated poor for water quality, respectively. The water quality index for the Southeast Coast region is rated good, with only 4% of this region's NEP estuarine area rated poor for water quality.

Figure 2-4. Water quality index data for U.S. NEP estuaries (U.S. EPA/NCA).

The sampling conducted by EPA's NCA is designed to estimate the percent of NEP estuarine area (nationally or regionally) in varying conditions; these estimates are displayed as pie diagrams. Many of the figures in this report illustrate environmental measurements made at specific locations (colored dots on maps); however, these dots (color) represent the value of the index specifically at the time of sampling. Additional sampling may be required to define variability and to confirm impairment or the lack of impairment at specific locations.

Dissolved Nitrogen and Phosphorus | Nutrient concentrations for summertime conditions in the nation's NEP estuaries are rated good for DIN concentrations and fair for DIP concentrations. Nutrient concentrations in summer are expected to be generally lower than at other times of year, except on the West Coast, where Pacific upwelling events often produce higher nutrient concentrations in the summer. Because of the expectation for lower nutrient concentrations, reference conditions were modified (reduced by 50%) for NEP estuaries of the Northeast Coast, Southeast Coast, and Gulf Coast regions.

DIN concentrations were uniformly low throughout the nation's NEP estuaries, with only 3% of the nation's NEP estuarine area characterized by poor conditions. Most DIN concentrations that exceeded reference conditions were in the NEP waters of the Northeast Coast (10%) and Puerto Rico (23%) regions. DIP concentrations exceeded the regional reference conditions in 12% of the nation's NEP estuarine area. Elevated summer DIP concentrations were observed in 10% to 20% of the area of most NEP regions (except for NEP estuaries of the Southeast Coast region, where only 6% exceeded these values). In addition, elevated DIN and DIP concentrations in the NEP estuaries of the Northeast Coast, Gulf Coast, and Puerto Rico regions correspond to elevated chlorophyll *a* concentrations in these estuaries.

Chlorophyll a | High concentrations of chlorophyll *a* in a waterbody indicate the potential for problems related to the overproduction of algae and increased eutrophic conditions. The collective NEP estuaries of the United States are rated fair for chlorophyll *a* concentrations, with 52% of the nation's NEP estuarine area rated fair and 4% of the area rated poor. The Gulf Coast, Southeast Coast, and Puerto Rico regions were also rated fair for this component indicator, whereas chlorophyll *a* conditions in the Northeast Coast and West Coast regions were rated good.

Water Clarity | Water clarity for the nation's NEP estuaries is rated fair. Three different regional reference conditions were established for measuring water clarity conditions (Table 2-1).

The NCA estimates that 18% of the nation's NEP estuaries do not meet regional reference conditions for good water clarity. NEP estuaries with poor water clarity are distributed throughout the country, but the West Coast (35%), Gulf Coast (31%), and Puerto Rico (17%) regions have the greatest proportion of NEP waters not meeting the conditions for good water clarity.

Table 2-1. Reference Conditions for Water Clarity in the Nation's NEP Estuaries

Reference Condition (ambient surface light that reaches a depth of 1 meter)	Area Type
5%	Areas having high natural levels of suspended solids in the water (e.g., Delaware Estuary, Barataria-Terrebone Estuarine Complex, Mobile Bay) or extensive wetlands
20%	Areas having extensive SAV beds (e.g., Indian River Lagoon, southern Laguna Madre of the Coastal Bend Bays) or desiring to re-establish SAV (e.g., Tampa Bay)
10%	The remainder of the country

Interpretation of Instantaneous Dissolved Oxygen Information

Although NCA results do not suggest that low dissolved oxygen concentrations are a pervasive problem, the instantaneous measurements on which these results are based may have underestimated the magnitude and duration of low dissolved oxygen events at any given site. Long-term observations by other investigators have revealed increasing trends in the frequency and areal extent of hypoxic events in some coastal areas. For example, extensive year-round or seasonal monitoring data over multiple years in such places as Narragansett Bay in Rhode Island have shown a much higher incidence of hypoxia than is depicted in the present NCA data, indicating that although hypoxic conditions do not exist continuously, they can occur occasionally to frequently for generally short durations of time (hours).

Dissolved Oxygen | Dissolved oxygen condition for the nation's NEP estuaries is rated good; however, the majority of NEP estuaries are not located in areas where severe hypoxic and anoxic water conditions have occurred historically, such as the waters found offshore of the Mississippi Delta region in the Gulf of Mexico. In addition, NCA estimates do not reflect the dystrophic nature of some estuarine systems, where dissolved oxygen levels are acceptable during daylight hours but decrease to low levels during the night. Many of these systems and their associated biota are adapted to this cycle, which is common in wetland, swamp, and blackwater ecosystems; however, because all NCA survey measurements were taken during daylight hours, these dystrophic events would not be detected by the NCA surveys.

The reference value used in the NCA analysis for poor dissolved oxygen is less than 2 mg/L in bottom waters. This guideline was chosen because this concentration is clearly indicative of potential harm to estuarine organisms. Approximately 3% of the NEP estuarine area experienced dissolved oxygen concentrations less than 2 mg/L in bottom waters. Although most regions of the country were rated good for dissolved oxygen concentrations, the Southeast Coast and Puerto Rico regions were rated fair.

Sediment Quality Index

The sediment quality index for the nation's collective NEP estuaries is rated fair to poor. This index is based on an assessment of sediment toxicity, sediment contaminant concentrations, and the percentage of sediment TOC, and about 15% of the nation's NEP estuarine area displayed a poor rating for one of these component indicators (Figure 2-5). The largest proportion of NEP estuarine area in poor condition was found in the Puerto Rico (33%), Northeast Coast (21%), and West Coast (17%) regions. Poor sediment quality condition in these regions is primarily the result of high TOC and sediment toxicity levels (Puerto Rico), elevated contaminant concentrations (Northeast Coast), and a high percentage of toxic sediments (West Coast). The Gulf Coast region received a fair to poor rating for sediment quality because 15% of this region's NEP estuarine area was rated poor for sediment contaminant concentrations. The Southeast Coast region received a good to fair regional rating for this index, with only 6% of the NEP estuarine area found to be in poor condition.

Sediment Toxicity | The NCA determined sediment toxicity by exposing test organisms to sediments from each sampling site and evaluating the effects of these sediments on the survival of the exposed organisms. Sediment toxicity tests using the benthic organism *Ampelisca abdita* showed significant mortalities associated with sediments in 7% of the nation's NEP estuarine area; therefore, sediment toxicity for the nation's collective NEP estuaries is rated poor. Regionally, sediment toxicity was observed most often in the NEP estuaries of the Puerto Rico (29%), West Coast (18%), and Northeast Coast (9%) regions.

Figure 2-5. Sediment quality index data for U.S. NEP estuaries (U.S. EPA/NCA).

Sediment Contaminant Criteria (Long et al., 1995)

ERM (Effects Range Median)—Determined for each chemical as the 50th percentile (median) in a database of ascending concentrations associated with adverse biological effects.

ERL (Effects Range Low)—Determined for each chemical as the 10th percentile in a database of ascending concentrations associated with adverse biological effects.

Sediment Contaminants | The NCA analyzed collected sediments for nearly 100 chemical contaminants at each sampling site, including 25 PAHs, 22 PCBs, 25 pesticides, and 15 metals. ERM and ERL values were used as guidelines to ascertain sediment condition, and poor condition was determined as an exceedance of one or more ERMs. Sediment contamination for the nation's NEP estuaries is rated fair, with ERM values exceeded in sediments from 8% of the nation's NEP estuarine area. The highest proportion of sediments exceeding these guidelines occurred in the NEP estuaries of the Northeast Coast (15%) and Gulf Coast (11%) regions, which were both rated fair for sediment contaminants. The West Coast and Puerto Rico were also rated fair for this component indicator, with 5% of each region's NEP estuarine area rated poor. Only the Southeast Coast region was rated good for sediment contaminant concentrations, with none of its estuarine area rated poor.

Total Organic Carbon | TOC in estuarine sediments is often a source of food for benthic organisms; however, high levels of sediment TOC can result in significant changes in an estuary's benthic community structure and the predominance of pollution-tolerant species. The nation's collective NEP estuaries were rated good for sediment TOC, with only 2% of the U.S. NEP estuarine area rated poor for this component indicator. In addition, all five NEP regions outlined in this report received good regional ratings for sediment TOC.

Benthic Index

As shown in Table 2-2, the criteria used to assess benthic condition differed for the various geographic regions of the United States. The benthic index for the nation's NEP estuaries is rated fair, with the index showing that 17% of the nation's NEP estuarine area supports benthic communities in poor condition (Figure 2-6). Benthic communities that are rated poor are characterized by lower-than-expected diversity and a high population of pollution-tolerant species, or they contain fewer-than-expected pollution-sensitive species, as measured by multimetric benthic indices. The Northeast Coast and Puerto Rico regions are both rated poor for the benthic index, with 26% and 65% of NEP estuarine area in those regions rated poor, respectively. The Gulf Coast region is rated fair to poor for this index, with 20% of the NEP estuarine area rated poor and an additional 27% rated fair for benthic communities. The Southeast Coast region is rated fair for benthic condition, with 15% of its NEP estuarine area rated as having poorer-than-expected benthic communities. Finally, the West Coast region is rated good for this index, with only 4% of the region's NEP estuarine area characterized as poor.

Figure 2-6. Benthic index data for U.S. NEP estuaries (U.S. EPA/NCA).

Table 2-2. Regional Criteria for Assessing Benthic Condition

Region		Fair	
Northeast Coast sites			
Acadian Province	Shannon-Weiner Diversity Index score is greater than 0.63	NA*	Shannon-Weiner Diversity Index score is less than or equal to 0.63
Virginian Province	Benthic index score is greater than 0.0	NA*	Benthic index score is less than 0.0
Southeast Coast sites	Benthic index score is greater than 2.5	Benthic index score is between 2.0 and 2.5	Benthic index score is less than 2.0
Gulf Coast sites	Benthic index score is greater than 5.0	Benthic index score is between 3.0 and 5.0	Benthic index score is less than 3.0
West Coast sites (compared to expected diversity)	Benthic index score is more than 90% of the lower limit (lower 95% confidence interval) of expected mean diversity for a specific salinity	Benthic index score is between 75% and 90% of the lower limit of expected mean diversity for a specific salinity	Less than 75% of observations had expected diversity
Puerto Rico sites (compared to upper 95% confidence interval for mean regional benthic diversity)	Benthic index score is more than 90% of the lower limit (lower 95% confidence interval) of mean diversity for unstressed habitats in Puerto Rico	Benthic index score is between 75% and 90% of the lower limit of mean diversity for unstressed habitats in Puerto Rico	Benthic index score is less than 75% of the lower limit of mean diversity for unstressed habitats in Puerto Rico
NEP Estuary or Region	Less than 10% of the NEP estuarine area has a poor benthic index score, and more than 50% of the NEP estuarine area has a good benthic index score	10% to 20% of the NEP estuarine area has a poor benthic index score, or more than 50% of the NEP estuarine area has a combined poor and fair benthic index score	More than 20% of the NEP estuarine area has a poor benthic index score

* By design, these indices discriminate between good and poor conditions only.

Fish Tissue Contaminants Index

Based on a weighted average of the regional scores, the fish tissue contaminants index for the nation's NEP estuaries is rated fair. Nationally, the index shows elevated levels of chemical contaminants in fish/shellfish tissues from 23% of the stations where fish were caught (Figure 2-7). The NCA collected fish for analysis of whole-body burdens of chemical contaminants (i.e., contaminants from the entire fish—fillets, head, skin, and organs), with the exception of a few stations that examined both edible fillets and whole-body burdens. The NCA examined samples (5–10 fish of a target species per station) from 330 stations throughout the nation's NEP estuarine waters and performed chemical analysis for about 90 specific contaminants.

The percentage of stations where fish were caught with elevated contaminant concentrations may have been increased in part due to the use of juvenile fish rather than fish of commercial size. The use of juvenile-sized fish could increase the likelihood of obtaining higher whole-body concentrations of contaminants, especially for those contaminants not found in muscle tissue. EPA Advisory Guidance describing risk-based concentrations of contaminants of concern for recreational and subsistence fishers (few contaminant guidelines exist for wildlife protection) applies to fillet, whole-body, and organ-specific concentrations (U.S. EPA, 2000b). Whole-body concentrations for many chemical contaminants (e.g., dioxins, PCBs, organochlorine pesticides) are higher than the concentrations found in muscle tissue (fillets); however, mercury concentrations can be severely underestimated using whole-body concentration data because mercury is concentrated primarily in the muscle tissue. Although

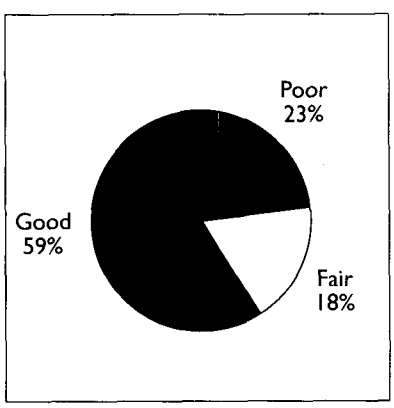


Figure 2-7. Fish tissue contaminants index data for U.S. NEP estuaries (U.S. EPA/NCA).

In the bioaccumulation process, chemical contaminants bioaccumulate in the tissues of aquatic organisms to concentrations many times higher than those found in seawater. In addition, these tissue concentrations in fish and other aquatic organisms may be increased at each successive level of the food web (Figure 2-8). As a result, top predators in a food web may have concentrations of chemical contaminants in their tissues at levels a million times higher than the concentrations found in seawater. A direct comparison of fish advisory contaminants and sediment contaminants is not possible because states often issue advisories for groups of chemicals; however, five of the top six contaminants most often associated with fish advisories (e.g., PCBs, DDT, dieldrin, chlordane, and dioxins) are among the contaminants most often responsible for a Tier 1 National Sediment Inventory classification (i.e., associated adverse effects to aquatic life or human health are probable) of waterbodies based on potential human health effects (U.S. EPA, 1997).

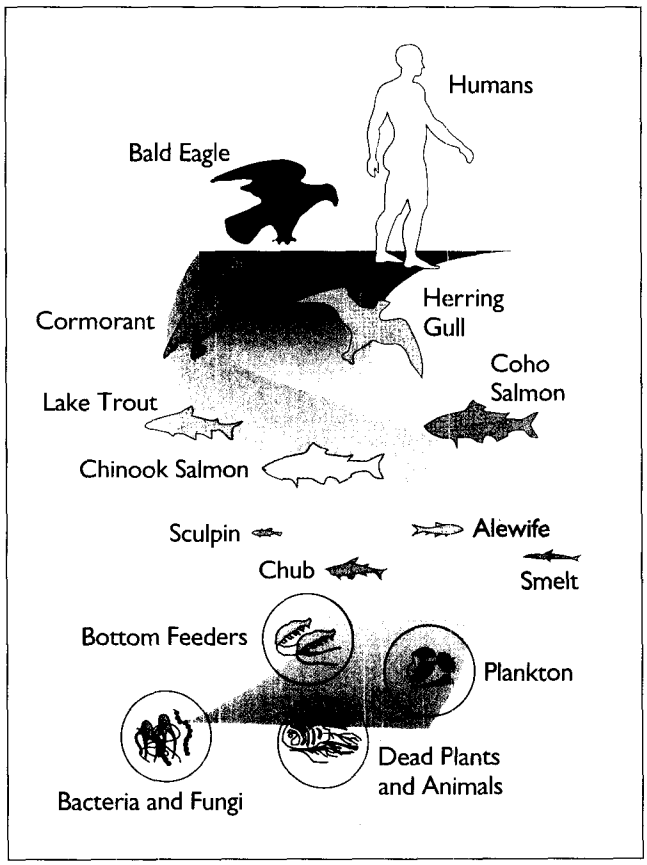


Figure 2-8. Bioaccumulation process (U.S. EPA/NCA).

mercury concentrations can be three to five times more concentrated in muscle tissue than in whole-body samples, about one-third of the coastal states often use whole-body concentrations to set fish advisories for waters where consumer groups eat whole fish.

The West Coast and Puerto Rico regions are rated poor for fish tissue contaminants in their NEP estuaries, with 32% and 40% of stations sampled, respectively, showing above-Guidance concentrations for at least one chemical contaminant. The Northeast Coast region is also rated poor, with 38% of the samples analyzed rated poor. Chemical contaminants detected in fish tissues generally included total PCBs, DDT and its metabolites, total PAHs, and mercury. Twelve percent of stations sampled in Gulf Coast NEP estuaries and 10% of stations sampled in Southeast Coast NEP estuaries showed elevated tissue concentrations, and both regions are rated good to fair for this index.

Population Pressures—A National Perspective

Population pressures on the coastal counties coincident to an individual NEP study area, or collectively on coastal counties coincident to all NEP study areas in a specific region, must be evaluated not only as total population, but also with thought to population density and population growth rate; therefore, total population values need to be assessed from both a temporal and spatial perspective. Population density provides a measure of how saturated the associated NEP-coincident coastal counties are with respect to human development. In contrast, the population growth rate over a specific time interval provides an indication of how quickly human development in an area occurs, as well as the coinciding infrastructure development that would be necessary to provide such essentials as residential housing and commercial development, highways and other transportation facilities, safe drinking water, and municipal and industrial treatment of wastes. Explosive population growth may not provide adequate time for state, county, or local government planning to meet increased infrastructure needs; to adequately monitor environmental indicators to assess trends affecting water, sediment, and habitat quality and the health of living resources; or to take action to reduce ecosystem degradation when it is identified. When assessed collectively, these measures provide information about the pressures society is exerting on the NEP coastal ecosystems.

For example, the NEP-coincident counties of the Northeast Coast region contained the highest total population in 2000 (38 million), followed by the West Coast (30 million), Gulf Coast (11 million), and Southeast Coast (3 million) regions (Table 2-3). Population density values also show that the NEP-coincident counties of the Northeast Coast had the highest regional density (1,055 persons/mi^2) in 2000, followed by the West Coast (421 persons/mi^2), Gulf Coast (287 persons/mi^2), and the Southeast Coast (168 persons/mi^2) regions; however, the NEP study area of San Juan Bay Estuary (Puerto Rico) had the highest population density in 2000 of any of the five regions (5,055 persons/mi^2). In contrast to total population and population density, population growth rates (1960–2000) for these same regions show a different pattern, with the Gulf Coast having the highest growth rate (133%), closely followed by both the Southeast Coast (131%) and the West Coast (100%), and lastly by the Northeast Coast (24%) region (Culliton et al., 1990; U.S. Census Bureau, 1991; 2001).

With respect to individual NEP study areas, there is a wide difference in total population, population density, and population growth rate, as well as in the size of the land area of NEP-coincident coastal counties.

Researchers assess population pressures to determine how increased population affects estuarine condition (John Theilgard).

Table 2-3. Total Population, Population Density, and Population Growth Rate for NEP-coincident Coastal Counties (U.S. Census Bureau, 1991; 2001)

NEP Estuarine Area	Land Area (mi^2)	Population for NEP-coincident Counties, 2000 (millions)	Population Density, 2000 (persons/mi^2)	Percent Population Growth Rate, 1960–2000
Northeast Coast	**35,894**	**37.876**	**1,055**	**24**
Casco Bay	4,671	0.646	138	48
New Hampshire Estuaries	2,002	0.433	216	148
Massachusetts Bays	2,829	4.224	1,493	23
Buzzards Bay	1,714	1.245	726	72
Narragansett Bay	5,001	4.922	984	28
Long Island Sound	6,750	14.647	2,170	14
Peconic Estuary	911	1.419	1,558	113
New York/New Jersey Harbor	5,470	16.943	3,097	13
Barnegat Bay	1,921	1.550	807	132
Delaware Estuary	12,138	9.376	772	35
Delaware Inland Bays	942	0.157	166	114
Maryland Coastal Bays	475	0.047	98	96
Southeast Coast	**18,963**	**3.192**	**168**	**131**
Albemarle-Pamlico Estuarine Complex	14,452	1.804	125	71
Indian River Lagoon	4,511	1.388	308	327
Gulf Coast	**39,482**	**11.334**	**287**	**133**
Charlotte Harbor	9,719	2.976	306	251
Sarasota Bay	1,320	0.590	447	304
Tampa Bay	5,214	3.339	640	190
Mobile Bay	2,827	0.540	191	49
Barataria-Terrebonne Estuarine Complex	8,824	1.627	184	28
Galveston Bay	6,720	4.376	651	182
Coastal Bend Bays	10,374	0.548	53	36
West Coast	**70,043**	**29.504**	**421**	**100**
Puget Sound	20,118	4.114	205	121
Lower Columbia River Estuary	11,875	1.644	138	78
Tillamook Bay	1,101	0.024	22	28
San Francisco Estuary	10,357	8.740	844	96
Morro Bay	3,308	0.247	75	204
Santa Monica Bay	26,794	14.828	553	99
Puerto Rico	**233**	**1.177**	**5,055**	**NA**
San Juan Bay Estuary	233	1.177	5,055	NA

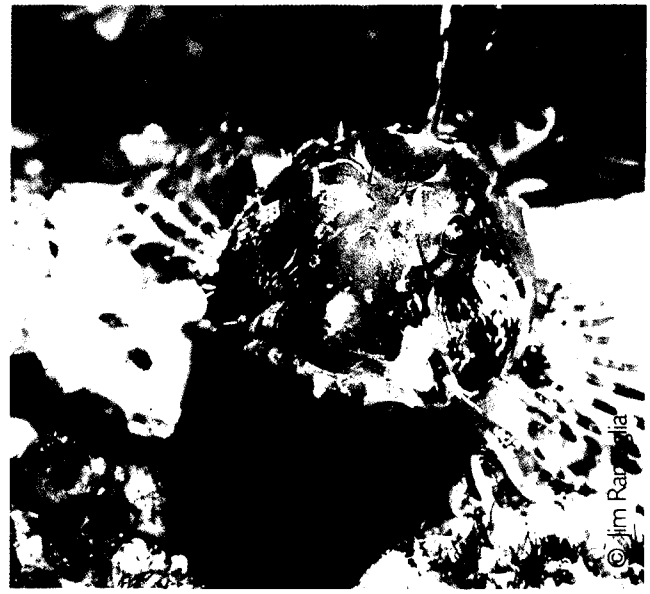
NA = not available

For example, the total population in 2000 for coastal counties coincident to NEP study areas ranged from 24,000 (Tillamook Bay) to 16,943,000 (New York/New Jersey Harbor)—almost a 1,000-fold difference. Population density also varied in the NEP-coincident coastal counties, ranging from 22 persons/mi^2 (Tillamook Bay) to 5,055 persons/mi^2 (San Juan Bay Estuary)—a more than a 200-fold difference. Finally, population growth rates from 1960 to 2000 varied widely and ranged from a low of 13% (New York/New Jersey Harbor) to a high of 304% (Sarasota Bay). In addition, the land areas of NEP-coincident coastal counties range in size from 233 mi^2 (San Juan Bay Estuary) to 26,794 mi^2 (Santa Monica Bay). The evaluation of these parameters is important in assessing population pressures on an individual estuary or coastal region.

Correlation between NEP CCR Index Scores and Population Pressures

The NCA data reveal some patterns with respect to an individual NEP study area's total population and population density and its overall condition score and rating. Mean overall condition improves with decreasing population, although the ranges vary widely. As shown in Table 2-4, for the 11 NEPs with populations greater than 2 million people, the overall condition scores range from 1.0 (rated poor) to 3.0 (rated fair), with a mean overall condition score of 2.26 (rated fair to poor). For the 8 NEPs with populations between 1 to 2 million people, the overall condition scores range from 1.5 (rated poor) to 5.0 (rated good), with a mean score of 3.30 (rated fair). For the 9 NEPs with populations less than 1 million people, the overall condition scores range from 1.75 (rated poor) to 5.0 (rated good), with a mean score of 3.45 (rated fair). Although it is clear that the NEPs with the greatest populations (> 2 million) show the lowest overall condition scores, as well as scores within the smallest range of values, the overall condition scores for the other two population ranges (1–2 million, < 1 million) vary widely. In addition, the mean overall condition score for the group of NEPs with the lowest overall population (< 1 million) is only slightly higher as compared to the score for the intermediate population group (1–2 million).

As shown in Table 2-5, the overall condition scores with respect to population density are very similar to those found with respect to total population. For the 5 NEP study areas with population densities greater than 2,000 persons/mi^2, the overall condition scores



Environmental degradation has led to major declines in native fish that depend upon estuaries for their existence (Jim Ramaglia).

Table 2-4. Comparison of Total Population of NEP-Coincident Coastal Counties with NCA Mean Overall Condition Scores

Total Population of NEP-Coincident Coastal Counties	Range in NCA Overall Condition Scores Observed	NCA Mean Overall Condition Score	Number of NEP Estuaries
> 2 million	1.0–3.0	2.26	11
1–2 million	1.5–5.0	3.30	8
< 1 million	1.75–5.0	3.45	9

range from 1.0 (rated poor) to 4.3 (rated good), with a mean overall condition score of 2.16 (rated fair to poor). These estuaries include San Juan Bay Estuary (5,055 persons/mi^2), New York/New Jersey Harbor (3,097 persons/mi^2), Long Island Sound (2,170 persons/mi^2), Peconic Estuary (1,558 persons/mi^2), and the Massachusetts Bays (1,493 persons/mi^2). It should be noted that although the Peconic Estuary had the highest overall condition score (4.33), no data were collected for a sediment quality index for this estuary; therefore, this score does not reflect an assessment of sediment toxicity, sediment contaminant concentrations, or sediment TOC. If the Peconic Estuary is not used in the population density analysis, then the overall condition scores of the other 4 NEPs range from 1.0 (rated poor) to 2.5 (rated fair), and the mean overall condition score drops from 2.16 (rated fair to poor) to 1.63 (rated poor). For the 8 NEPs with population densities ranging from 500 to 1,000 persons/mi^2, the overall condition scores range from 1.75 (rated poor) to 3.5 (rated fair), with a mean score of 2.58 (rated fair). Finally, for the 15 NEPs with the lowest population densities (less than 500 persons/mi^2), the overall condition scores range from 1.75 (rated poor) to 5.0 (rated good), with a mean score of 3.39 (rated fair). As shown for total population, there is a slight increase in the mean overall condition scores for these groups as the population density decreases.

Although the mean overall condition scores based on total population and population density for the NEP-coincident coastal counties appear to exhibit some patterns, it should be noted that within any of the total population groups (Table 2-4) or population density groups (Table 2-5), there is a high degree of variability in the range of overall condition scores for the individual NEPs because unmeasured indices or component indicators may exert effects on an estuary's overall condition score.

For example, one confounding issue is that for 9 of the 28 NEP estuaries (almost a third), component indicator data were not collected for one or more of the primary indices of estuarine condition. In the Northeast Coast region, NCA data for the fish tissue contaminants index and the sediment quality index were unavailable for Casco Bay and the Peconic Estuary, respectively. In the Southeast Coast region, NCA data for the fish tissue contaminants index and two components of the sediment quality index (sediment toxicity and sediment contaminant concentrations) were not available for the Indian River Lagoon. In the Gulf Coast region, data from the three Florida NEP estuaries were missing for evaluating the fish tissue contaminants index and two components of the sediment quality index (sediment toxicity and sediment contaminant concentrations). Finally, a benthic index could not be calculated for three of the West Coast region's seven estuaries (the Lower Columbia River Estuary, Morro Bay, and Santa Monica Bay). If data had been collected and/or applicable for these indices and component indicators, the overall condition scores for the individual NEP estuaries may have been considerably different from those developed using less than a full suite of data.

Table 2-5. Comparison of Population Density of NEP-Coincident Coastal Counties with NCA Mean Overall Condition Scores

Population Density of NEP-Coincident Coastal Counties	Range in NCA Overall Condition Scores Observed	NCA Mean Overall Condition Score	Number of NEP Estuaries
> 1,000 persons/mi^2	1.0–4.33	2.16	5
500–1,000 persons/mi^2	1.75–3.5	2.58	8
< 500 persons/mi^2	1.75–5.0	3.39	15

The previous sections of this chapter have discussed the national and regional ratings for the NEP estuaries, which are based on NCA scores for four primary indices of estuarine condition (water quality index, sediment quality index, benthic index, fish tissues contaminants index). The NCA results for the nation's 28 individual NEP estuaries for these four indices, as well as for the component indicators for the water and sediment quality indices, are shown in Figures 2-9 through 2-12. These figures provide an easy way to compare the various ratings and scores for each index and component indicator among the individual NEP estuaries, as well as regionally and nationally. The figures also show where data were unavailable to assess an index or component indicator for an individual estuary. The index ratings for the five NEP regions outlined in this report will be discussed further in the regional summary sections of Chapters 3 through 7.

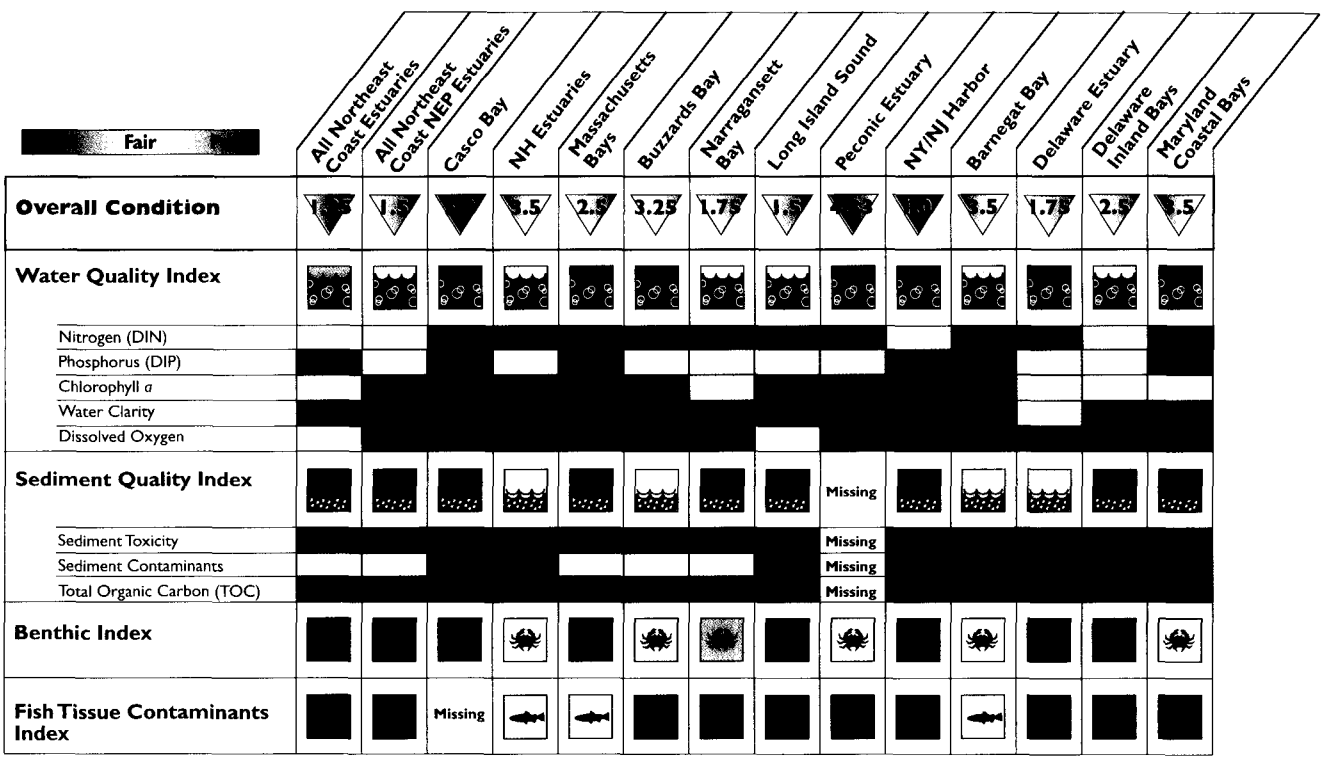


Figure 2-9. Comparison of NCA results for Northeast Coast NEP estuaries and all Northeast Coast estuaries (U.S. EPA/NCA).

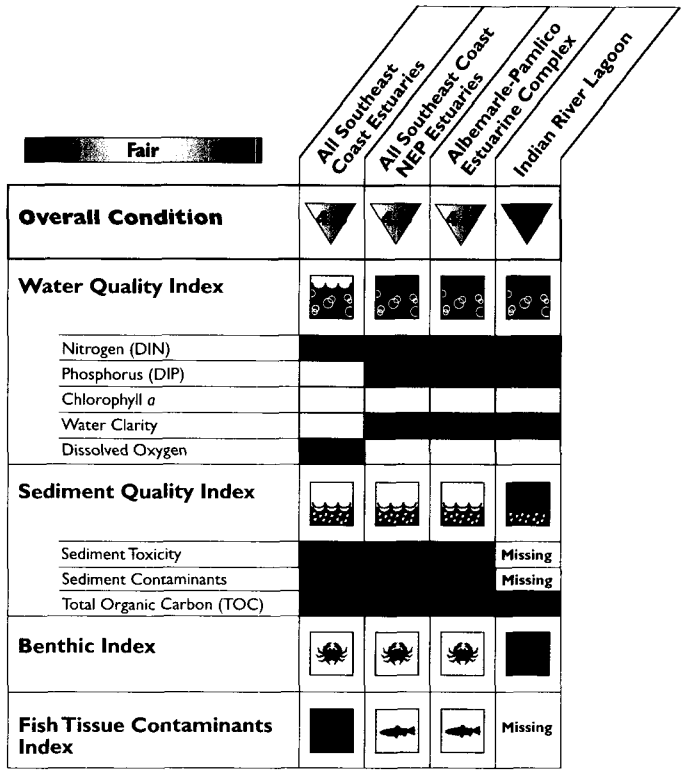


Figure 2-10. Comparison of NCA results for Southeast Coast NEP estuaries and all Southeast Coast estuaries (U.S. EPA/NCA).

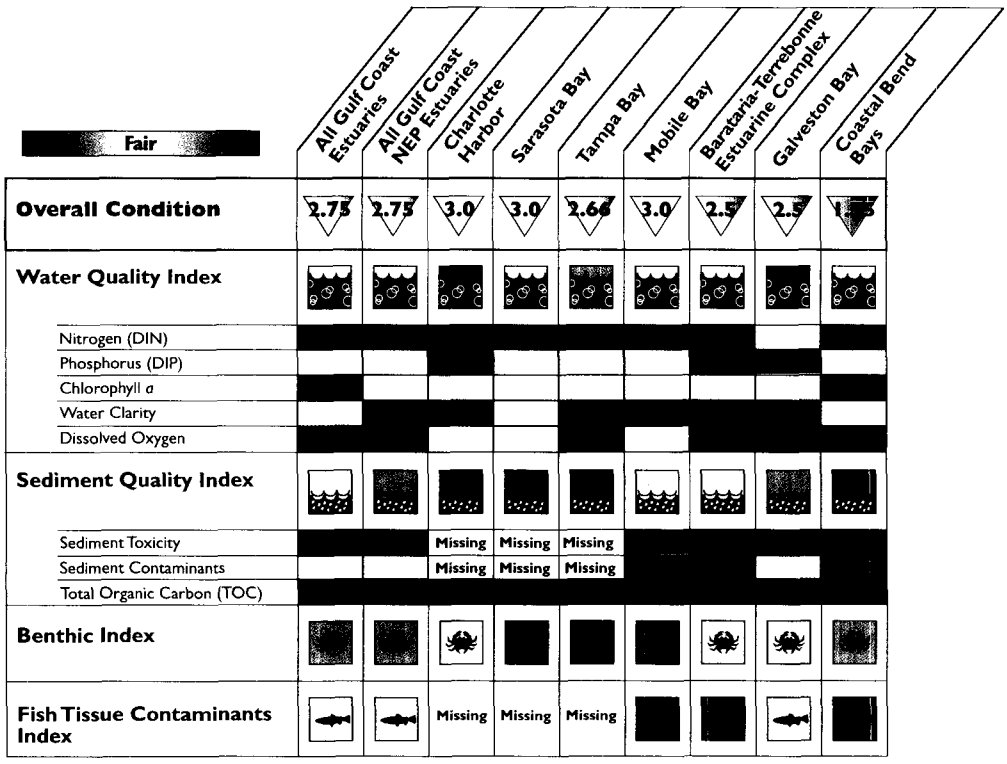


Figure 2-11. Comparison of NCA results for Gulf Coast NEP estuaries and all Gulf Coast estuaries (U.S. EPA/NCA).

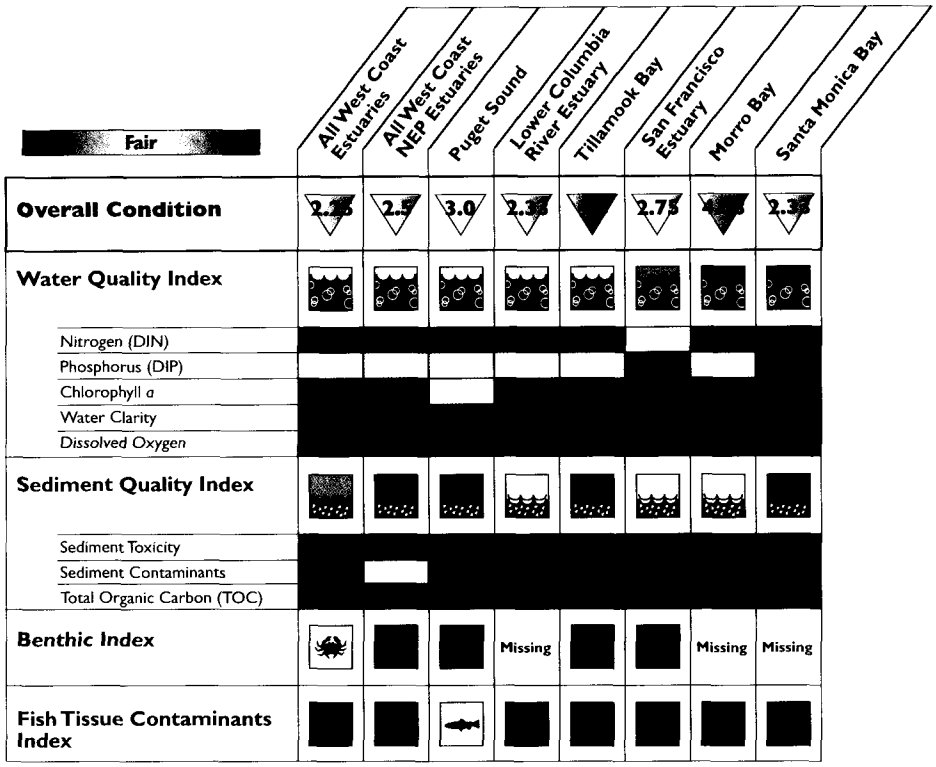
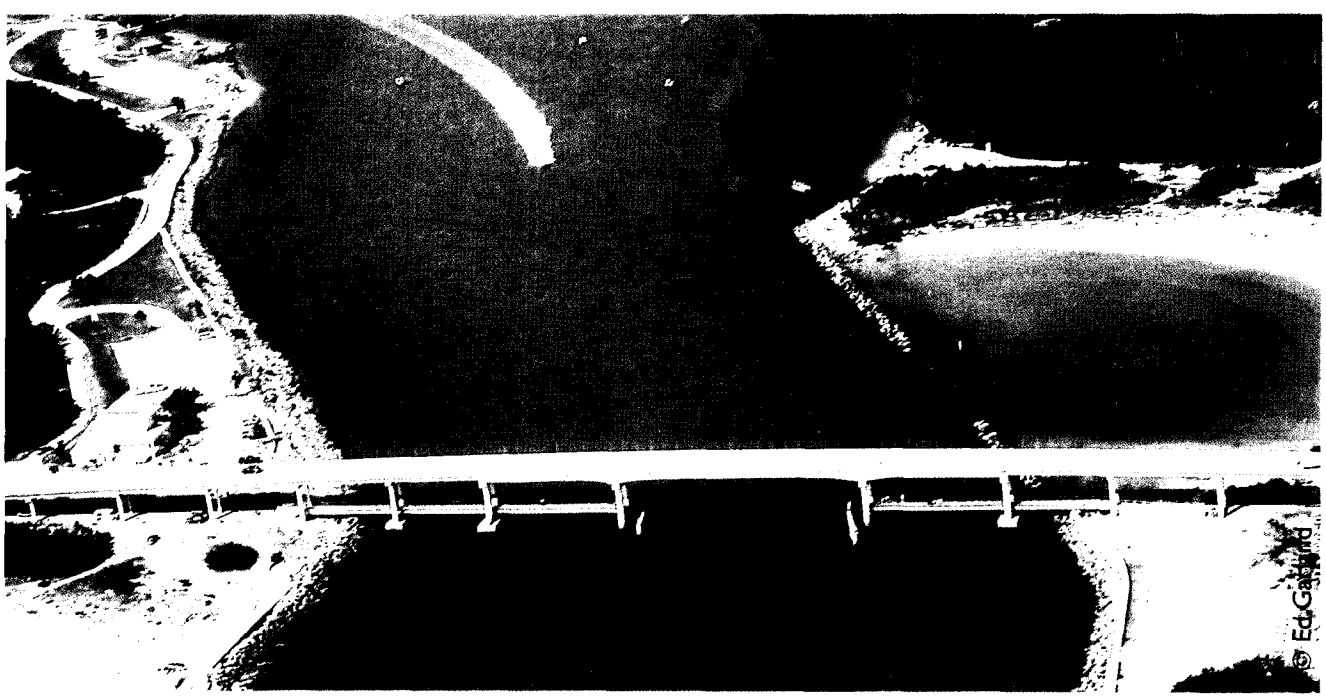


Figure 2-12. Comparison of NCA results for West Coast NEP estuaries and all West Coast estuaries (U.S. EPA/NCA).



The 28 NEPs identify habitat loss or alteration of habitat in the NEP estuaries as a primary environmental concern (Ed Garland).

NEP Environmental Concerns

There are a number of major environmental concerns that plague the nation's 28 NEP estuaries (ANEP, 2005; U.S. EPA, 2006d). As shown in Figure 2-13, several of these environmental concerns affect almost all of the NEPs, while others are a concern for a more limited number of NEPs and are related to site-specific differences in the climatic conditions, geology, or geomorphology of the individual estuaries. To address these issues, the 28 NEPs have made many of these environmental concerns the cornerstones of the priority management activities for their respective programs. The major environmental concerns for the NEP estuaries include those discussed below.

Habitat Loss/Alteration (28 NEPs)

All 28 of the NEPs identify habitat loss or alteration of habitat as a primary environmental concern. Estuaries are the transitional zones that provide high-quality habitat for a diverse array of organisms, including food, shelter, migratory corridors, and breeding and nursery areas for fish, shellfish, and waterfowl. Healthy estuaries and their associated wetlands and marshes protect water quality by sequestering toxicants, filtering nutrients from runoff and storing water, reducing flood potential, and protecting shorelines from erosion during hurricane and storm-related events; however, these areas are the habitats that are most affected by human development, including dredging and dredge-disposal activities; construction of groins, seawalls, and other hardened structures; and hydrologic modifications.

Declines in Fish and Wildlife Populations (25 NEPs)

Human population growth and the associated activities of residential and commercial development threaten the biological diversity, habitat quality, and productivity of our nation's estuaries. Environmental degradation associated with habitat loss, fragmentation or alteration, water pollution from toxic chemicals and nutrients, overexploitation of natural resources, and introduction of invasive species have all led to major declines in some of the native fish and wildlife populations that depend upon estuaries for their existence. In addition to the 25 NEPs that identify declines in fish and wildlife species as an environmental concern, 14 of these NEPs (~50%) identify that these declines have occurred in some recreationally or commercially valuable fish and shellfish species.

Excessive Nutrients (21 NEPs)

Nutrients such as nitrogen and phosphorus are naturally occurring and vital elements needed to support a healthy ecosystem; however, excessive amounts of nutrients can result in serious environmental problems. For example, algal blooms rob the water column of dissolved oxygen and diminish water clarity, reducing the growth of SAV (e.g., seagrasses). Loss of SAV acreage can result in loss of critical habitat needed to sustain healthy communities of fish and shellfish. From Delaware south to Florida's Atlantic and Gulf Coast estuaries, excessive nutrients have also been linked to fish kills by toxic algae such as *Pfiesteria piscicida* (N.C. Department of Health and Human Services, 2003). Nutrients can enter estuaries via runoff of agriculturally and residentially applied fertilizers and animal wastes, discharges from wastewater treatment plants (WWTPs), leaching from malfunctioning septic systems, and discharges of sanitary wastes from recreational boats. It is noteworthy that although excessive nutrients remain a concern in many estuaries, $53 billion in funding has been spent over the past 18 years to rebuild and upgrade WWTPs, resulting in expanded capacity for secondary and tertiary treatment of wastewater to remove nutrients, heavy metals, and organic contaminants (U.S. EPA, 2006a).

Toxic Chemical Contaminants (20 NEPs)

During the past 50 years, 70,000 synthetic chemicals have been released into the nation's estuarine and marine environments via stormwater runoff, industrial discharges, agricultural runoff, and deposition of toxicants from air pollution (ANEP, 2005). The chemical contaminants of major concern include metals (e.g., mercury), PCBs, PAHs, a variety of organochlorine pesticides (e.g., DDT, dieldrin, and chlordane), and herbicides. These chemicals may become adsorbed to estuarine sediments and affect the structure and diversity of benthic communities. In addition, they provide a conduit for chemical contaminants to move up the food chain because fish and other wildlife feed on benthic organisms living in areas with contaminated sediments.

Pathogenic Microorganisms (19 NEPs)

Pathogenic microorganisms (pathogens) include bacteria, viruses, and algae that produce diseases in plants, animals, and humans. In addition to human health risks from recreational contact with contaminated seawater and consumption of contaminated fish and shellfish, pathogen contamination in estuaries can result in economic losses due to shellfish-harvesting closures. Pathogens can cause disease conditions, such as gastroenteritis, salmonellosis, hepatitis A, and, in the case of the bacteria *Vibrio vulnificus*, can even cause death in some individuals (Rippey, 1994). Pathogen sources may include WWTP discharges, malfunctioning septic systems, land runoff from confined animal feeding operations (CAFOs) or concentrations of migratory waterfowl, and sanitary wastes from recreational boats.

Alteration of Freshwater Flows (11 NEPs)

In many parts of the United States, fresh water is an increasingly scarce natural resource. Human activities have altered the timing and volume of freshwater flows into some estuaries through dam construction and extensive withdrawals of water for irrigation or municipal drinking water use. Alteration in the timing and volume of freshwater flows can have devastating repercussions for estuarine plants and animals, especially in regions where rainfall is minimal. Alterations in freshwater discharges can result in changes in salinity, nutrient, and sediment levels in estuarine waters, which can affect seasonal fish-spawning activities, shellfish condition, avian nesting activities, and the health of wildlife that are dependent on the estuaries (ANEP, 2005).

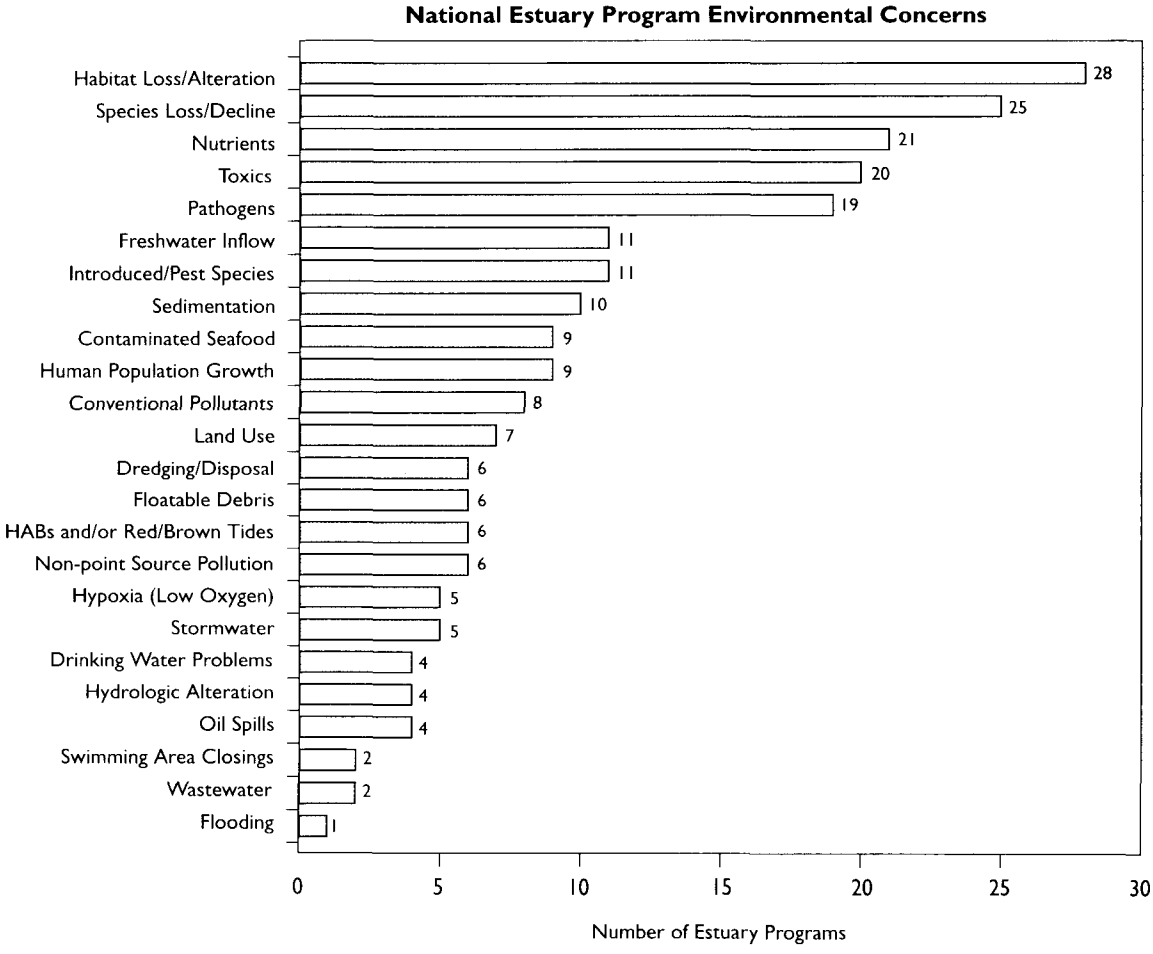


Figure 2-13. List of environmental concerns of the nation's 28 individual NEPS (U.S. EPA, 2006d).

Introduction of Invasive Species (11 NEPs)

Invasive species can be plants, animals, and other organisms such as microorganisms (e.g., bacteria, viruses, algae) that are typically introduced through human activities. An invasive species is one that is non-native to the ecosystem under consideration and whose introduction causes economic or environmental harm or human health concerns (USDA, 2006). The food webs of some NEP estuaries have been altered by the introduction of non-indigenous, exotic species, including both plants and animals. These invading, opportunistic species have, through predation of and competition with native species, led to the alteration or eradication of many native plants and animals. Invasive species can also affect commercial and recreational fishing, recreational boating, and beach ecology; interfere with industrial processes and navigation; cause wetlands loss; and modify nutrient cycling and soil fertility (ANEP, 2005). Many invasive species are transported by cargo ships, which discharge millions of gallons of ballast water at large commercial shipping ports in the United States. Other species are imported intentionally into the United States through the aquarium or water garden trade (USGS, 2006a). The European milfoil (*Myriophyllum spicatum*) is a prime example of an invasive SAV species that can become permanently established where it is introduced. In many estuarine rivers and bays along the Atlantic, Gulf, and Pacific coasts, water milfoil has thrived and has become the dominant SAV.

Although some environmental concerns are universal among the NEP estuaries, others are restricted to only a few NEPs. Each individual NEP must address, monitor, and effectively manage a slightly different suite of environmental concerns relative to their own estuary. Further information on some of the more important environmental concerns confronting each of the 28 NEP estuaries is described in the latter half of each NEP profile (Chapters 3 through 7) in the section entitled *Indicators of Estuarine Condition.*

CHAPTER 3

NORTHEAST COAST NATIONAL ESTUARY PROGRAM COASTAL CONDITION

CHAPTER 3

NORTHEAST COAST NATIONAL ESTUARY PROGRAM COASTAL CONDITION

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).

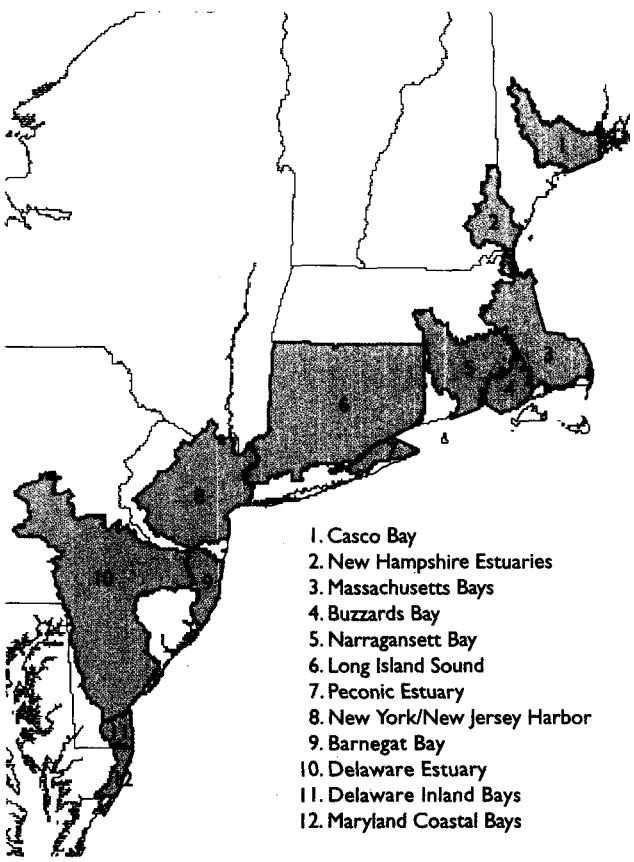


Figure 3-1. The Northeast Coast region is home to 12 NEP estuaries.

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

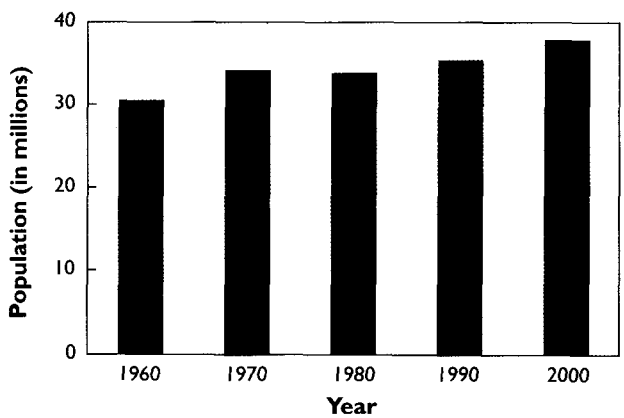


Figure 3-2. Population of NOAA-designated coastal counties of the Northeast Coast region's NEP study areas, 1960–2000 (U.S. Census Bureau, 1991; 2001).

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.

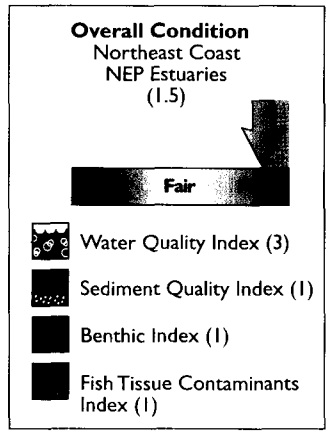


Figure 3-3. The overall condition of the Northeast Coast NEP estuarine area is poor (U.S. EPA/NCA).

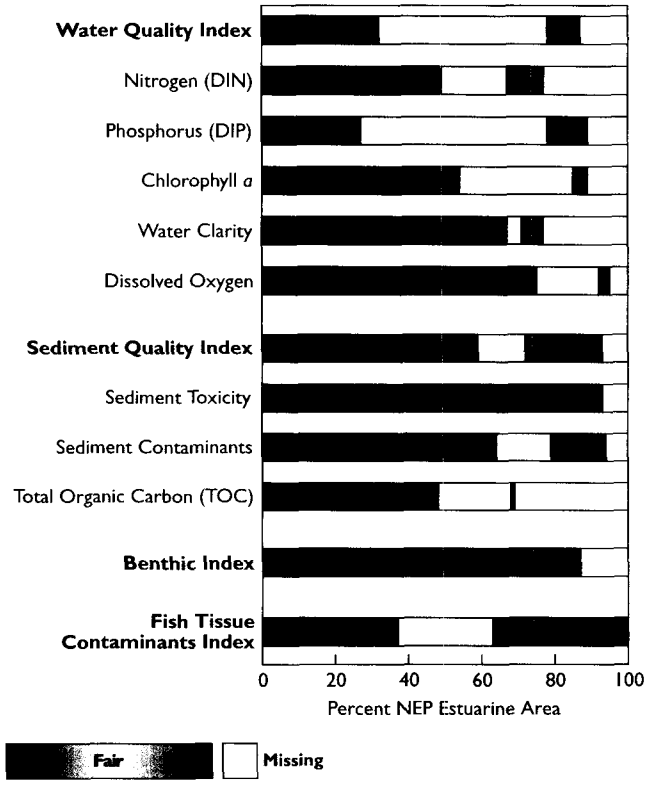


Figure 3-4. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Northeast Coast region (U.S. EPA/NCA).

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.**

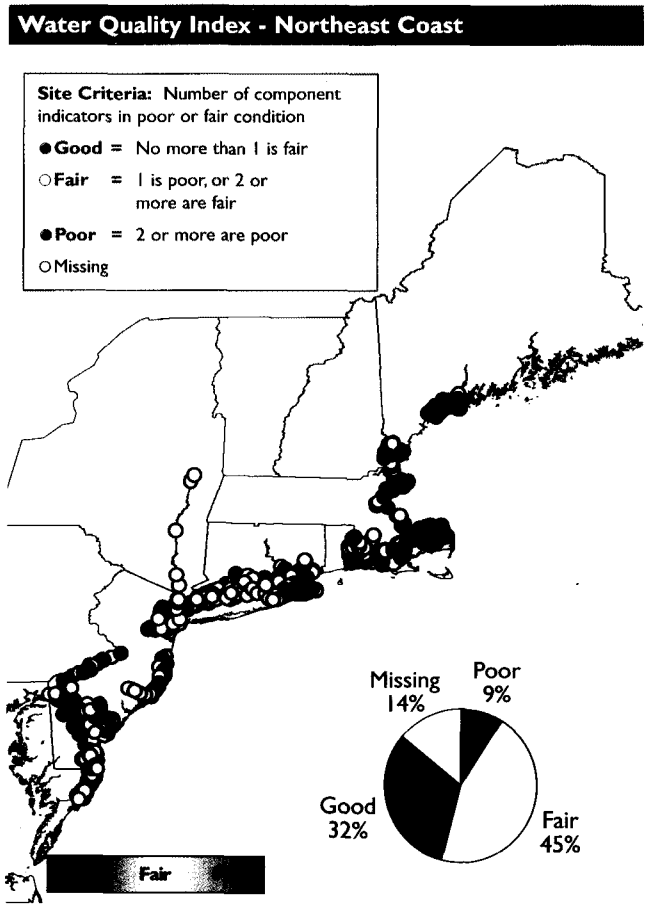


Figure 3-5. Water quality index data for the Northeast Coast NEP estuarine area (U.S. EPA/NCA).

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.

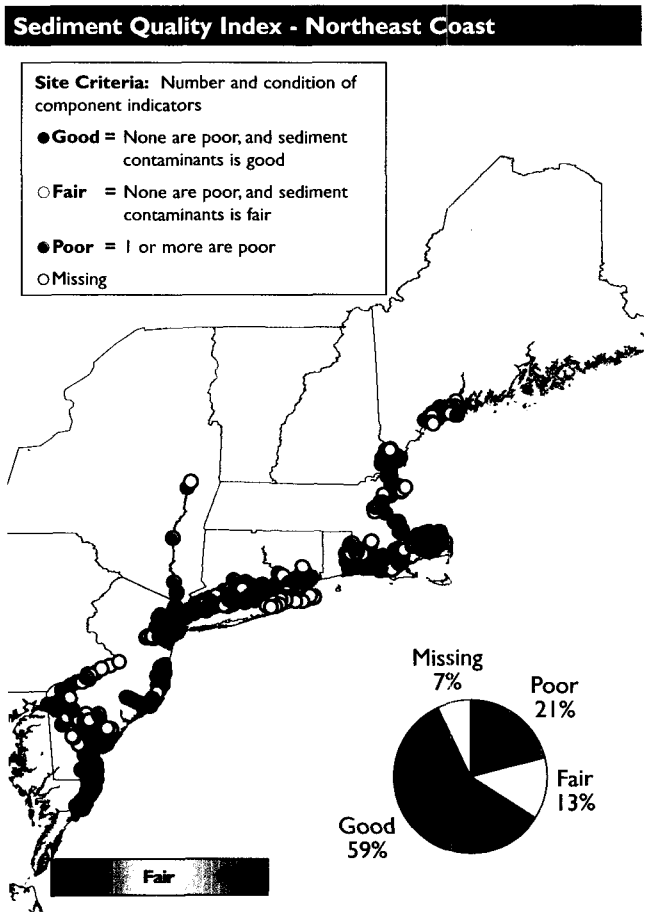


Figure 3-6. Sediment quality index data for the Northeast Coast NEP estuarine area (U.S. EPA/NCA).

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.

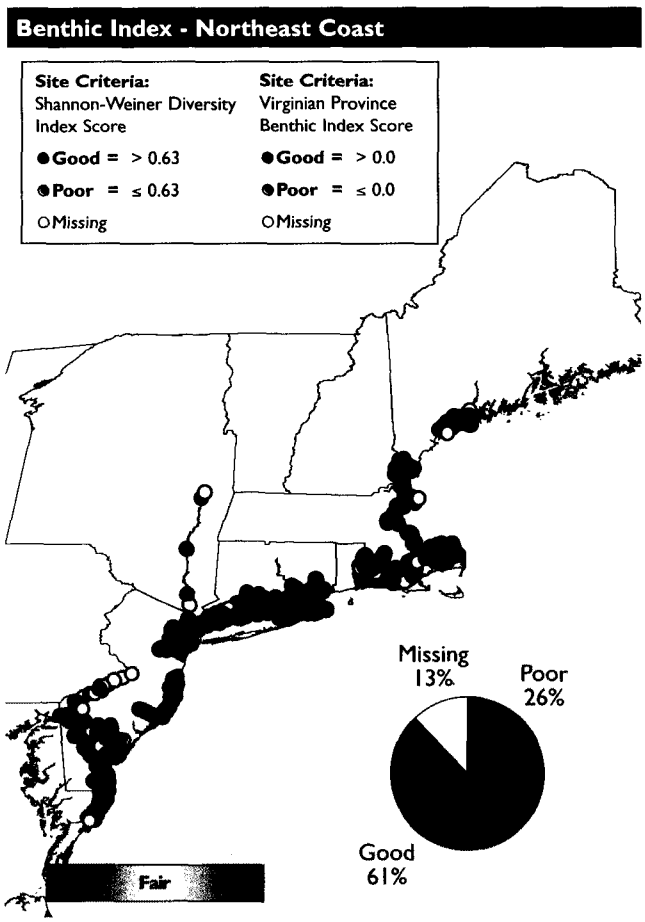


Figure 3-7. Benthic index data for the Northeast Coast NEP estuarine area (U.S. EPA/NCA).

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).

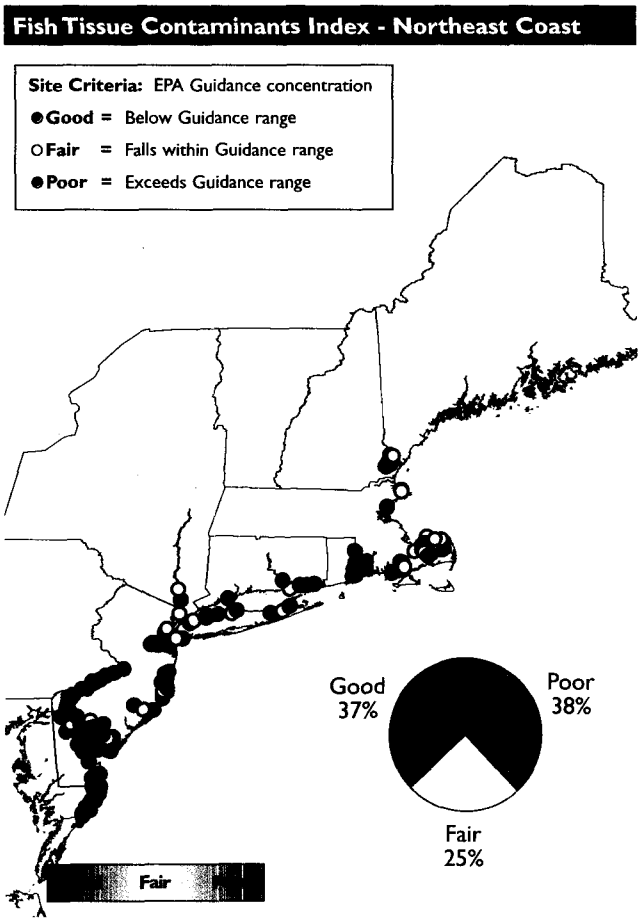


Figure 3-8. Fish tissue contaminants index data for the Northeast Coast NEP estuarine area (U.S. EPA/NCA).

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),

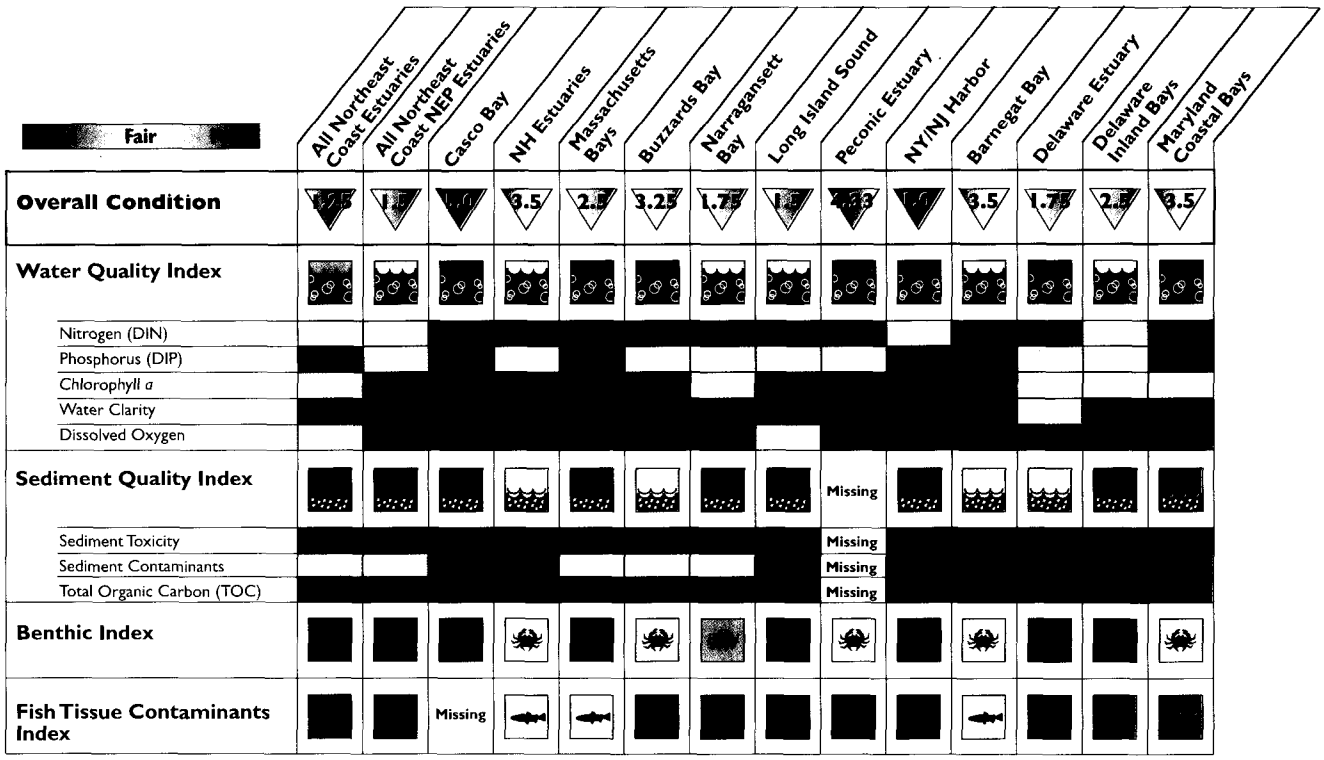


Figure 3-9. Comparison of NCA results for Northeast Coast NEP estuaries and all Northeast Coast estuaries (U.S. EPA/NCA).

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*)

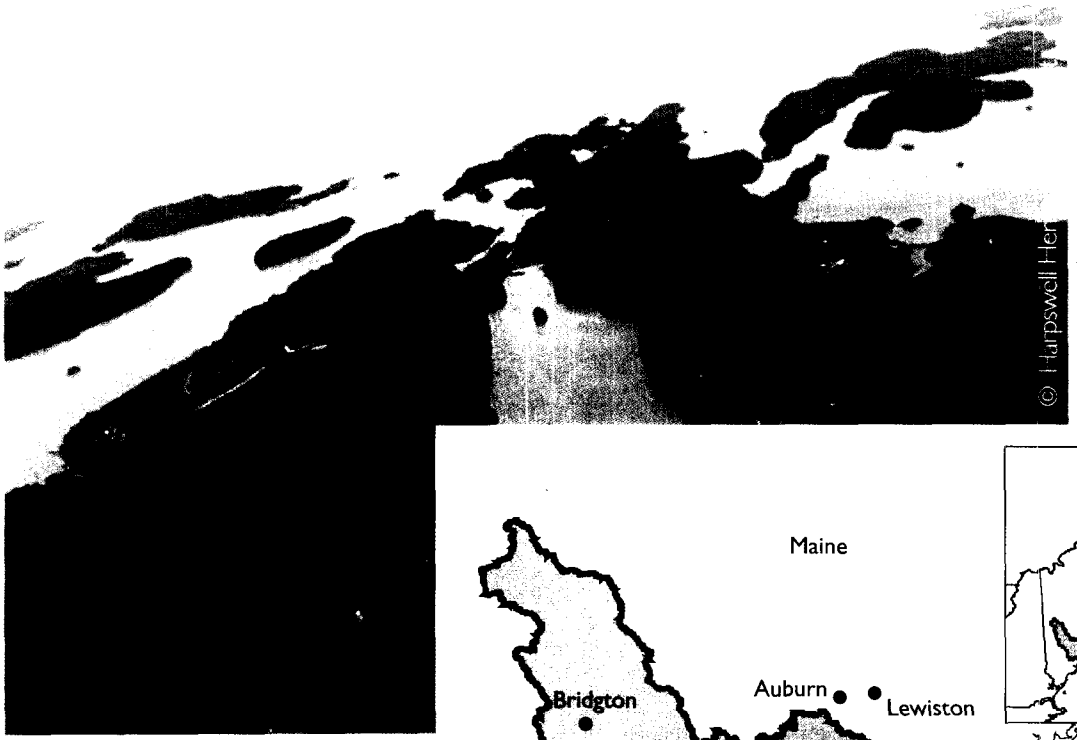
The final estuarine index, the fish tissue contaminants index, is rated good for Peconic Estuary, the Delaware Inland Bays, and the Maryland Coastal Bays; good to fair for the New Hampshire Estuaries; fair for the Massachusetts Bays and Barnegat Bay; and poor for Buzzards Bay, Narragansett Bay, Long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

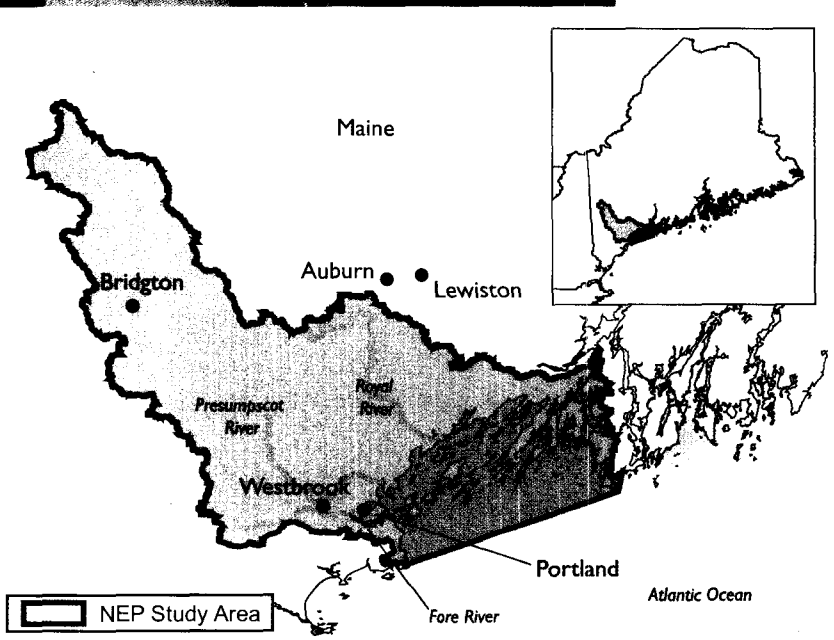
The overall condition score for the collective NEP estuaries of the Northeast Coast region (1.5) was lower than the overall condition scores for the collective NEP estuaries of the Southeast Coast (4.0), Gulf Coast (2.75), or West Coast (2.5) regions and comparable to the score for Puerto Rico (1.5). 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





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.

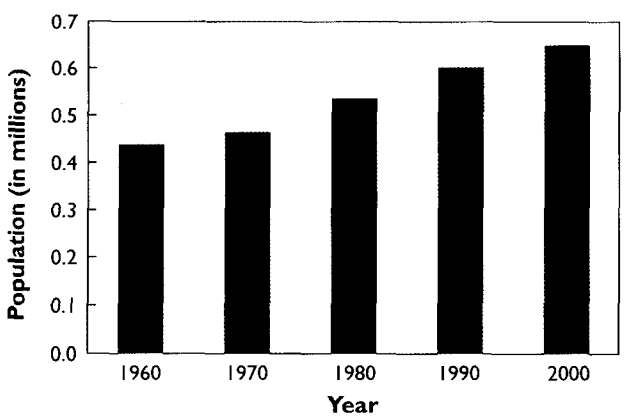


Figure 3-10. Population of NOAA-designated coastal counties of the CBEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

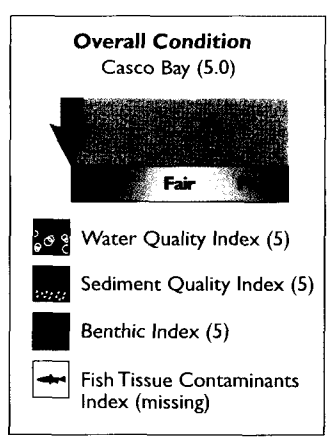


Figure 3-11. The overall condition of the CBEP estuarine area is good (U.S. EPA/NCA).

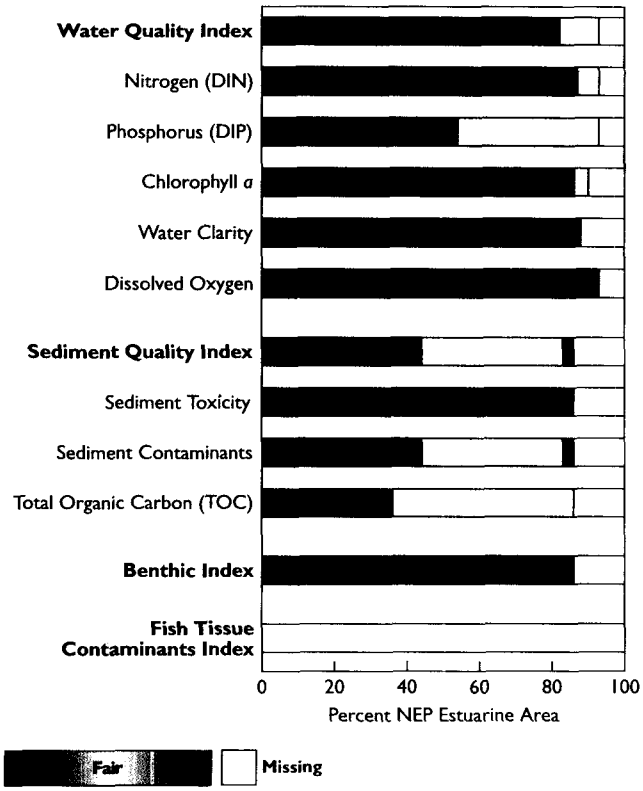


Figure 3-12. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Casco Bay (U.S. EPA/NCA).

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.

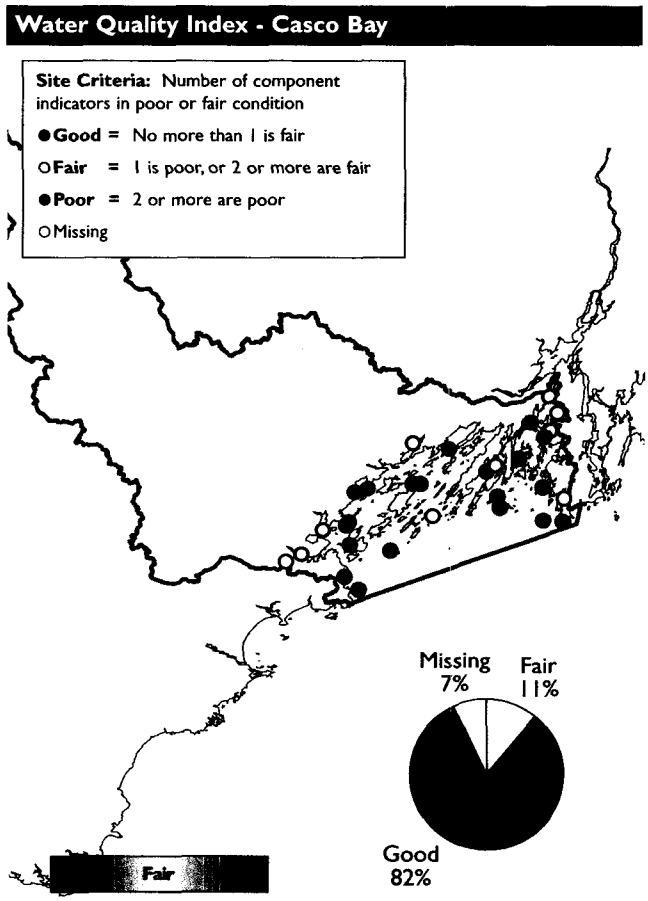


Figure 3-13. Water quality index data for Casco Bay (U.S. EPA/NCA).

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.

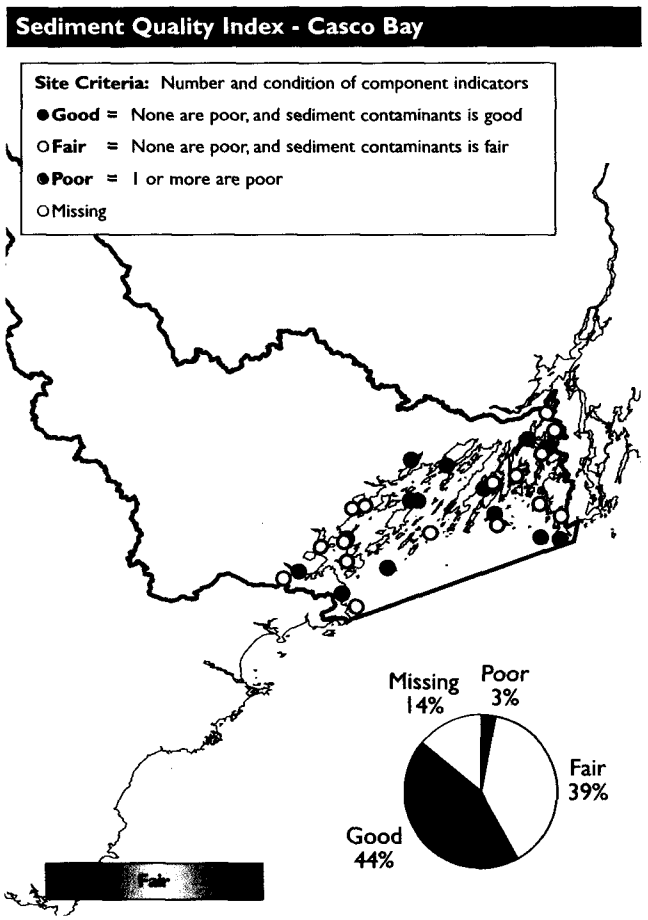


Figure 3-14. Sediment quality index data for Casco Bay (U.S. EPA/NCA).

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.

Casco Bay Estuary Partnership

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.

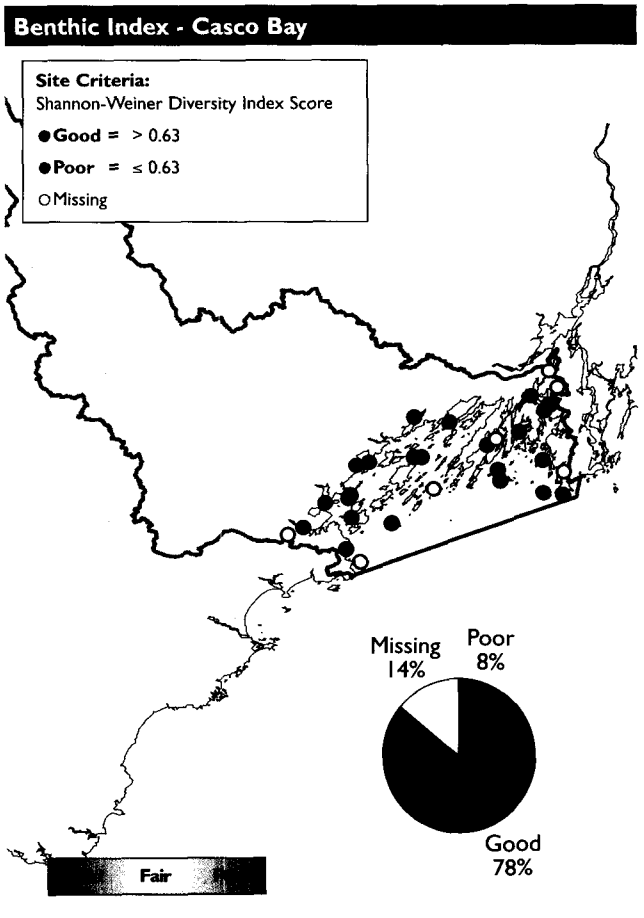


Figure 3-15. Benthic index data for Casco Bay (U.S. EPA/NCA).

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

HIGHLIGHT

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).

Casco Bay Estuary Partnership

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.

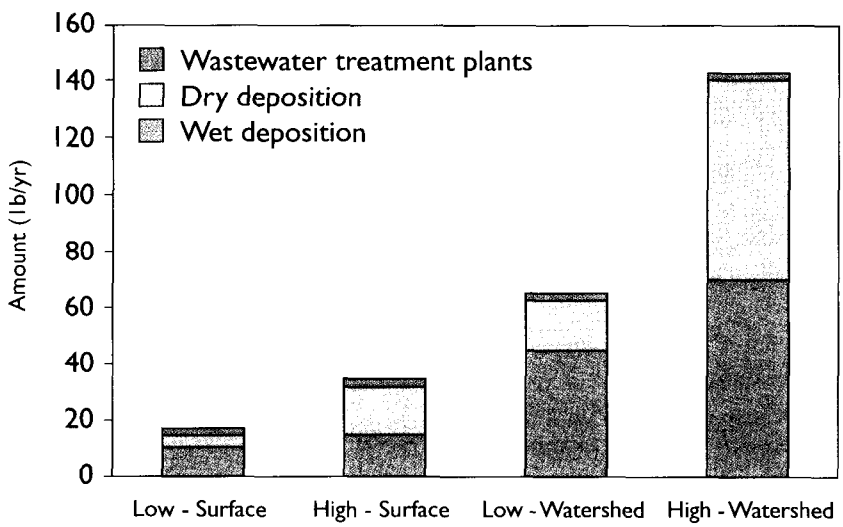
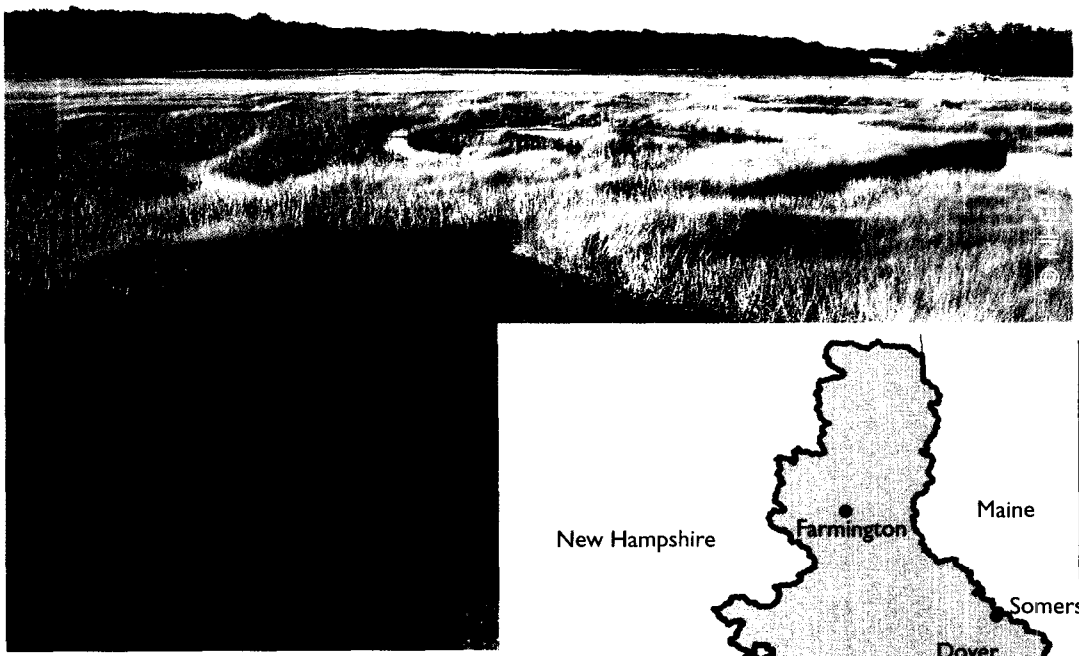
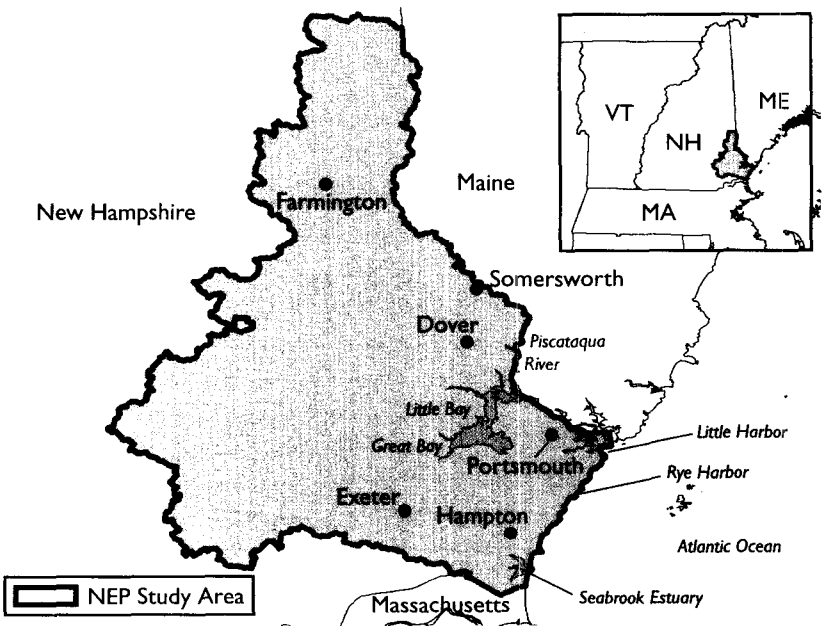


Figure 3-16. Atmospheric deposition (wet and dry) may account for 84% to 92% of the overall mercury loading to Casco Bay. The overall contribution of dry deposition to the total mercury loading on the surface of Casco Bay and on the Casco Bay watershed is estimated, and the high and low ranges of this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

New Hampshire Estuaries Project





NewHampshire Estuaries Project

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).

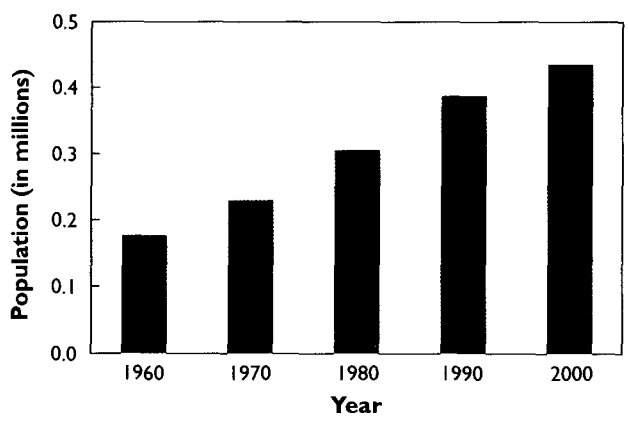


Figure 3-17. Population of NOAA-designated coastal counties of the NHEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

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.

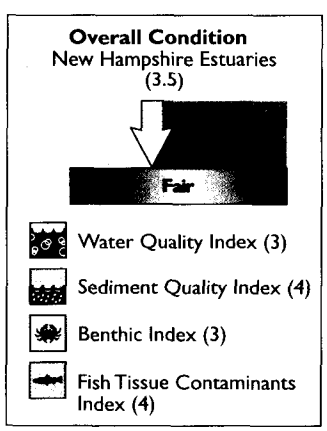


Figure 3-18. The overall condition of the NHEP estuarine area is fair (U.S. EPA/NCA).

New Hampshire Estuaries Project

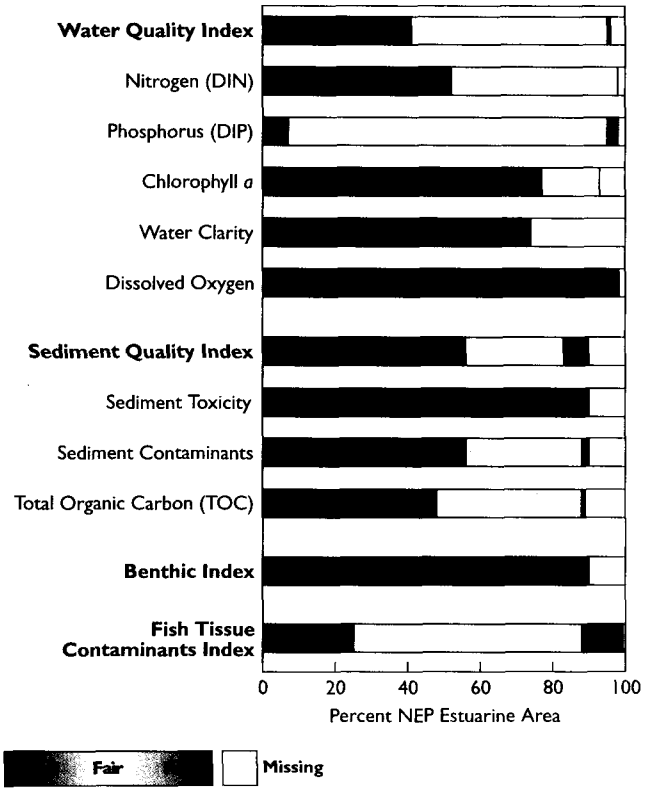


Figure 3-19. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — New Hampshire Estuaries (U.S. EPA/NCA).

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.

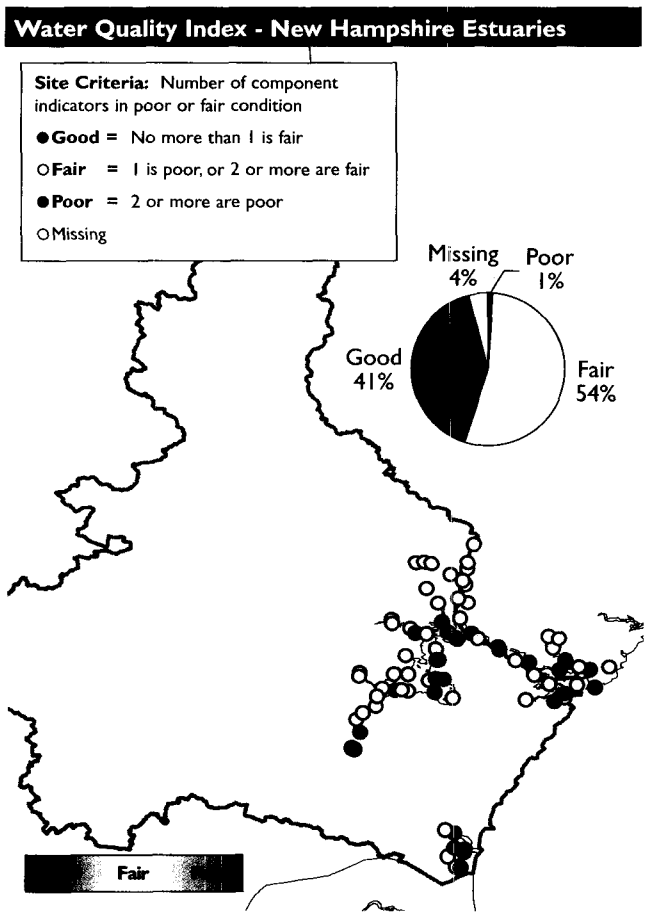


Figure 3-20. Water quality index data for the New Hampshire Estuaries, 2000–2001 (U.S. EPA/NCA).

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.

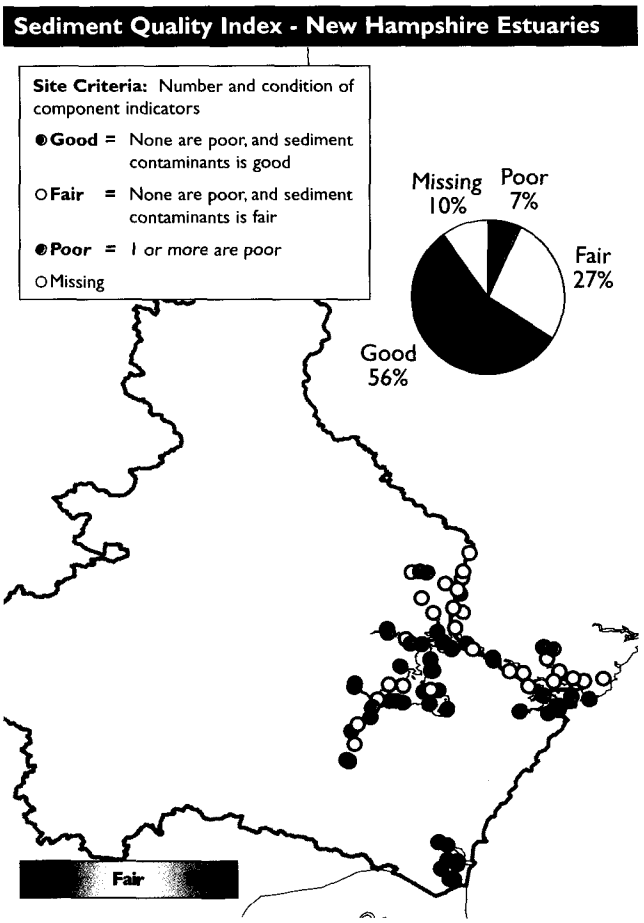


Figure 3-21. Sediment quality index data for the New Hampshire Estuaries, 2000–2001 (U.S. EPA/NCA).

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.

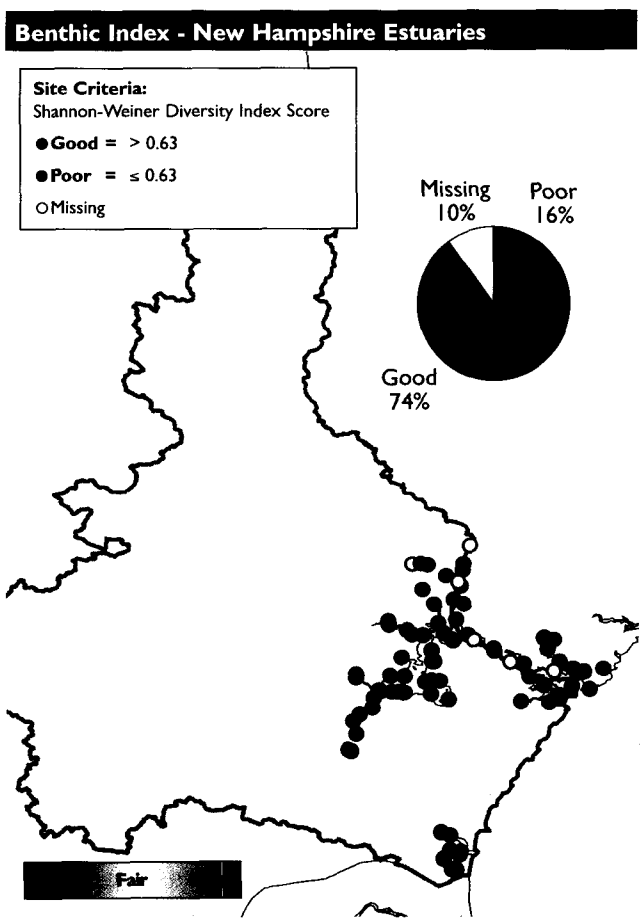


Figure 3-22. Benthic index data for the New Hampshire Estuaries, 2000–2001 (U.S. EPA/NCA).

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.

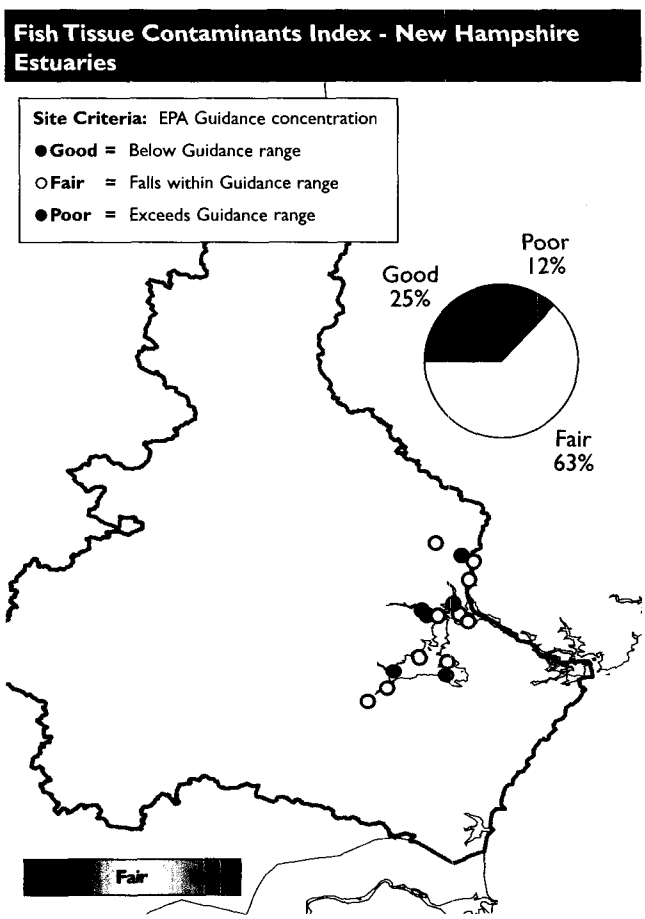


Figure 3-23. Fish tissue contaminants index data for the New Hampshire Estuaries, 2000–2001 (U.S. EPA/NCA).

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 3 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).

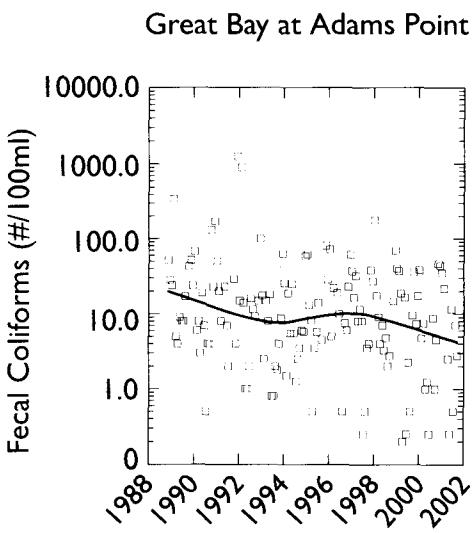


Figure 3-24. Fecal coliform concentrations between 1988 and 2002 in Great Bay at Adams Point (NHEP, 2003).

New Hampshire Estuaries Project

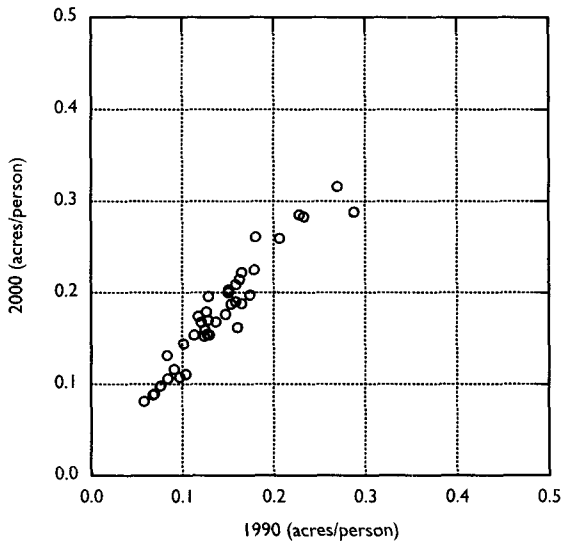
HIGHLIGHT

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.

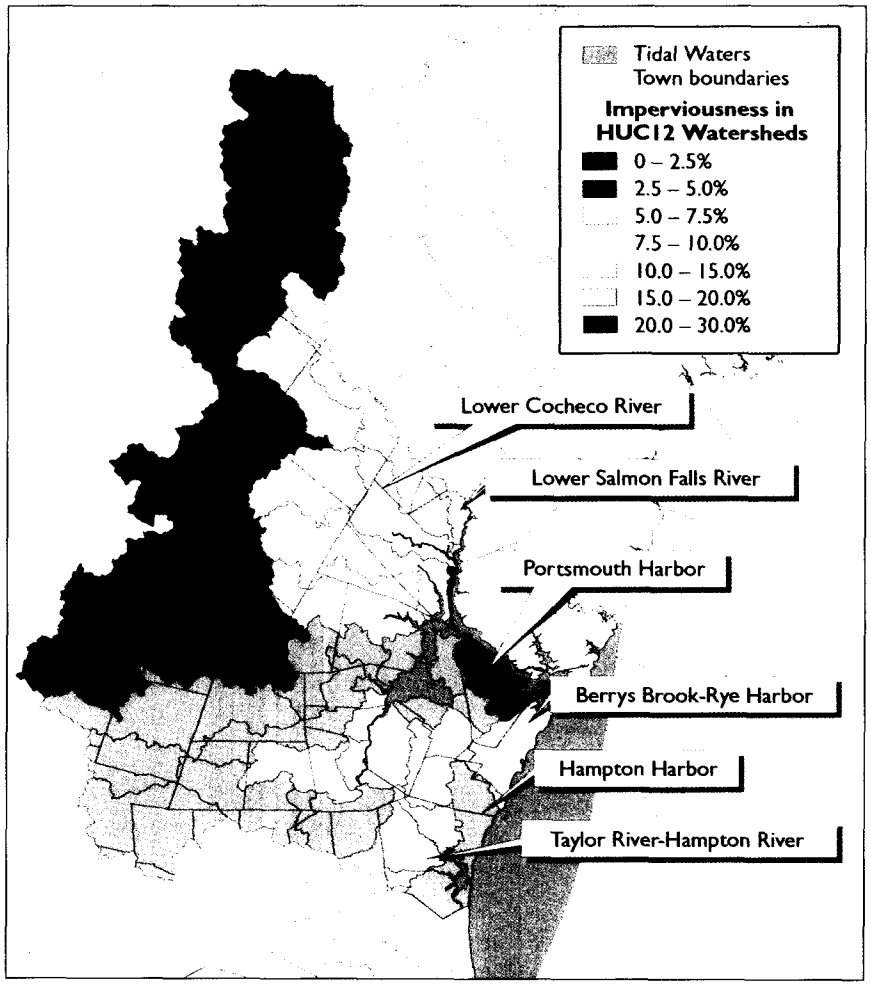
Eleven of the 42 towns had more than 10% of their land area covered by impervious surfaces. Studies conducted in other regions of the country have demonstrated water quality deterioration where impervious surfaces cover greater than 10% of the watershed area (Schueller, 1995); therefore, it is the goal 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).

New Hampshire Estuaries Project

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.

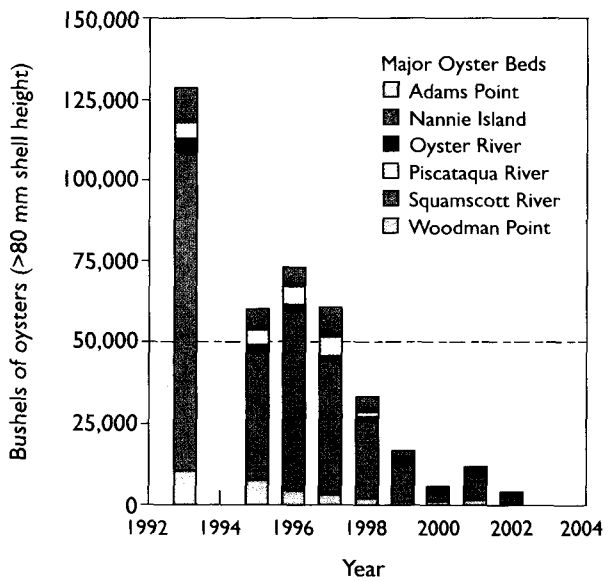


Figure 3-25. Standing stock of harvestable-size oysters in Great Bay between 1992 and 2004 (NHEP, 2003).

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 5 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).

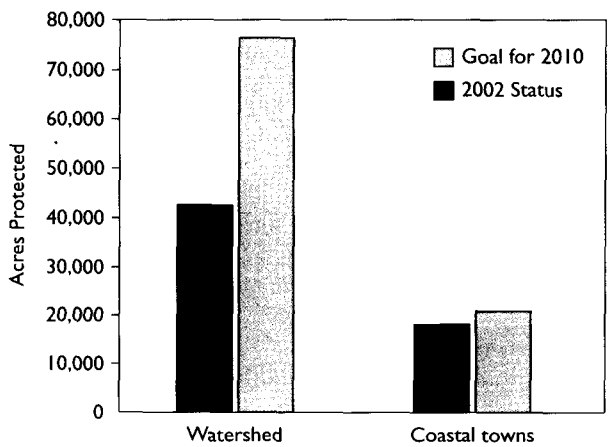
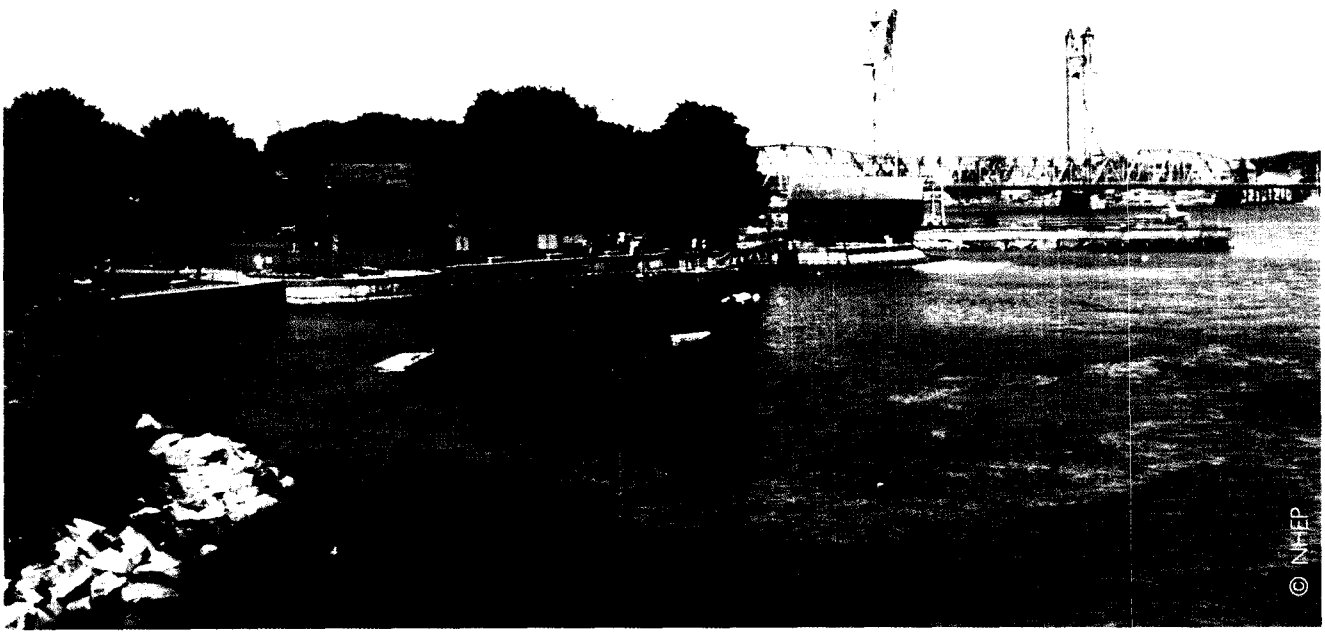


Figure 3-26. Acres of protected lands in New Hampshire's coastal watershed and coastal towns (NHEP, 2003).

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).

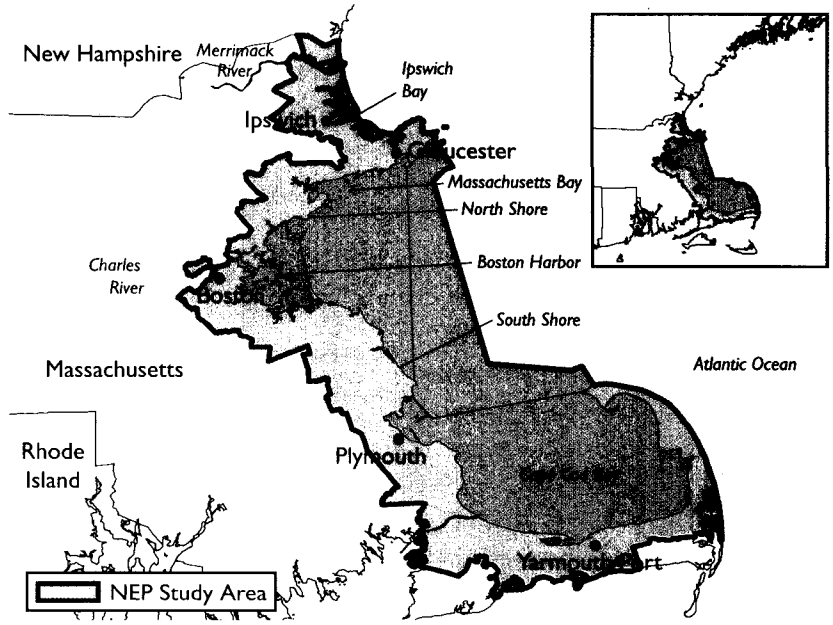
Conclusion

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



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.

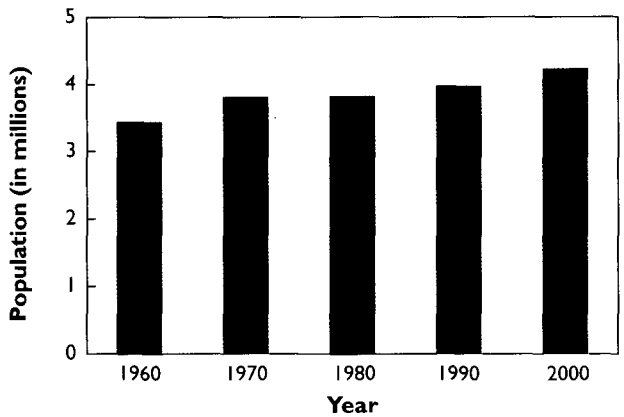


Figure 3-27. Population of NOAA-designated coastal counties of the MBP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

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.

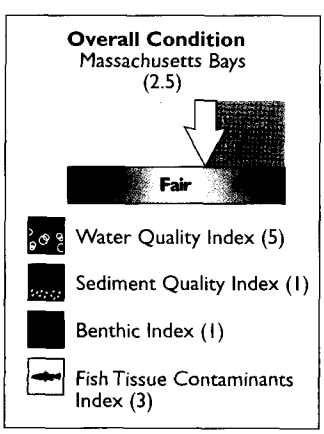


Figure 3-28. The overall condition of the MBP estuarine area is fair (U.S. EPA/NCA).

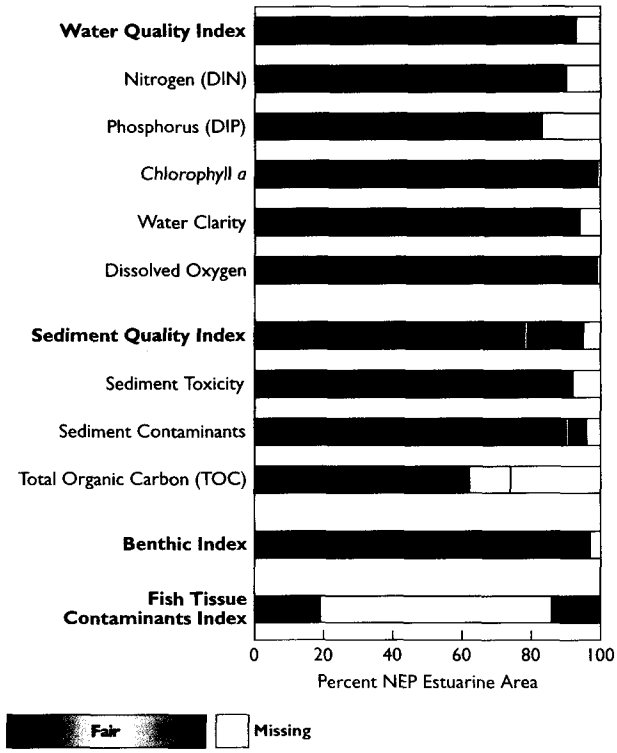


Figure 3-29. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Massachusetts Bays (U.S. EPA/NCA).

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.

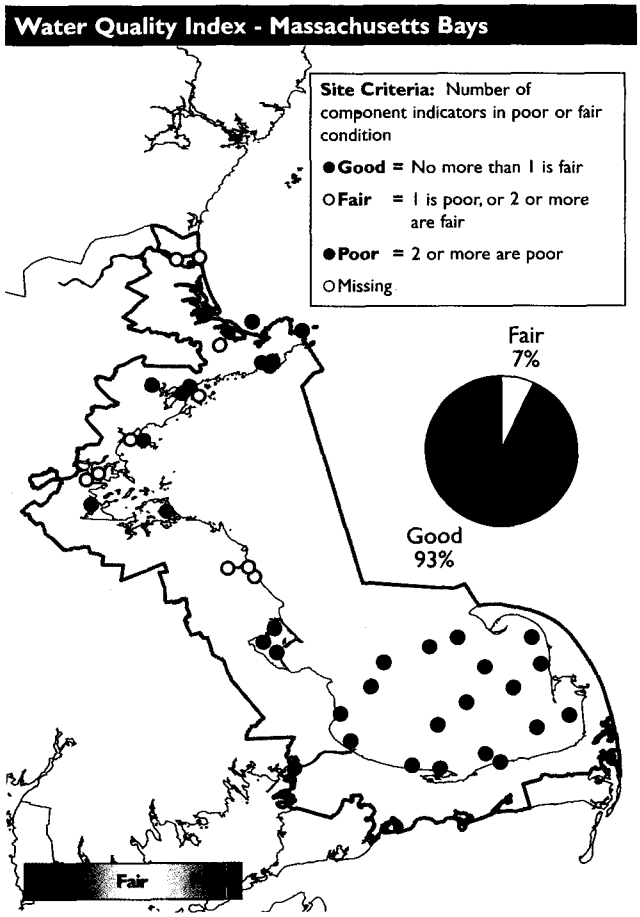


Figure 3-30. Water quality index data for the Massachusetts Bays, 2000–2001 (U.S. EPA/NCA).

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.

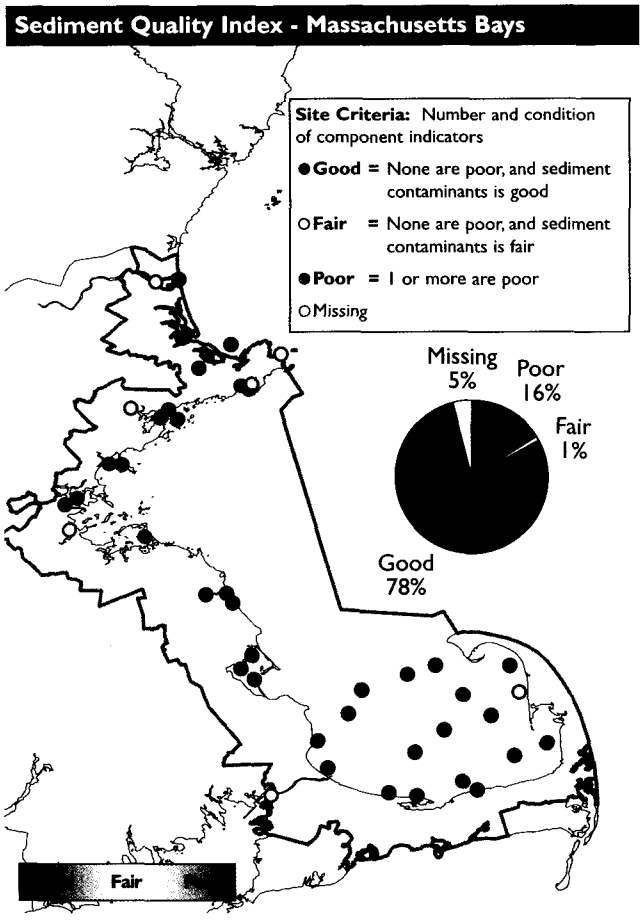


Figure 3-31. Sediment quality index data for the Massachusetts Bays, 2000–2001 (U.S. EPA/NCA).

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.

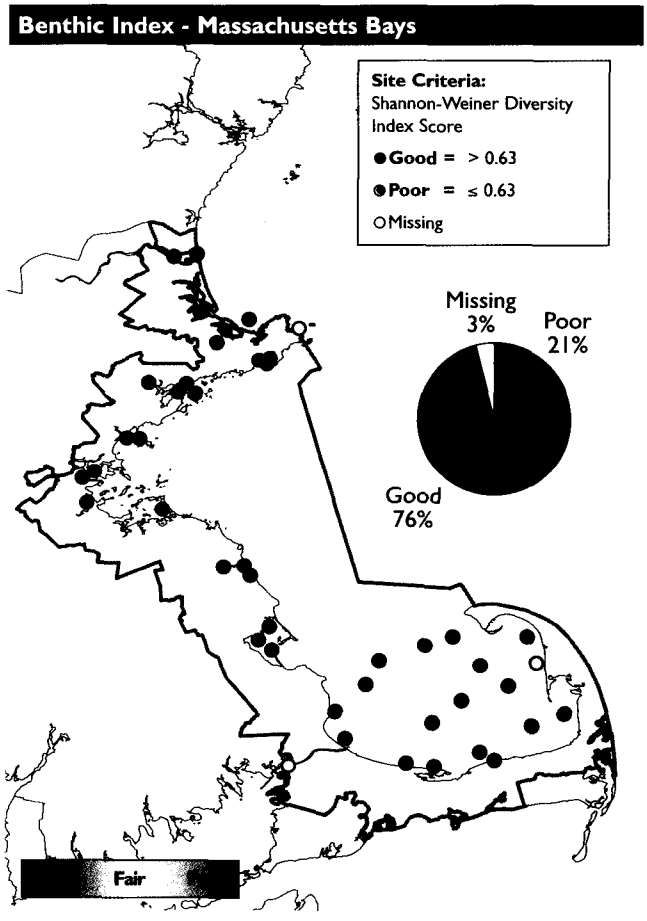


Figure 3-32. Benthic index data for the Massachusetts Bays, 2000–2001 (U.S. EPA/NCA).

Massachusetts Bays Program

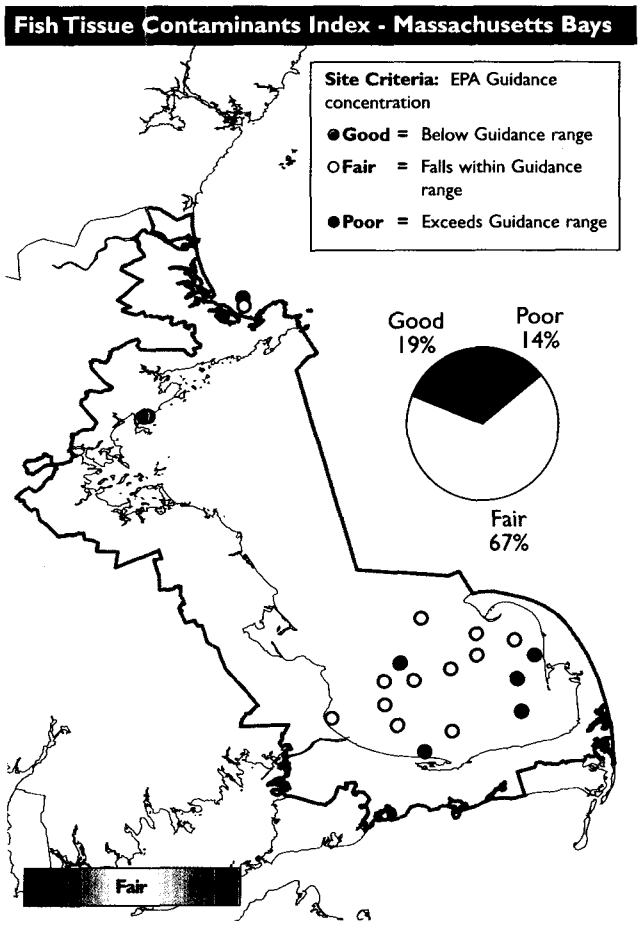


Figure 3-33. Fish tissue contaminants index data for the Massachusetts Bays, 2000–2001 (U.S. EPA/NCA).

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

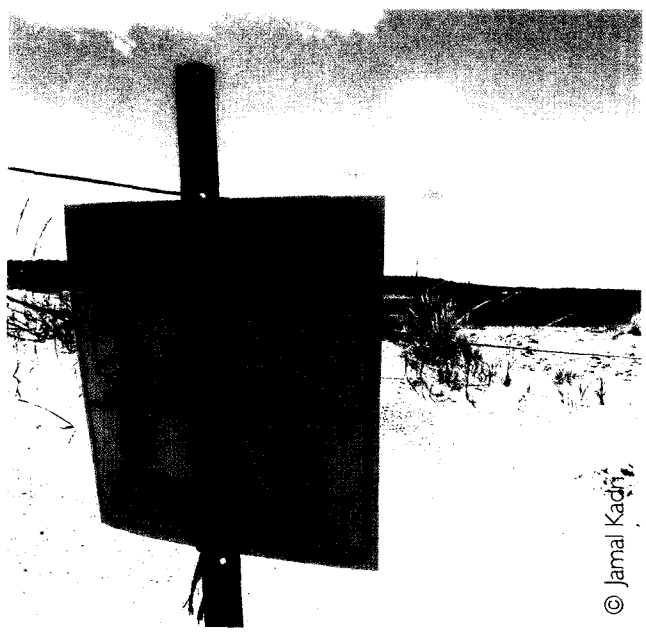
The MBP and the Massachusetts Office of Coastal Zone Management (Massachusetts CZM) are conducting research routinely to measure conditions in coastal wetlands on Cape Cod. In 1997, the Wetland Health Assessment Toolbox (WHAT) multi-metric protocol was developed to help estimate the overall ecological 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).

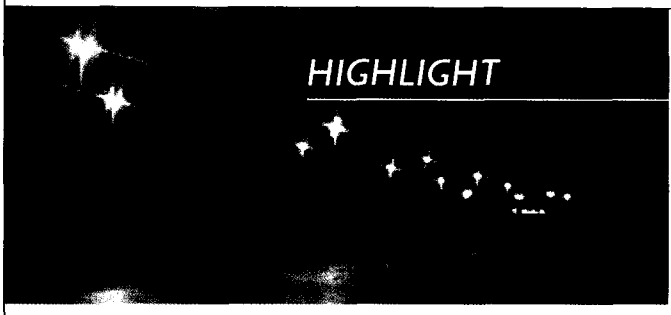
The MBP is helping the Massachusetts CZM develop an eelgrass health assessment index to expand monitoring of this productive habitat within the Bays. Mooring-chain scarring and dredging are two primary causes of eelgrass habitat loss in the Massachusetts Bays. The extent of nutrient over-enrichment and 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 multi-faceted approach to resource management that links habitat protection with land-use planning. The goal of this 3-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).

Massachusetts Bays Program



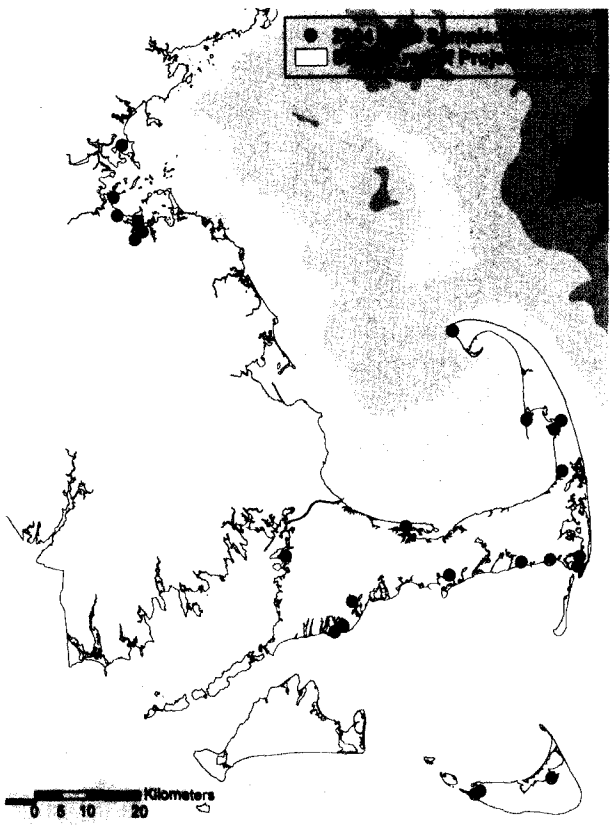
Monitoring and Ecological Assessment of the Massachusetts Bays Ecosystem

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).

Massachusetts Bays Program

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 past 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).

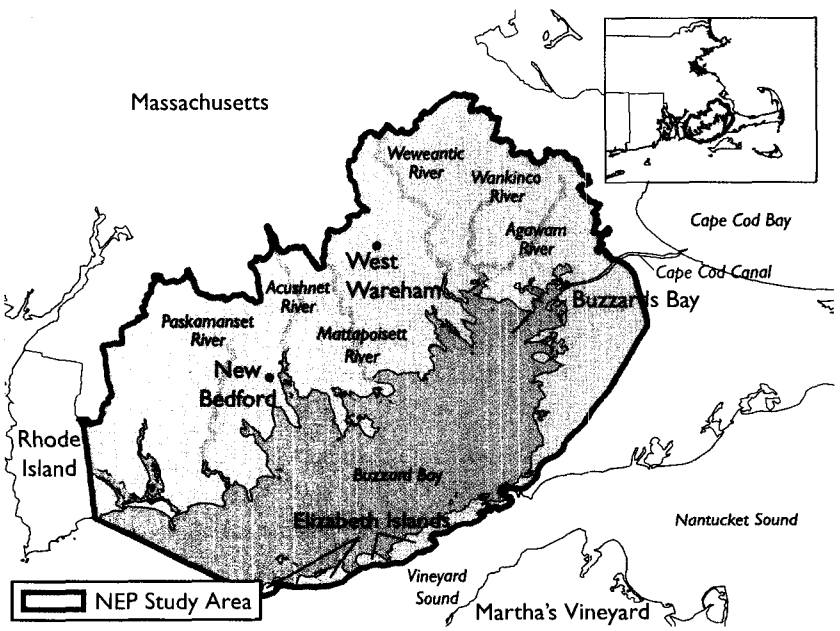
Currently, the MBP is working with EPA and the Massachusetts Watershed Initiative to develop a Wetlands Restoration Atlas for tidally restricted coastal wetlands from Winthrop to Quincy, which will be used to aid in the assessment of anadromous fish runs. The MBP is also pursuing No-Discharge Zone designations 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 MPB study area (Robin Hunter, FWS).

Buzzards Bay National Estuary Program



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).

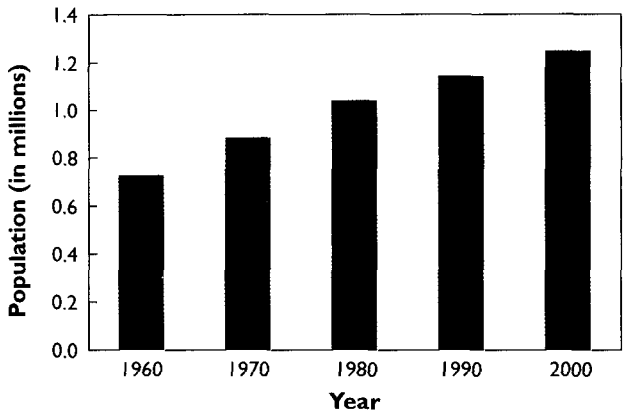


Figure 3-34. Population of NOAA-designated coastal counties of the BB NEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

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.

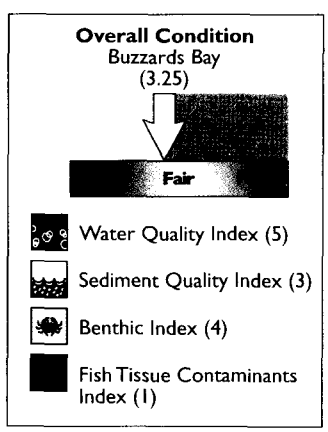


Figure 3-35. The overall condition of the BB NEP estuarine area is fair (U.S. EPA/NCA).

Buzzards Bay National Estuary Program

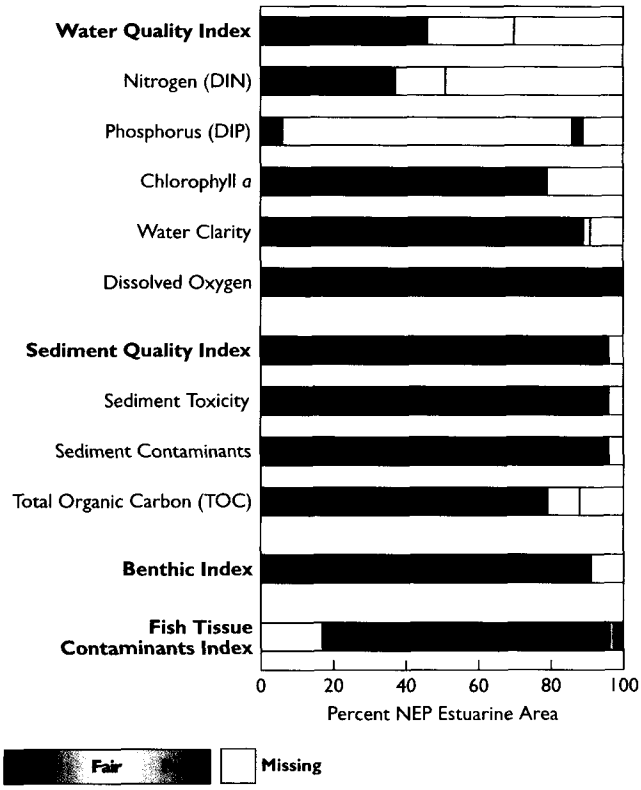


Figure 3-36. Percentage of estuarine area achieving each rating for all indices and component indicators — Buzzards Bay (U.S. EPA/NCA).

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.

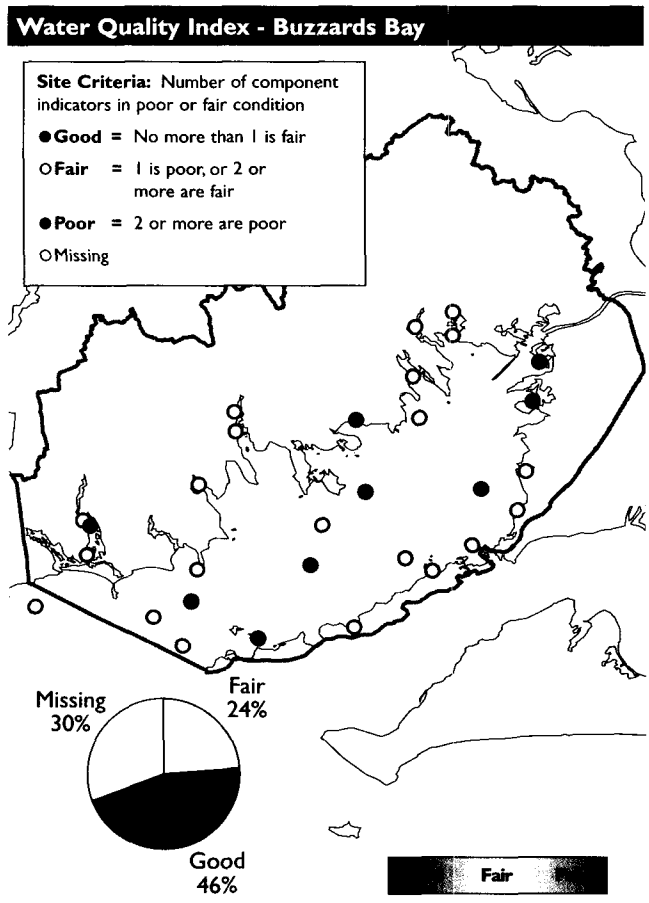


Figure 3-37. Water quality index data for Buzzards Bay, 2000–2001 (U.S. EPA/NCA).

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.

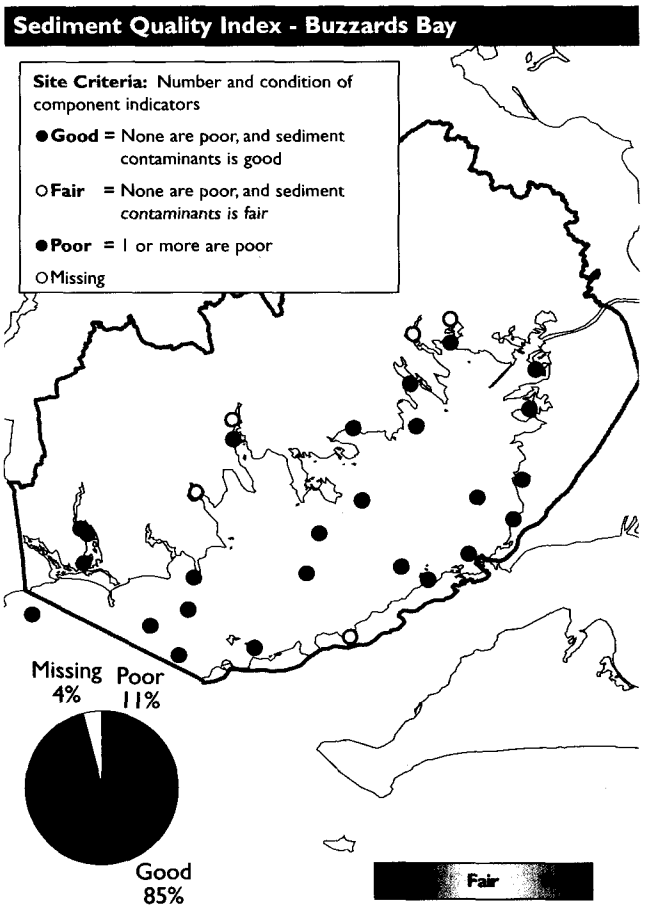


Figure 3-38. Sediment quality index data for Buzzards Bay, 2000–2001 (U.S. EPA/NCA).

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.

Buzzards Bay National Estuary Program

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).

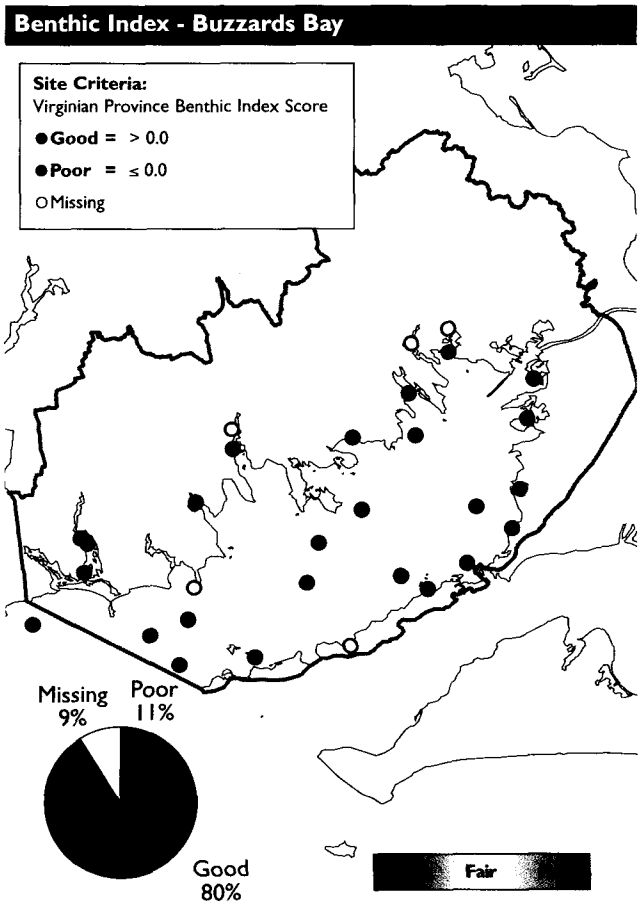


Figure 3-39. Benthic index data for Buzzards Bay, 2000–2001 (U.S. EPA/NCA).

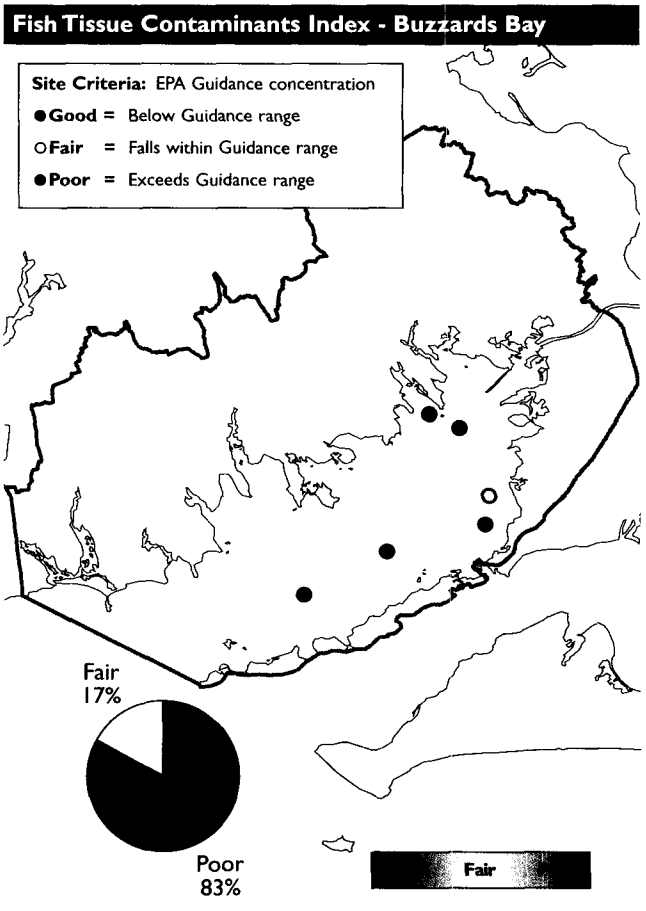


Figure 3-40. Fish tissue contaminants index data for Buzzards Bay, 2000–2001 (U.S. EPA/NCA).

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).

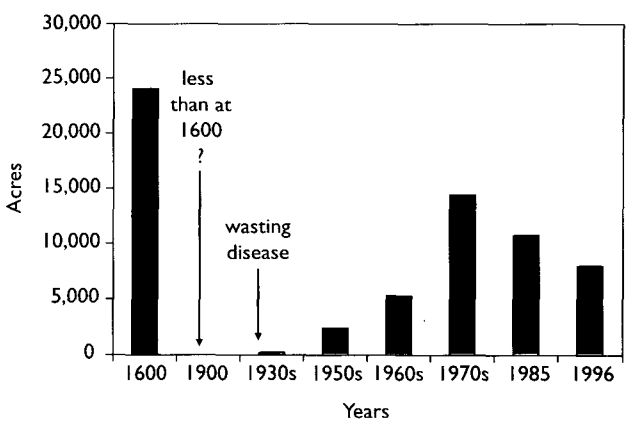


Figure 3-41. Eelgrass abundance measured by the BB NEP (BB NEP, 2005).

Buzzards Bay National Estuary Program

HIGHLIGHT

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.

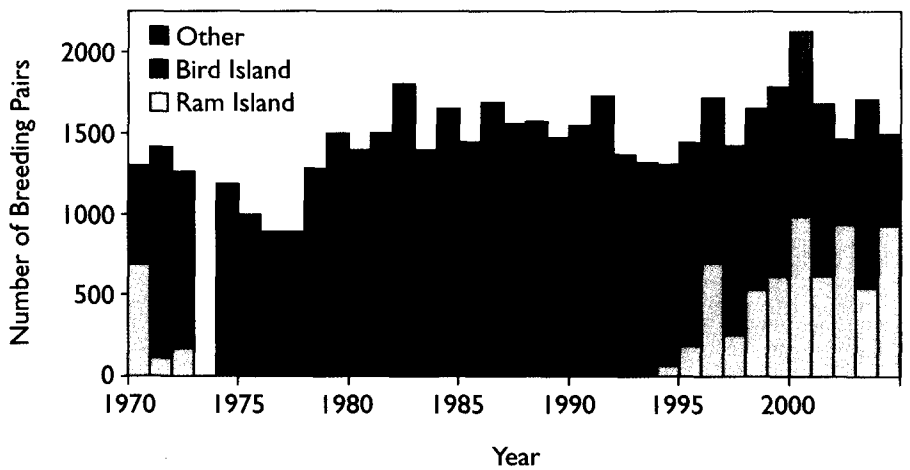
The Massachusetts Division of Fisheries and Wildlife (MassWildlife) reports on the numbers of roseate tern nests by individual island. The New Bedford Superfund trustees have awarded more than a million dollars to protect and preserve tern habitat on Bird Island through beach replenishment and restoration, 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 D Eon. 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).

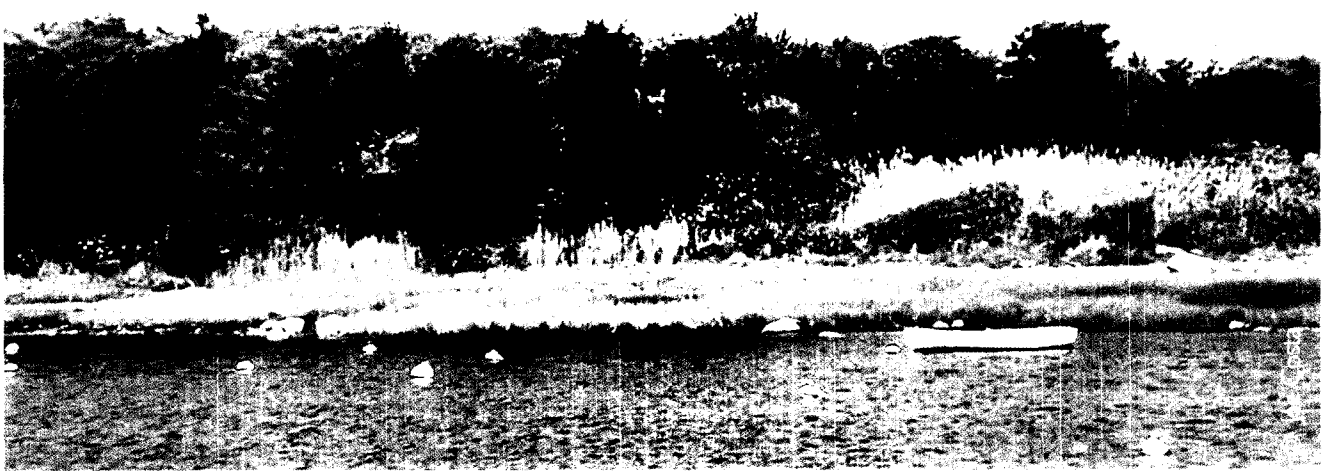
Current Projects, Accomplishments, and Future Goals

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

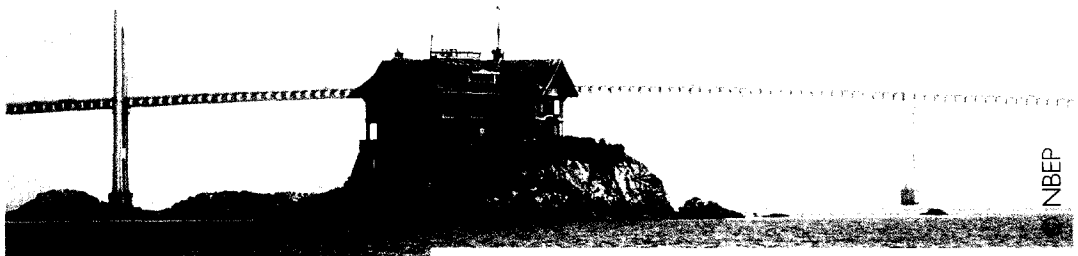
- The number of acres of shellfish beds closed because of bacterial contamination has declined nearly 25% since the *Buzzards Bay Comprehensive Conservation and Management Plan* was completed in 1991 (BB NEP, 1992; BBP NEP, 1999; CBB, 2003).
- The BB NEP assisted in the construction of a test center 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).

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.

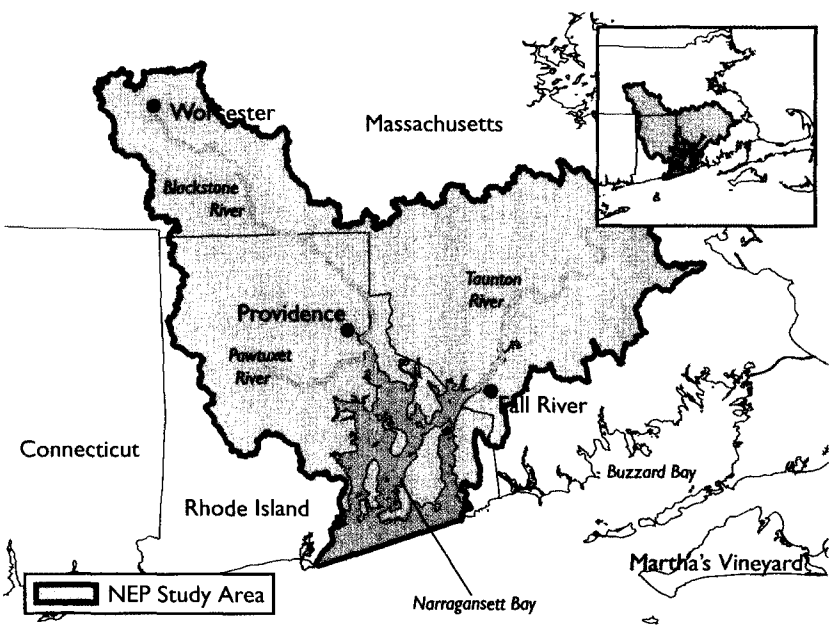


Narragansett Bay Estuary Program



NARRAGANSETT BAY ESTUARY PROGRAM

www.nbep.org



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

Narragansett Bay Estuary Program

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.

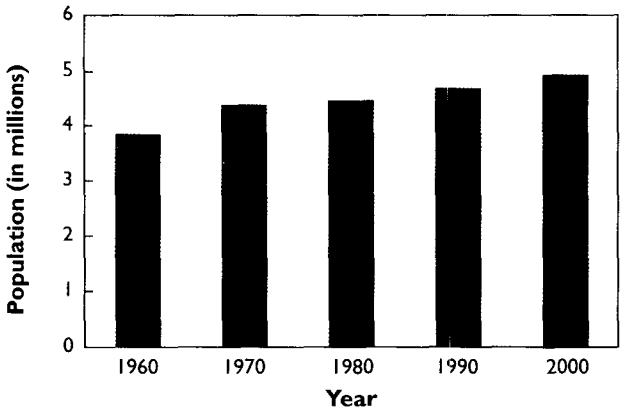


Figure 3-42. Population of NOAA-designated coastal counties of the NBEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

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.

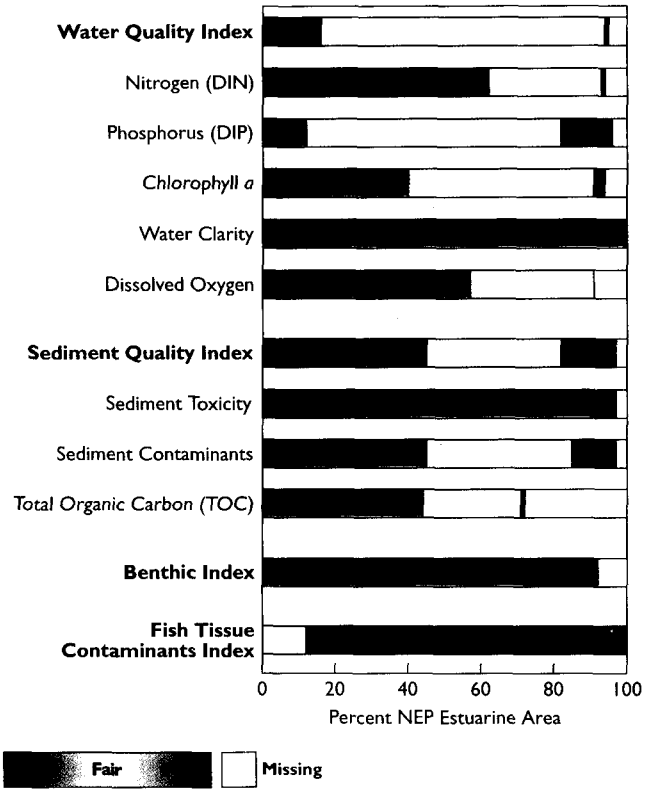


Figure 3-44. Percentage of estuarine area achieving each rating for all indices and component indicators — Narragansett Bay (U.S. EPA/NCA).

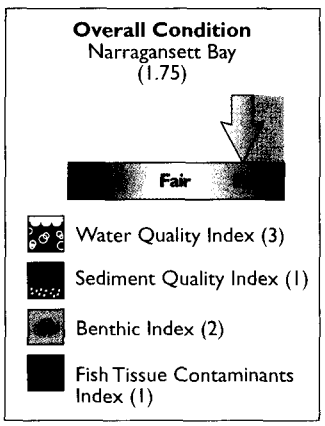


Figure 3-43. The overall condition of the NBEP estuarine area is poor (U.S. EPA/NCA).

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.

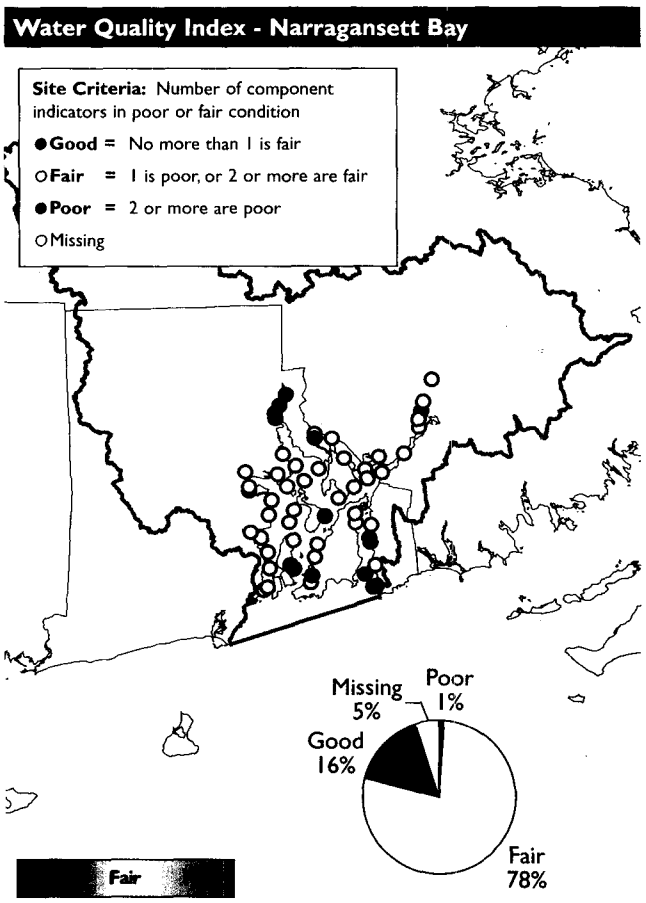


Figure 3-45. Water quality index data for Narragansett Bay, 2000–2001 (U.S. EPA/NCA).

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.

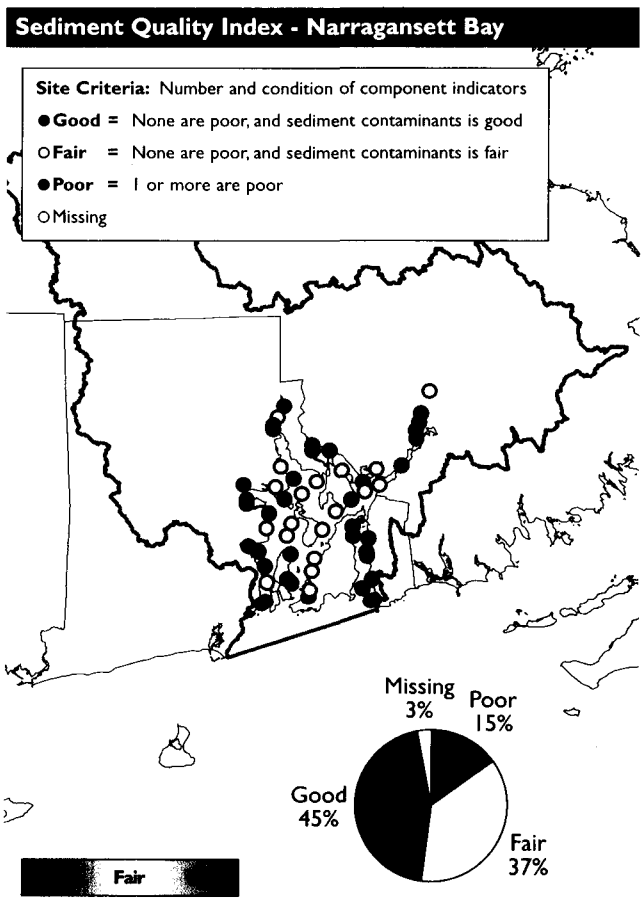


Figure 3-46. Sediment quality index data for Narragansett Bay, 2000–2001 (U.S. EPA/NCA).

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.

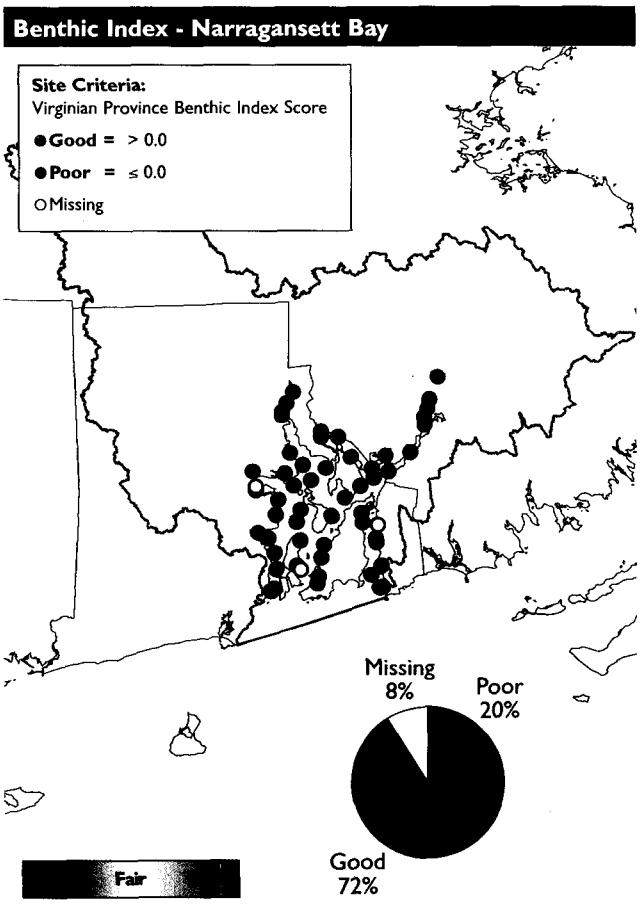


Figure 3-47. Benthic index data for Narragansett Bay, 2000–2001 (U.S. EPA/NCA).

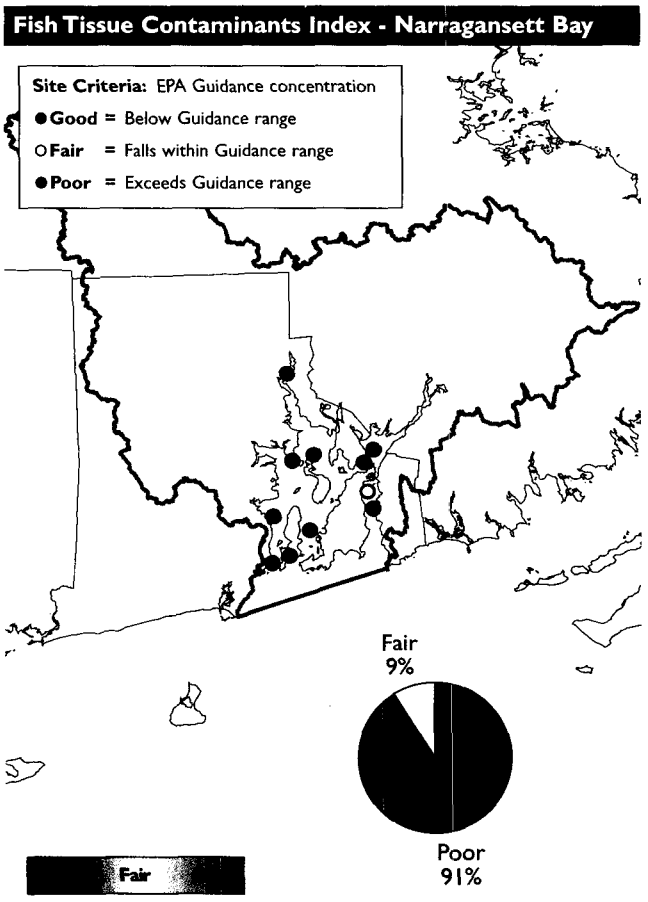


Figure 3-48. Fish tissue contaminants index data for Narragansett Bay, 2000–2001 (U.S. EPA/NCA).

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).

Narragansett Bay Estuary Program

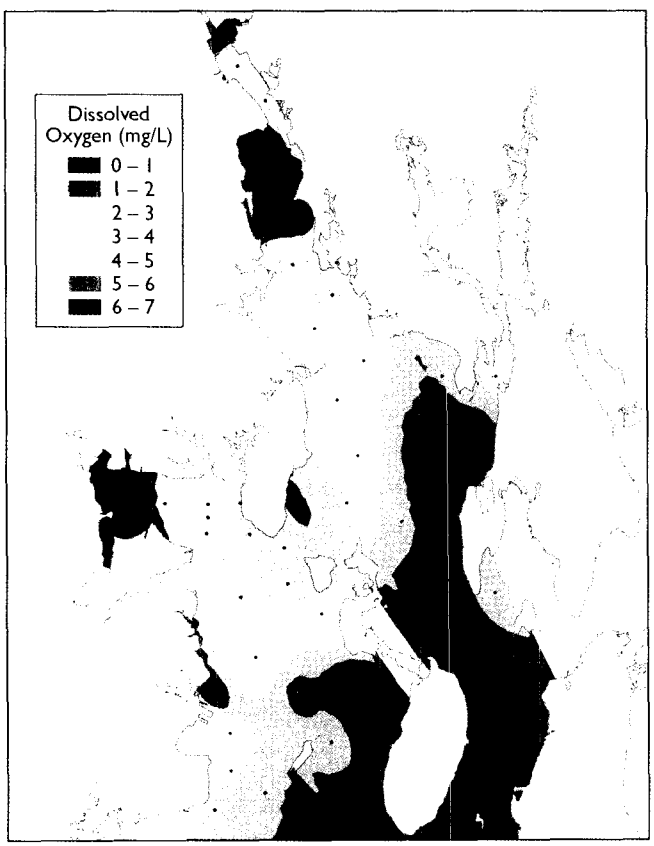
HIGHLIGHT

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).

Narragansett Bay Estuary Program

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.

Narragansett Bay Estuary Program

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).

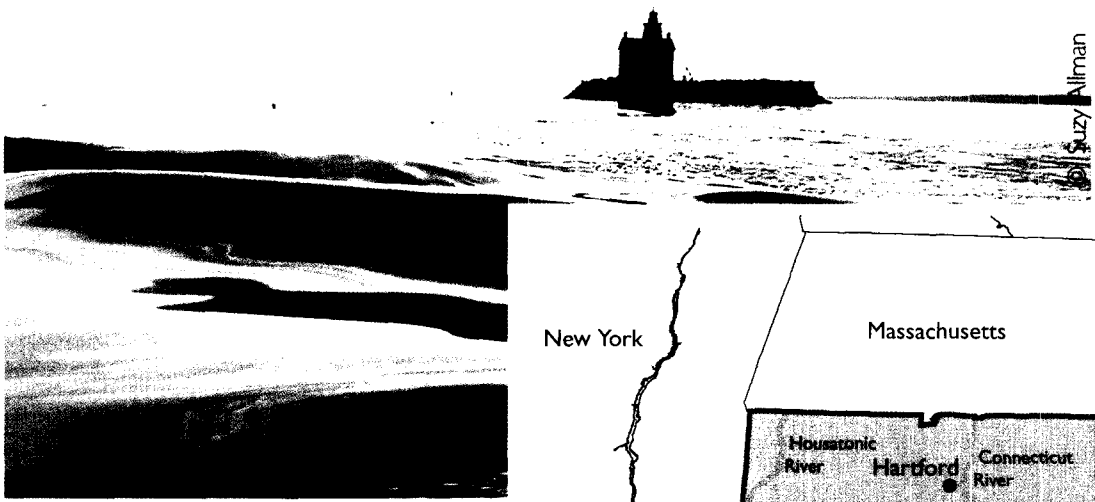
The NBEP will continue to serve as a coordinating entity for Bay actions and for organizing and creating collaborative efforts to meet common goals. The program will focus on expanding its partnership activities with municipalities, agencies, and non-profit organizations; securing the scientific data 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



LONG ISLAND SOUND STUDY

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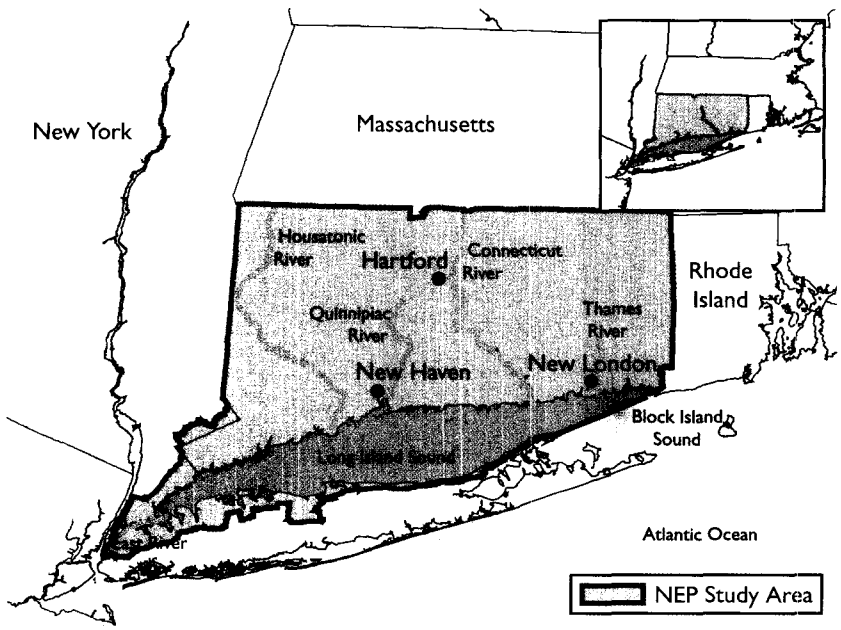


Background

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.

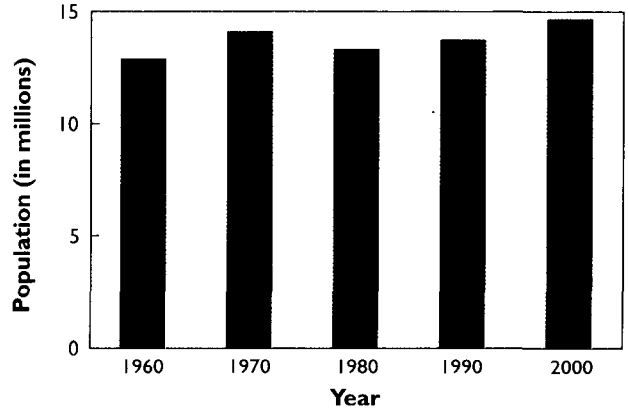


Figure 3-49. Population of NOAA-designated coastal counties of the LISS study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

Long Island Sound Study

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.

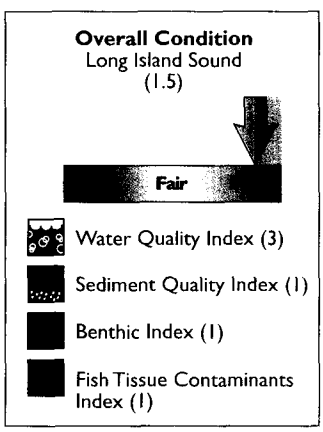


Figure 3-50. The overall condition of the LISS estuarine area is poor (U.S. EPA/NCA).

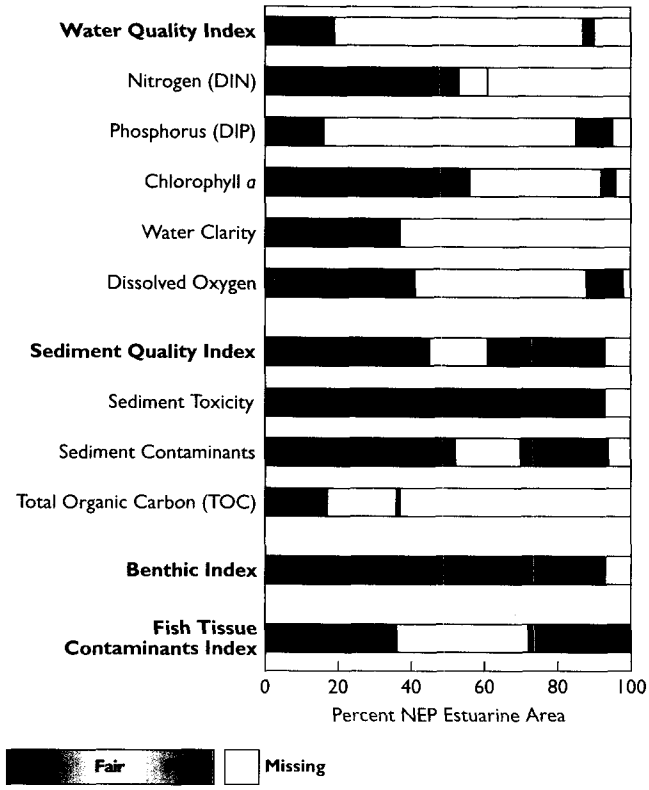


Figure 3-51. Percentage of estuarine area achieving each rating for all indices and component indicators — Long Island Sound (U.S. EPA/NCA).

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.

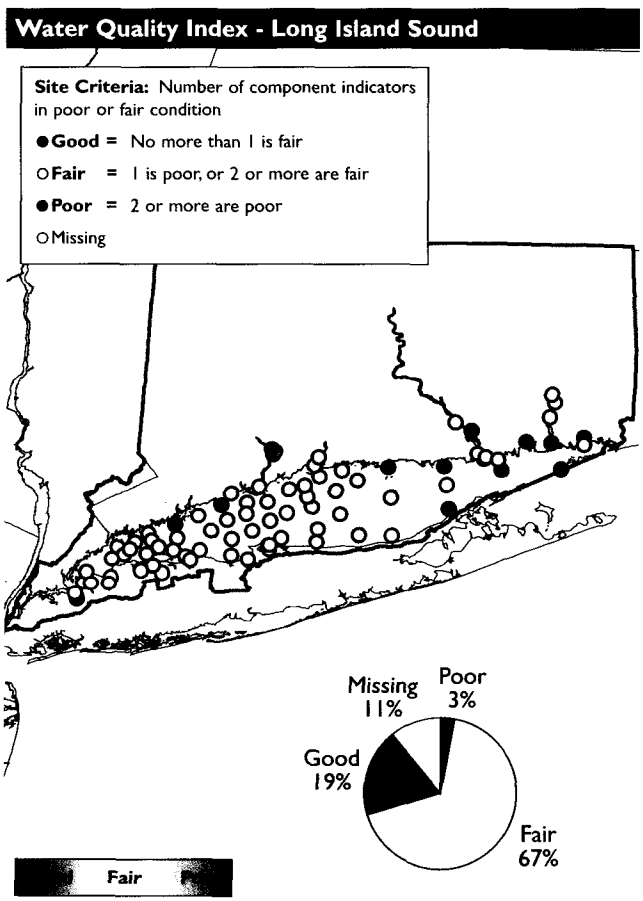


Figure 3-52. Water quality index data for Long Island Sound, 2000–2001 (U.S. EPA/NCA).

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.

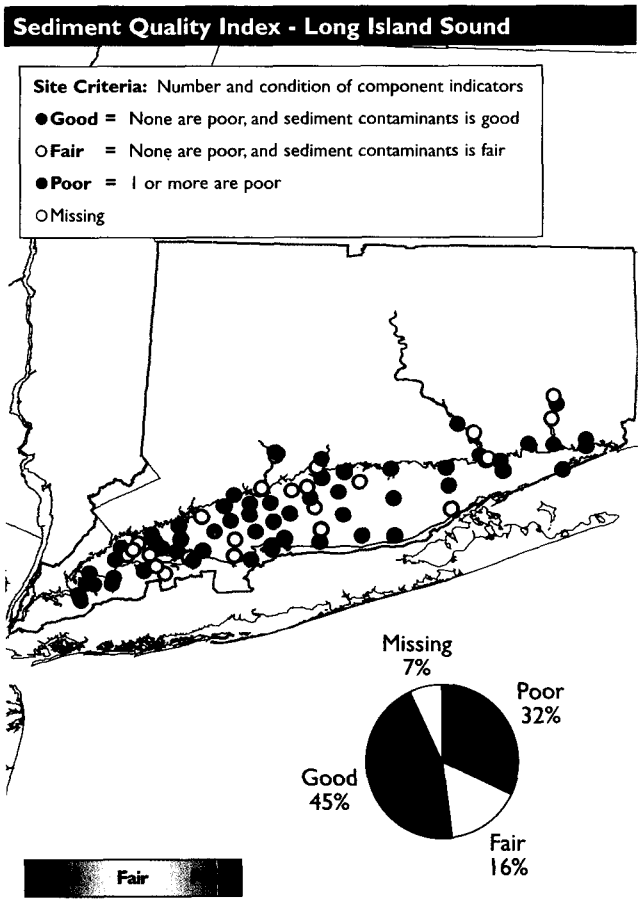
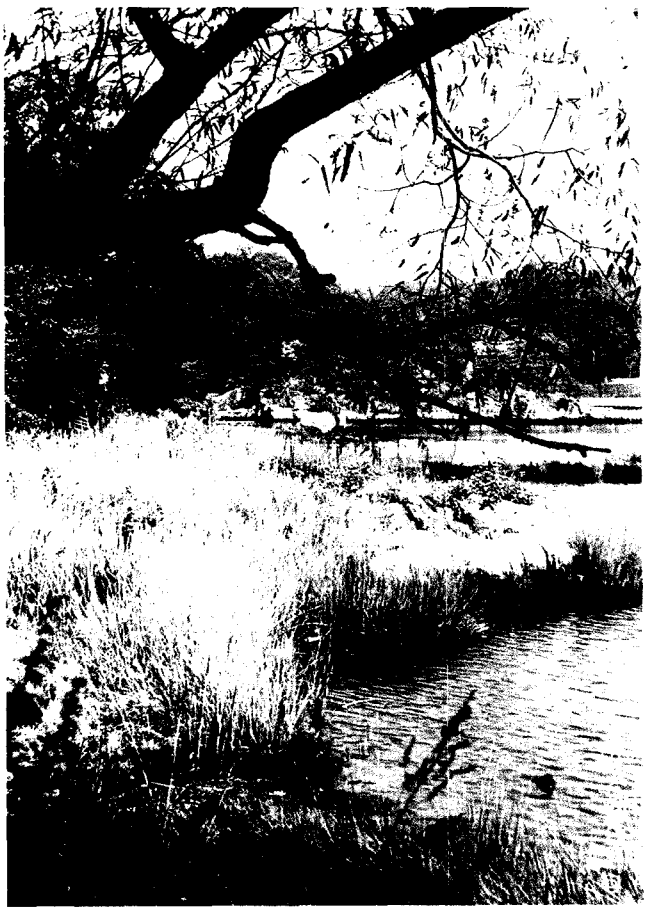


Figure 3-53. Sediment quality index data for Long Island Sound, 2000–2001 (U.S. EPA/NCA).

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.



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.

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.

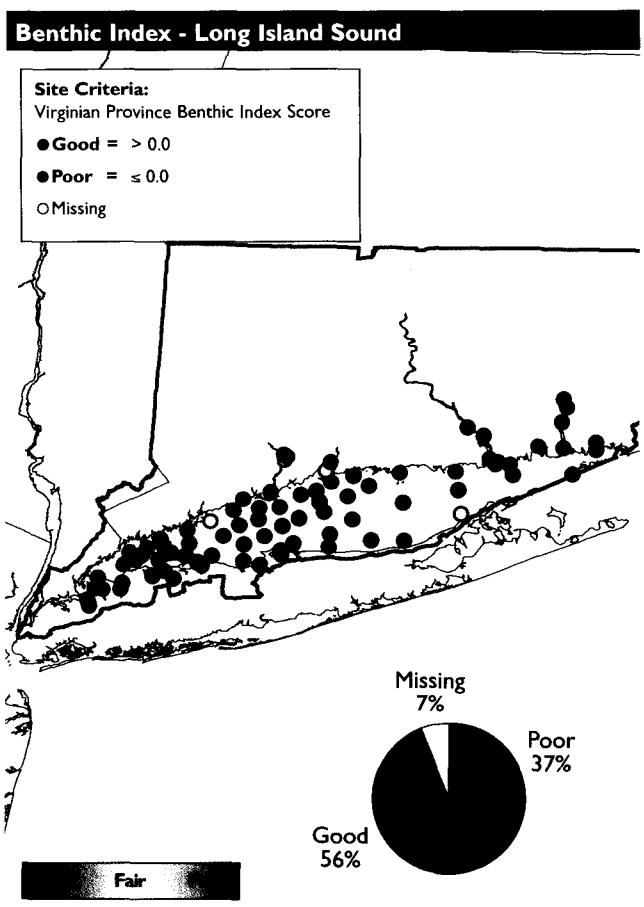


Figure 3-54. Benthic index data for Long Island Sound, 2000–2001 (U.S. EPA/NCA).

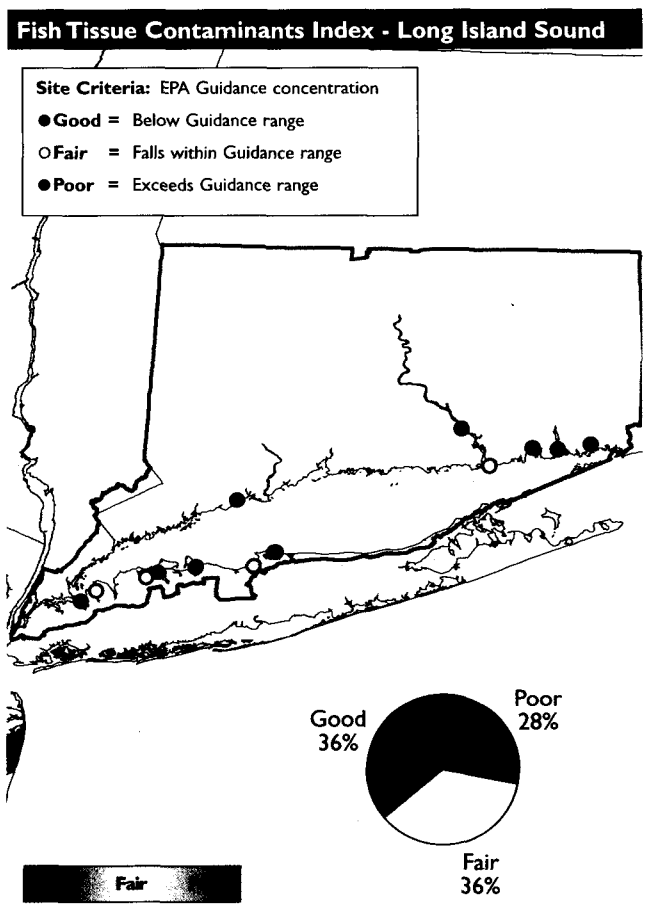


Figure 3-55. Fish tissue contaminants index data for Long Island Sound, 2000–2001 (U.S. EPA/NCA).

HIGHLIGHT

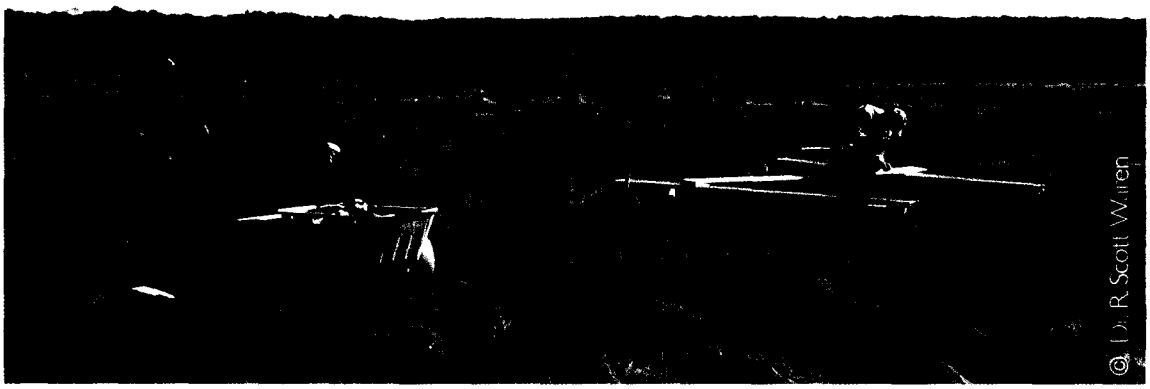
Tidal Marsh Loss in Long Island Sound

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).

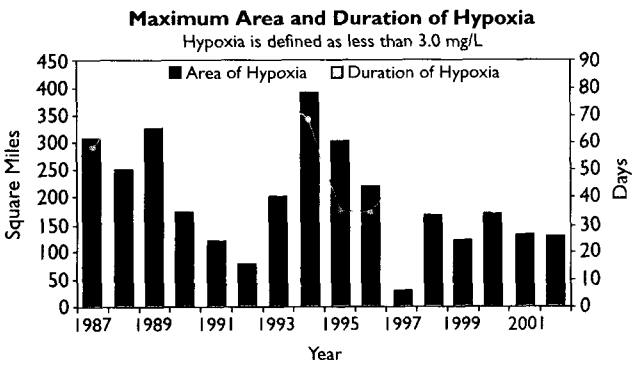


Figure 3-56. Hypoxia in Long Island Sound appears to have generally improved since 1987 (data obtained from CT DEP).

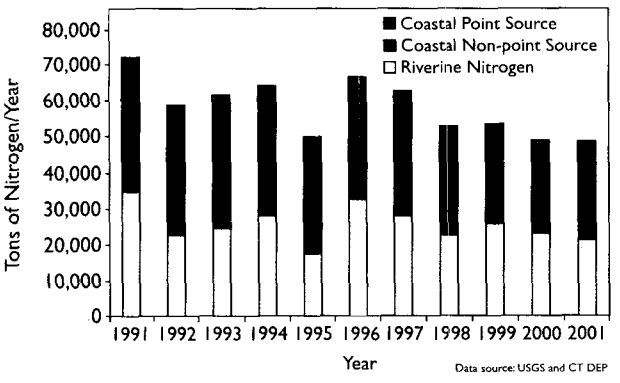


Figure 3-57. Trends in nitrogen loading to Long Island Sound (data obtained from USGS and CT DEP).

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.

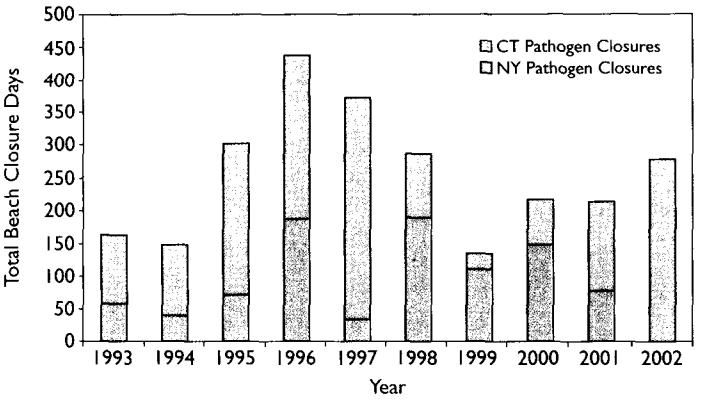


Figure 3-58. Trends in beach closures in Long Island Sound (1993–2002) (data obtained from CT DEP and NYSDEC).

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.

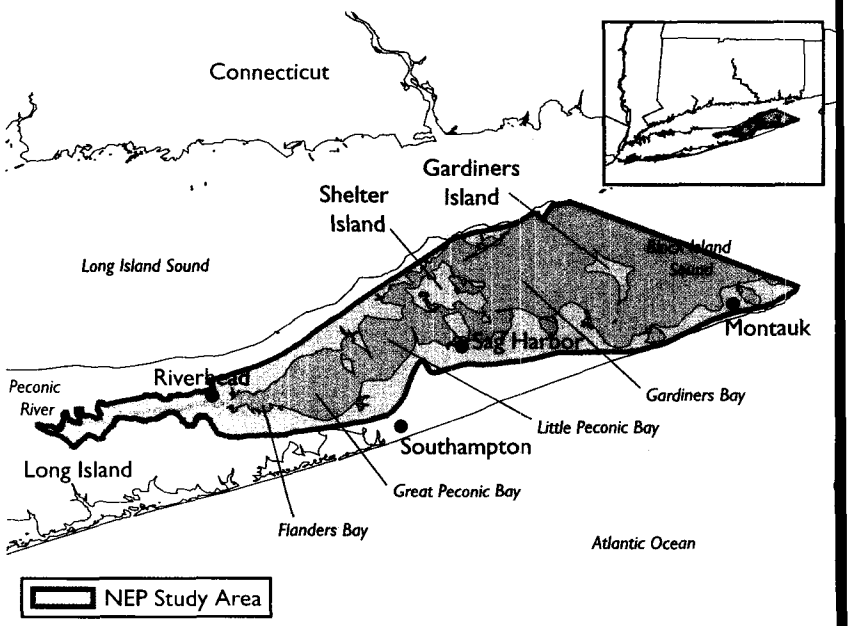
Future goals outlined in the LISS CCMP include the following:

- **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.

Peconic Estuary Program



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

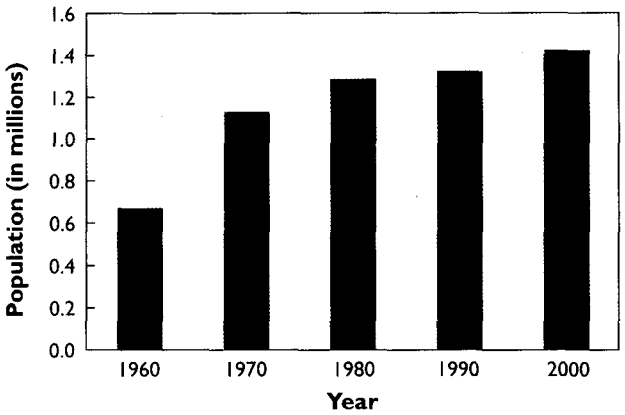


Figure 3-59. Population of NOAA-designated coastal county of the PEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

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.

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,

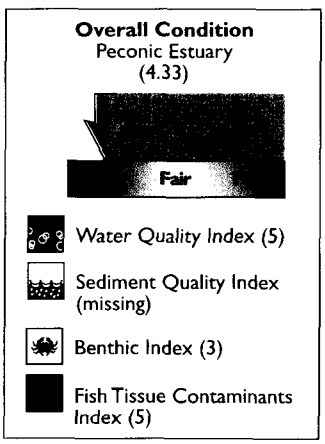


Figure 3-60. The overall condition of the PEP estuarine area is good (U.S. EPA/NCA).

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.

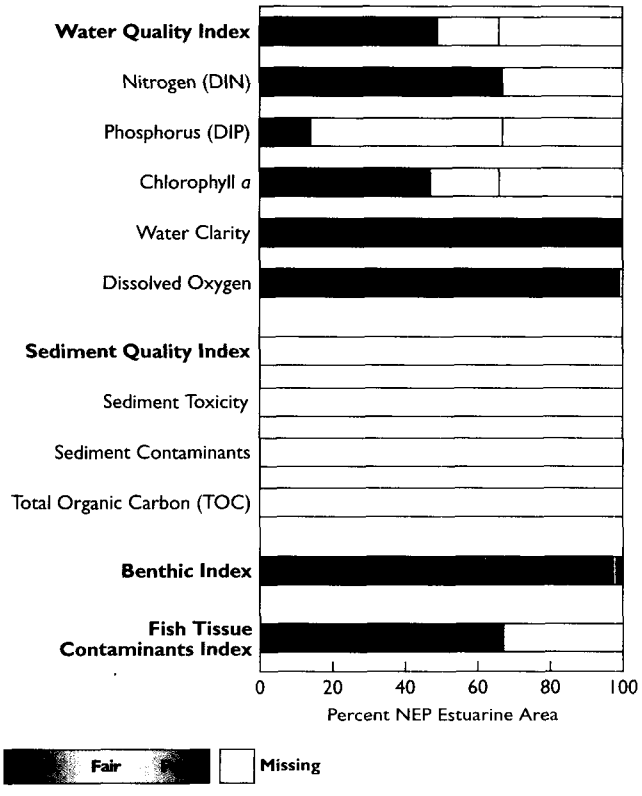


Figure 3-61. Percentage of estuarine area achieving each rating for all indices and component indicators — Peconic Estuary (U.S. EPA/NCA).

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

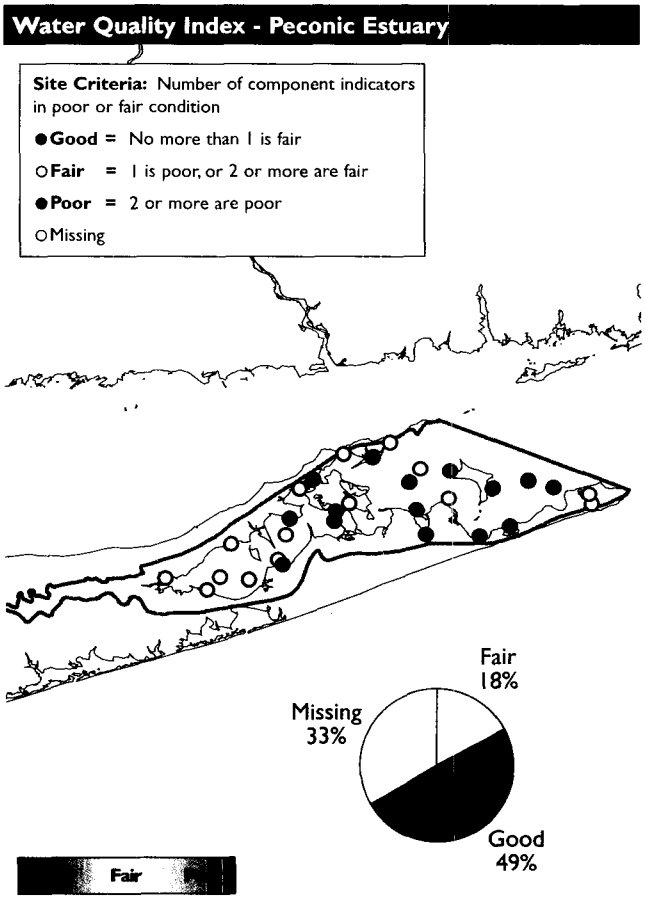


Figure 3-62. Water quality index data for the Peconic Estuary, 2000–2002 (U.S. EPA/NCA).

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.

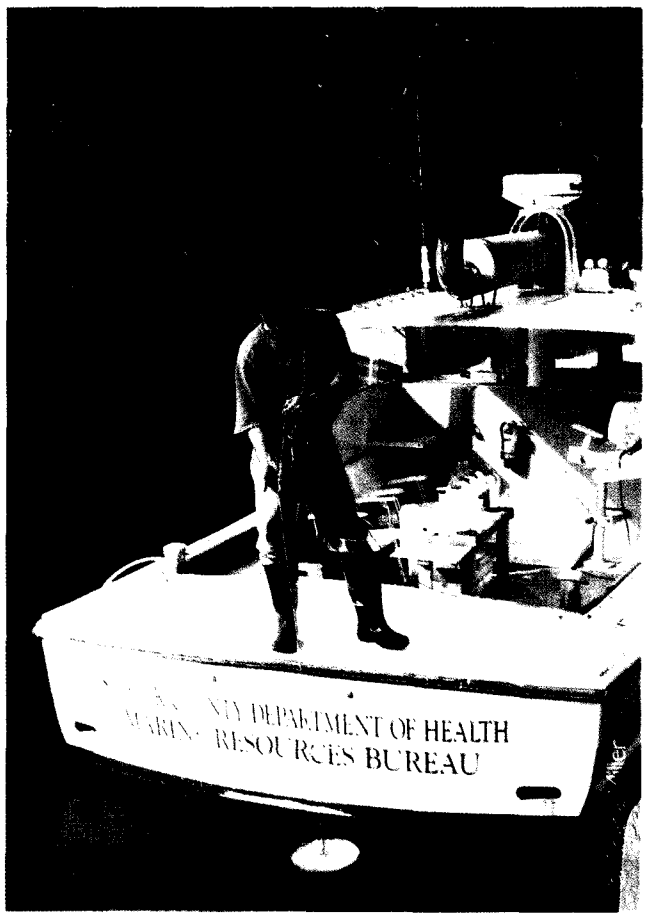
Sediment Quality Index

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.

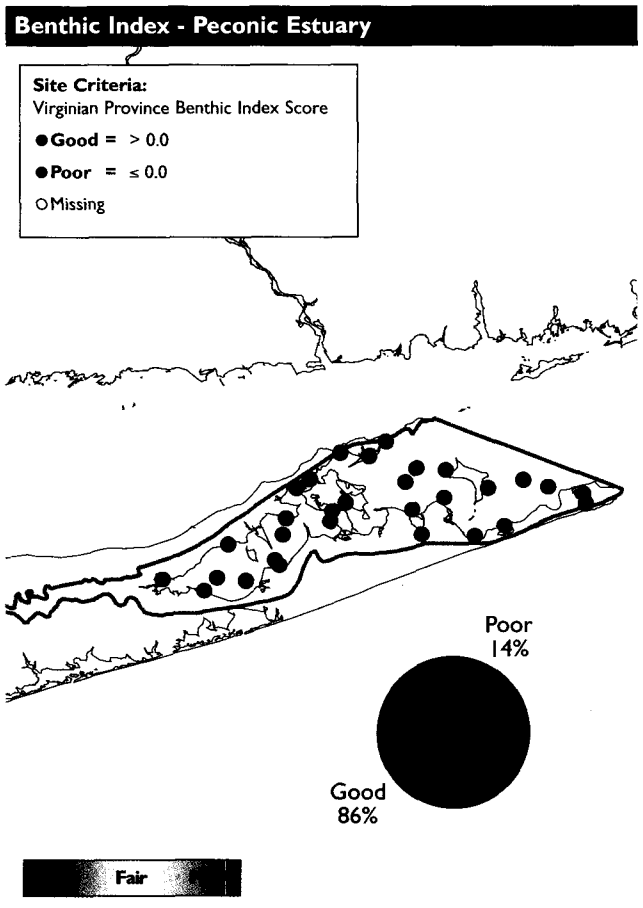


Figure 3-63. Benthic index data for the Peconic Estuary, 2000–2002 (U.S. EPA/NCA).

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.

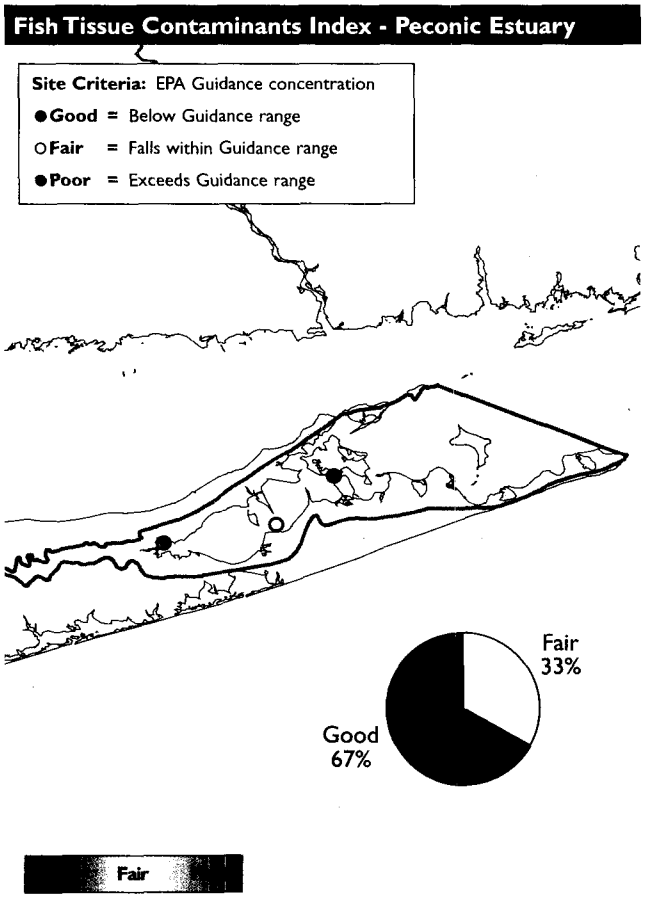


Figure 3-64. Fish tissue contaminants index data for the Peconic Estuary, 2000–2002 (U.S. EPA/NCA).

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.

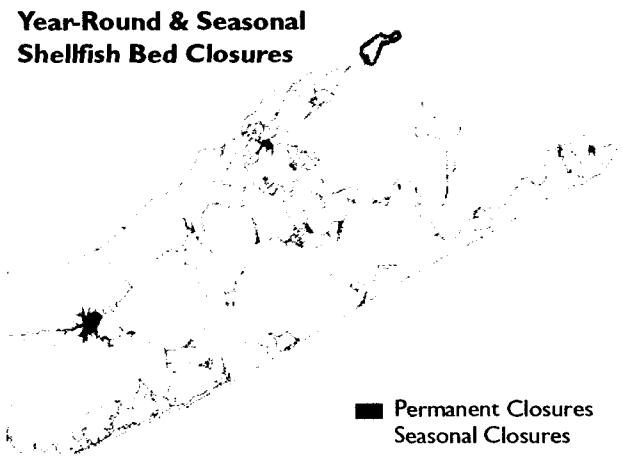


Figure 3-65. Permanent and seasonal shellfish closures in Peconic Bay on January 1, 2004 (PEP).

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).

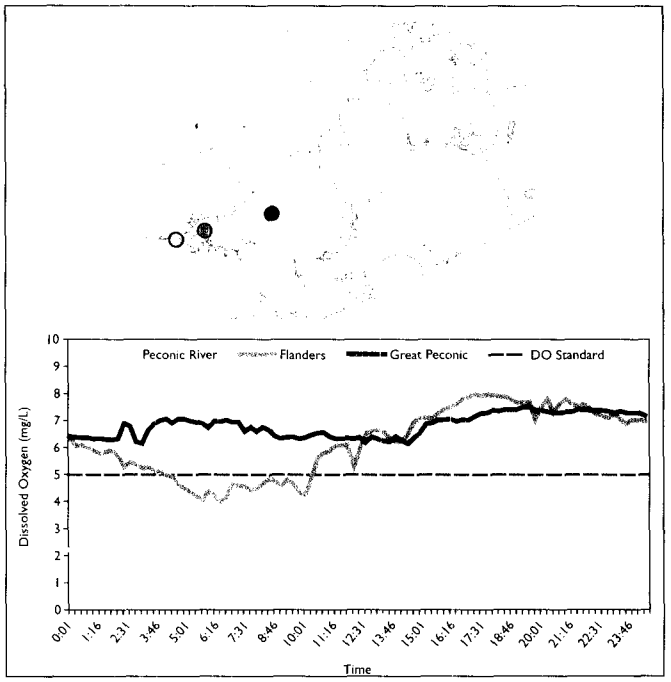


Figure 3-66. Dissolved oxygen concentrations at the three continuous monitoring locations on July 15, 2004 (Balla et al., 2005).

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

HIGHLIGHT

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

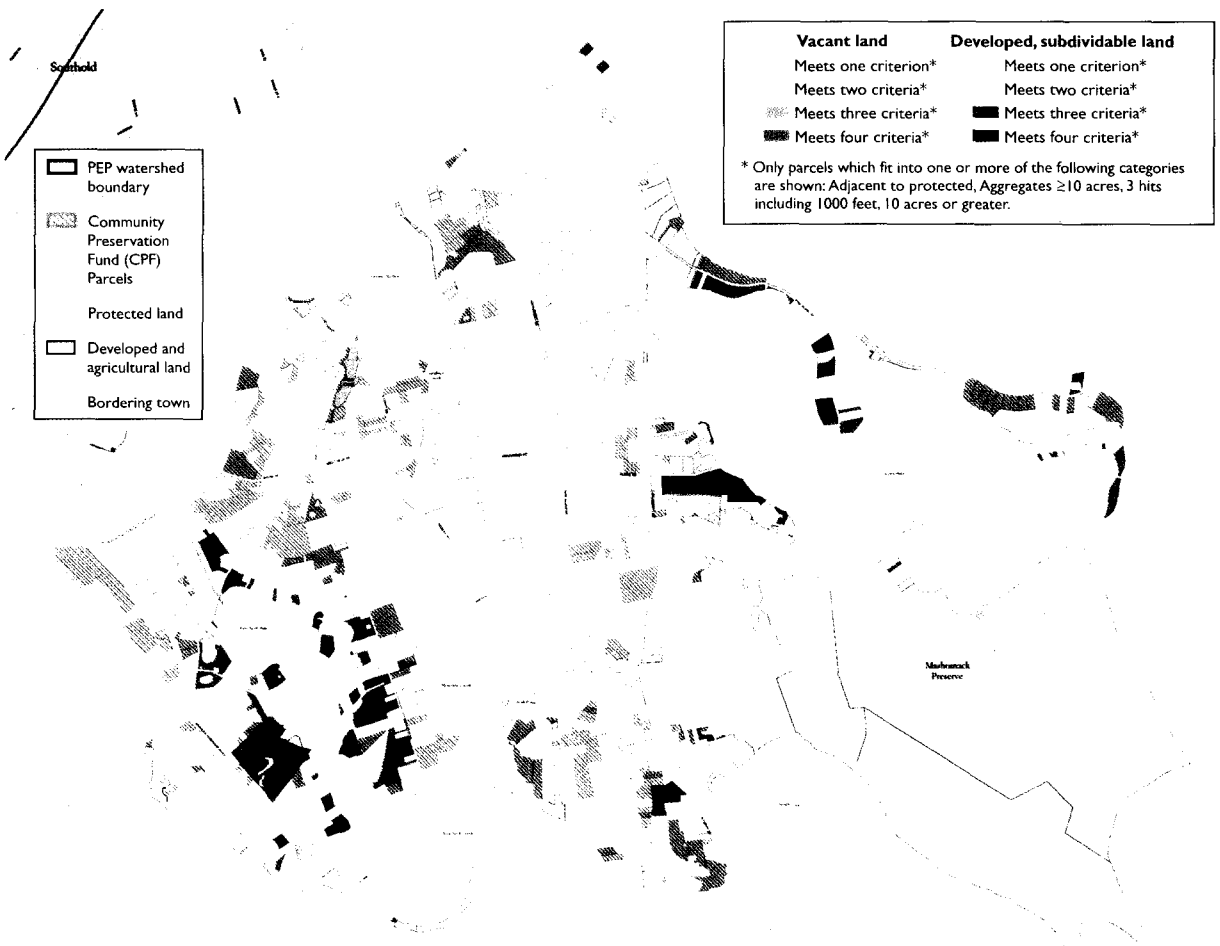
Non-market Benefits Associated with Open Space Acquisition in Riverhead, NY, Using a 3% Discount Rate (Gringalunas et al., 2004)

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:

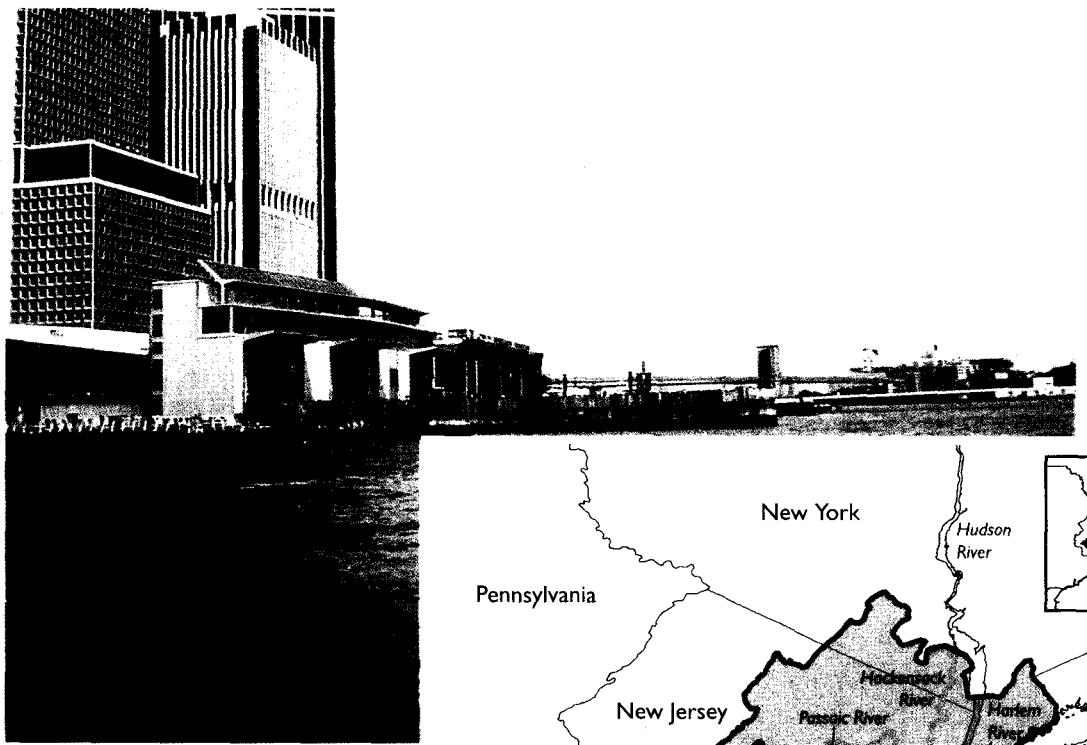
- **Restoration projects** – Between 1993 and 2005, more than 120 priority demonstration and implementation projects were funded using federal and state funds totaling more than $20.2 million. Projects include upgrades to STPs; restoration of wetlands, eelgrass beds, and fish passages; construction of 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.

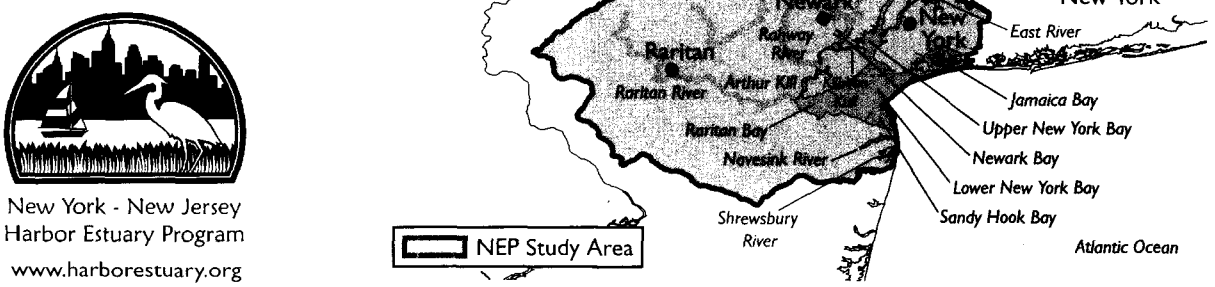
Conclusion

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





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.

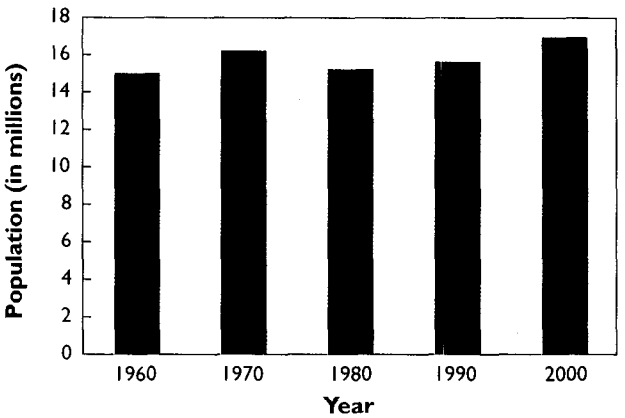


Figure 3-67. Population of NOAA-designated coastal counties of the HEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

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/

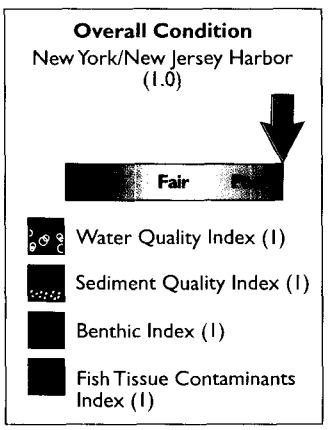


Figure 3-68. The overall condition of the HEP estuarine area is poor (U.S. EPA/NCA).

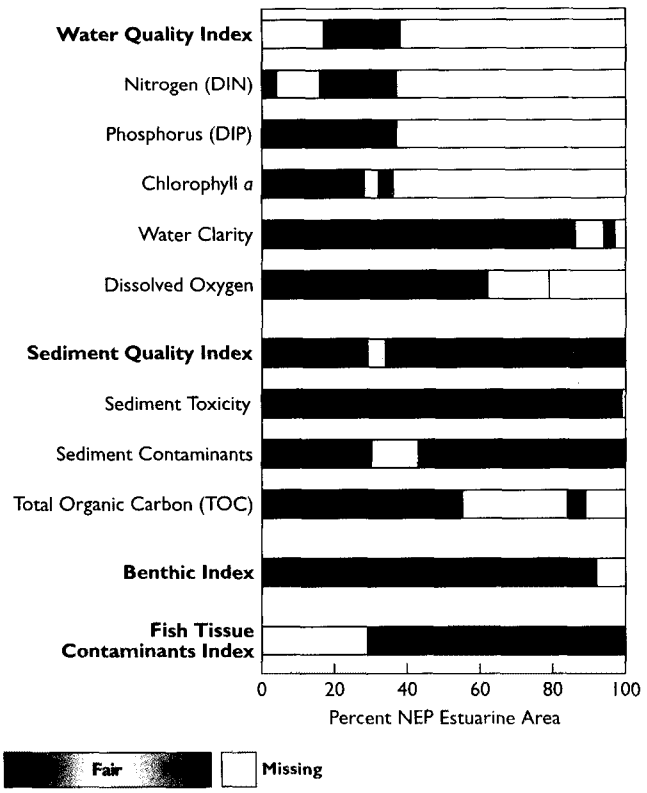


Figure 3-69. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — New York/New Jersey Harbor (U.S. EPA/NCA).

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

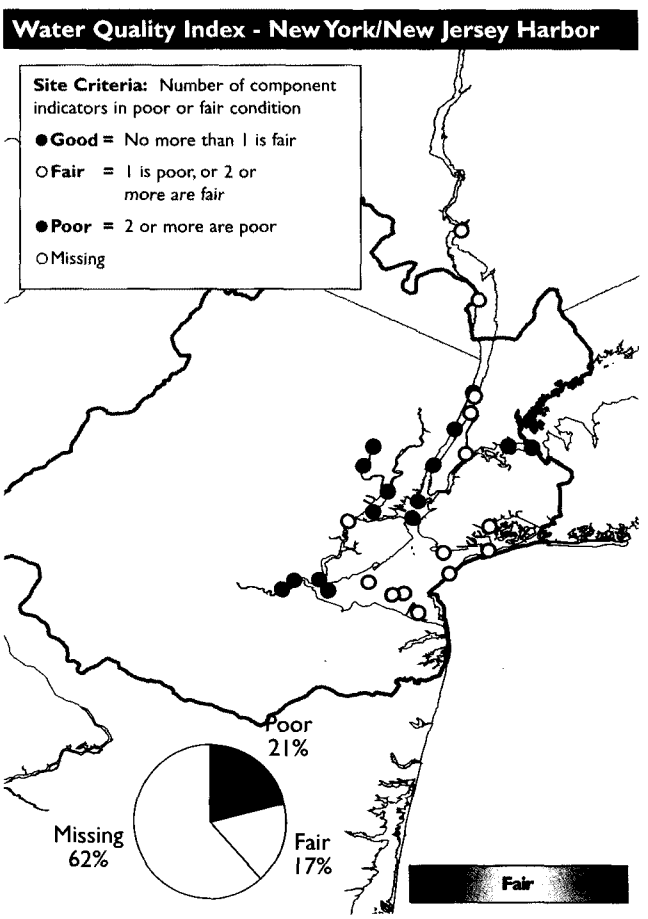


Figure 3-70. Water quality index data for New York/New Jersey Harbor, 2000–2001 (U.S. EPA/NCA).

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.

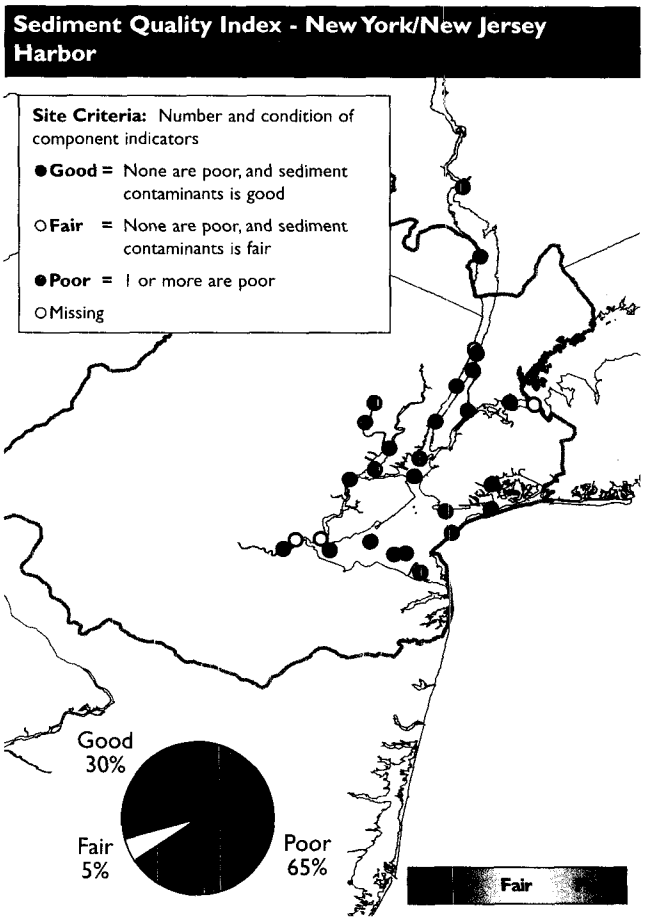


Figure 3-71. Sediment quality index data for New York/New Jersey Harbor, 2000–2001 (U.S. EPA/NCA).

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).

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.

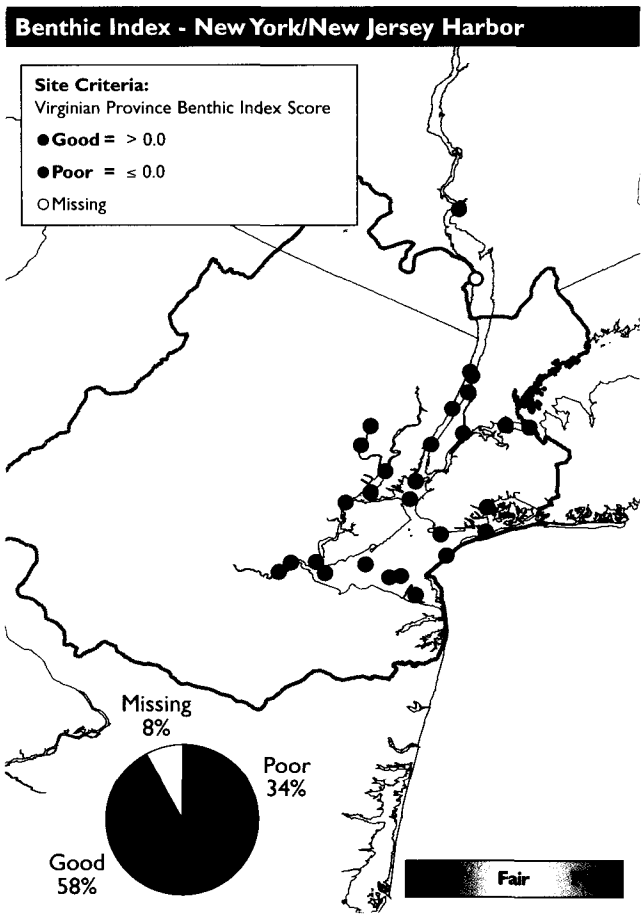


Figure 3-72. Benthic index data for New York/New Jersey Harbor, 2000–2001 (U.S. EPA/NCA).

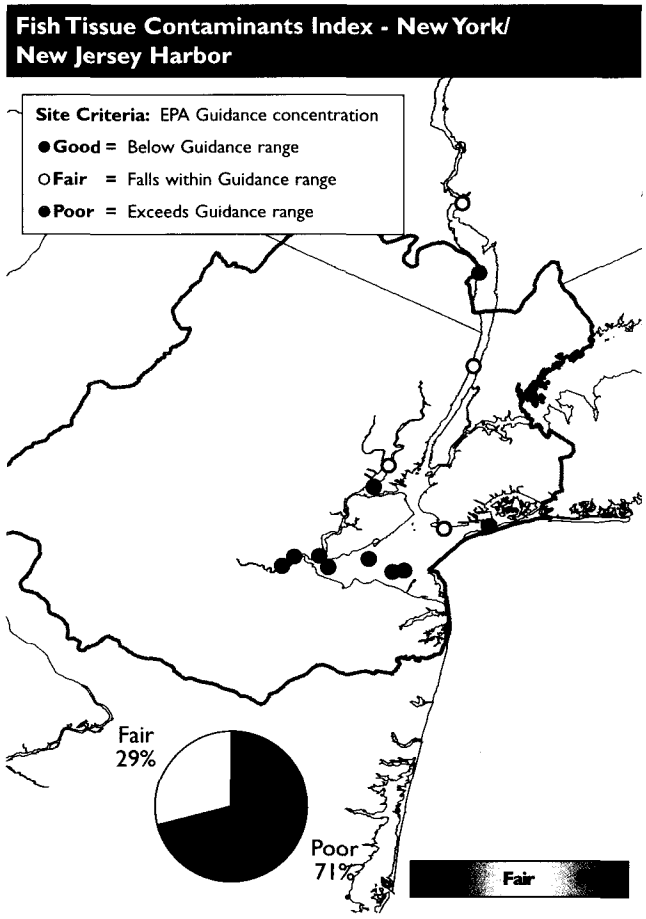


Figure 3-73. Fish tissue contaminants index data for New York/ New Jersey Harbor, 2000–2001 (U.S. EPA/NCA).

New York/New Jersey Harbor Estuary Program

HIGHLIGHT

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

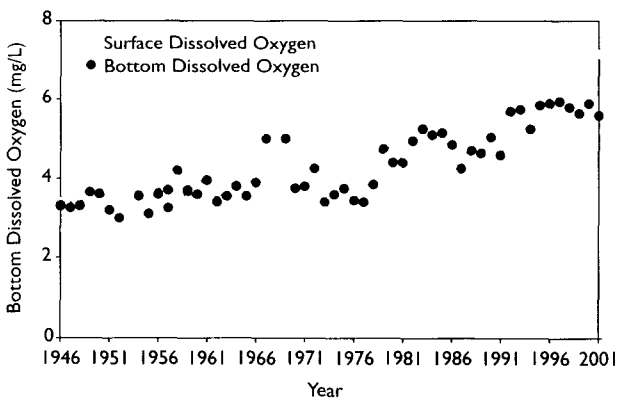


Figure 3-74. Trends in dissolved oxygen levels in surface and bottom waters of the New York/New Jersey Harbor (Steinberg et al., 2004).

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

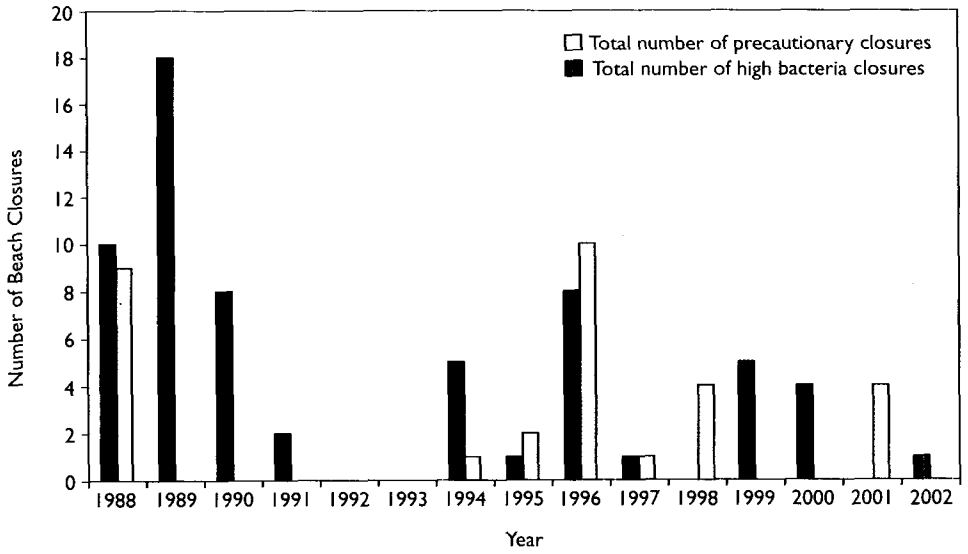


Figure 3-75. Number of beach closures by year at New Jersey beaches located in New York/New Jersey Harbor (Yuhas, 2002a).

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

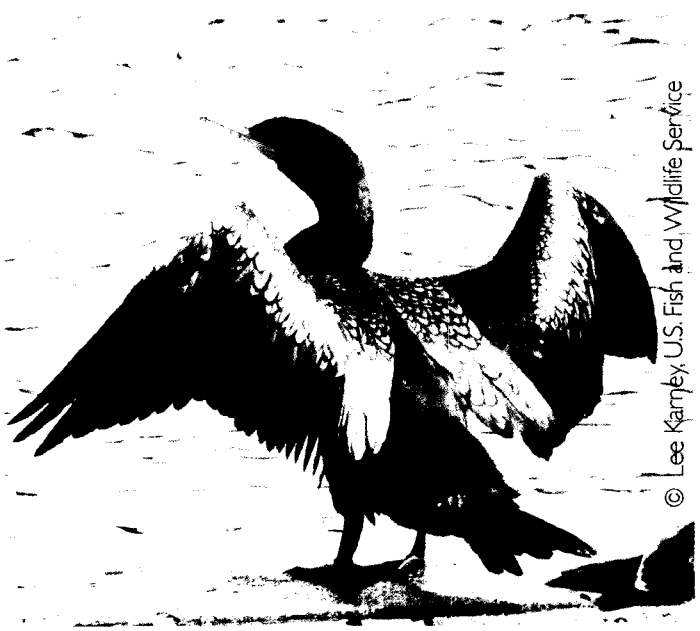
One of the most remarkable characteristics of the New York/New Jersey Harbor is the diverse range of living resources that populate the estuary's waters and coastal wetlands. The HEP, along with the NYSDEC, NJDEP, and other local agencies, is heavily involved in monitoring and assessing the abundance 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).



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

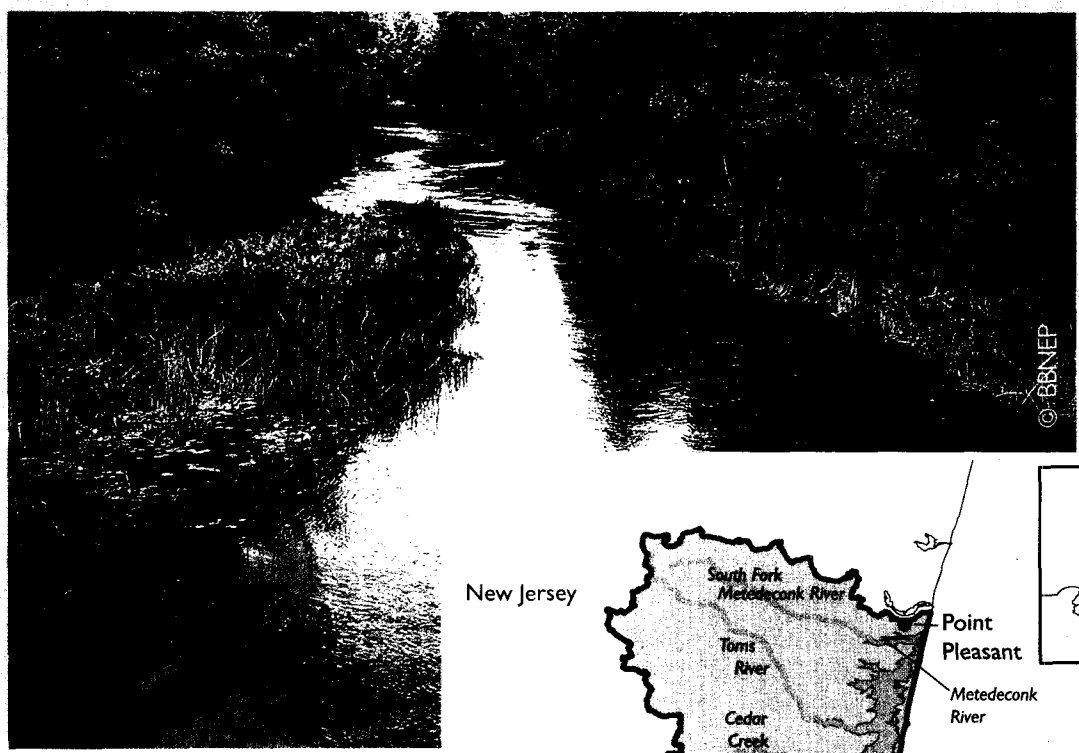
Some of the major environmental accomplishments of the HEP include the following:

- 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).

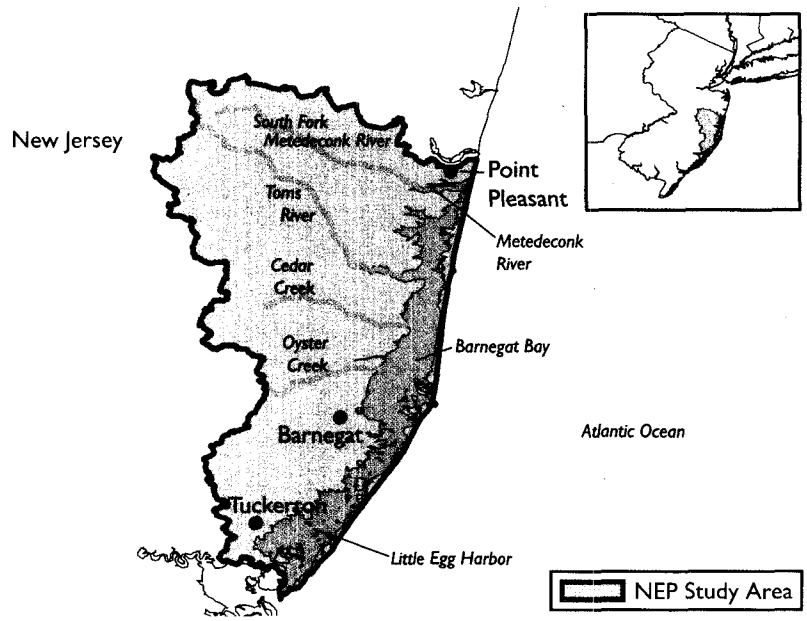
Conclusion

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



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).

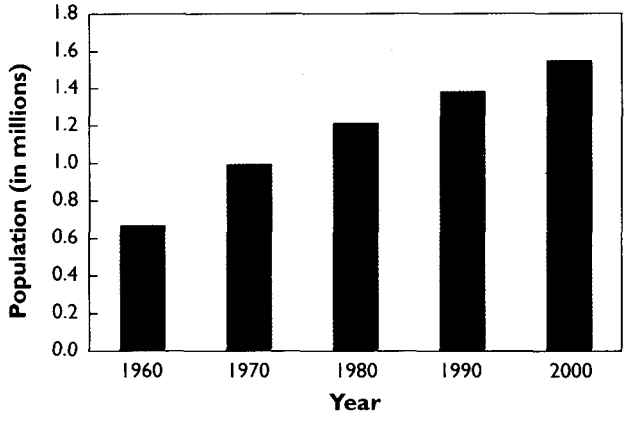


Figure 3-76. Population of NOAA-designated coastal counties of the BBNEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

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.

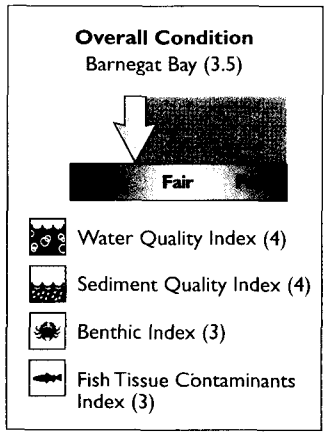


Figure 3-77. The overall condition of the BBNEP estuarine area is fair (U.S. EPA/NCA).

Barnegat Bay National Estuary Program

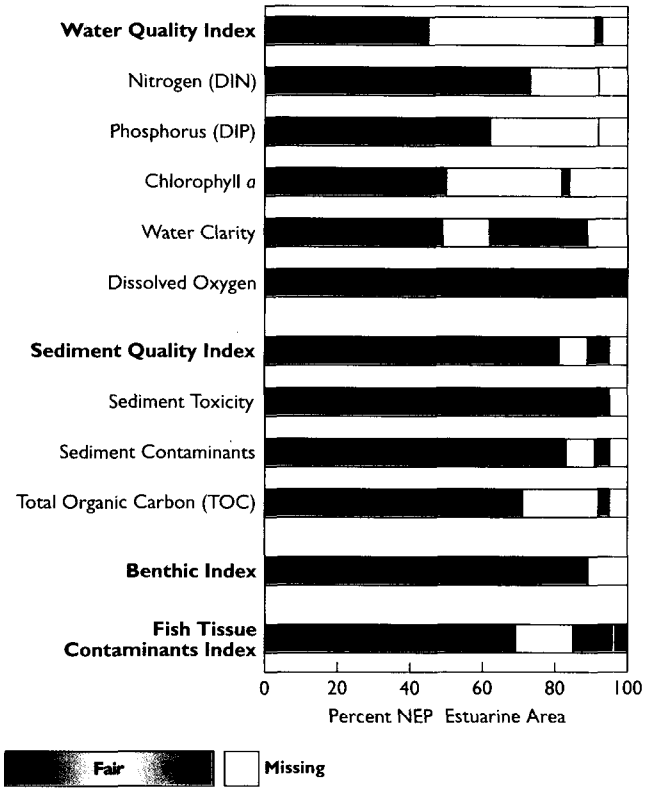


Figure 3-78. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Barnegat Bay (U.S. EPA/NCA).

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.

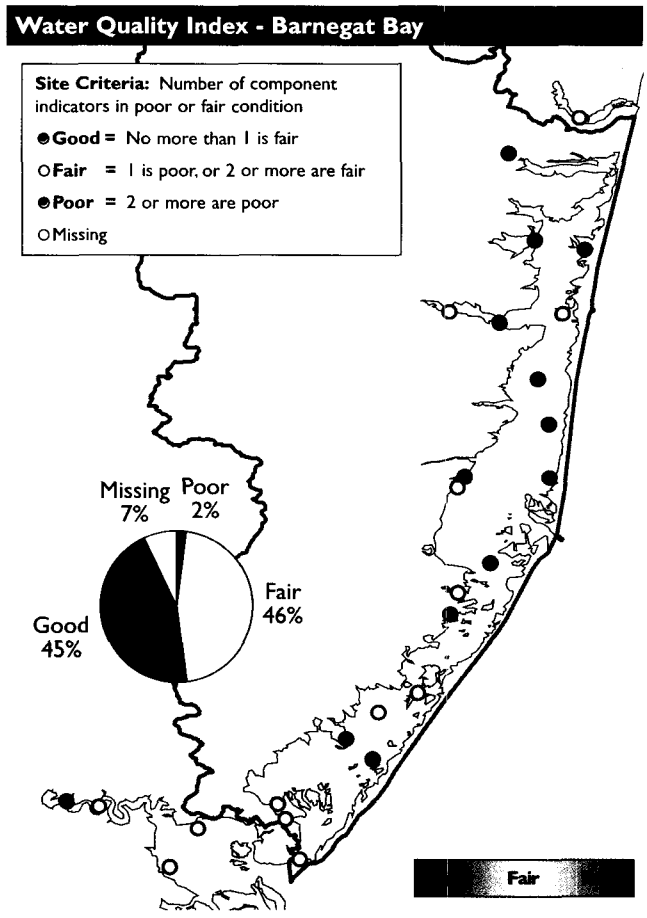


Figure 3-79. Water quality index data for Barnegat Bay, 2000–2001 (U.S. EPA/NCA).

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.

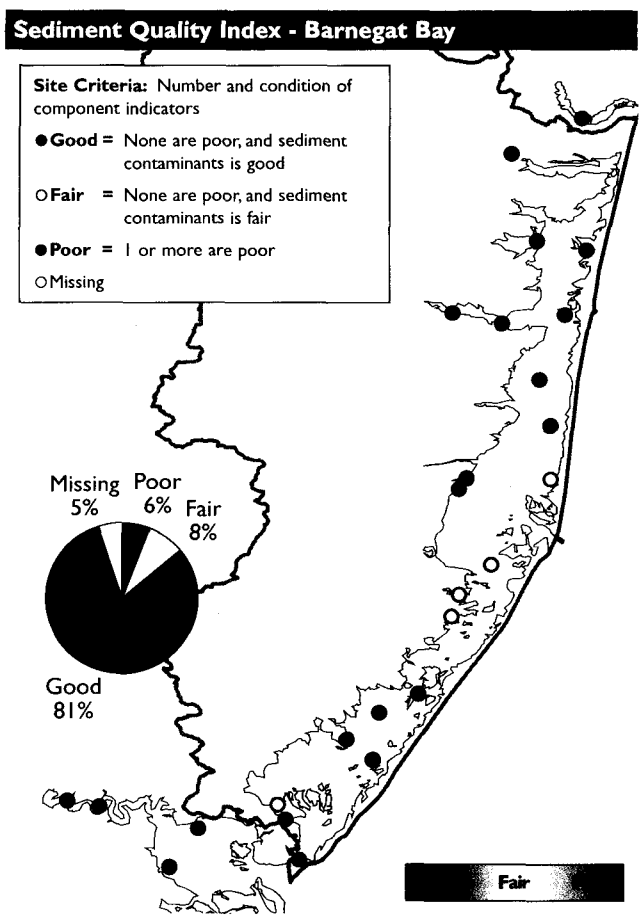


Figure 3-80. Sediment quality index data for Barnegat Bay, 2000–2001 (U.S. EPA/NCA).

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).

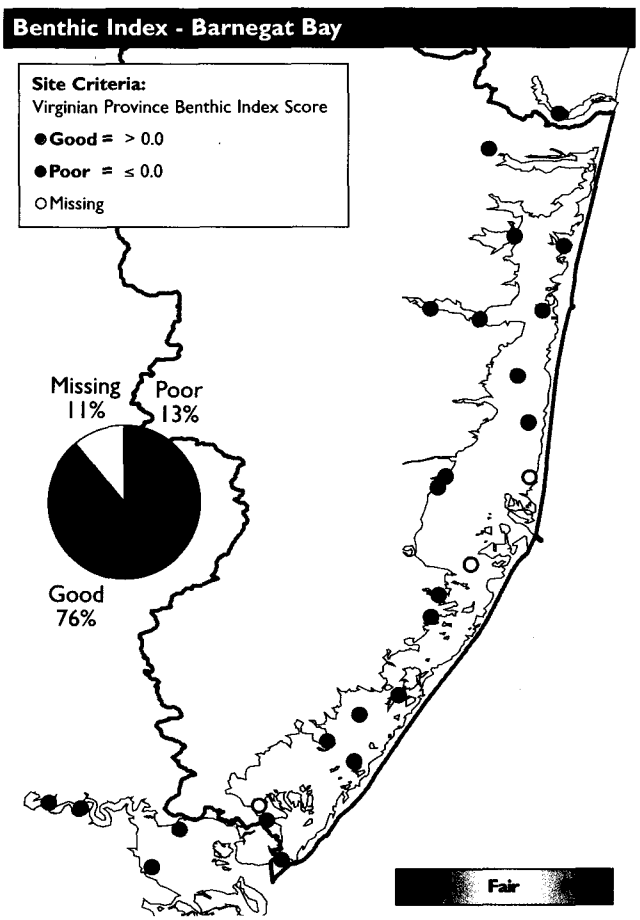


Figure 3-81. Benthic index data for Barnegat Bay, 2000–2001 (U.S. EPA/NCA).

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.

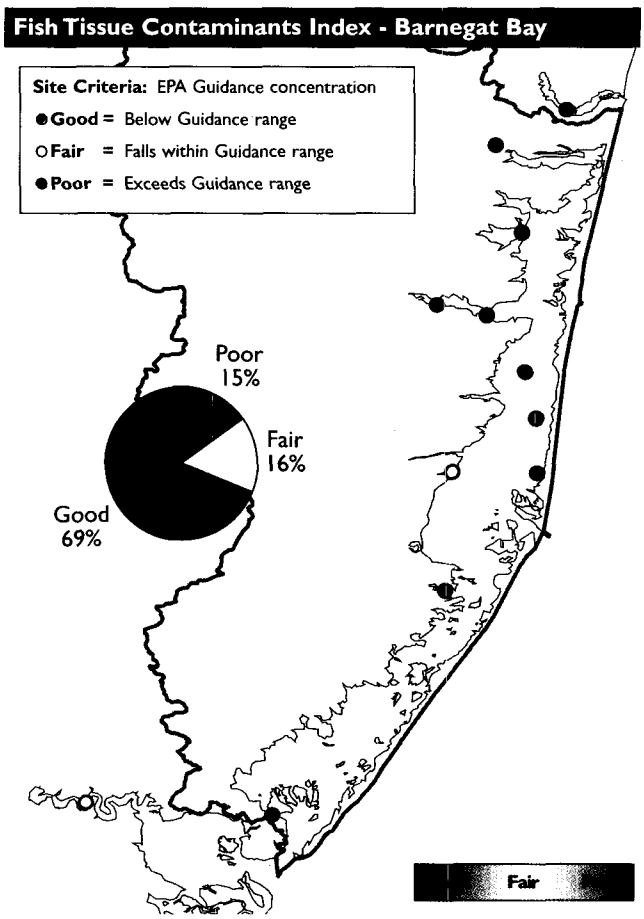


Figure 3-82. Fish tissue contaminants index data for Barnegat Bay, 2000–2001 (U.S. EPA/NCA).

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

Barnegat Bay National Estuary Program

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.

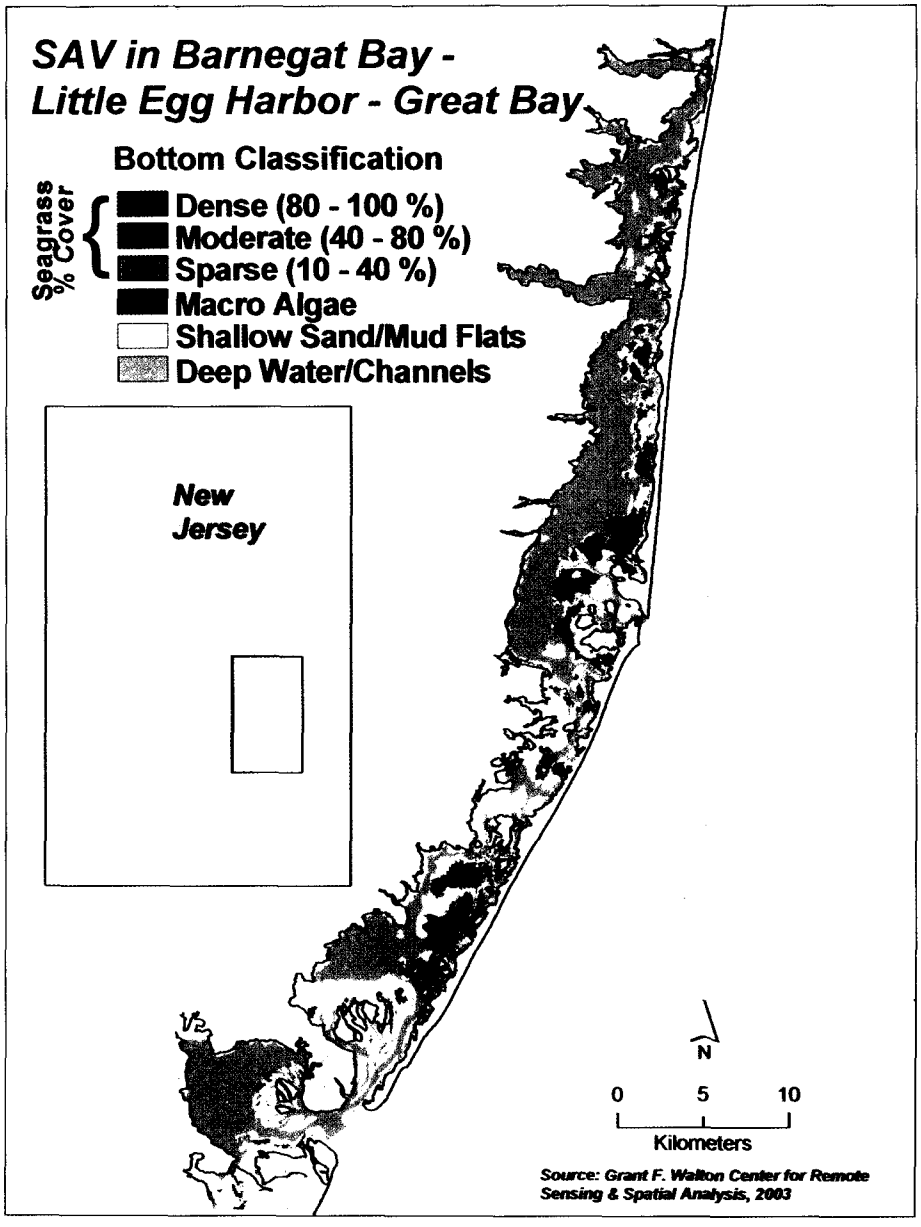
During the past 30 years, significant declines in SAV have occurred in New Jersey estuaries (Lathrop and Bognar, 2001), resulting in the reduction of essential fish habitat and the potential loss of important commercial and recreational species. In addition, nutrient enrichment has caused blooms of phytoplankton 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 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:

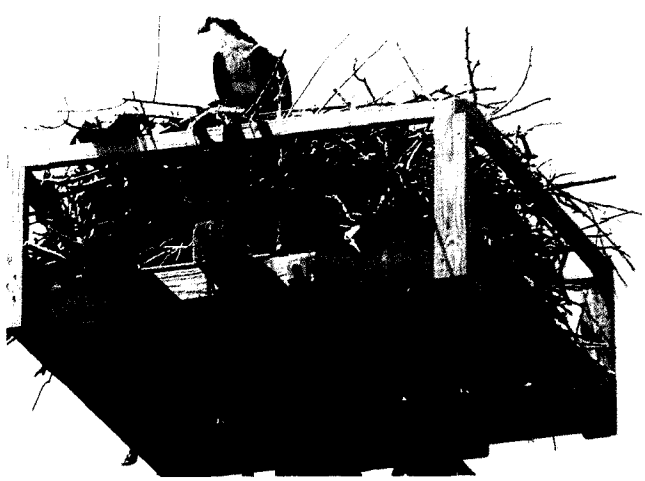
- Number (and duration) of bathing beach closures
- Acres of shellfish beds open/closed
- Presence of HABs (e.g., acres of coverage)
- Freshwater inputs to the Bay (e.g., changes in stream flow, water allocation).

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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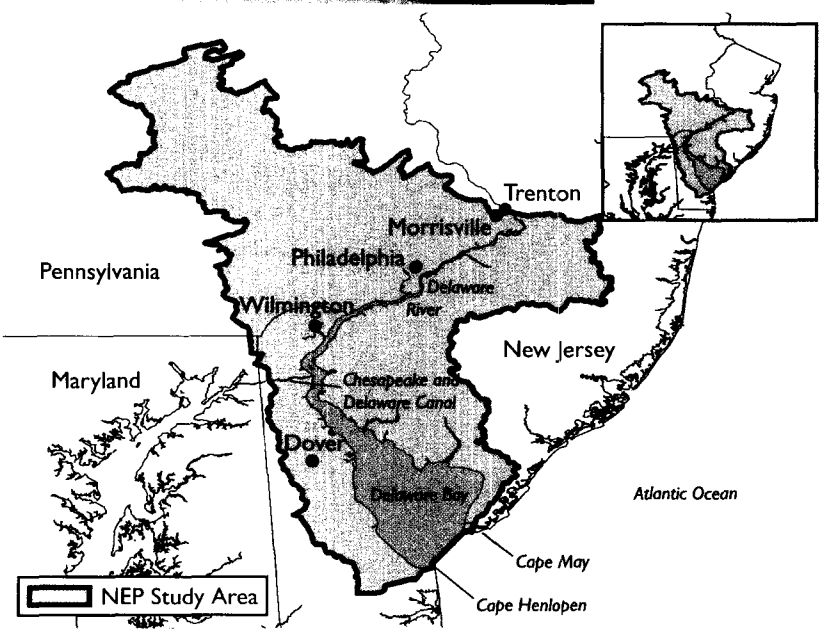


Background

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).

Partnership for the Delaware Estuary

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.

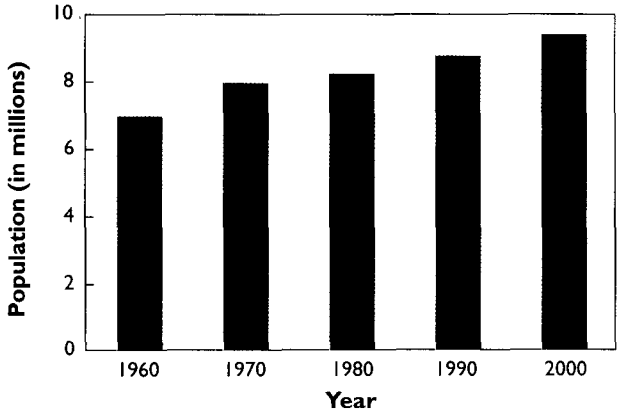


Figure 3-83. Population of NOAA-designated coastal counties of the PDE study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

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.

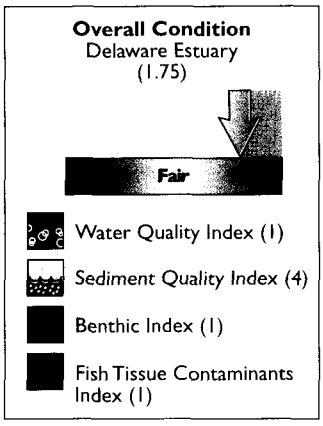


Figure 3-84. The overall condition of the PDE estuarine area is poor (U.S. EPA/NCA).

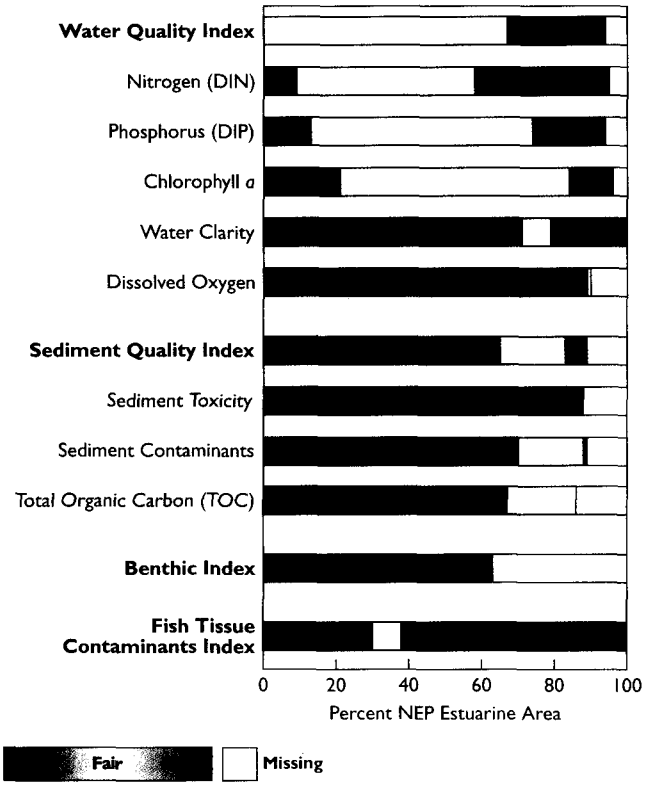


Figure 3-85. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Delaware Estuary (U.S. EPA/NCA).

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.

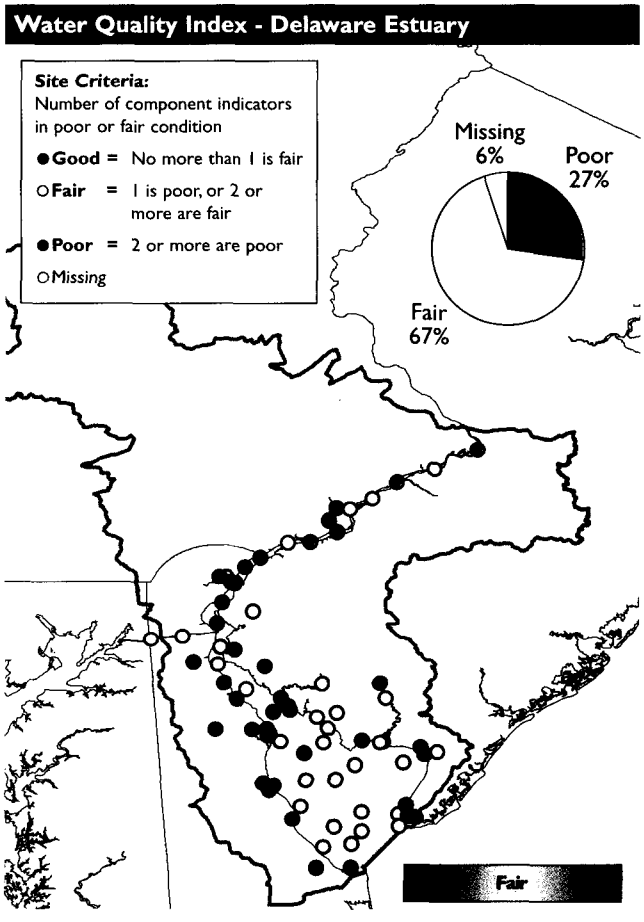


Figure 3-86. Water quality index data for the Delaware Estuary, 2000–2001 (U.S. EPA/NCA).

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.

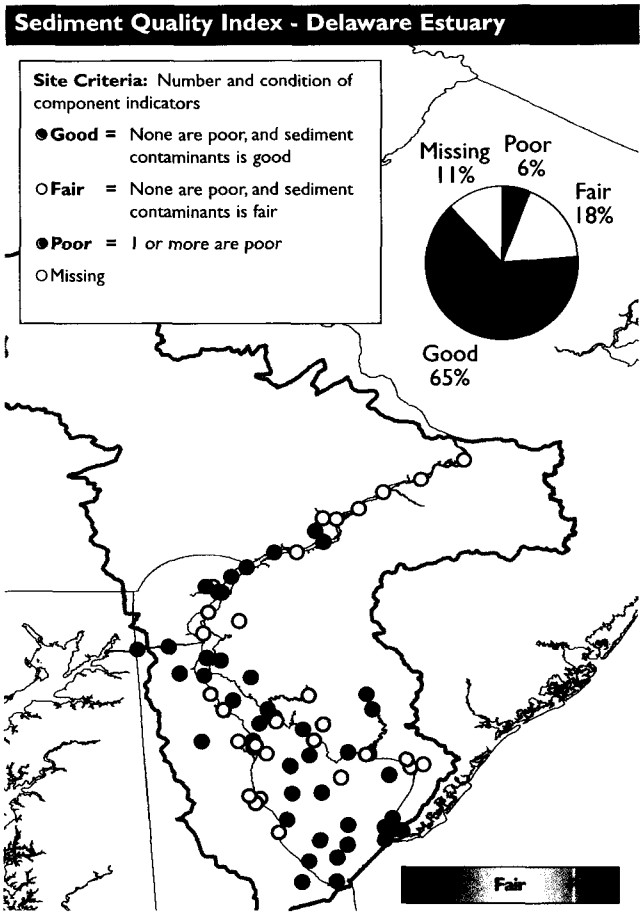


Figure 3-87. Sediment quality index data for the Delaware Estuary, 2000–2001 (U.S. EPA/NCA).

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).

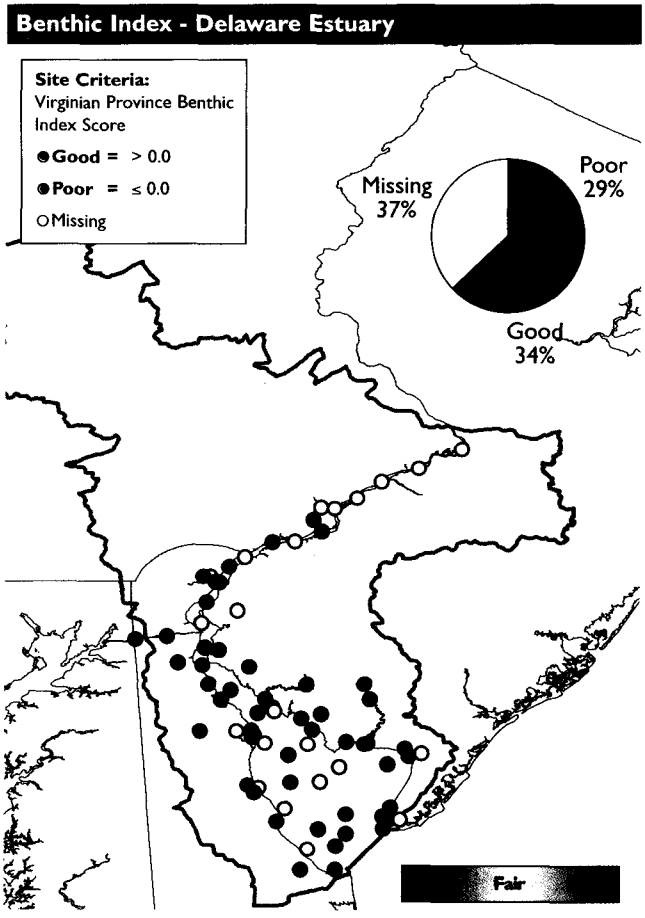


Figure 3-88. Benthic index data for the Delaware Estuary, 2000–2001 (U.S. EPA/NCA).

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.

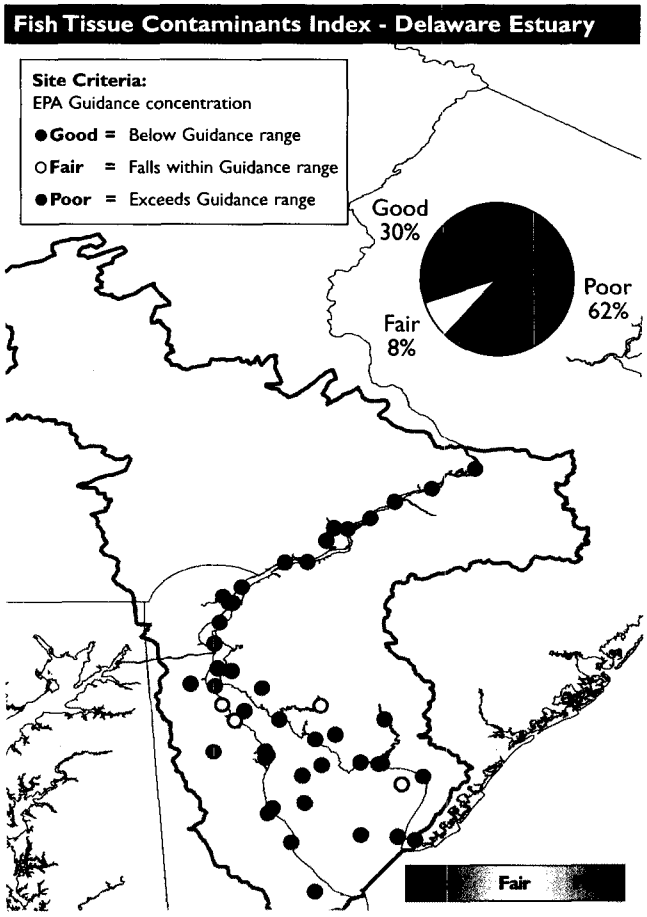


Figure 3-89. Fish tissue contaminants index data for the Delaware Estuary, 2000–2001 (U.S. EPA/NCA).

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).

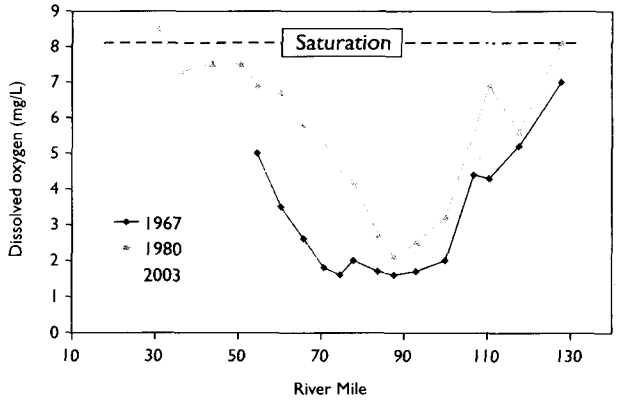


Figure 3-90. Annual dissolved oxygen levels for 1967, 1980, and 2003 along the main channel of the Delaware River from Trenton, NJ, to the mouth of the Delaware Bay (Santoro, 2004).

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).

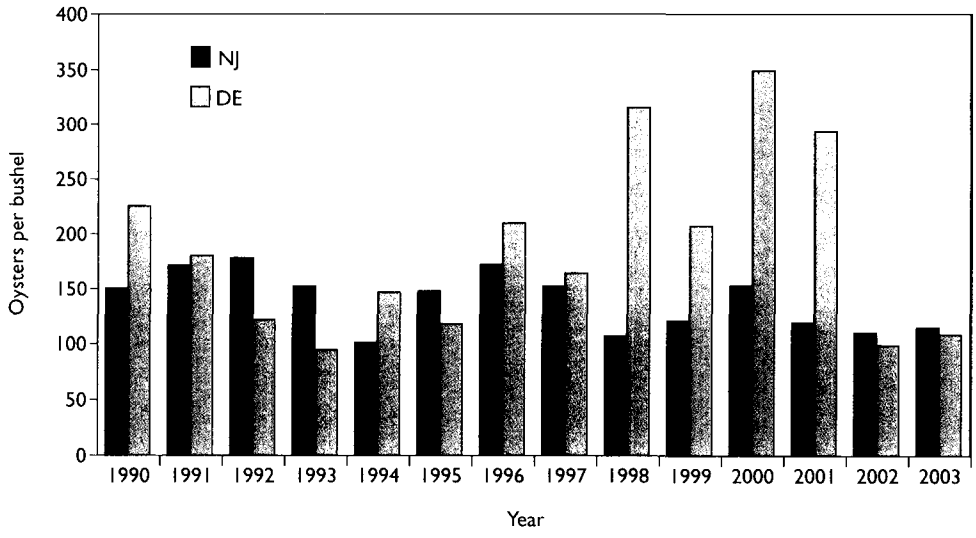


Figure 3-91. Fluctuations in oyster abundance in the Delaware Estuary (Santoro, 2004).

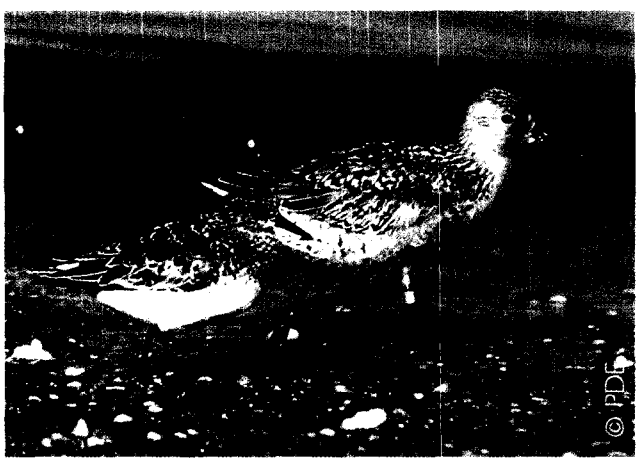
Partnership for the Delaware Estuary

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

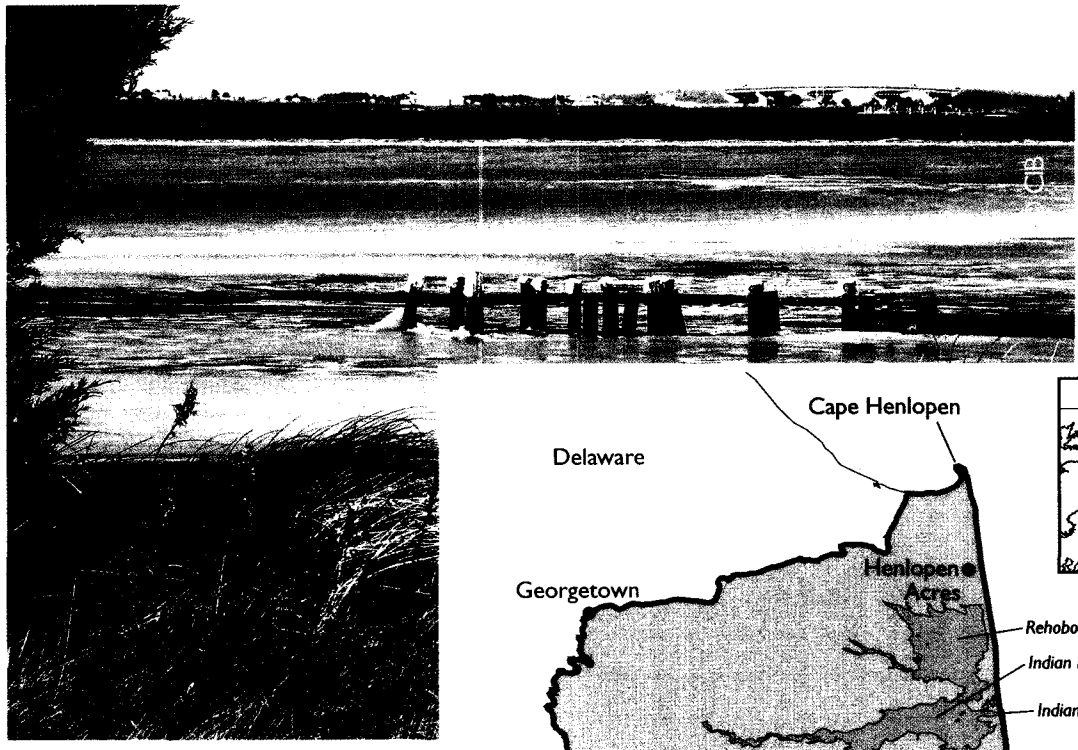
Examples of major water-quality-related accomplishments during the past several years for the PDE and its key partners in Delaware, New Jersey, and Pennsylvania are the following:

- 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 5 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 2 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 2 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



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.

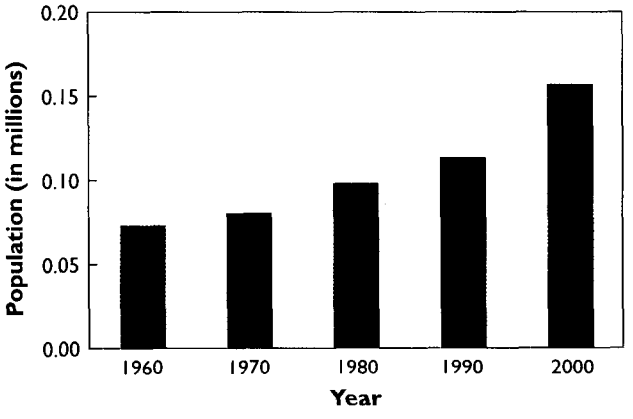


Figure 3-92. Population of NOAA-designated coastal county of the CIB study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

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.

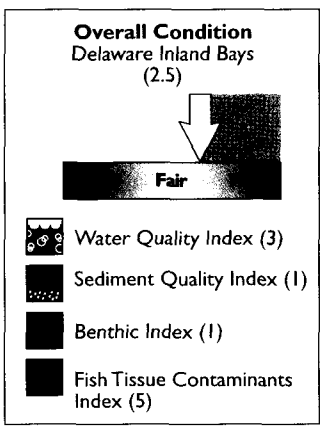


Figure 3-93. The overall condition of the CIB estuarine area is fair (U.S. EPA/NCA).

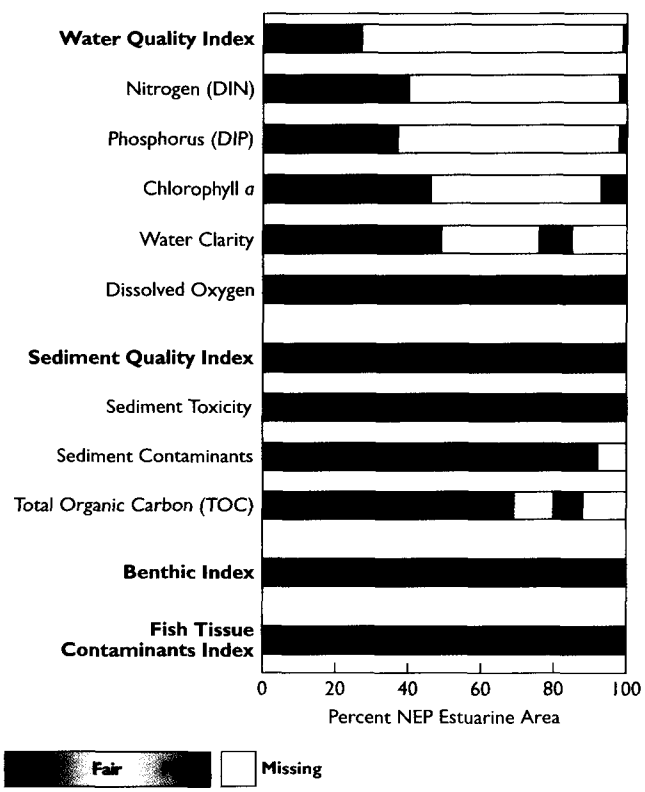


Figure 3-94. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Delaware Inland Bays (U.S. EPA/NCA).

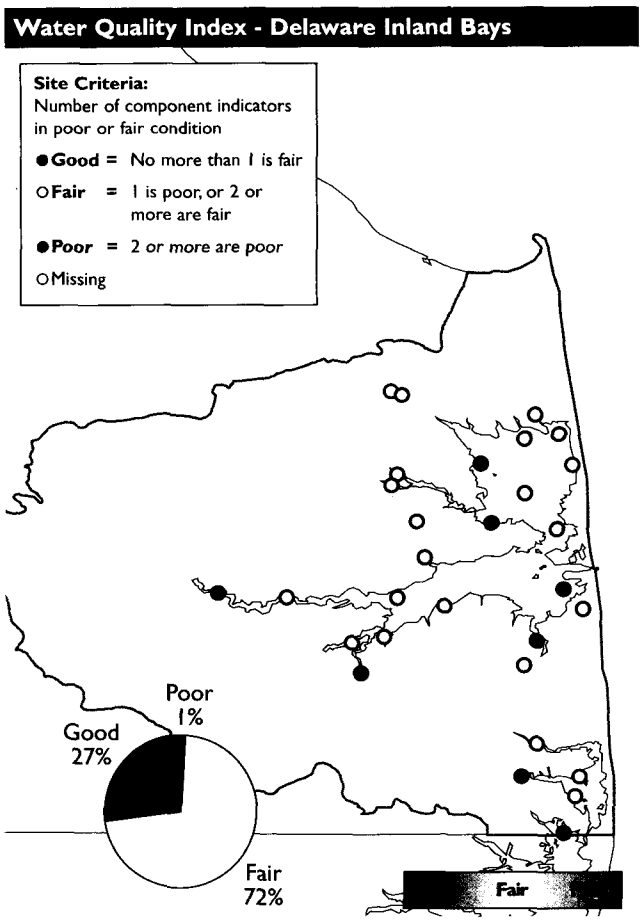


Figure 3-95. Water quality index data for the Delaware Inland Bays, 2000–2001 (U.S. EPA/NCA).

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.

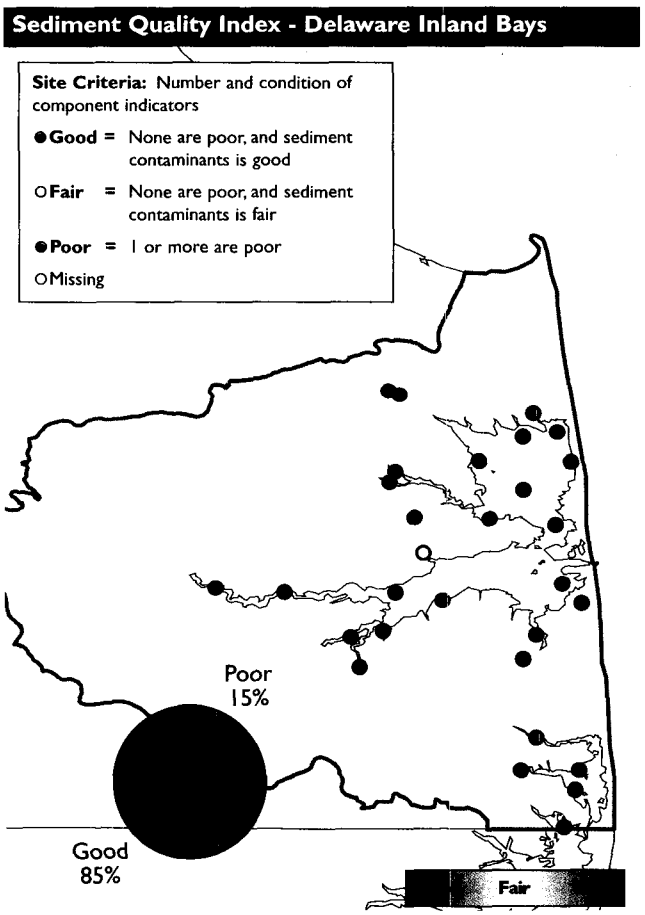


Figure 3-96. Sediment quality index data for the Delaware Inlands Bays, 2000–2001 (U.S. EPA/NCA).

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.

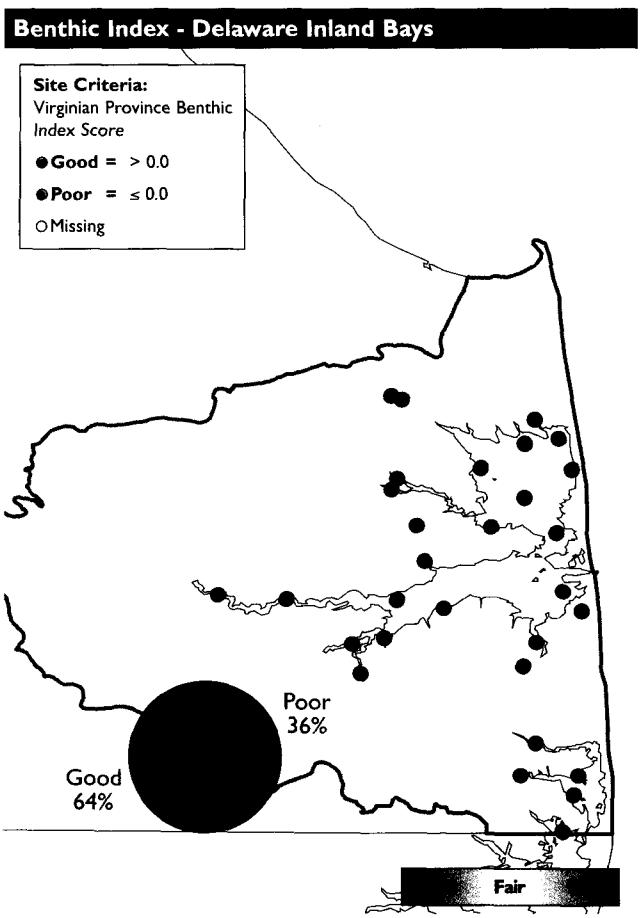


Figure 3-97. Benthic index data for the Delaware Inland Bays, 2000–2001 (U.S. EPA/NCA).

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.

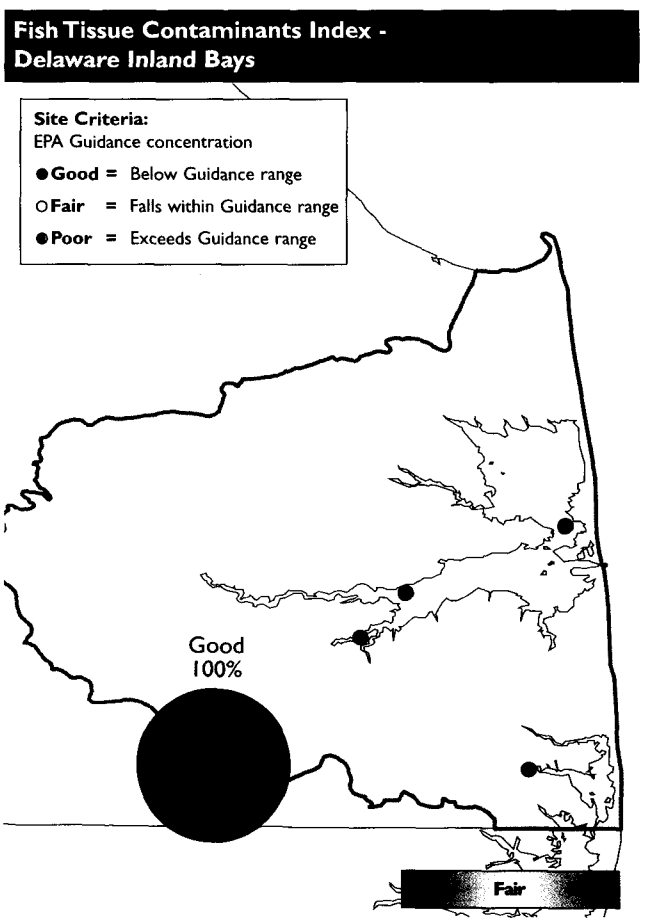


Figure 3-98. Fish tissue contaminants index data for the Delaware Inland Bays, 2000–2001 (U.S. EPA/NCA).

Center for the Inland Bays

HIGHLIGHT

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).

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).

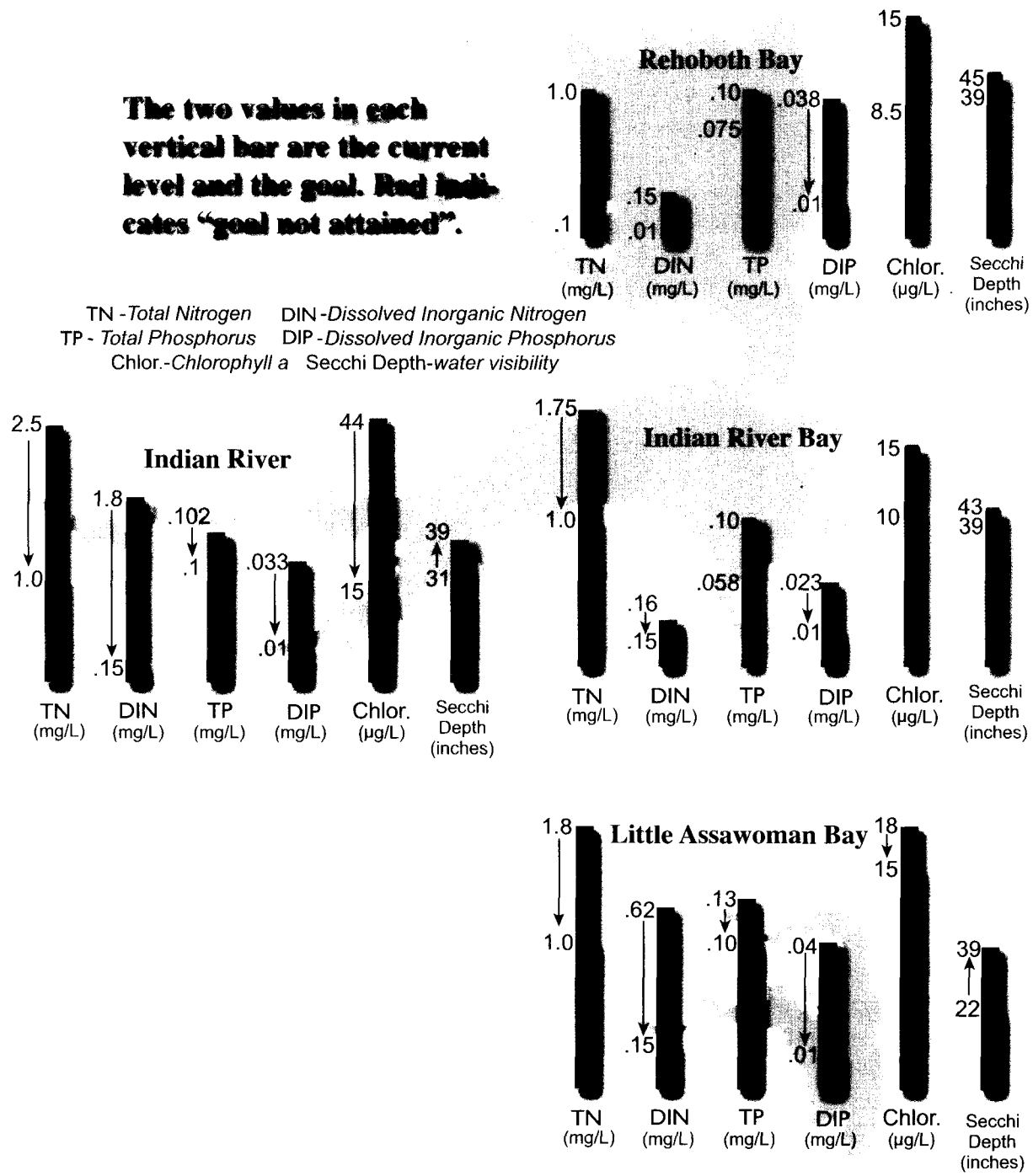


Figure 3-99. Water quality parameters as compared to water quality goals for the Delaware Inland Bays for the 1990s (CIB, 2004)

Center for the Inland Bays

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).

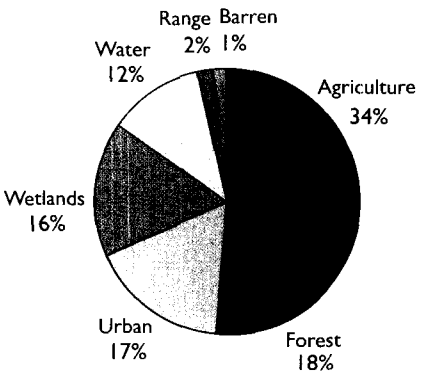


Figure 3-100. Delaware Inland Bays land use in 2002 (CIB, 2004).

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).

Center for the Inland Bays

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.

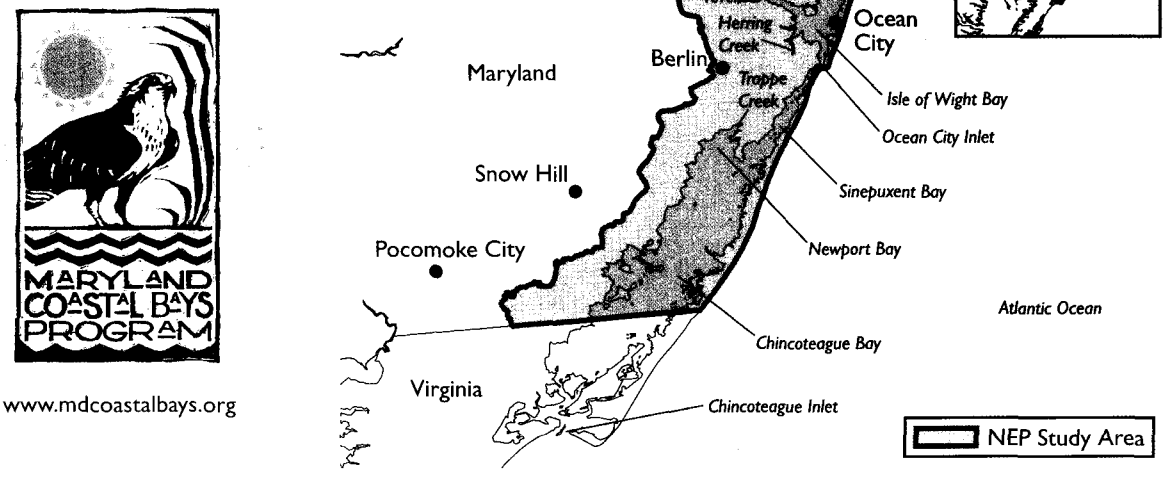
Some of the CIB's ongoing projects and major accomplishments in the Delaware Inland Bays' watershed include the following:

- 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).

Maryland Coastal Bays Program

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

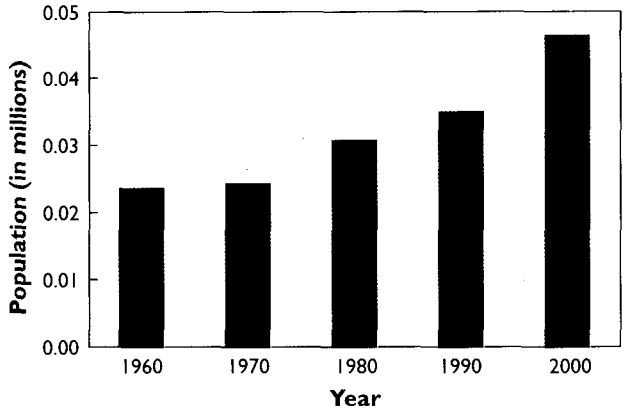


Figure 3-101. Population of NOAA-designated coastal county of the MCBP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

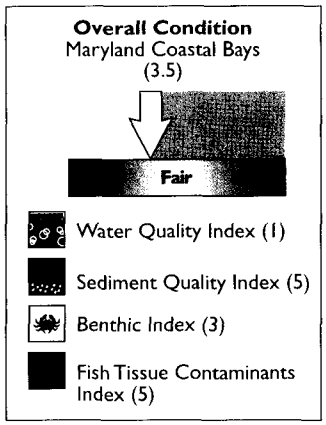


Figure 3-102. The overall condition of the MCBP estuarine area is fair (U.S. EPA/NCA).

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.

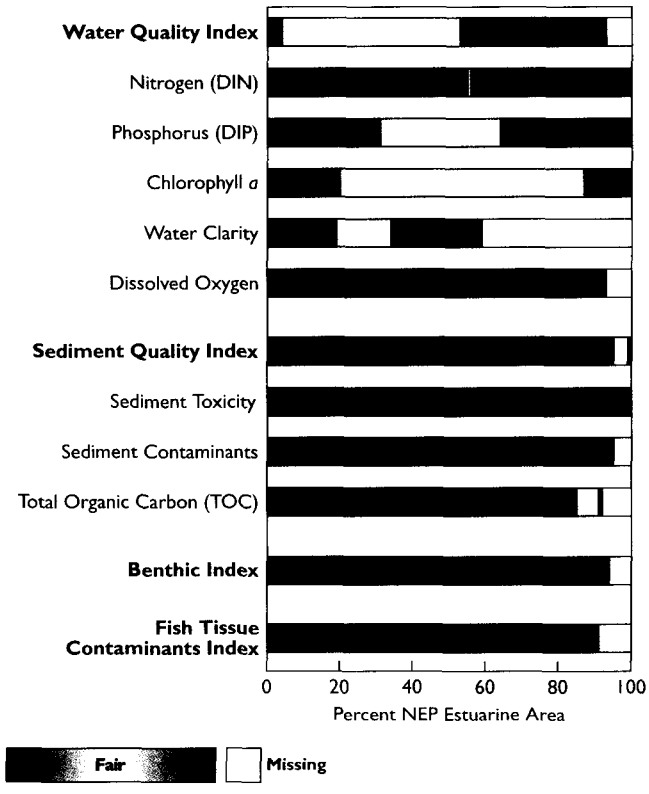


Figure 3-103. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Maryland Coastal Bays (U.S. EPA/NCA).

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.

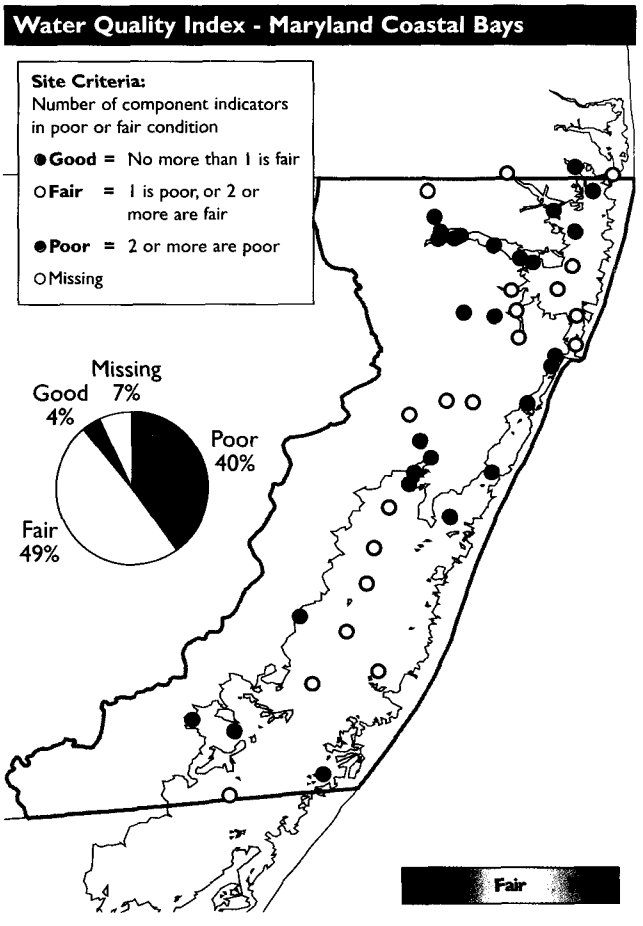


Figure 3-104. Water quality index data for the Maryland Coastal Bays, 2000–2001 (U.S. EPA/NCA).

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.

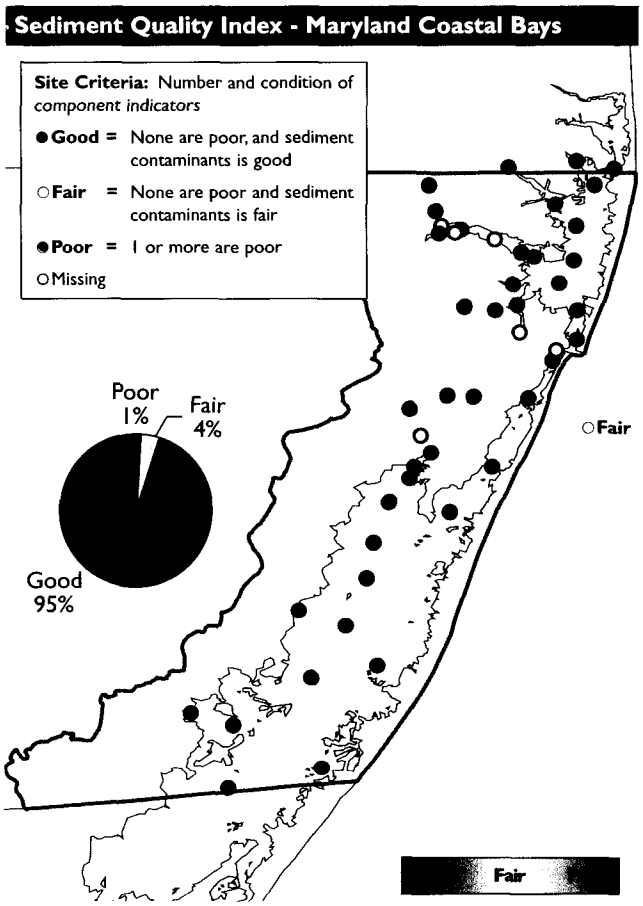


Figure 3-105. Sediment quality index data for the Maryland Coastal Bays, 2000–2001 (U.S. EPA/NCA).

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.

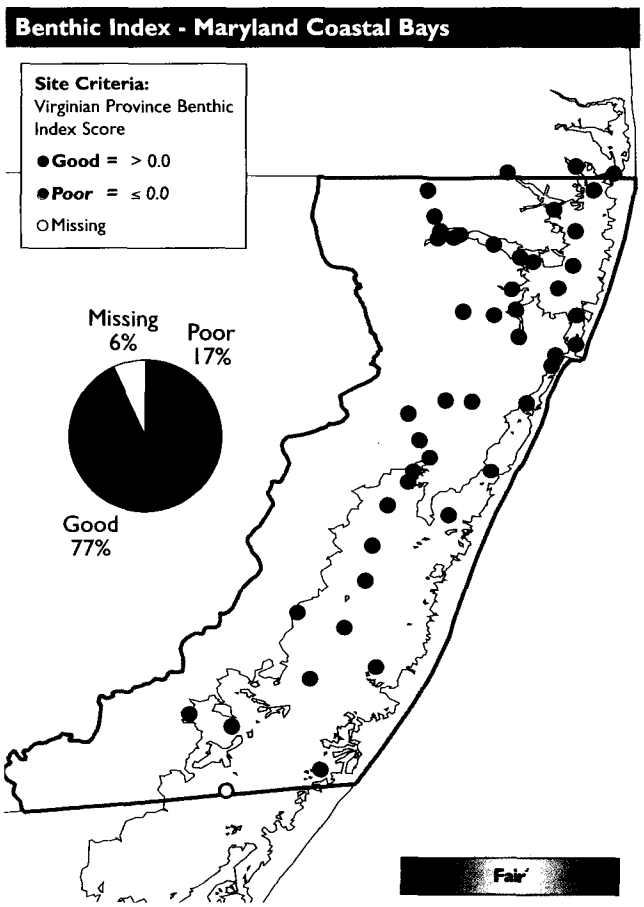


Figure 3-106. Benthic index data for the Maryland Coastal Bays, 2000–2001 (U.S. EPA/NCA).

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.

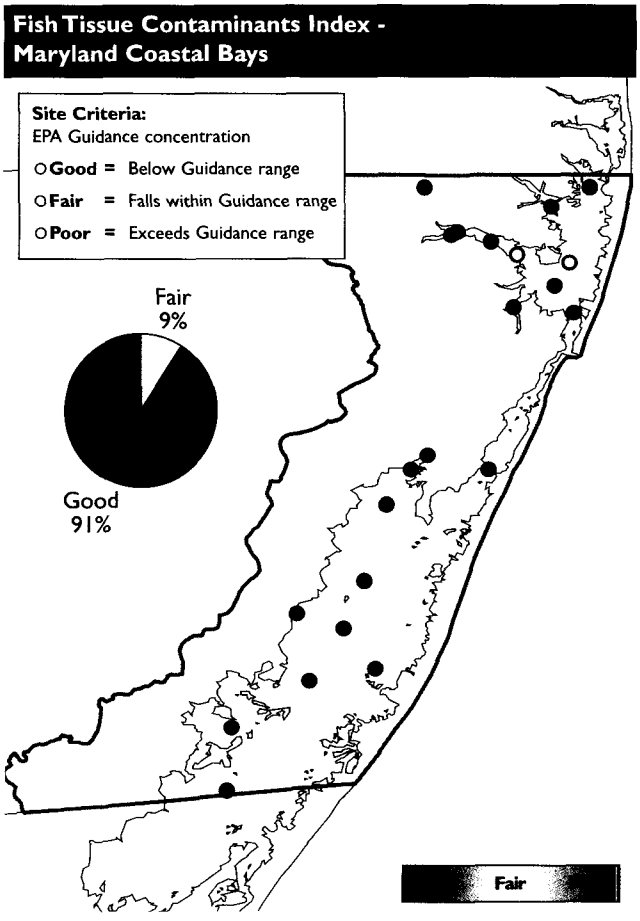


Figure 3-107. Fish tissue contaminants index data for the Maryland Coastal Bays, 2000–2001 (U.S. EPA/NCA).

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

Maryland Coastal Bays Program

HIGHLIGHT

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.

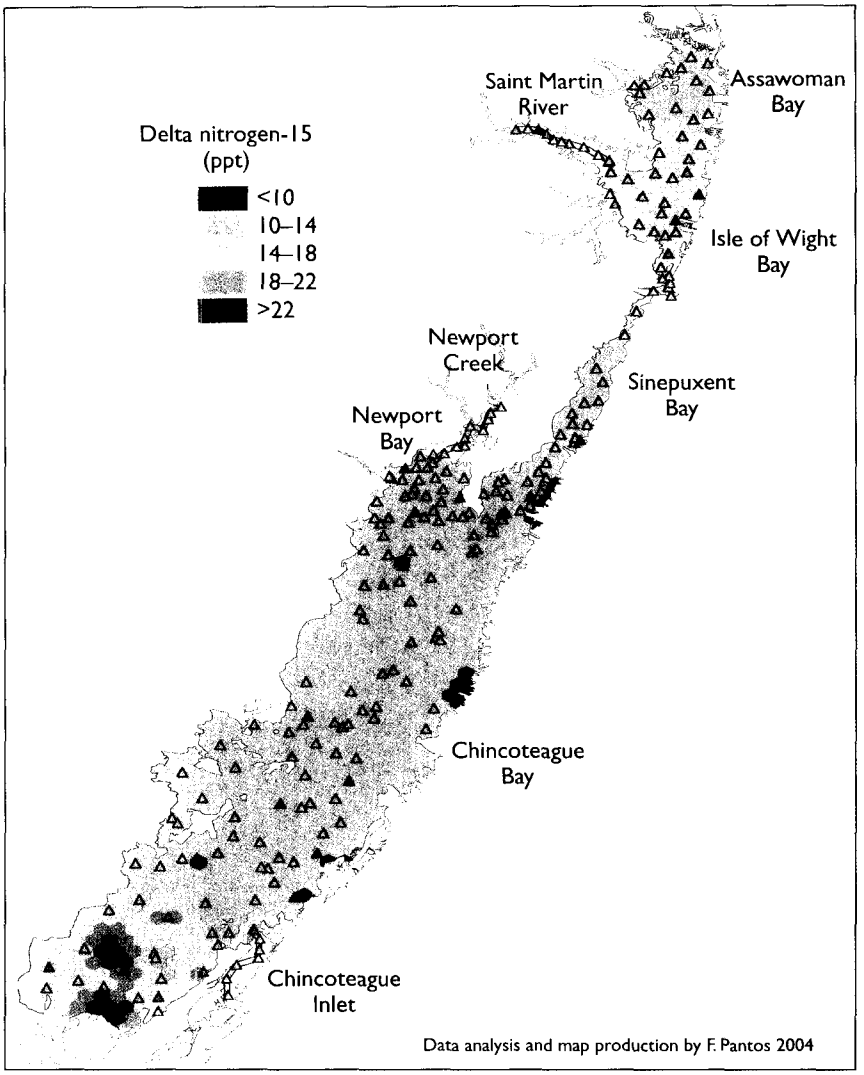
In June 2004, a field-sampling program was conducted to measure the 6 indicators at approximately 250 sites in the Maryland Coastal Bays. Secchi depths were determined, and water samples were analyzed for dissolved oxygen, chlorophyll *a*, total phosphorus, and total nitrogen concentrations. Isotopic 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).



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

Maryland Coastal Bays Program

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).

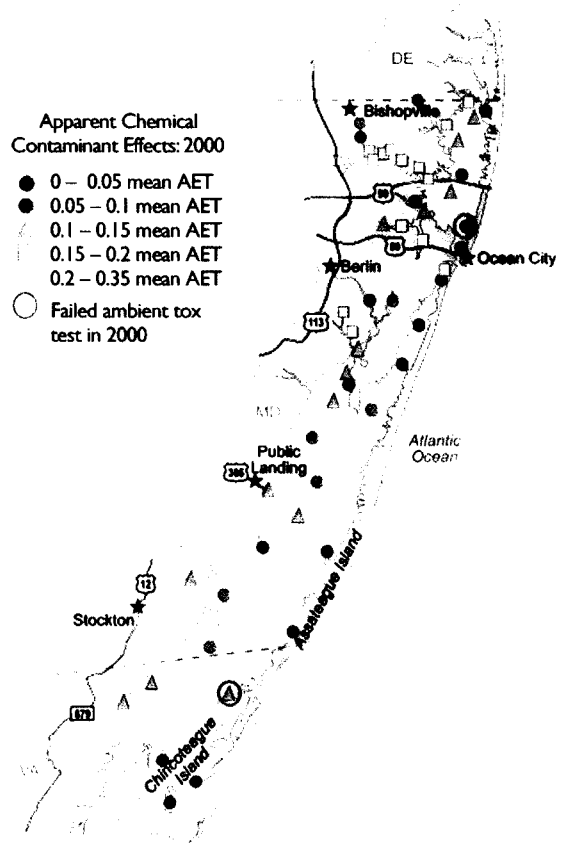


Figure 3-108. Map of mean Apparent Effects Threshold measurements for samples collected in 2000 by the Maryland Geological Survey (Wazniak et al., 2004).

Assateague Island National Seashore, Maryland (NPS).

Maryland Coastal Bays Program

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).

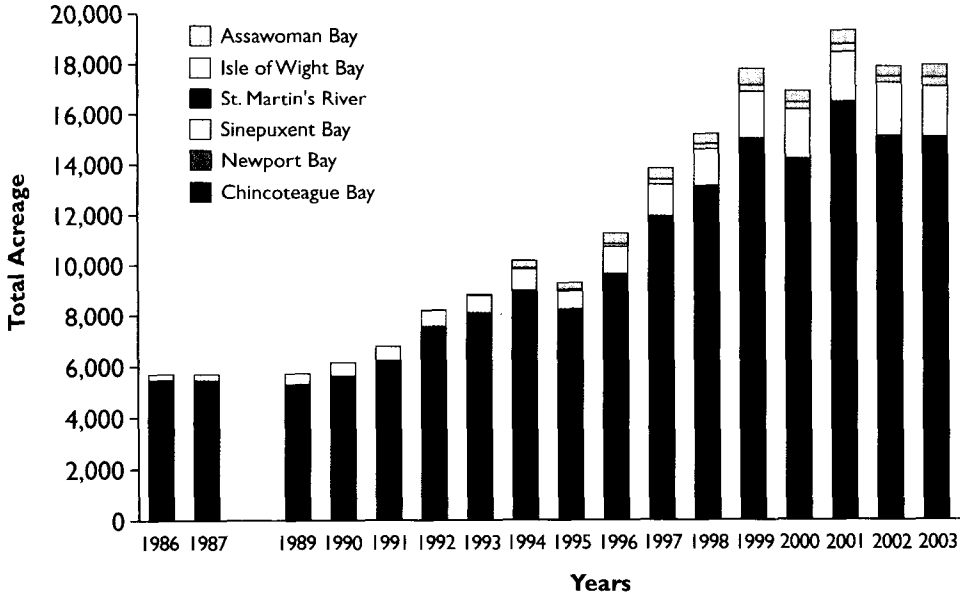


Figure 3-109. Seagrass abundance in the Maryland Coastal Bays (Wazniak and Hall, 2005).

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 10 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).

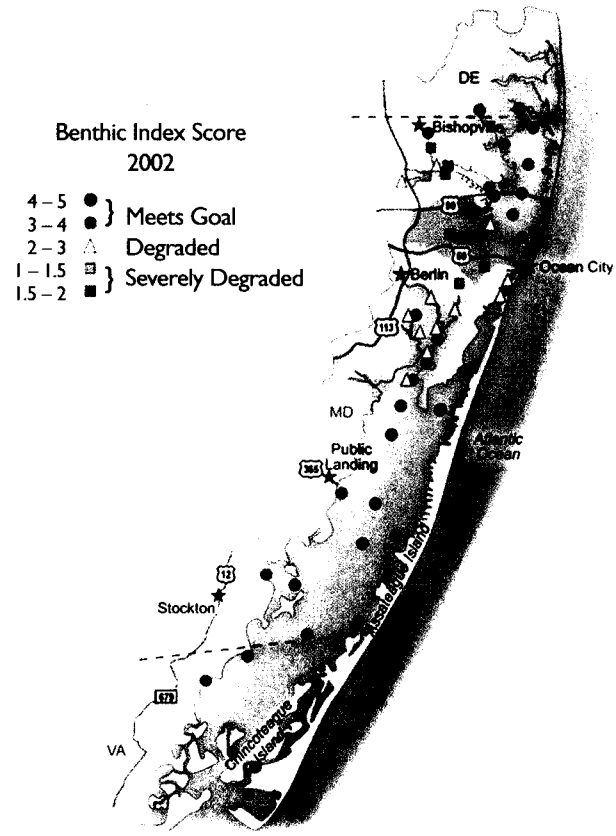


Figure 3-110. Map of 2002 MAIA benthic index results for the Maryland Coastal Bays (Wazniak et al., 2004).

Maryland Coastal Bays Program

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.

CHAPTER 4

SOUTHEAST COAST NATIONAL ESTUARY PROGRAM COASTAL CONDITION

CHAPTER 4

SOUTHEAST COAST NATIONAL ESTUARY PROGRAM COASTAL CONDITION

Background

The Southeast Coast region extends from southern Virginia to Florida and includes two NEP estuaries: the Albemarle-Pamlico Estuarine Complex in North Carolina and Virginia and the Indian River Lagoon in Florida (Figure 4-1). Both estuarine systems are characterized by shallow lagoons located behind extensive barrier island chains that are punctuated with one or more narrow inlets or channels to the ocean. The flat coastal plain, small tidal range, and barrier islands that typify the Southeast Coast combine to minimize the influence of tides on water circulation in the region's two NEP estuaries; therefore, circulation within these systems is driven by different factors than in the river-dominated or tidally dominated estuaries found in other regions of the United States (NOAA, 1985).

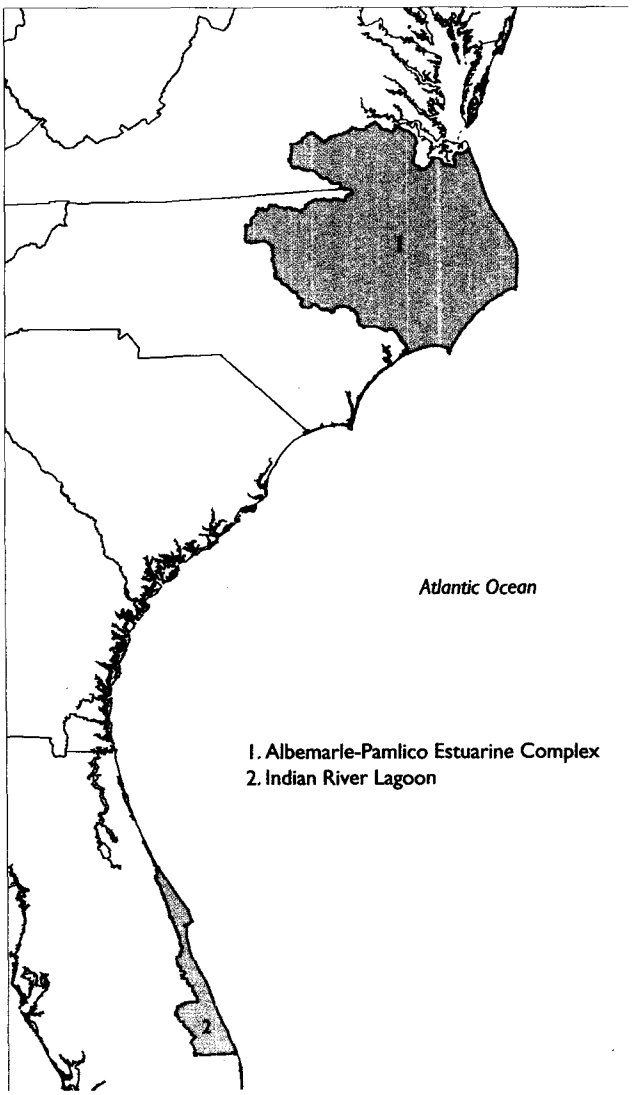


Figure 4-1. The Southeast Coast region is home to two NEP estuaries.

Due to the vast forested acreage that dominates the Southeast region's coastal drainage areas, freshwater inflow to the NEP estuaries typically brings only small to moderate amounts of sediment; however, sediment loading to these estuaries can be higher in areas where land use is dominated by intensive agriculture and where soils that are subject to erosion are farmed. Precipitation patterns also influence freshwater input from rivers flowing into these estuaries. The region's annual average precipitation of about 40 inches decreases slightly from the north to the central portion of the region, and then increases to up to 64 inches in southern Florida. The Southeast Coast NEP estuaries contribute about 35% of all freshwater discharges to East Coast waters (NOAA, 1985).

Population Pressures

The population of the 41 NOAA-designated coastal counties coincident with the NEP study areas of the Southeast Coast region increased by more than 131.4% during the past 40 years, from 1.4 million people in 1960 to 3.2 million people in 2000 (Figure 4-2) (U.S. Census Bureau, 1991; 2001). This increase resulted in a population density of 168 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 308 persons/mi^2 for the Indian River Lagoon to 125 persons/mi^2 for the

Albemarle-Pamlico Estuarine Complex (U.S. Census Bureau, 2001). Development and population pressures are especially strong surrounding these NEP estuaries, which are centers of commercial fishing and recreational activity for the coastal communities of the Southeast Coast region.

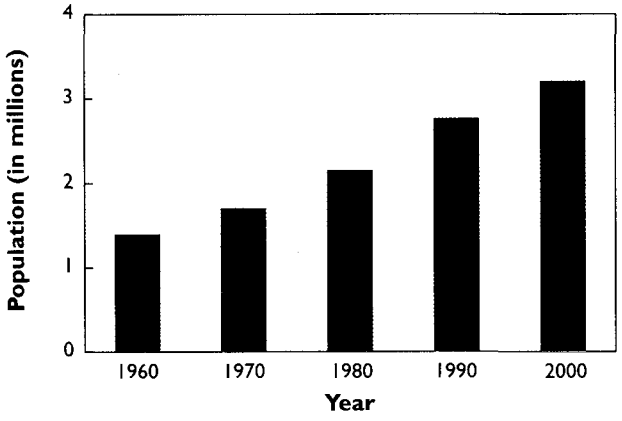


Figure 4-2. Population of the 41 NOAA-designated coastal counties of the Southeast Coast NEP study areas, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Southeast Coast Region

Based on data collected by the NCA, the overall condition of the collective NEP estuaries of the Southeast Coast region is rated good to fair (Figure 4-3). Due to the rotating basin-monitoring schedule for Florida, the NCA sampled only the northern portion of the Indian River Lagoon for this assessment (approximately 230 mi^2). Because of their size, the estuaries of the Albemarle-Pamlico Estuarine Complex generally drive the coastal condition estimates for the Southeast Coast NEP estuarine area. The ratings for the NCA indices of estuarine condition (water quality, sediment quality, benthic, and fish tissue contaminants) for the Southeast Coast NEP estuaries ranged from good to fair, and neither estuary received a poor rating for any of the component indicators. Figure 4-4 shows the percentage of the Southeast Coast NEP estuarine area rated good, fair, poor, or missing for each parameter considered. 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.

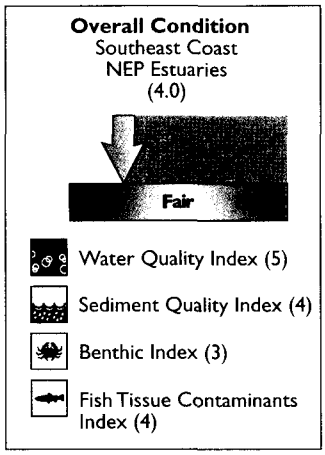


Figure 4-3. The overall condition of the Southeast Coast NEP estuarine area is good to fair (U.S. EPA/NCA).

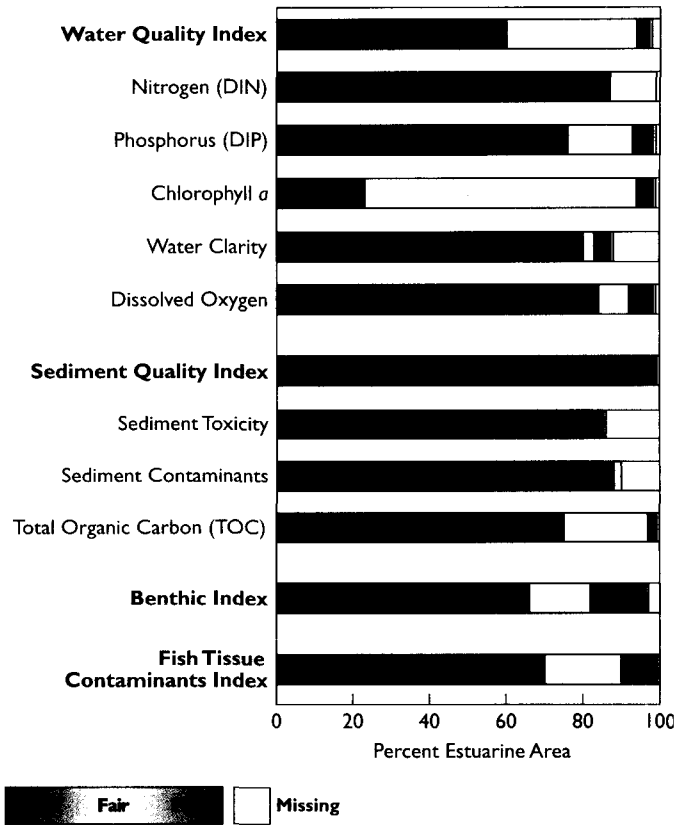


Figure 4-4. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Southeast Coast region (U.S. EPA/NCA).

Water Quality Index

The water quality index for the collective NEP estuaries of the Southeast Coast region is rated good (Figure 4-5). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Thirty-five percent of the region was rated fair for this index, indicating that some vigilance may be required regarding DIP and chlorophyll *a* concentrations.

Dissolved Nitrogen and Phosphorus | The Southeast Coast region is rated good for DIN concentrations because 12% of the region's NEP estuarine area was rated fair for this component indicator and none of the area was rated poor. The Southeast Coast region is also rated good for DIP concentrations, with 17% of the region's NEP estuarine area rated fair and 6% of the area rated poor. NCA data on DIN and DIP concentrations were unavailable for 1% of the Southeast Coast NEP estuarine area.

Chlorophyll a | The Southeast Coast region is rated fair for chlorophyll *a* concentrations because 71% of the region's NEP estuarine area was rated fair for this component indicator and 5% of the area was rated poor. NCA data on chlorophyll *a* concentrations were unavailable for 1% of the Southeast Coast NEP estuarine area.

Water Clarity | Water clarity in the collective NEP estuaries of the Southeast Coast region is rated good. Three percent of the region's NEP estuarine area was rated fair for this component indicator, and only 6% of the area was rated poor.

Dissolved Oxygen | The Southeast Coast region is rated fair for dissolved oxygen concentrations because 8% of the region's NEP estuarine area was rated fair for this component indicator and 7% of the area was rated poor.

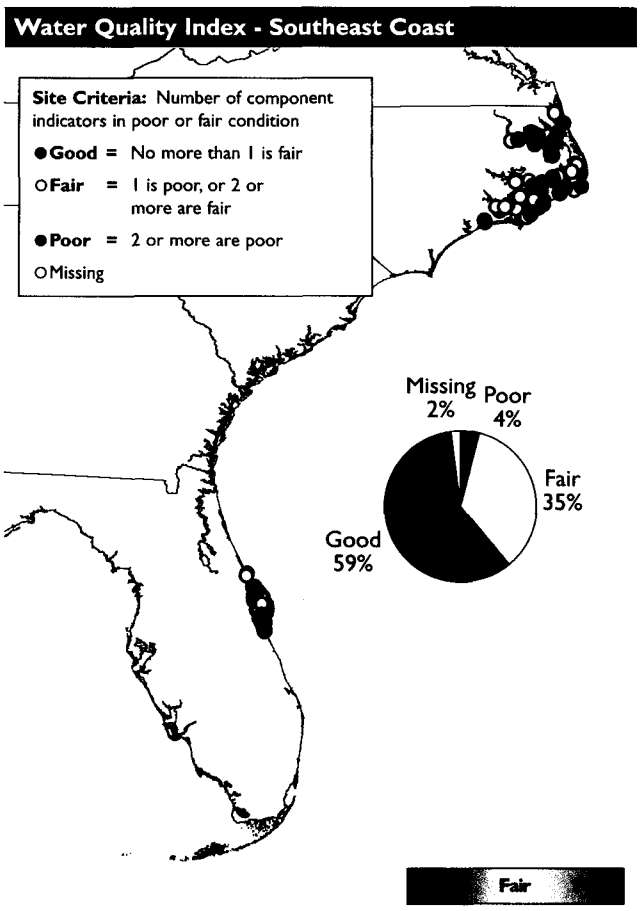


Figure 4-5. Water quality index data for the Southeast Coast NEP estuarine area, 2000–2002 (U.S. EPA/NCA).

Sediment Quality Index

The sediment quality index for the Southeast Coast region is rated good to fair because 6% of the region's NEP estuarine area was rated poor for sediment quality condition (Figure 4-6). This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC.

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.**

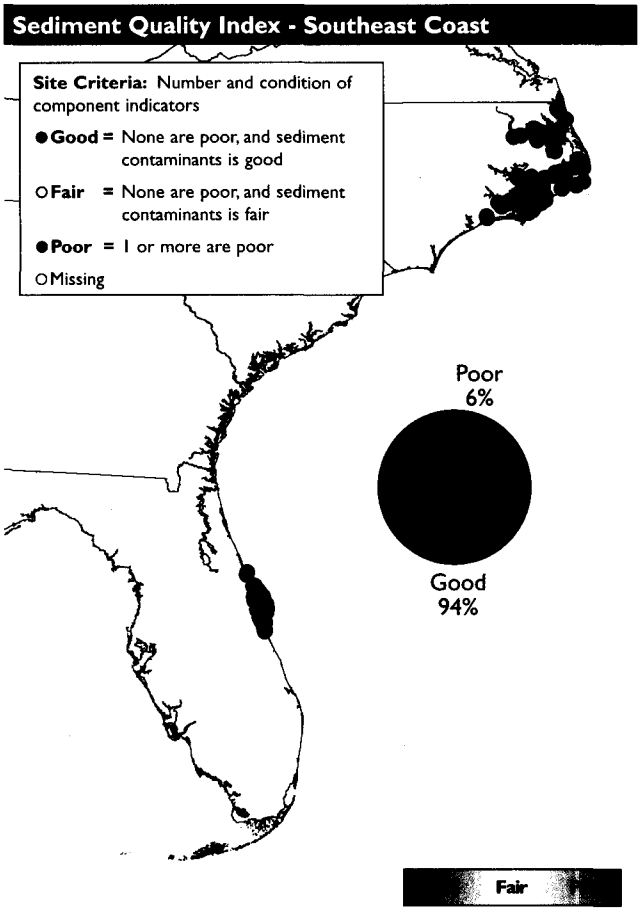


Figure 4-6. Sediment quality index data for the Southeast Coast NEP estuarine area, 2000–2002 (U.S. EPA/NCA).

TOC concentrations were the only sediment quality component indicator measured in the Indian River Lagoon; therefore, the sediment quality index for the Southeast Coast NEP estuarine area is not based on a full assessment of sediment toxicity or sediment contaminant concentrations in all of the region's NEP estuaries.

Sediment Toxicity | The Southeast Coast region is rated good for sediment toxicity; however, this assessment is based solely on data collected for the Albemarle-Pamlico Estuarine Complex because NCA data on sediment toxicity were unavailable for the Indian River Lagoon. Eighty-three percent of the Southeast Coast NEP estuarine area was rated good for sediment toxicity, and only 3% of the area was rated poor, with poor samples collected at one site in Currituck Sound and one site in Pamlico Sound. NCA data on sediment toxicity were unavailable for 14% of the Southeast Coast NEP estuarine area.

Sediment Contaminants | The Southeast Coast region is rated good for sediment contaminant concentrations; however, this assessment is based solely on data collected for the Albemarle-Pamlico Estuarine Complex because NCA data on sediment contaminants were unavailable for the Indian River Lagoon. Based on these parameters, 88% of the Southeast Coast NEP estuarine area was rated good for sediment contaminant concentrations, 2% of the area was rated fair, and none of the area was rated poor. NCA data on sediment contaminant concentrations were unavailable for 10% of the Southeast Coast NEP estuarine area.

Total Organic Carbon | The Southeast Coast region is rated good for TOC concentrations. TOC concentrations were rated good in 75% of the region's NEP estuarine area, fair in 22% of the area, and poor in only 3% of the area, with the sites rated poor located in North Carolina's Little Alligator River, Slocum Creek, and Neuse River.

Benthic Index

The benthic index for the collective NEP estuaries of the Southeast Coast region is rated fair. The Southeast Coast Benthic Index, developed by Van Dolah et al. (1999), integrates measures of species diversity and populations of indicator species to distinguish between degraded (poor) and reference benthic communities. Fifteen percent of the Southeast Coast NEP estuarine area was rated poor for benthic condition, 66% was rated good, and 16% was rated fair (Figure 4-7).

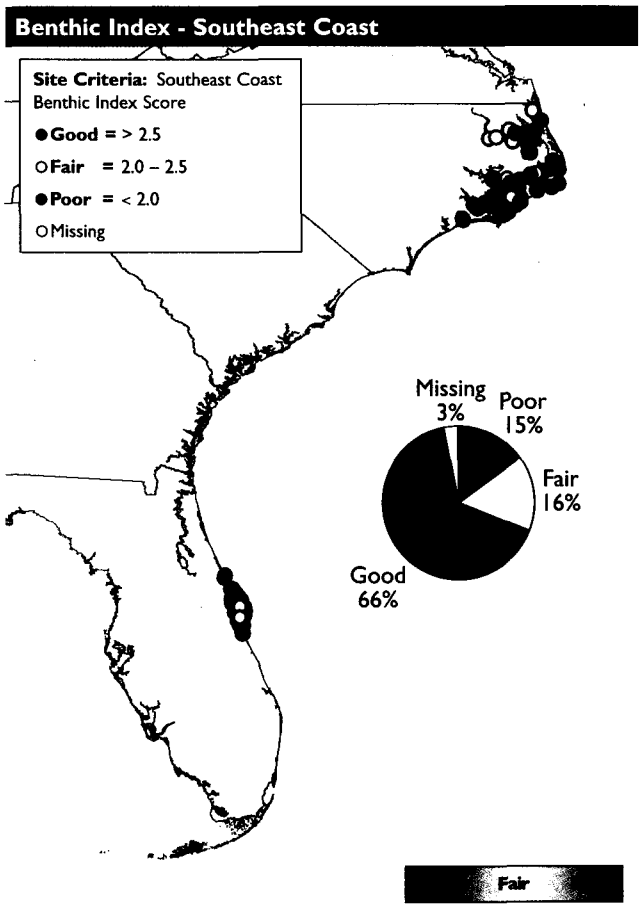


Figure 4-7. Benthic index data for the Southeast Coast NEP estuarine area, 2000–2002 (U.S. EPA/NCA).

Although only 15% of the Southeast Coast NEP estuarine area had degraded benthic resources, 80% of the sampling sites representing this degraded area were geographically correlated with some measure of poor water or sediment quality (Figure 4-8). Poor benthic condition co-occurred with equal frequency for degraded sediment quality and water quality (60% of the sites with poor benthic condition).

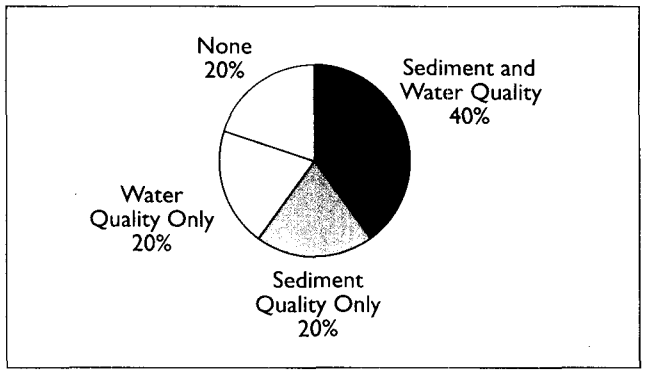


Figure 4-8. Percent of sampling sites in the Southeast Coast NEP estuaries where poor benthic condition overlaps with other indices rated poor (U.S. EPA/NCA).

Fish Tissue Contaminants Index

Fish tissue contaminants data for the Southeast Coast NEP estuarine area were collected for the Albemarle-Pamlico Estuarine Complex; however, data were not collected for the Indian River Lagoon. Figure 4-9 shows that only 10% of all stations sampled where fish were caught exceeded the EPA Advisory Guidance values used in this assessment, resulting in a rating of good to fair for the region's fish tissue contaminants index (70% of the stations were rated good). These contamination estimates are an approximation because they are based on the analysis of whole-body samples, rather than fillets only. For mercury, which has a high affinity for muscle tissue, these data may be an underestimation; however, for the chemical contaminants that concentrate in fish organs and fatty tissues, the data may be an overestimation. Although the fish sampled may not represent the same species sought by commercial fishermen and consumers, the analysis does represent the potential for accumulation of contamination in these estuarine environments.

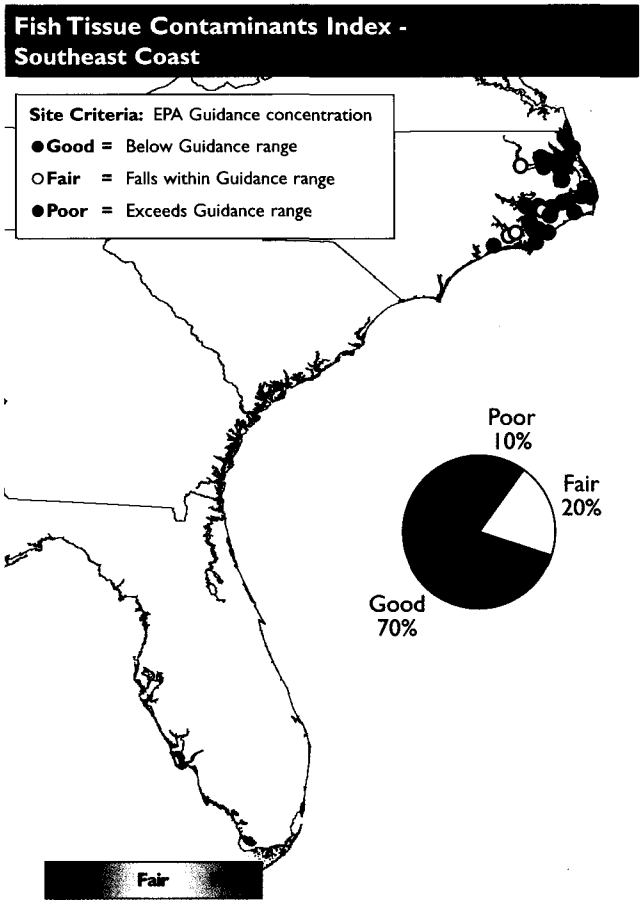


Figure 4-9. Fish tissue contaminants index data for the Southeast Coast NEP estuarine area, 2000–2002 (U.S. EPA/NCA).

NEP Estuaries and the Condition of the Southeast Coast Region

The purpose of the NEP is to identify, restore, and protect the nationally significant estuaries of the United States. The Southeast Coast region supports diverse agricultural activities such as large-scale agriculture production and aquaculture and is home to two NEP estuaries: the Albemarle-Pamlico Estuarine Complex and the Indian River Lagoon. The Albemarle-Pamlico Estuarine Complex NEP study area contains large tracts of forested and undeveloped land, including 11 National Wildlife Refuges (e.g., Great Dismal Swamp, Back Bay, Mackay Island, Currituck, Roanoke River, Alligator River, Pocosin Lakes, Pea Island, Mattamuskeet, Swan Quarter, and Cedar Islands). The Complex's watershed also contains the Cape Lookout and Cape Hatteras national seashores; the Croatan National Forest; and many state-owned parks, forests, and research reserves (Martin et al., 1996). In addition, several U.S. Department of Defense (DoD) lands are located in this watershed. Similar to the Albemarle-Pamlico Estuarine Complex, portions of the Indian River Lagoon NEP study area have escaped much of the urbanization that has overrun other portions of Florida's coastal areas, and the estuarine area of the Lagoon includes the Merritt Island National Wildlife Refuge, Canaveral National Seashore, Hobe Sound National Wildlife Refuge, Pelican Island National Wildlife Refuge, and several state parks. The citrus industry is a dominant agricultural land use within the Indian River Lagoon study area.

Because the areas surrounding the Southeast Coast NEP estuaries have not been developed as major metropolitan urban centers, a key question when assessing these two estuaries is whether their condition accurately reflects the condition of all Southeast Coast estuaries (both NEP and non-NEP). A comparison of NCA data from the two Southeast Coast NEP estuaries and all Southeast Coast estuaries reveals that the two groups of estuaries have similar overall condition ratings, as well as similar ratings for most of the NCA estuarine indices.

Based on the NCA survey results, both the collective Southeast Coast NEP estuaries and all Southeast Coast estuaries combined are rated good to fair for overall condition, with both groups receiving an overall condition score of 4.0 (Figure 4-10). A comparison of NCA data for both groups of estuaries shows that the collective Southeast Coast NEP estuaries are rated good for the water quality index, good to fair for the sediment quality index, fair for the benthic index, and good to fair for the fish tissue contaminants index. The group of all Southeast Coast estuaries combined are rated good to fair for the water quality and sediment quality indices, fair for the benthic index, and good for the fish tissues contaminants index. With respect to the water quality and sediment quality component indicators, both groups of estuaries are rated good for DIN concentrations and all three sediment quality component indicators (sediment toxicity, sediment contaminants, and sediment TOC) and fair for chlorophyll *a* concentrations. The collective Southeast Coast NEP estuaries are rated good for DIP concentrations and water clarity and fair for dissolved oxygen concentrations, whereas the group of all Southeast Coast estuaries

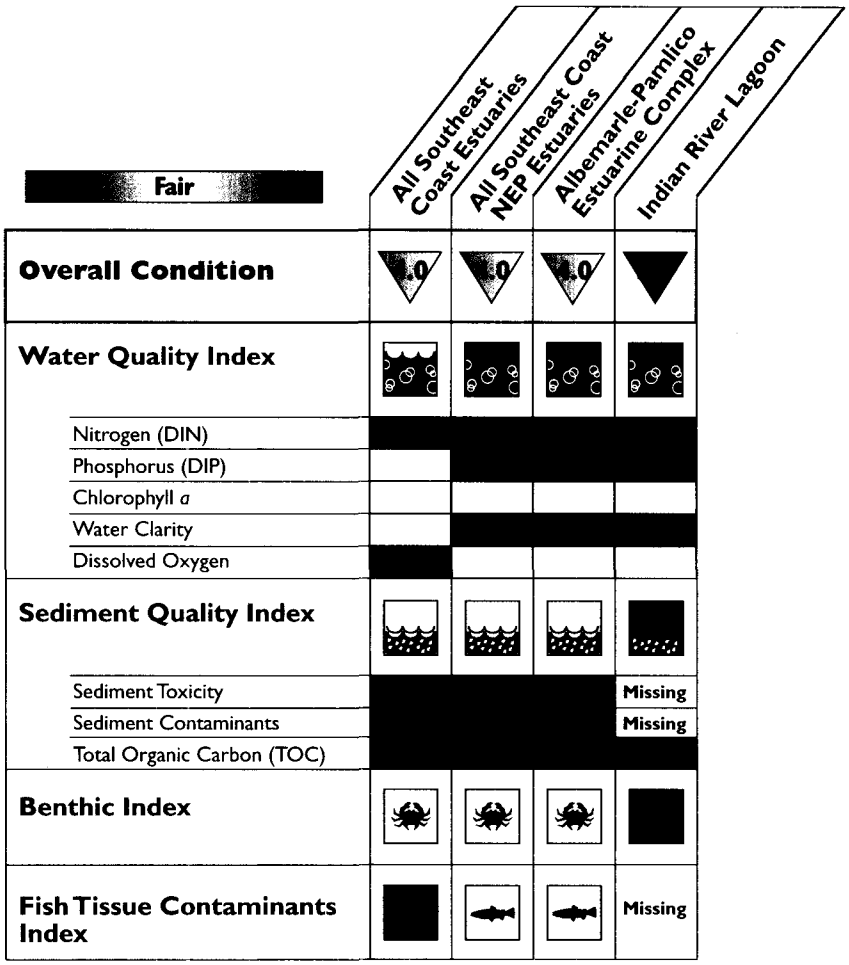


Figure 4-10. Comparison of NCA results for Southeast Coast NEP estuaries and all Southeast Coast estuaries (U.S. EPA/NCA).

combined are rated fair for DIP concentrations and water clarity and good for dissolved oxygen concentrations.

With respect to the two Southeast Coast NEP estuaries, both estuaries received higher or comparable overall condition scores to the overall condition score for the collective Southeast Coast NEP estuaries (4.0, rated good to fair). The Indian River Lagoon (5.0) is rated good for overall condition, whereas the overall condition rating for the Albemarle-Pamlico Estuarine Complex (4.0) is good to fair. It should be noted, however, that the NCA survey data for the Indian River Lagoon are incomplete because NCA data were not available to assess the fish tissue contaminants index or the sediment toxicity and sediment contaminants component indicators for this estuary. In addition, only the northern portion of the Indian River Lagoon was surveyed by the NCA in 2000 and 2001. Much of this area is included within the federally protected National Aeronautics and Space Administration (NASA)/Kennedy Space Center/Merritt Island Wildlife Refuge complex and the Canaveral National Seashore and remains relatively undeveloped. In contrast, much of the southern portion of the Indian River Lagoon (which was not surveyed by NCA) is suburban or urban in character; includes extensive agricultural areas; and continues to experience rapid development. An assessment that includes all indices and component indicators and that assesses both the northern and southern portions of the Lagoon may have resulted in a different overall condition rating for the Indian River Lagoon.

The NCA survey data show that the two NEP estuaries of the Southeast Coast are both rated good for the water quality index and that the ratings for all five of

the water quality component indicators are comparable between the two estuaries. For both the Albemarle-Pamlico Estuarine Complex and the Indian River Lagoon, DIN and DIP concentrations and water clarity are rated good, and chlorophyll *a* and dissolved oxygen concentrations are rated fair.

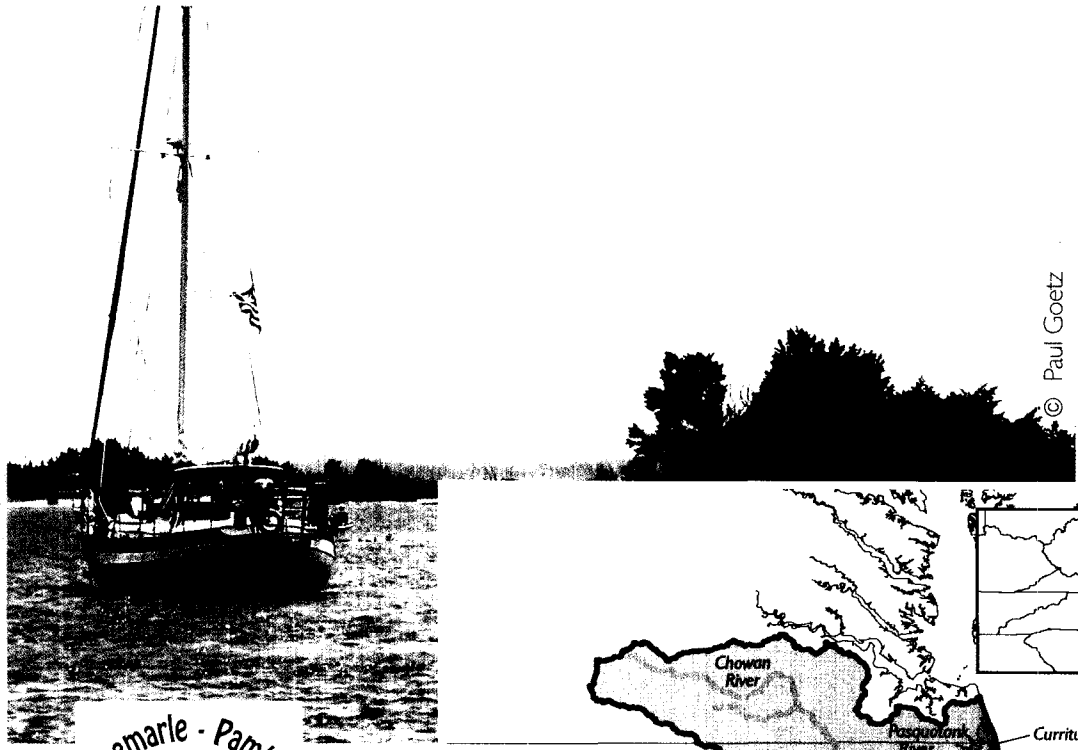
The sediment quality index ratings differ slightly between the Albemarle-Pamlico Estuarine Complex and the Indian River Lagoon. The sediment quality index for the Albemarle-Pamlico Estuarine Complex is rated good to fair, with all three component indicators (sediment toxicity, sediment contaminants, and sediment TOC) also rated good. The sediment quality index for the Indian River Lagoon is rated good; however, this rating is based only on measurements of one component indicator (sediment TOC, rated good) collected in the northern part of the Lagoon.

The benthic index, which denotes the health of an estuary's benthic community, is rated fair for the Albemarle-Pamlico Estuarine Complex and good for the Indian River Lagoon.

The fish tissue contaminants index is rated good to fair for the Albemarle-Pamlico Estuarine Complex. The NCA did not collect data on fish tissue contaminant concentrations for the Indian River Lagoon; therefore, a fish tissues contaminants index for this estuary was not developed for this report.

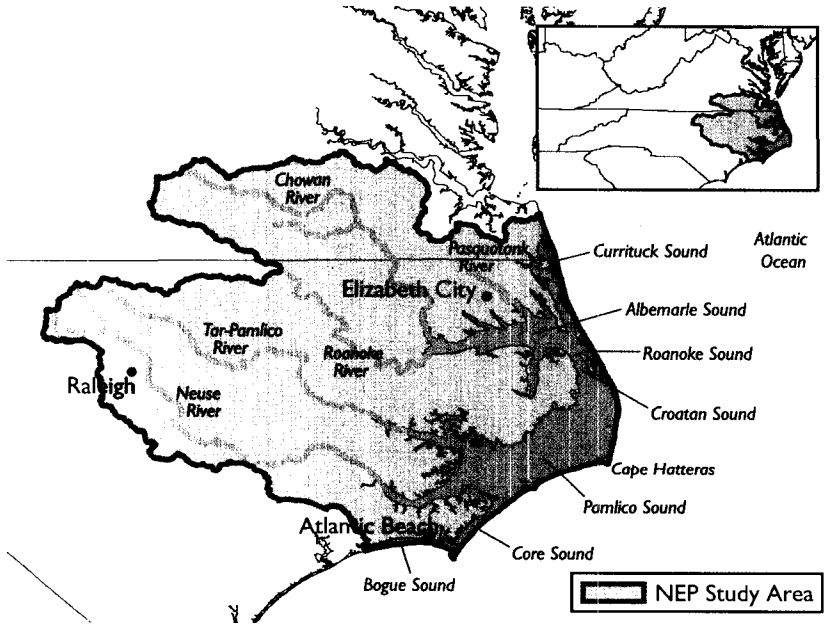
Nationally, the overall condition score (4.0) for the collective NEP estuaries of the Southeast Coast region ranked highest when compared to the Gulf Coast (2.75), West Coast (2.5), Northeast Coast (1.5), and Puerto Rico (1.5) NEP regions. Population pressures, measured as population density (number of persons/mi^2), did not correlate well with the overall condition ratings for the Southeast Coast NEP estuaries. For example, although the Albemarle-Pamlico Estuarine Complex has a lower calculated population density of 125 persons/mi^2, this estuary is rated good to fair for overall condition, with an overall condition score of 4.0. In contrast, the Indian River Lagoon, with a higher population density (305 persons/mi^2), is rated good for overall condition, with a overall condition score of 5.0; however, inclusion of the missing data for two of the sediment quality component indicators (sediment toxicity and sediment contaminants) and for the fish tissue contaminants index may have resulted in a lower overall condition score for the Indian River Lagoon.

Albemarle-Pamlico National Estuary Program



Albemarle - Pamlico
National Estuary Program
North Carolina

www.apnep.org



Background

The Albemarle-Pamlico Estuarine Complex drains approximately 30,000 mi^2 of watershed and comprises the largest lagoonal estuarine system in the United States. This NEP has a 23,000-mi^2 study area that extends south from Prince George County, VA, to Carteret County, NC, and includes 7 sounds (Albemarle, Bogue, Core, Croatan, Currituck, Pamlico, and Roanoke) (APNEP, 2006).

Freshwater inputs to this system are provided by five major rivers — the Pasquotank, Chowan, and Roanoke rivers that flow into Albemarle Sound and the Tar-Pamlico and Neuse rivers that flow into Pamlico Sound. This region features a variety of habitat types, including significant pocosins (southeastern shrub bogs), pine savannahs, hardwood swamp forests, bald cypress swamps, salt marshes, brackish marshes, freshwater marshes, and beds of SAV (Martin et al., 1996). On the eastern side of the Albemarle-Pamlico Estuarine Complex, a chain of islands forms a barrier with the Atlantic Ocean. The Complex is uniquely characterized by random wind-driven tides, which result in less-predictable variations in water circulation and salinity patterns (Focazio, 2006a). Economically, this estuarine

system represents the Southeast region's key resource base for commercial fishing, tourism, recreation, and resort development. Economic benefits are also derived from the use of the area's natural resources for mining, forestry, and agriculture (APNEP, 2006).

The Albemarle-Pamlico National Estuary Program (APNEP) was among the first NEPs established by EPA in 1987. The central focus of the APNEP is to work closely with citizens' groups, businesses, researchers, local governments, and state and federal agencies to implement the key objectives of the APNEP's *Comprehensive Conservation and Management Plan* (APNEP, 1994) through the APNEP's Advisory Board and committees. Recent APNEP projects have illustrated new methods of environmental protection and restoration, including conservation easements, stormwater-runoff control systems, greenroofs, composting techniques that turn agriculture and crab-processing waste into fertile soil, and the development of new fishing gears that reduce the unintended capture of non-target species such as sea turtles. Other APNEP projects include opening historic spawning areas for shad and herring that had previously been blocked by dams and roads and replenishing scallop beds that were decimated by a red tide event in 1987 (APNEP, 2006).

Environmental Concerns

The issues of environmental concern for the APNEP are water quality, habitat quality, and fishery resources. Impairment of waters in the Albemarle-Pamlico Estuarine Complex can primarily be attributed to non-point sources of pollution, of which agricultural and urban runoff are the most prevalent. A smaller, but still significant amount of water quality impairment in the system can be attributed to point-source discharges along the rivers flowing into the Complex. Ecological stressors, including nutrient pollution, phytoplankton growth, exotic species growth, and other factors, place viable habitat areas in the region at risk, and the extent of wetland habitat in the region is considerably diminished relative to historical distributions due to changes in land-use patterns. Downward trends in commercial landings are indicative of declining stocks of local populations of finfish and shellfish species, including Atlantic croaker, Atlantic sturgeon, Eastern oyster, red drum, striped bass, summer flounder, weakfish, and herring. The overall CPUE from these estuaries is also declining, despite improvements in fishing gear and methods. In general, overfishing and habitat loss are believed to be major causes of the declines in catch; however, a variety of other factors, including habitat alteration, weather events and seasonal cycles, and water quality degradation, may also play a role (APNEP, 2006).

Population Pressures

The population of the 35 NOAA-designated coastal counties (25 coastal counties in North Carolina and 10 in Virginia) coincident with the APNEP study area increased by more than 71.1% during a 40-year period, from 1.1 million people in 1960 to 1.8 million people in 2000 (Figure 4-11) (U.S. Census Bureau, 1991; 2001). This rate of growth for the APNEP study area is low compared to the population growth rate of 131.4% for the collective NEP-coincident coastal counties of the Southeast Coast region. In 2000, the population density of this study area's 35 coastal counties was 125 persons/mi^2, slightly lower than the population density of 168 persons/mi^2 for the collective NEP-coincident coastal counties of the Southeast Coast region (U.S. Census Bureau, 2001). Population pressures for the APNEP study area may be slightly lower than for other NEPs, in part because a large amount of the state and federal land surrounding this estuary is designated for protection as national seashore, wildlife areas, or forests. As a result, development is concentrated in the remaining non-federal or non-state areas.

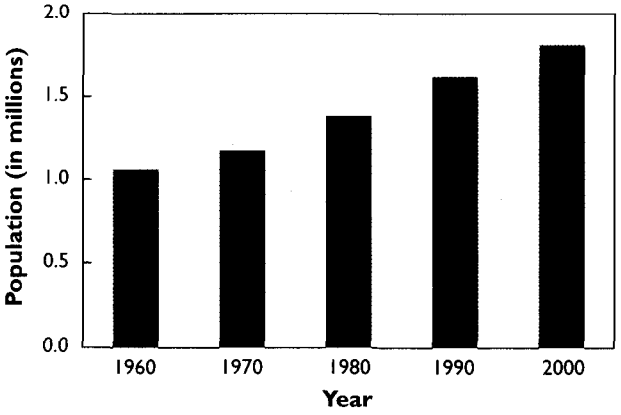


Figure 4-11. Population of NOAA-designated coastal counties of the APNEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

Albemarle-Pamlico National Estuary Program

NCA Indices of Estuarine Condition—Albemarle-Pamlico Estuarine Complex

The overall condition of the Albemarle-Pamlico Estuarine Complex is rated good to fair based on the four indices of estuarine condition used by the NCA (Figure 4-12). The water quality index for the Complex is rated good, the sediment quality and fish tissue contaminants indices are rated good to fair, and the benthic index is rated fair. Figure 4-13 shows the percentage of estuarine area rated good, fair, poor, or missing for each parameter considered. This assessment is based on data collected by EMAP from 66 NCA sites sampled in the APNEP 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.

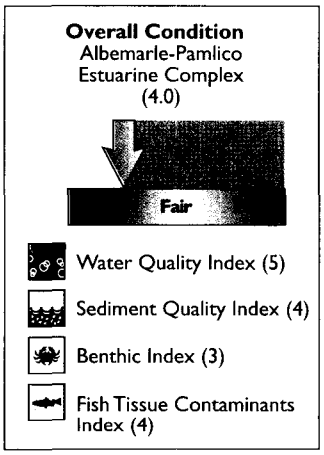


Figure 4-12. The overall condition of the APNEP estuarine area is good to fair (U.S. EPA/NCA).

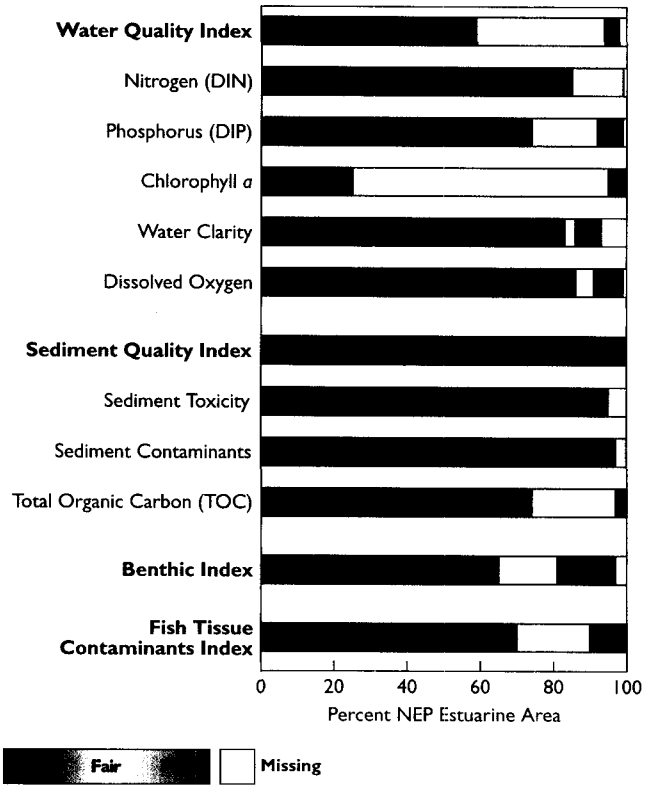
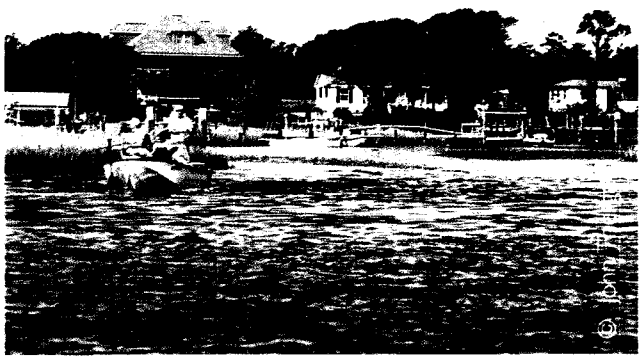


Figure 4-13. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Albemarle-Pamlico Estuarine Complex (U.S. EPA/NCA).



Water Quality Index

The water quality index for the Albemarle-Pamlico Estuarine Complex is rated good (Figure 4-14). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Only 4% of the Complex's estuarine area was rated poor for water quality; however, 35% was rated fair.

Dissolved Nitrogen and Phosphorus | The Albemarle-Pamlico Estuarine Complex is rated good for DIN and DIP concentrations. Eighty-five percent of the estuarine area was rated good for DIN concentrations, 14% of the area was rated fair, and none of the area was rated poor. Similarly, 74% of the estuarine area was rated good for DIP concentrations, 18% of the area was rated fair, and 7% of the area was rated poor.

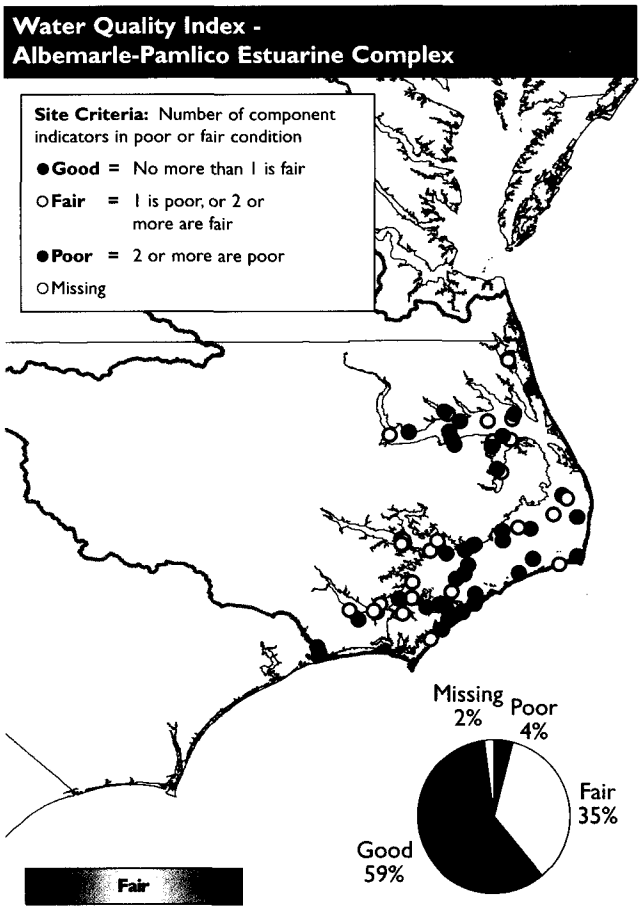


Figure 4-14. Water quality index data for the Albemarle-Pamlico Estuarine Complex, 2000–2001 (U.S. EPA/NCA).

The measured DIP values used in this assessment are an approximation because these values were based on filtered, acid-preserved phosphorus, which provides a measure of total phosphorus, not of DIP only. Literature suggests that DIP represents about 97% of the total phosphorus measurement for estuaries of the Southeast Coast region (Van Dolah et al., 2002).

Chlorophyll a | The Albemarle-Pamlico Estuarine Complex is rated fair for chlorophyll *a* concentrations, with 25% of the estuarine area rated good for this component indicator, 70% of the area rated fair, and 5% of the area rated poor.

Water Clarity | The Albemarle-Pamlico Estuarine Complex 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. Eighty-three percent of the estuarine area was rated good for water clarity, 3% of the area was rated fair, and only 7% of the area was rated poor. NCA data on water clarity were unavailable for 7% of the APNEP estuarine area.

Dissolved Oxygen | The Albemarle-Pamlico Estuarine Complex is rated fair for dissolved oxygen concentrations. Although 86% of the estuarine area was rated good for this component indicator, 8% was rated poor, and 5% was rated fair.

Sediment Quality Index

The sediment quality index for the Albemarle-Pamlico Estuarine Complex is rated good to fair, with 7% of the estuarine area rated poor and 93% of the area rated good for sediment quality condition (Figure 4-15). This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC.

Sediment Toxicity | The Albemarle-Pamlico Estuarine Complex is rated good for sediment toxicity. Ninety-two percent of the estuarine area was rated good for this component indicator, and only 3% of the area was rated poor. NCA data on sediment toxicity were unavailable for 5% of the APNEP estuarine area.

Sediment Contaminants | The Albemarle-Pamlico Estuarine Complex is rated good for sediment contaminant concentrations, with 97% of the estuarine area rated good, 3% of the area rated fair, and none of the area rated poor.

Total Organic Carbon | The Albemarle-Pamlico Estuarine Complex is rated good for sediment TOC. Twenty-three percent of the estuarine area was rated fair for this component indicator, 74% of the area was rated good, and the remaining 3% of the area was rated poor.

Albemarle-Pamlico National Estuary Program

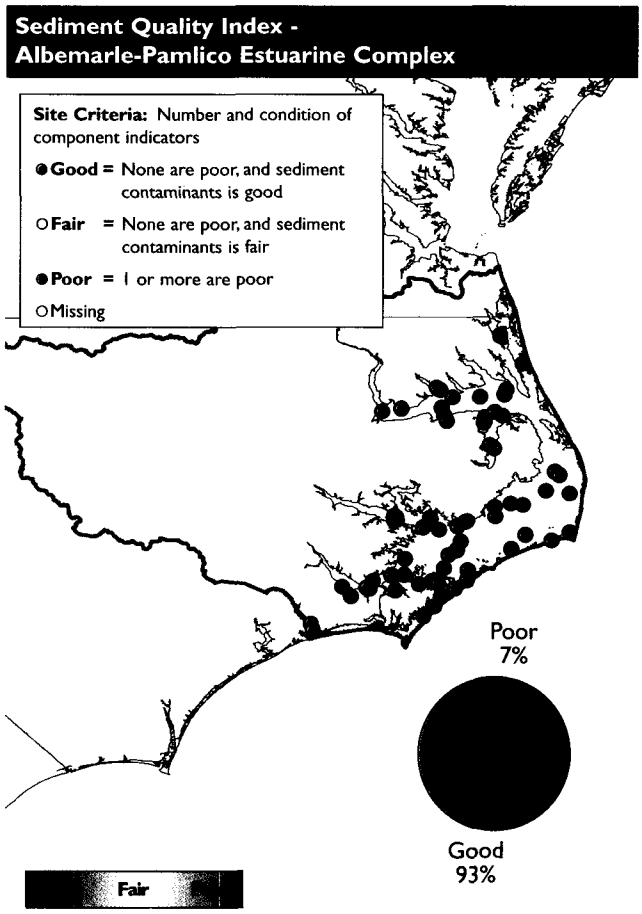


Figure 4-15. Sediment quality index data for the Albemarle-Pamlico Estuarine Complex, 2000–2001 (U.S. EPA/NCA).

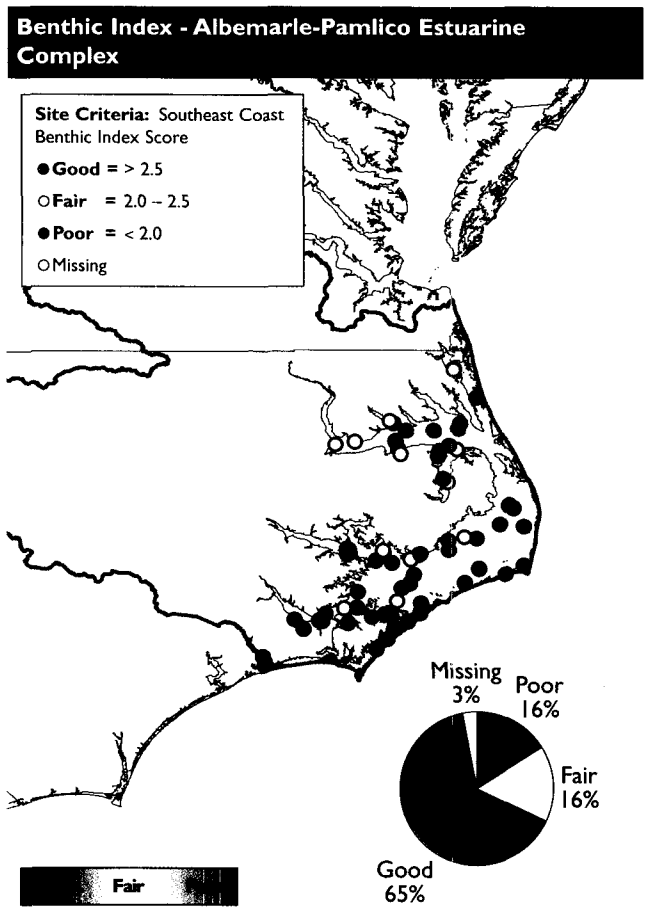


Figure 4-16. Benthic index data for the Albemarle-Pamlico Estuarine Complex, 2000–2001 (U.S. EPA/NCA).

Benthic Index

As measured by the Southeast Coast Benthic Index, benthic condition for the Albemarle-Pamlico Estuarine Complex is rated fair. Sixty-five percent of the estuarine area was rated good for benthic condition, 16% of the area was rated fair, and 16% of the area was rated poor (Figure 4-16), with sites rated poor located in portions of the Neuse River and Albemarle Sound.

Although only 16% of the estuarine area exhibited degraded benthic condition, 92% of the sampling sites representing this degraded area were also associated with some measure of adverse water quality or sediment quality (Figure 4-17). Poor benthic condition co-occurred most frequently with degraded sediment quality (75% of sites with poor benthic condition).

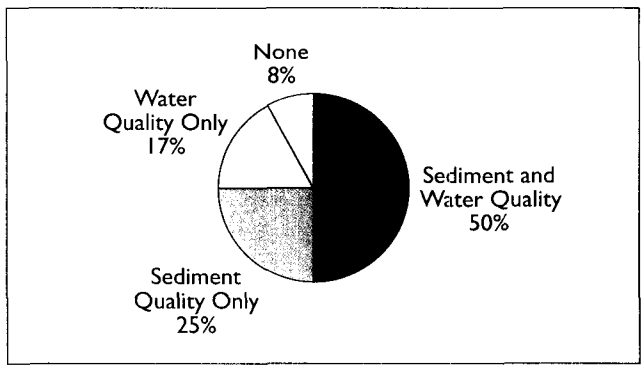


Figure 4-17. Percent of sampling sites in the Albemarle-Pamlico Estuarine Complex where poor benthic condition overlaps with other indices rated poor (U.S. EPA/NCA).

Fish Tissue Contaminants Index

The fish tissue contaminants index for the Albemarle-Pamlico Estuarine Complex is rated good to fair. Figure 4-18 shows that 10% of stations sampled where fish were caught exceeded risk-based EPA Advisory Guidance values using whole-fish contaminant concentrations and were rated poor, 20% of the stations were rated fair, and 70% of the stations were rated good. The only contaminants measured with elevated concentrations in fish tissues were total PAHs and total PCBs.

Humans can be exposed to toxic chemicals by eating contaminated fish (John Theilgard).

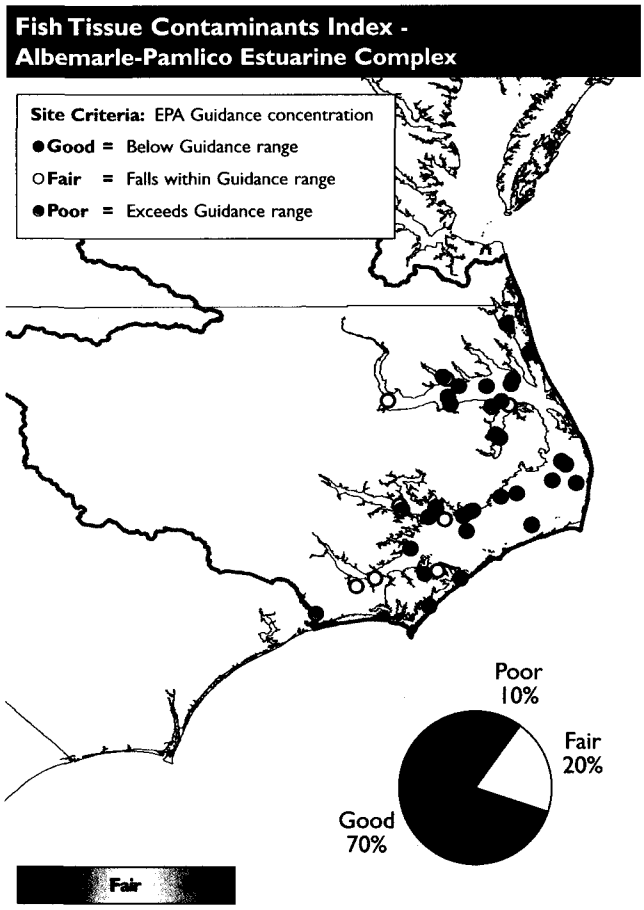


Figure 4-18. Fish tissue contaminants index data for the Albemarle-Pamlico Estuarine Complex, 2000–2001 (U.S. EPA/NCA).

Albemarle-Pamlico National Estuary Program

HIGHLIGHT

The FerryMon Project

The Albemarle-Pamlico Estuarine Complex provides critical foraging and nursery habitats for finfish and shellfish populations along the mid-Atlantic and southeastern coasts of the United States. Changes in water quality, precipitated by rapidly changing land uses in tributary watersheds and the increased frequency of tropical storms, have emphasized the need for predictive modeling to guide policy and management decisions regarding ecosystem response to those stressors. Compounding this need is a relative lack of monitoring data despite the importance of the habitat.

To address this problem, the University of North Carolina at Chapel Hill's Institute of Marine Sciences in Morehead City, NC; Duke University's Marine Lab in Beaufort, NC; and others joined ranks to found the FerryMon project. The goals of the project are the following:

- Determine ecosystem response to excess nutrient inputs
- Quantify the relationships between the land-use activities, hydrologic processes, and ecological response of receiving waters
- Assess and predict ecosystem response and the relationships between nutrient inputs, phytoplankton blooms, and associated water quality changes
- Provide information critical to long-term water quality management.

FerryMon, a ferry-based water quality monitoring project, utilizes North Carolina Department of Transportation (NCDOT) ferries that traverse the Neuse River and Pamlico Sound on three routes (see table below), following a regular schedule 365 days a year. The ferries are fitted with automated water quality monitoring equipment that measures temperature, conductivity, pH, dissolved oxygen, turbidity, and chlorophyll fluorescence in surface water. Subsequent measurement of nutrients, diagnostic algal pigments, colored dissolved organic material, and suspended solids is made possible by a refrigerated grab sampler, and

Information about the Ferry Routes in the FerryMon Project (FerryMon, 2006)

Ferry Route	1	2	3
Initiated	November 2000	February 2001	May 2001
Origination	Cherry Branch	Cedar Island	Swan Quarter
Destination	Minnesott Beach	Ocracoke Island	Ocracoke Island
Ferry Name	*Floyd Lupton*	*Carteret*	*Silver Lake*
Average Speed (knots)	8.0	10.7	10.4
Number of Crossings/Day	40	4	1
Number of Data Points/Day	300	200	200–300

logged data are downloaded at the laboratories via a cellular telephone modem. Use of the ferries to monitor water quality offers an economy of scale for the rapid construction of databases not provided by conventional monitoring platforms (Buzzelli et al., 2003).

Although the FerryMon project only monitors surface waters along the route of each ferry, the project's observing platform does have several advantages, including the following:

- High spatial and temporal resolution
- Repetition in time and space
- Capturing of base, diel, tidal, synoptic, seasonal, annual, and interannual scales
- Reliable data collection (i.e., data collection ceases only when wind velocity is greater than 40 knots or during times of dense fog)
- Professionally maintained, high-quality ferries (U.S. Coast Guard-certified to carry passengers for hire)
- Free use of ferries (i.e., low-cost analysis).

An initial return on the investment of retrofitting the ferries has been the availability of an intensive temporal and spatial water quality baseline data set for an area holding the distinction of being the largest estuary in the United States for which there is the least available data. The availability of data from the FerryMon project allows for rapid analysis of the Sound's status and trends, thus supporting the wisest and most sustainable use of the resource. Monitoring results and additional information about the project are available at http://www.ferrymon.org.

The *Carteret* collects water quality measurements along its route between Cedar Island and Ocracoke Island (NCDOT).

Albemarle-Pamlico National Estuary Program Indicators of Estuarine Condition

Although the APNEP does not currently have a set of formalized indicators to determine estuarine condition, the APNEP STAC is expected to complete the development of indicators in 2006. Currently, agencies that work in partnership with the APNEP use a group of informal indicator measures to evaluate environmental conditions in the Complex. In addition, more detailed information on environmental indicators is collected and reported on a basin-wide level and by individual subbasins in the Albemarle-Pamlico region. Some stressors that have been evaluated to compare the subbasins of the Albemarle-Pamlico Estuarine Complex (in support of past EPA studies) include total non-point source loadings (kg/yr) to each subbasin and the numbers of fish consumption advisories, HAB occurrences, Superfund and hazardous waste sites, coastal marinas per subbasin, and water quality exceedances. The following section will describe some of the recent trends and environmental measures studied on a Complex-wide basis, as compiled by state partners managing the Albemarle-Pamlico region for water and sediment quality, fish and wildlife, and habitat conditions.

Water Quality and Sediment Quality

Data on the water quality condition of the Albemarle-Pamlico Estuarine Complex are collected by a number of APNEP partners. The North Carolina Department of Environment and Natural Resources' (NCDENR's) Division of Water Quality (DWQ) samples ambient stations for nutrients, dissolved oxygen, pH, conductivity, temperature, metals, turbidity, hardness, fecal coliform bacteria, and total suspended solids. The North Carolina DWQ also analyzes algal samples to document HABs and to investigate the causes of fish kills (NCDENR, 2006). Water quality data is also collected by the FerryMon project (see Highlight article).

Although trends in nutrient concentrations in the Complex appear to be very site-specific, the waters of these estuaries are generally rich in phosphorus and relatively nitrogen-limited (Harned and Davenport, 1990; APNEP, 2006). Water quality measurements and trend analysis conducted across the entire Albemarle-Pamlico Estuarine Complex demonstrated some noticeable long-term patterns between 1945 and 1988, including the following:

- Increased dissolved oxygen levels (in general)
- Increased pH (in general)
- Decreased levels of suspended solids
- Increased chlorophyll *a* levels (Harned and Davenport, 1990).

A major source of nutrient loading to the waters of the Albemarle-Pamlico Estuarine Complex is runoff from agricultural activities (Harned and Davenport, 1990). Enhanced runoff of nutrients in the spring season has been a major contributor to nuisance HABs during the summer months. Atmospheric deposition accounts for an average of 27% of total nitrogen inputs and 22% of total phosphorus inputs to the drainage basin of the Albemarle-Pamlico Estuarine Complex (McMahon and Woodside, 1997). Major hurricanes in 1999 (Floyd) and 2003 (Isabel) had a significant impact on the water quality and growth of phytoplankton in the Complex, with salinity levels in these lagoonal estuaries decreasing dramatically after these storm events. Chlorophyll *a* levels typically increased substantially after the storm events, but eventually returned to pre-storm levels (Peierls et al., 2003).

Habitat Quality

The measures that have been used in past studies to measure habitat quality across the subbasins of the Albemarle-Pamlico Estuarine Complex include acreages of wetlands, SAV, nursery areas, and shellfish-harvesting areas. An estimated 25% to 50% of the wetlands lining the tributaries or inland areas have been lost to development, dredging, draining, or filling of marsh habitat (NCDENR, 2003). Losses and gains for the major basins of the Albemarle-Pamlico Estuarine Complex during 2002 and 2003 are presented in Table 4-1.

The extent and health of SAV in the Albemarle-Pamlico Estuarine Complex is a function of several variables, including depth, salinity, sediment texture, concentration of suspended sediments, epiphyte encrustation, weather, climate, and nutrient availability. Most of these potential stresses are natural, but some are exacerbated by human activities. Eighty percent of SAV

coverage in the estuarine area is located in southern and eastern Pamlico Sound. Eelgrass, shoalgrass, and widgeongrass dominate these environments, and such a mixture of species is unique to North Carolina. Preliminary analyses suggest that the estimated area of marine SAV in the Complex's estuarine area is approximately 200,000 acres (APNEP, 2006).

Table 4-1. Change in the Extent of Wetland Habitat in the Major Subbasins of the Albemarle-Pamlico Estuarine Complex, 2002–2003 (NCDENR, 2003)

Subbasin	Overall Change (%)	
Pasquotank	4	(loss)
Chowan	0.8	(loss)
Roanoke	1.9	(loss)
Tar-Pamlico	5	(loss)
Neuse	25	gain
White Oak (eastern portion only)	6.2	gain

Living Resources

Fish and wildlife living in the Albemarle-Pamilico Estuarine Complex help serve as continuous monitors of environmental quality and increase the likelihood of detecting spills, non-point sources, or other highly variable impacts that are often missed by chemical-sampling water quality processes. The NCDENR pays particular attention to monitoring the more important commercial species of finfish and shellfish across the subbasins of the Albemarle-Pamlico Estuarine Complex to estimate the population structures and commercial value of these species. The blue crab population is monitored to help evaluate the effects of environmental stressors in different areas of the Albemarle-Pamlico region. Of the natural stressors examined, low dissolved oxygen and elevated water temperatures have correlated well with lowered concentrations of hemocyanin in blue crabs. Hemocyanin is a substance found in crab blood, and low concentrations are correlated with the crabs' increased susceptibility to parasitic infections and reproductive problems (APNEP, 2006).

Current Projects, Accomplishments, and Future Goals

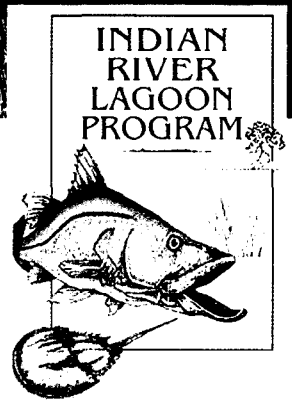
The APNEP continues to work toward fulfilling the goals of its CCMP and has already seen some major accomplishments, including the following:

- Restoration of more than 1,100 miles of anadromous fish habitat through the removal of three dams
- Enhancement of interagency and interstate coordination through creation of the APNEP
- Organizational restructuring to promote region-wide interstate citizen involvement through collaboration and coordination
- Development of bycatch reduction gear (e.g., sea turtle exclusion devices) and practices to reduce fisheries impacts
- Restoration of two miles of riparian habitat along the Roanoke River through livestock fencing and riverbank-stabilization practices (APNEP, 2006).

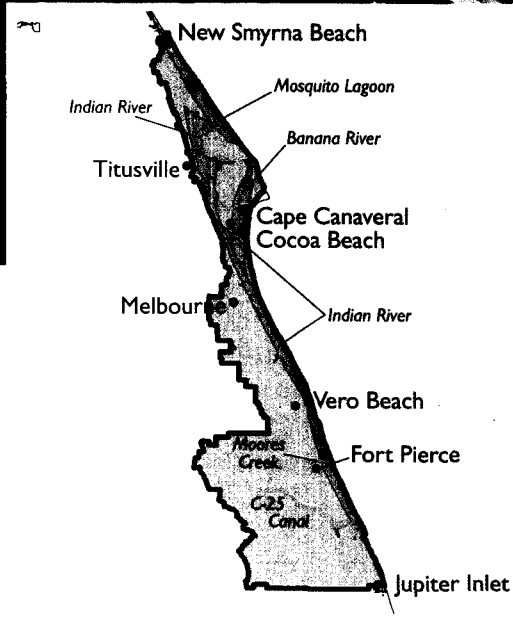
Conclusion

Based on data collected by the NCA, the overall condition of the Albemarle-Pamlico Estuarine Complex is rated good to fair. Data collected by NCA and the APNEP partners indicate that the Complex is in good condition with respect to most indicators of estuarine health; however, factors such as chlorophyll *a*, dissolved oxygen, and sediment quality may signal declining health, especially in some tributary river areas.

Indian River Lagoon National Estuary Program



www.sjrwmd.com/programs/outreach/irlnep



Background

Located along Florida's east coast and stretching 156 miles from Volusia County to Palm Beach County, FL, the Indian River Lagoon is one of the most diverse estuaries in North America and one of Florida's most popular fishing destinations, with more than 1 million anglers visiting the Lagoon area each year (U.S. EPA, 2000c). The Lagoon and its surrounding watershed include a wide variety of habitats that support a diverse assemblage of plants and animals (SJRWMD, 2004). These habitats range from xeric scrub through pine flatwoods, tropical and temperate hardwood hammocks, salt marshes, mangrove swamps, and other intertidal communities to seagrass meadows and other SAV communities (Hill, 2002).

This region's broad diversity of habitats support more than 4,300 different species, including 700 saltwater and freshwater fish species and 310 bird species (SJRWMD, 2004). Thirty-six of the species found in this region are classified as threatened or endangered, including the Southeastern beach mouse, Atlantic salt-marsh snake, bald eagle, and Florida scrub jay

(SJRWMD, 2004; U.S. EPA, 2006d). In addition, an estimated one-third of Florida's endangered West Indian manatees live in the Indian River Lagoon. Commercially, the estuary is one of the most important waterways in Florida and is a productive nursery ground for an estimated $300 million in annual commercial fishing revenues, including $100 million from inshore species. The Indian River Lagoon accounts for 50% of Florida's total East Coast fisheries landings (SJRWMD, 1994). In addition, tourism and recreation contribute $540 million to the local economy, and the influx of tourists and part-time residents to the area is considerable (SJRWMD, 2002).

In 1987, the Florida Legislature passed the Surface Water Improvement and Management (SWIM) Act, which designated the Indian River Lagoon as a priority waterbody in need of restoration and special protection (Florida Statutes, Chapter 373.451–373.4595). Created in 1990, the Indian River Lagoon NEP (IRLNEP) fosters active participation by other federal agencies, notably the FWS, NASA, and USACE. It also manages a local government cost-share program that assists counties and municipalities with planning and implementing pollution-abatement projects, typically small-scale efforts with an emphasis on stormwater treatment. For instance, both the St. John's River Water Management District (SJRWMD) and South Florida Water Management District (SFWMD) focus on projects designed to improve water and sediment quality, restore or enhance the seagrass community in the Lagoon, or rehabilitate wetlands, recovering many of the natural functions of these areas.

Environmental Concerns

The primary environmental concerns for the Indian River Lagoon include the loss or alteration of habitat, the impact of alterations to the area's hydrology, and the discharge of pollutant-laden wastewater and stormwater into the Lagoon. Approximately 75% of the Lagoon's salt marshes and mangrove wetlands have been lost or altered. In addition, the conversion of native uplands and wetlands to urban and agricultural land uses has negatively affected the rate, timing, volume, and quality of water flow to the St. Lucie River and the Indian River Lagoon, resulting in excessive discharges of fresh water that have degraded shellfish habitat, closed shellfish-harvesting areas, reduced water clarity, promoted algae growth, and contributed to the destruction of seagrass beds and other valuable habitats. Estuarine hydrology and salinity are also affected by releases from Lake Okeechobee and other drainage systems. Metals, pesticides, and herbicides present in surface runoff and water from the canal system bioaccumulate in the food chain and have been associated with an increased incidence of fish abnormalities, decreases in the health of fisheries, and impacts on the resident bottlenose dolphin population (Sime, 2002; SJRWMD, 2006).

Population Pressures

The population of the 6 NOAA-designated coastal counties (Brevard, Indian River, Martin, Okeechobee, St. Lucie, and Volusia) coincident with the IRLNEP study area increased by more than 327% during a 40-year period, from 0.3 million people in 1960 to almost 1.4 million people in 2000 (Figure 4-19) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the IRLNEP study area is almost four times the rate of 71.1% calculated for the Albemarle-Pamlico Estuarine Complex and more than twice the rate of 131.4% calculated for all NEP-coincident coastal counties of the Southeast Coast region. In 2000, the population density of these 6 coastal counties was 308 persons/mi^2, almost double the density of 168 persons/mi^2 for the collective NEP-coincident coastal counties of the Southeast Coast region (U.S. Census Bureau, 2001). Population pressures for the IRLNEP area are likely higher due to the extensive development of the area associated with the Kennedy Space Center at Cape Canaveral and from the residential development that has occurred in these counties. Despite the area's high population growth, a good portion of the land surrounding the IRLNEP study area is associated with state and federal lands that have been designated for protection as national seashore, wildlife areas, or forests.

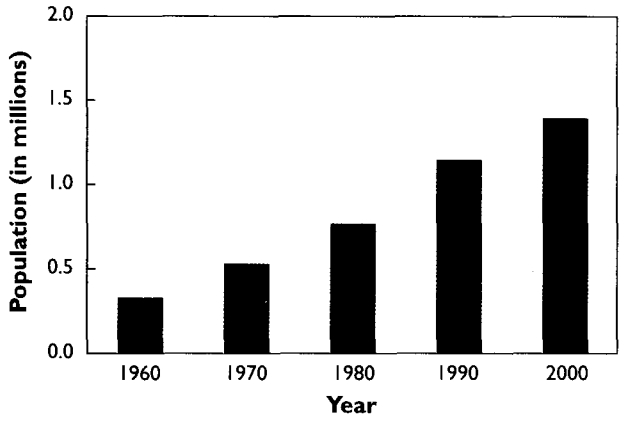


Figure 4-19. Population of NOAA-designated coastal counties of the IRLNEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

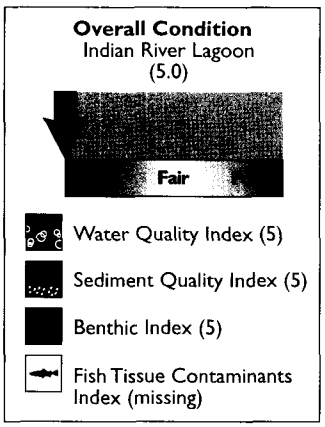


Figure 4-20. The overall condition of the IRLNEP estuarine area is good (U.S. EPA/NCA).

NCA Indices of Estuarine Condition—Indian River Lagoon

The overall condition of the Indian River Lagoon is rated good based on three of four indices of estuarine condition used by the NCA (Figure 4-20). The water quality, sediment quality, and benthic indices were each rated good for the Indian River Lagoon, and data were unavailable to calculate a fish tissue contaminants index for this estuary. Figure 4-21 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 45 NCA sites sampled by EMAP in the IRLNEP estuarine area in 2001 and 2002. Due to the rotating basin schedule in Florida, the NCA only sampled the northern portion of the Lagoon (approximately 230 mi^2) in 2001 and 2002; the remainder of the estuarine area was sampled in 2003, but these data are not yet available. 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.

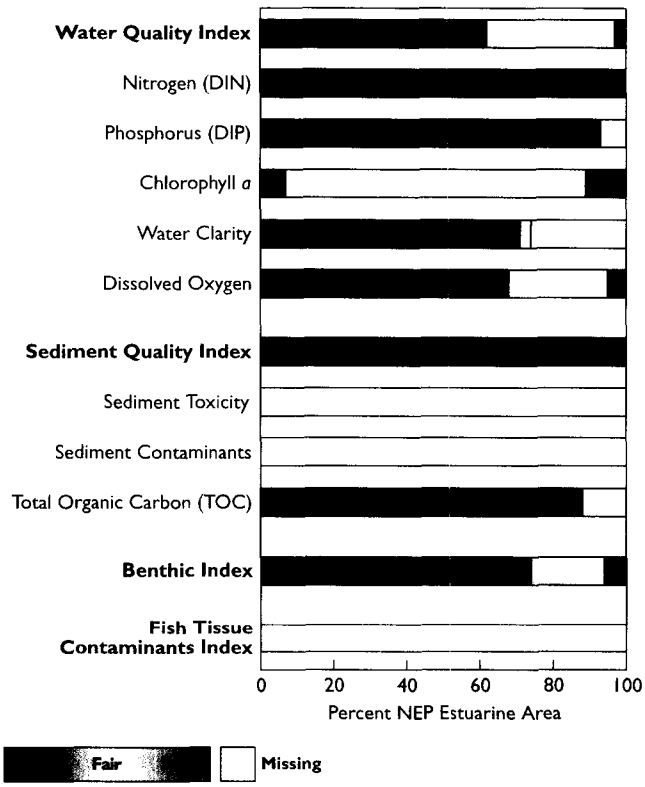


Figure 4-21. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Indian River Lagoon (U.S. EPA/NCA).

Water Quality Index

The water quality index for the northern portion of the Indian River Lagoon is rated good (Figure 4-22). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Only 3% of the Lagoon's estuarine area was rated poor for water quality, and 36% of the area was rated fair.

Dissolved Nitrogen and Phosphorus | The Indian River Lagoon is rated good for nutrient concentrations, with 100% and 93% of the estuarine area rated good for DIN and DIP concentrations, respectively. Only 7% of the Lagoon's estuarine area was rated fair for DIP concentrations.

Chlorophyll a | Concentrations of chlorophyll *a* in the northern portion of the Indian River Lagoon are problematic, and the Lagoon is rated fair for this component indicator. Overall, the Lagoon received a fair rating because 11% of the estuarine area was rated poor for chlorophyll *a* concentrations, and the combined value for fair and poor ratings was 93%. Only 7% of the IRLNEP estuarine area was rated good for chlorophyll *a* concentrations.

Water Clarity | Despite the fair rating for chlorophyll *a* concentrations, the Indian River Lagoon is rated good for water clarity. Water clarity was rated poor at a sampling site if light penetration at 1 meter was less than 20% of surface illumination. None of the estuarine area of the Indian River Lagoon was rated poor for water clarity, 4% of the area was rated fair, and 91% of the area was rated good.

Dissolved Oxygen | The Indian River Lagoon is rated fair for dissolved oxygen concentrations. Although 68% of the estuarine area was rated good for this component indicator, 5% of the area was rated poor, and 27% of the area was rated fair.

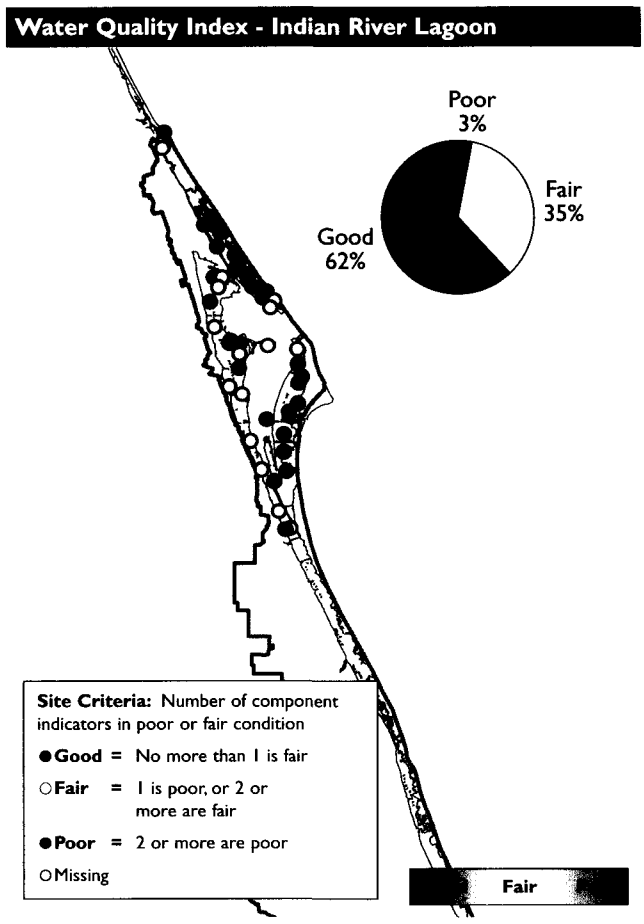


Figure 4-22. Water quality index data for the Indian River Lagoon, 2001–2002 (U.S. EPA/NCA).

Sediment Quality Index

The sediment quality index for the Indian River Lagoon is rated good; however, this rating is based only on NCA data for one component indicator (sediment TOC). Data on sediment toxicity and sediment contaminant concentrations were not assessed in the 2001–2002 NCA surveys. All of the IRLNEP estuarine area (100%) was rated good for the sediment quality index (Figure 4-23).

Sediment Toxicity | The NCA surveys did not collect sediment toxicity data for the Indian River Lagoon in 2000 and 2001; therefore, sediment toxicity in the Lagoon has not been rated for this report.

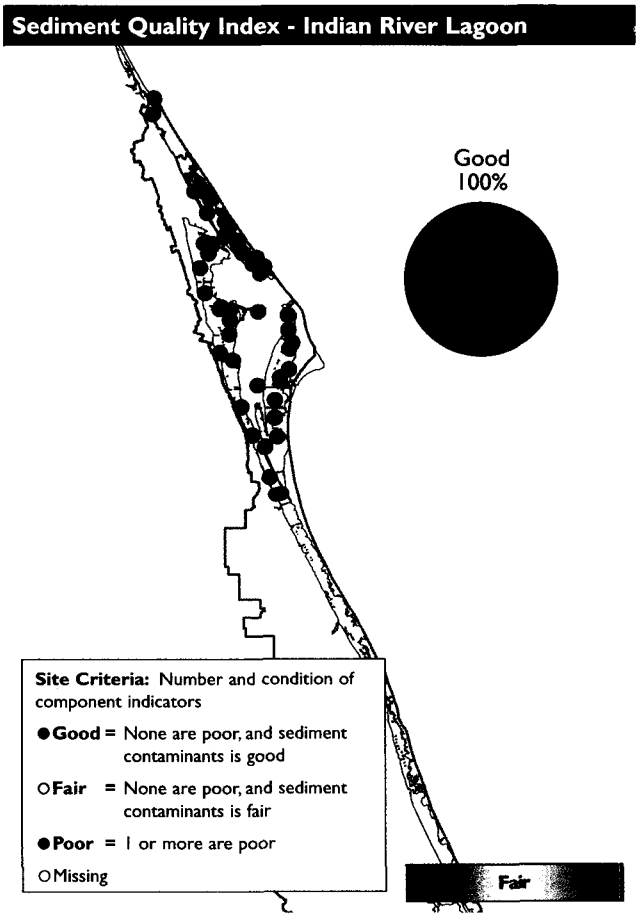


Figure 4-23. Sediment quality index data for the Indian River Lagoon, 2001–2002 (U.S. EPA/NCA).

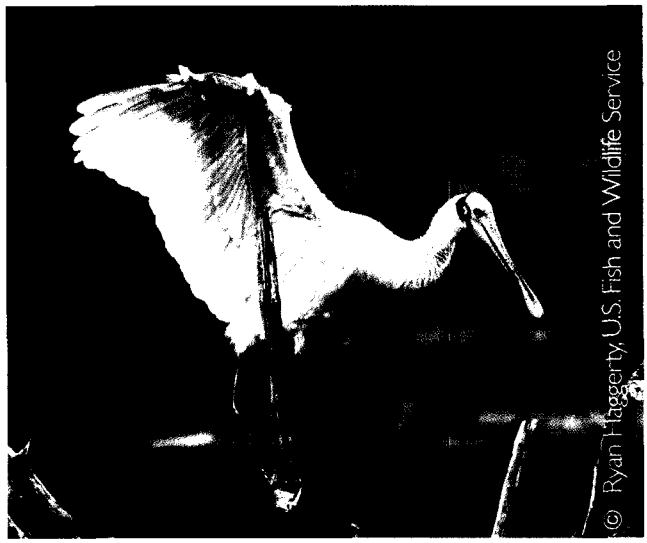
Sediment Contaminants | The NCA surveys did not collect sediment contaminants data for the Indian River Lagoon in 2000 and 2001; therefore, sediment contaminant concentrations in the Lagoon have not been rated for this report.

Total Organic Carbon | The Indian River Lagoon is rated good for TOC concentrations, with only 12% of the estuarine area rated fair and the remaining 88% rated good for this component indicator.

Benthic Index

Based on the Southeast Coast Benthic Index, the benthic condition of the Indian River Lagoon is rated good. The benthic index shows that 6% of the estuarine area was rated poor, 20% of the area was rated fair, and 74% of the area was rated good (Figure 4-24).

Although only 6% of the estuarine area exhibited degraded benthic condition, 33% of the sampling sites representing this degraded area were associated with some measure of adverse water quality (Figure 4-25). There were no areas of degraded benthic condition associated with poor TOC concentrations; however, no sediments were analyzed for sediment toxicity or sediment contaminant concentrations, so the co-occurrence of degraded benthic condition with either of these component indicators could not be evaluated.



The roseate spoonbill feeds on shrimp, small fish, and aquatic insects (Ryan Hagerty, FWS).

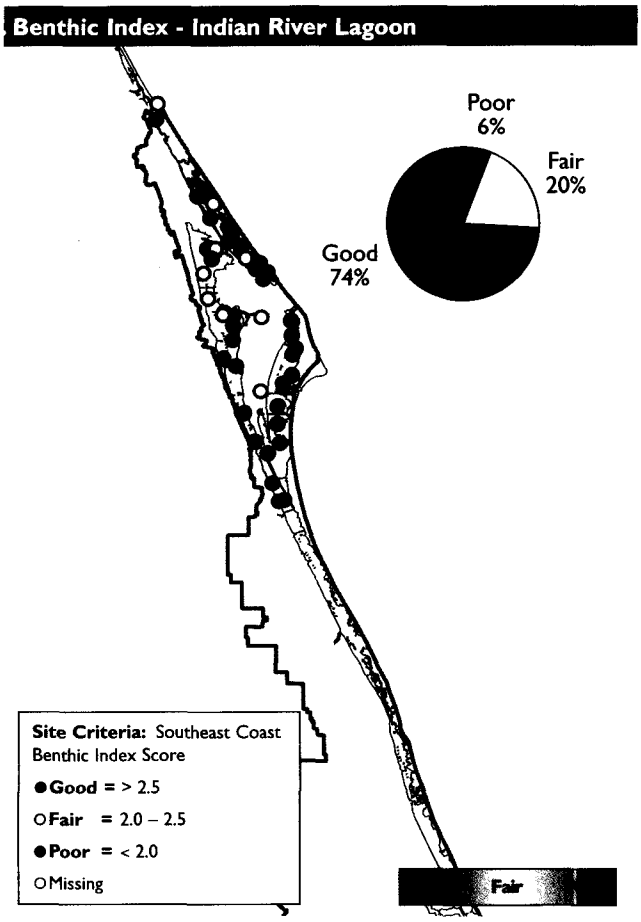


Figure 4-24. Benthic index data for the Indian River Lagoon, 2001–2002 (U.S. EPA/NCA).

Fish Tissue Contaminants Index

The NCA survey did not assess the level of fish tissue contaminants in the northern portion of the IRLNEP study area during 2001 or 2002; therefore, a fish tissue contaminants index for the Indian River Lagoon was not developed for this report.

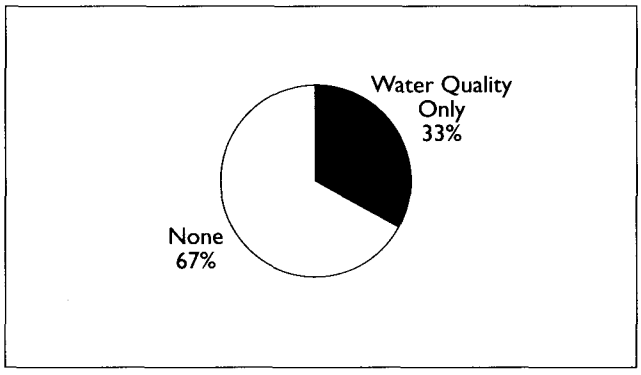


Figure 4-25. Percent of sampling sites in the Indian River Lagoon where poor benthic condition overlaps with other indices rated poor (U.S. EPA/NCA).

Hands-on educational activities help children learn about the Indian River Lagoon estuary (Ed Garland).

Indian River Lagoon National Estuary Program

Seagrass Monitoring in the Indian River Lagoon

The primary habitat of concern within the Indian River Lagoon is the Lagoon's seagrass community. Seagrass beds are valuable because they provide habitat and nursery areas for estuarine animals, enhance water quality by removing nutrients and stabilizing sediments, and serve as one of the planet's most productive ecosystems (Dawes, 1981; Zieman, 1982; Lewis, 1984; Virnstein et al., 1987). The seagrass community is sensitive to water quality conditions, particularly those parameters that affect water clarity, such as turbidity, suspended matter, color, and chlorophyll *a* concentrations (a surrogate for phytoplankton). As a result, the seagrass community in the Indian River Lagoon is an effective indicator of water quality (IRLNEP, 1996; Steward et al., 2003).

The IRLNEP, through the program's sponsor, the SJRWMD, has developed a monitoring program to assess the state of the Lagoon's seagrass community. This monitoring program has two major components: Lagoon-wide mapping and a series of fixed transects at selected sites throughout the Lagoon.

Lagoon-wide seagrass mapping provides an overall picture of seagrass resources throughout the Indian River Lagoon. Lagoon-wide maps are produced every two to three years, with the production process involving several steps, including aerial photography, ground-truthing, photo-interpretation and delineation of polygons containing seagrass beds, registration of these polygons to a base map, digitization of these polygons into GIS, and production of seagrass maps (Dobson et al., 1995). Appropriate management measures are developed and implemented to address problems or to provide protection for specific areas, and both problem and healthy areas are designated based primarily on the abundance of seagrass. Comparisons of these maps with historic maps can be used to detect changes in seagrass coverage, set targets for seagrass restoration, and document seagrass recovery (Virnstein and Morris, 1996).

Although these seagrass maps are produced every two to three years, aerial photos are taken each year to document any changes that occur during the period between map development. Photos are taken at USGS Quadrangle map scale (1:24K; 1 inch = 2,000 feet), generally during the spring, when water clarity conditions are best for photography (Virnstein and Morris, 1996). These maps have several limitations, including (1) the interval between mapping events; (2) that smaller seagrass beds (< 1/4 acre) are not mapped; (3) that certain seagrass species (such as *Halophila*) or areas of sparse seagrass are often not visible in aerial photographs and are not usually mapped; and (4) that locating the edge of a bed may have errors up to 100 feet (Virnstein and Morris, 1996).

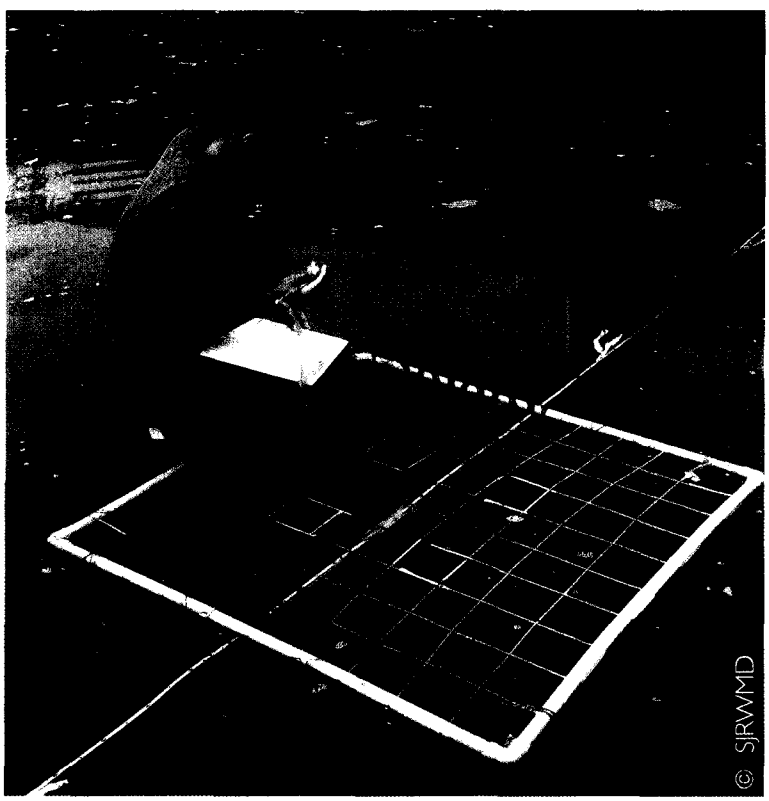
Fixed-seagrass transects are used to determine whether local areas are healthy or stressed; whether conditions are stable, improving, or declining; and the amount of change in the health or extent of seagrass beds. Sampling fixed transects allows researchers the ability to reliably detect small-scale changes in depth distribution, abundance, and species composition over time (Morris et al., 2001).

Presently, more than 80 seagrass transects have been established in the Indian River Lagoon. These transects are monitored twice each year—in the summer and winter—on dates that roughly correspond to times of maximum and minimum seagrass abundance. Measurements are made every 33 feet along each transect and include data on the depth, percent cover of seagrass, and canopy height of each seagrass species present. Shoot counts are made at the center and deep edges of seagrass beds. In addition, researchers estimate percent cover and biomass of drift algae present, measure light attenuation at the deep edge of the seagrass bed, and

take an underwater video as an archival record of conditions at the time of sampling (Morris et al., 2001)

Data collected through transect monitoring can be analyzed at several geographic and temporal scales. Three geographic scales (e.g., Lagoon-wide, by segment, and site-specific) and two temporal scales (e.g., annual and seasonal) can be used to present and analyze the data (Morris et al., 2001).

The use of large-scale mapping coupled with fixed transects is an effective method of evaluating the health of the seagrass community in the Indian River Lagoon. Lagoon-wide maps provide information about patterns and trends from a "big picture" perspective, whereas individual transects provide similar information on a localized basis. This information is valuable when developing or evaluating the effectiveness of management strategies.



Seagrass monitoring in the Indian River Lagoon, Florida (SJRWMD).

Indian River Lagoon National Estuary Program Indicators of Estuarine Condition

Water and Sediment Quality

Indicators of water quality for the IRLNEP include the following:

- Chlorophyll *a* levels (µg/L)
- Reduction of muck accumulation (extent and volume removed).

In recent years, algal blooms in the Indian River Lagoon have been a concern. Several of these blooms have included HAB species, which are considered potentially harmful to human health or natural resources. In order to track the occurrence of HABs, chlorophyll *a* levels are monitored by the IRLNEP as one of the key indicators of water quality. Increased nutrient concentrations are reflected in elevated chlorophyll *a* concentrations found in the southern Banana River and the Cocoa-Melbourne/Palm Bay area, where the 10-year chlorophyll *a* average concentration is greater than 8 µg/L. Although nutrient concentrations are also elevated, chlorophyll *a* levels are lower in the Vero Beach area, most likely due to increased flushing through nearby ocean inlets. A similar reduced algal response to elevated nutrient concentrations is seen in the Fort Pierce and St. Lucie River areas, where shorter residence times and increased flushing may also play a role (Steward et al., 2003). Overall, it appears that the fair rating assigned by the analysis of NCA data for the northern portion of the Indian River Lagoon agrees with the IRLNEP monitoring data for chlorophyll *a*. Both sets of data suggest that chlorophyll *a* levels are somewhat elevated and in need of mitigation measures, but that there are still many areas of the Lagoon system where levels remain low.

The amount of muck (e.g., mineral soils, clays, and silts mixed with organic matter) removed from the Indian River Lagoon is an important metric that is primarily monitored near the mouth of the Lagoon's tributaries. Re-suspension of estuary muck during wind events decreases water clarity, which has a negative effect on the health and extent of seagrass and other SAV. Based on NEP monitoring data, turbidity levels have not shown a declining trend over time in the Indian River Lagoon; however, the analysis of NCA data for the northern portion of the Lagoon shows that water clarity throughout the Lagoon is generally good. Water clarity varies considerably throughout the Lagoon's reaches, and suspended solids likely have the most significant influence on turbidity levels in central portions of the Lagoon (Steward et al., 2003).

Habitat Quality

Seagrass coverage is the primary biological indicator of ecosystem health used by the IRLNEP. According to IRLNEP data, the Lagoon experienced a net gain in seagrass coverage of nearly 4,000 acres from 1992 to 1999. The long drought in the late 1990s may have been largely responsible for this positive trend, but the cumulative effects of restoration work should help to maintain this growth. SAV beds in Indian River Lagoon include *Halodule*, *Ruppia*, *Syringodium*, *Thalassia*, and three *Halophila* species (Steward et al., 2003). One species, Johnson's seagrass (*Halophila johnsonii*), is a federally listed species found only in the coastal lagoons of eastern Florida between Sebastian Inlet and Biscayne Bay (Smithsonian Marine Station at Fort Pierce, 2006).

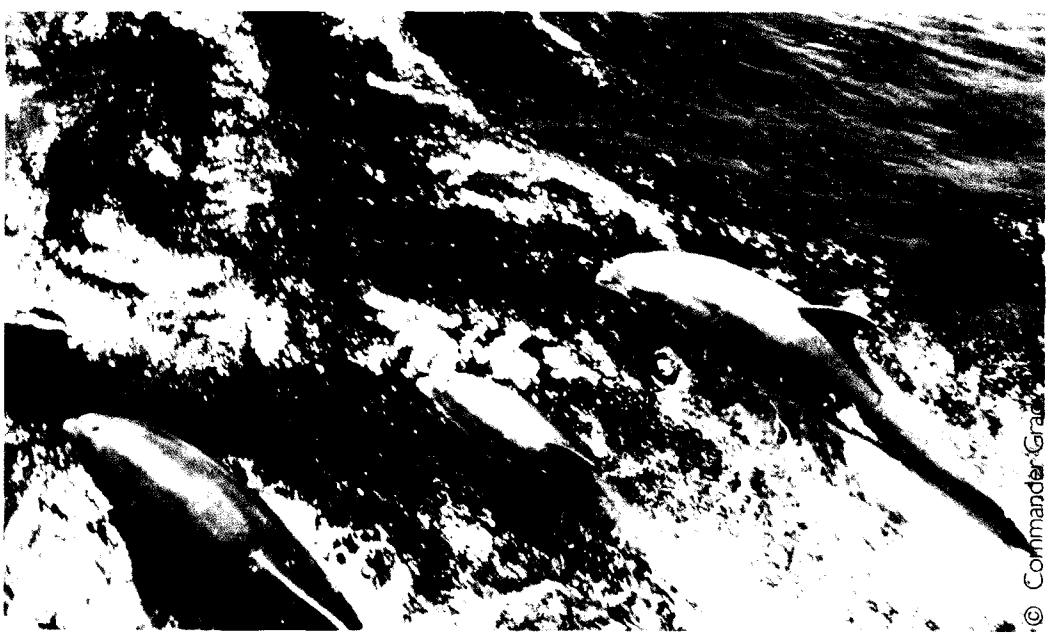
Assessment of seagrass resources in the Indian River Lagoon is based on the number of acres of seagrass coverage over time (net gain or loss), the maximum depth of the edge of seagrass beds, and the percent of sunlight reaching the target depth of about 5.6 feet. Segments of the Indian River Lagoon containing the largest acreage of seagrass coverage are found around North Merritt Island, within and adjacent to the federally protected NASA/Kennedy Space Center/Merritt Island National Wildlife Refuge complex (north Indian River Lagoon and northern Banana River), and at the Canaveral National Seashore (southern Mosquito Lagoon). These segments have shown little change in seagrass coverage since the 1940s (Steward et al., 2003). In Hobe Sound, located at the very southern end of the Indian River Lagoon, seagrass coverage exceeds 90% coverage of potential habitat (SJRWMD, 2004). The

largest area of poor seagrass coverage extends from the Cocoa area to the Melbourne/Palm Bay area. This area has experienced the greatest loss (70%) of seagrass coverage since the early 1940s. Across the entire Lagoon, potential seagrass coverage is approximately 118,000 acres. In 1999, seagrass coverage was approximately 59% of the Lagoon's total potential seagrass acreage (Steward et al., 2003).

Living Resources

Although stormwater management and enhancing seagrass production remain the highest priorities, the IRLNEP has identified invasive, exotic species and aquatic animal health as emerging challenges to the Lagoon's ecosystem. During the past several years, there has been increasing concern over the number of wildlife-related disease and mortality events in the Lagoon, possibly a symptom of a wider-scale problem regarding the overall health of the estuarine system. Despite considerable progress and success in rehabilitating impounded wetlands as habitat and improving water quality conditions in the Lagoon during the past two decades, a number of fairly recent, possibly interconnected wildlife-related mysteries remain unsolved. They include the skin disease *Lobomycosis*, which is occurring on much of the Lagoon's resident dolphin population; fibropapillomas lesions on many of the green turtles found in the Lagoon; an increased incidence of tumors in hard clams; decreases in the population of horseshoe crabs; the recent appearance of saxitoxin in puffer fish in the northern Lagoon, resulting in a ban on catching puffers throughout the Lagoon and health advisories regarding human consumption of these fish; the sporadic occurrence of "spicy" tasting clams; and the appearance of invasive species, such as the Australian spotted jellyfish (*Phyllorhiza punctata*) in the central Lagoon and the exotic macroalgae *Caulerpa brachypus* in the southern portion of the estuary (SJRWMD, 2004).

To address these problems, the IRLNEP is taking the lead in forming an Indian River Lagoon Task Force. The goal of this task force will be to integrate monitoring and research results to determine if a commonality of cause exists and to prevent or reduce future occurrences. Key stakeholders in supporting CCMP implementation have continued to respond to the IRLNEP's priority challenges of reducing stormwater discharges to the Lagoon and enhancing valuable wildlife habitat through invasive plant control, endangered lands acquisition, and reconnection of impounded wetlands to the estuary (SJRWMD, 2004).



The Indian River Lagoon has a resident dolphin population (Commander Grady Tuell, NOAA Corps).

Current Projects, Accomplishments, and Future Goals

The greatest tangible improvement to date in the Indian River Lagoon is the hydrologic reconnection of more than 23,000 acres of impounded wetlands since 1989 under the SWIM Act (in addition to nearly 5,000 acres reconnected through other programs). These impoundment reconnections restore many natural functions provided by salt marshes and mangrove wetlands (Steward et al., 2003).

There is also a noticeable increase in public awareness of the Lagoon's problems and its ecology, as well as an understanding of the projects that are underway to benefit the Lagoon's recovery and management. Much has been accomplished, but the IRLNEP recognizes that more work remains to be done to reach restoration targets established for seagrass and coastal wetlands. Preventative safeguards, vigilance, and education are needed to ensure that achievements in addressing problems in the Indian River Lagoon are maintained and that progress continues in protecting and restoring the water quality and natural resources of the Lagoon (Steward et al., 2003).

There is also good progress taking place within the Indian River Lagoon watershed. More than 56,000 acres of wetlands and uplands have been acquired for various purposes (such as water quality remediation projects and habitat preservation). The various agencies and local governments with jurisdiction over the Indian River Lagoon basin have made good progress in ending discharges of treated wastewater, removing harmful muck deposits, and making incremental improvements in stormwater management throughout the basin. In recent years, the IRLNEP has tackled some of the most important and controversial issues to address pollution in the Indian River Lagoon basin, such as addressing the impact of septic tanks on water quality, promoting the acquisition of environmentally sensitive lands, promoting the development of regional stormwater management plans, and participating in the development of local management plans for threatened and endangered species.

Some of the ongoing goals of the IRLNEP include:

- Attaining and maintaining water and sediment of sufficient quality to support a healthy, macrophyte-based estuarine Lagoon ecosystem
- Attaining and maintaining a functioning macrophyte-based ecosystem that supports endangered and threatened species, fisheries, and wildlife
- Improving the understanding and management of impacts of invasive and exotic species and the emerging challenges to aquatic animal health
- Achieving heightened public awareness and coordinated interagency management of the Indian River Lagoon ecosystem (Steward et al., 2003).

Conclusion

Based on data collected by the NCA, the overall condition of the Indian River Lagoon is rated good. In general, the IRLNEP considers seagrass coverage in the Indian River Lagoon to be a key indicator of trends in environmental condition. Areas with good seagrass coverage are located adjacent to fairly undeveloped watersheds or close to inlets, whereas areas of extensive SAV loss and sparse seagrass are adjacent to highly developed watersheds or shoreline areas. The areas with poorest water quality are Cocoa to Melbourne/Palm Bay, the southern Banana River, and the Vero Beach, Fort Pierce, and St. Lucie River areas. Areas of the Indian River Lagoon adjacent to larger tributaries and major drainages systems experience elevated levels of nutrients and total suspended solids.

CHAPTER 5

GULF COAST NATIONAL ESTUARY PROGRAM COASTAL CONDITION

CHAPTER 5

GULF COAST NATIONAL ESTUARY PROGRAM COASTAL CONDITION

Background

The Gulf Coast region extends from the lush tropical southern tip of Florida, including the Florida Keys, westward to the saline lagoons of South Texas at the Mexican border. The Gulf of Mexico receives runoff from almost two-thirds of the continental United States, primarily funneled through the Mississippi River drainage basin (NOAA, 1985). Within the Gulf Coast region, there are seven NEP estuaries—Charlotte Harbor, Sarasota Bay, Tampa Bay, Mobile Bay, the Barataria-Terrebonne Estuarine Complex, Galveston Bay, and the Coastal Bend Bays (Figure 5-1).

The entire Gulf Coast region is characterized by flat coastal plains and high levels of sediment deposition. Some of the estuaries in this region have large deltas at their river mouths (e.g., Mobile-Tensaw River Delta in Mobile Bay), where suspended sediment carried by runoff is deposited in shallow coastal waters. In other areas, sediment deposited by ocean currents has formed offshore sand bars that enclose shallow saline lagoons known as bar-built estuaries (e.g., Laguna Madre of the Coastal Bend Bays), which are most common along the Texas coast. The inlets to these estuaries are often narrow, and the exchange of water with the ocean is highly restricted; as a result, the circulation patterns in these waterbodies are driven primarily by wind (NOAA, 1985). In general, the shallow coastal plain estuaries characteristic of the Gulf Coast region receive little tidal influence, and tidal range in the region is small, with a minimum of 1 foot in Louisiana and Texas and a maximum of 3.6 feet in Florida (NOAA, 1985). Hurricanes and their accompanying heavy rains, an ever-present risk during the June-to-late-November hurricane season, have a dramatic effect on the Gulf Coast NEP estuaries by increasing freshwater inflow from storm precipitation and saltwater intrusion from wind-driven storm surge. Annual rainfall averages 48 inches in western Florida; increases to 56 inches in Alabama, Mississippi, and Louisiana; and then dramatically decreases to 24 inches in south Texas (NOAA, 1985).

The Gulf Coast NEP estuaries provide critical feeding, spawning, and nursery habitats for a rich assemblage of fish, wildlife, and plant species, including endangered species such as sea turtles, the Gulf

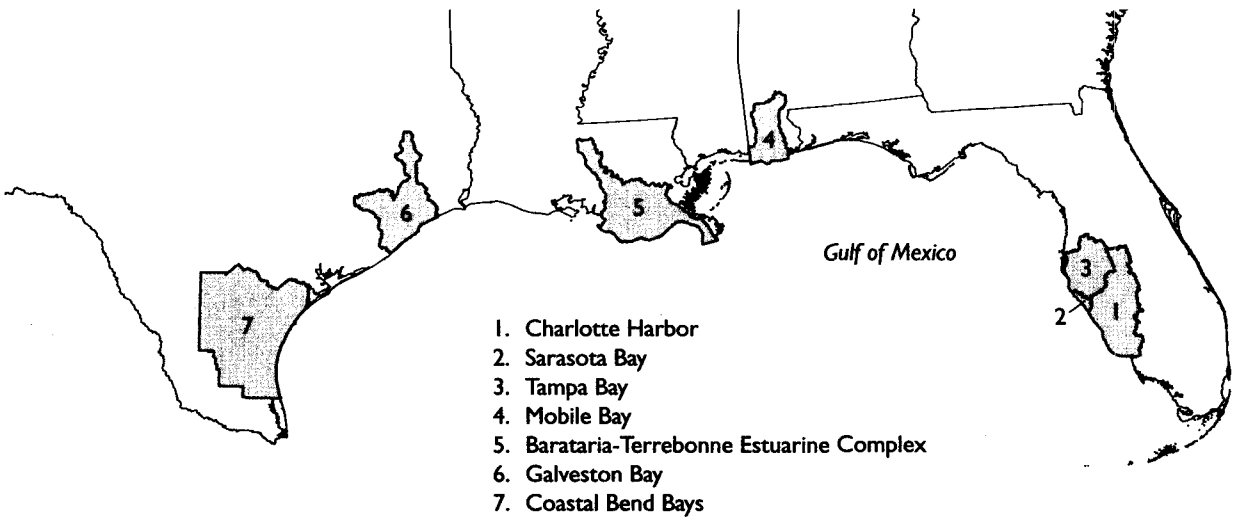


Figure 5-1. The Gulf Coast region is home to seven NEP estuaries.

sturgeon, the Perdido Key beach mouse, the manatee, the white-topped pitcher plant, and the red-cockaded woodpecker. These estuaries also support SAV communities that stabilize shorelines from erosion, reduce non-point source loadings, improve water clarity, and provide wildlife habitat. Increasingly, the varied estuarine habitats found along the Gulf Coast region are under pressure from human development.

Population Pressures

The population of the 48 NOAA-designated coastal counties coincident with the study areas of the Gulf Coast NEP estuaries increased by more than 133% during a 40-year period, from 4.9 million people in 1960 to 11.3 million people in 2000 (Figure 5-2) (U.S. Census Bureau, 1991; 2001). Population density for these coastal counties was 287 persons/mi^2 in 2000; however, the population densities of the individual NEP study areas varied considerably, from a high of 651 persons/mi^2 in Galveston Bay to 53 persons/mi^2 in the Coastal Bend Bays (U.S. Census Bureau, 2001). Development and population pressures are especially strong in these 48 Gulf Coast counties because the coincident NEP study areas serve as centers of commerce, contain substantial commercial and recreational fisheries, and provide recreational areas for coastal communities.

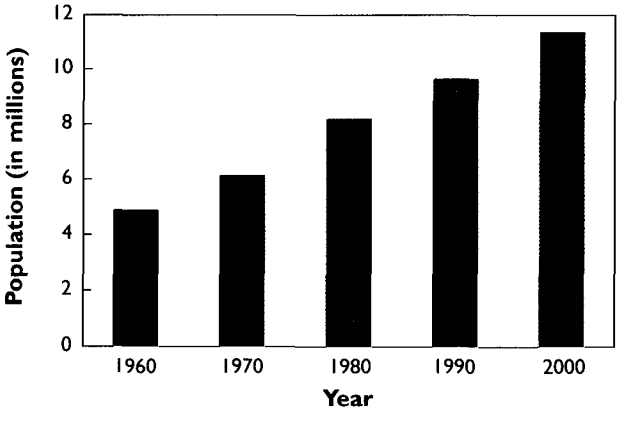
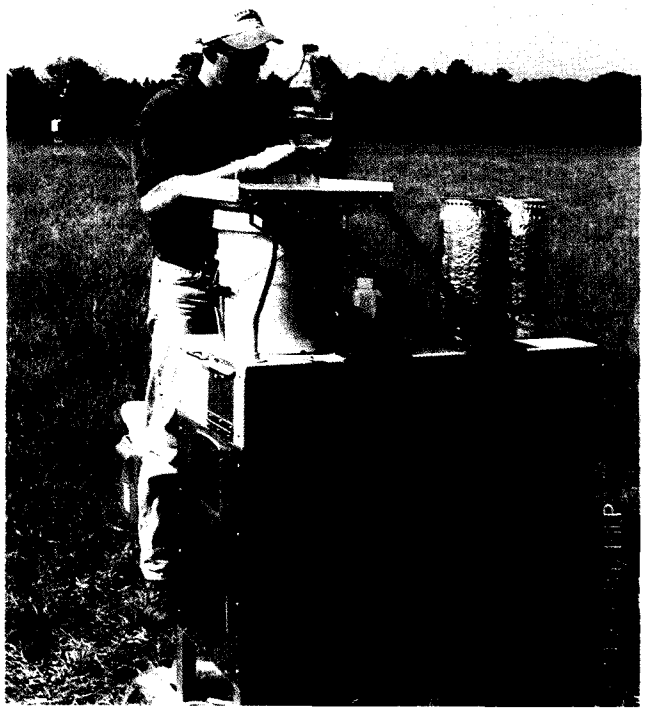


Figure 5-2. *Population of the 48 NOAA-designated coastal counties of the Gulf Coast NEP study areas, 1960–2000 (U.S. Census Bureau, 1991; 2001).*

The following sections of this report discuss 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 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 assessments 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.



Atmospheric deposition is often monitored in NEP study areas because it can contribute to estuarine nitrogen loadings (Mobile Bay NEP).

NCA Indices of Estuarine Condition—Gulf Coast Region

The overall condition of the collective NEP estuaries of the Gulf Coast region is rated fair based on the four indices of estuarine condition used by the NCA (Figure 5-3). The region's water quality index is rated fair, the sediment quality and benthic indices are rated fair to poor, and the fish tissue contaminants index is rated good to fair. Figure 5-4 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 collected by the NCA and its state partners from 221 sites sampled in the Gulf Coast region's NEP estuaries in 2000, 2001, and 2002. Samples were collected during the summer, the most stressful period of the year, and neither environmental stressors (e.g., nutrients, TOC) nor aquatic life communities showed any major evidence of degradation. 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.

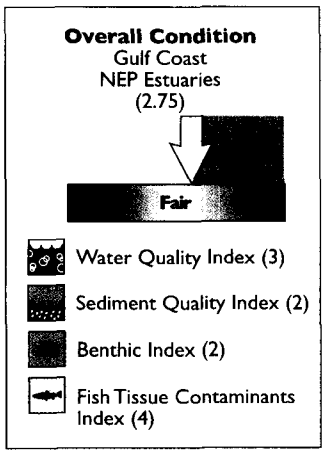


Figure 5-3. The overall condition of the Gulf Coast region's NEP estuarine areas is fair (U.S. EPA/NCA).

The sampling conducted by EPA's NCA has been designed to estimate the percent of estuarine area (nationally or in a region or state) in varying conditions, which are displayed as pie diagrams. Many of the figures in this report illustrate environmental measurements made at specific locations (colored dots on maps); however, these dots (color) represent the value of the indicator specifically at the time of sampling. Additional sampling may be required to define variability and confirm impairment or the lack of impairment at specific locations.

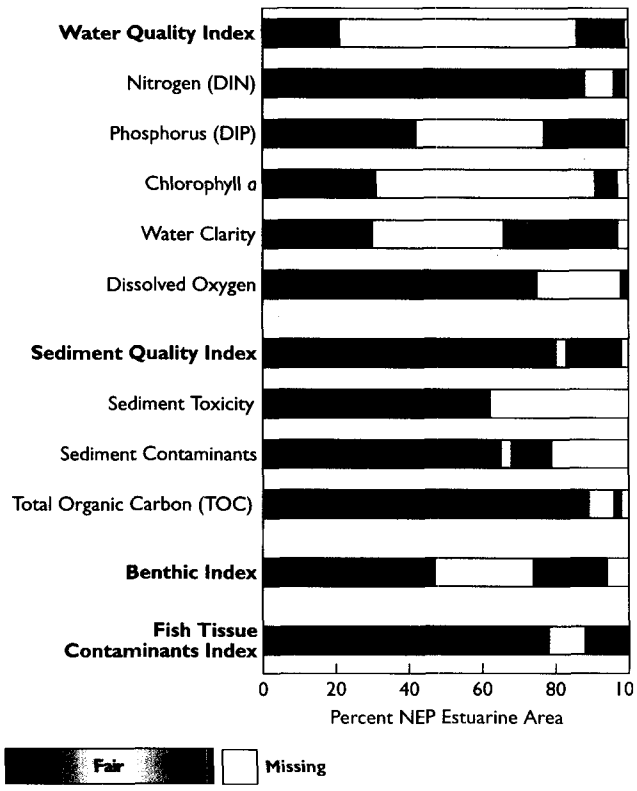


Figure 5-4. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Gulf Coast region (U.S. EPA/NCA).

Gulf Coast NEP estuaries provide breeding and wintering habitat for royal terns (*Sterna maxima*) (Mobile Bay NEP).

Water Quality Index

Based on NCA results, the water quality index for the collective NEP estuaries of the Gulf Coast region is rated fair (Figure 5-5). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. The NCA survey data indicates that 21% of the Gulf Coast region's NEP estuarine area was rated good for water quality, 65% of the area was rated fair, and 13% of the area was rated poor. In NOAA's Estuarine Eutrophication Survey (NOAA, 1997), the Gulf of Mexico as a whole was ranked poor for eutrophic condition, with an estimated 38% of the estuarine area having a high expression of eutrophication.

Dissolved Nitrogen and Phosphorus | The Gulf Coast region is rated good for DIN concentrations, with 88% of the region's NEP estuarine area rated good for this component indicator, 8% rated fair, and 3% rated poor. Elevated DIN concentrations are not expected to occur during the summer in Gulf Coast waters because freshwater input is generally lower and dissolved nutrients are more rapidly utilized by phytoplankton during this season. The Gulf Coast region is rated fair for DIP concentrations because 22% of the NEP estuarine area was rated poor for this component indicator.

Chlorophyll a | The Gulf Coast region is rated fair for chlorophyll *a* concentrations. Although poor chlorophyll *a* conditions occurred rarely in this region (6% of the NEP estuarine area), 60% of the area was rated fair for this component indicator, and 31% of the area was rated good. NCA data on chlorophyll *a* concentrations were unavailable for 3% of the Gulf Coast NEP estuarine area.

Water Clarity | Water clarity in the Gulf Coast NEP estuarine area is rated poor. Thirty-one percent of the Gulf Coast region's NEP estuarine area was rated poor, 30% was rated good, and 36% was rated fair. NCA data on water clarity were unavailable for 3% of the Gulf Coast NEP estuarine area.

Dissolved Oxygen | The Gulf Coast region is rated good for dissolved oxygen conditions in its NEP estuaries. The NCA results for these estuaries show that only 2% of the estuarine area was rated poor for dissolved oxygen concentrations, 23% of the estuarine area was rated fair, and 75% of the area was rated good.

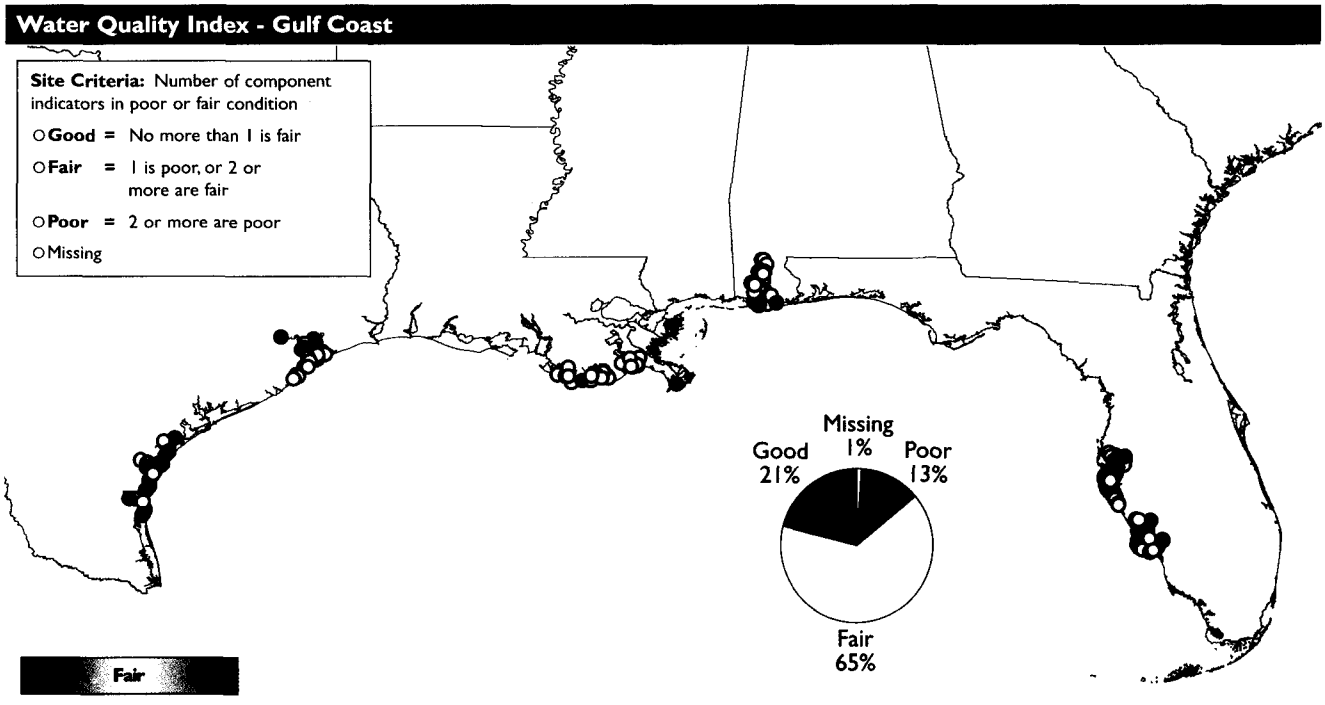


Figure 5-5. Water quality index data for the Gulf Coast NEP estuarine area, 2000–2002 (U.S. EPA/NCA).

Sediment Quality Index

The sediment quality index for the collective NEP estuaries of the Gulf Coast region is rated fair to poor because 18% of the region's NEP estuarine area was rated either fair or poor for sediment quality (Figure 5-6). This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC.

Sediment Toxicity | Sediment toxicity in the Gulf Coast region is rated good because only 1% of the region's NEP estuarine area was rated poor for this component indicator. It should be noted that data on sediment toxicity were unavailable for 38% of the Gulf Coast NEP estuarine area, including the region's three Florida estuaries (Charlotte Harbor, Sarasota Bay, and Tampa Bay).

Sediment Contaminants | The Gulf Coast region is rated fair for sediment contaminant concentrations, with 11% of the region's NEP estuarine area rated poor for this component indicator. It should be noted that NCA data on sediment contaminant concentrations were unavailable for 21% of the Gulf Coast NEP estuarine area, including the region's three Florida estuaries (Charlotte Harbor, Sarasota Bay, and Tampa Bay).

Total Organic Carbon | The Gulf Coast region is rated good for sediment TOC. Eighty-nine percent of the estuarine area was rated good for TOC concentrations, and 2% of the area was rated poor.

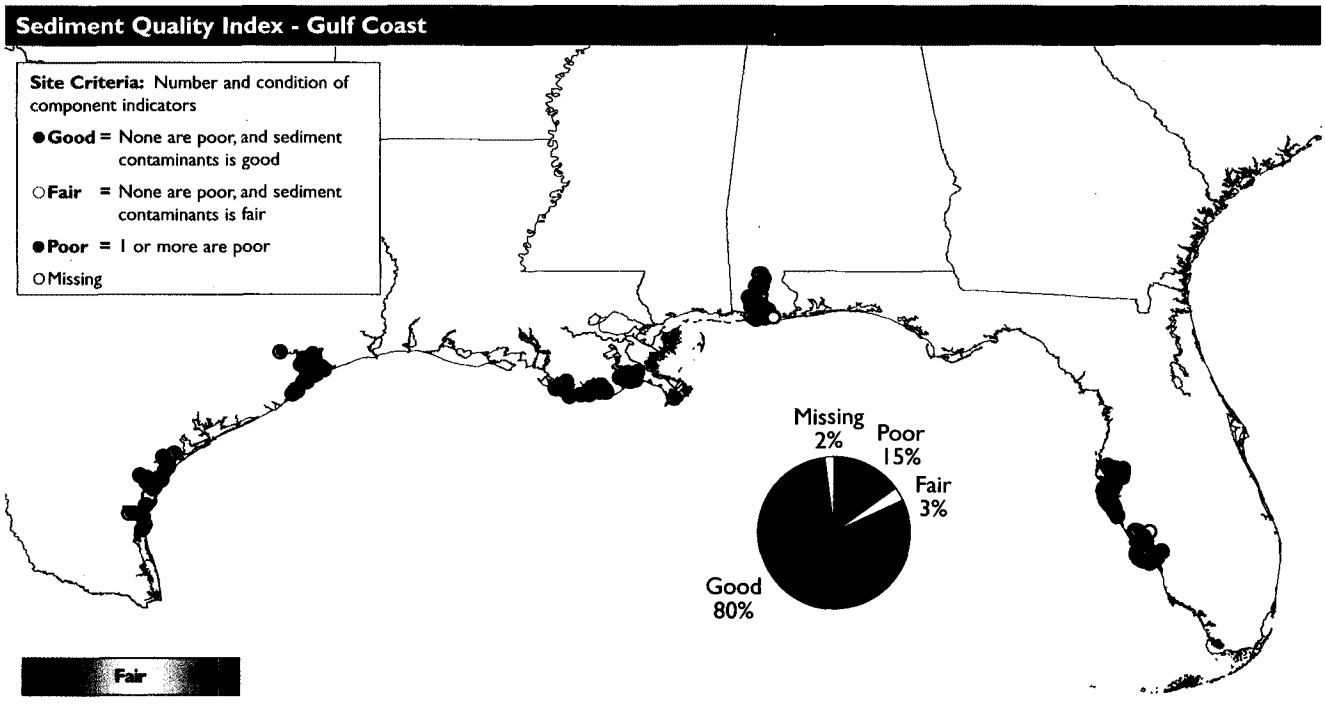


Figure 5-6. Sediment quality index data for the Gulf Coast NEP estuarine area, 2000–2002 (U.S. EPA/NCA).

Benthic Index

The condition of benthic invertebrate communities in the collective Gulf Coast NEP estuaries is rated fair to poor. The composition of benthic invertebrate communities reflects long-term exposure to sediment quality in estuaries, and short-term changes in benthic communities occur in response to hypoxic events and disturbance. Indices of biotic integrity have been developed for aquatic systems to describe the condition of biotic communities. Engle and Summers (1999) developed a Gulf Coast Benthic Index that integrates measures of diversity and populations of indicator species to distinguish between degraded and reference benthic communities. Based on NCA survey data and the Gulf Coast Benthic Index, 20% of the Gulf Coast region's NEP estuarine area showed degraded benthic resources (Figure 5-7).

Field trips can be used to teach students about Gulf Coast NEP estuaries (CHNEP).

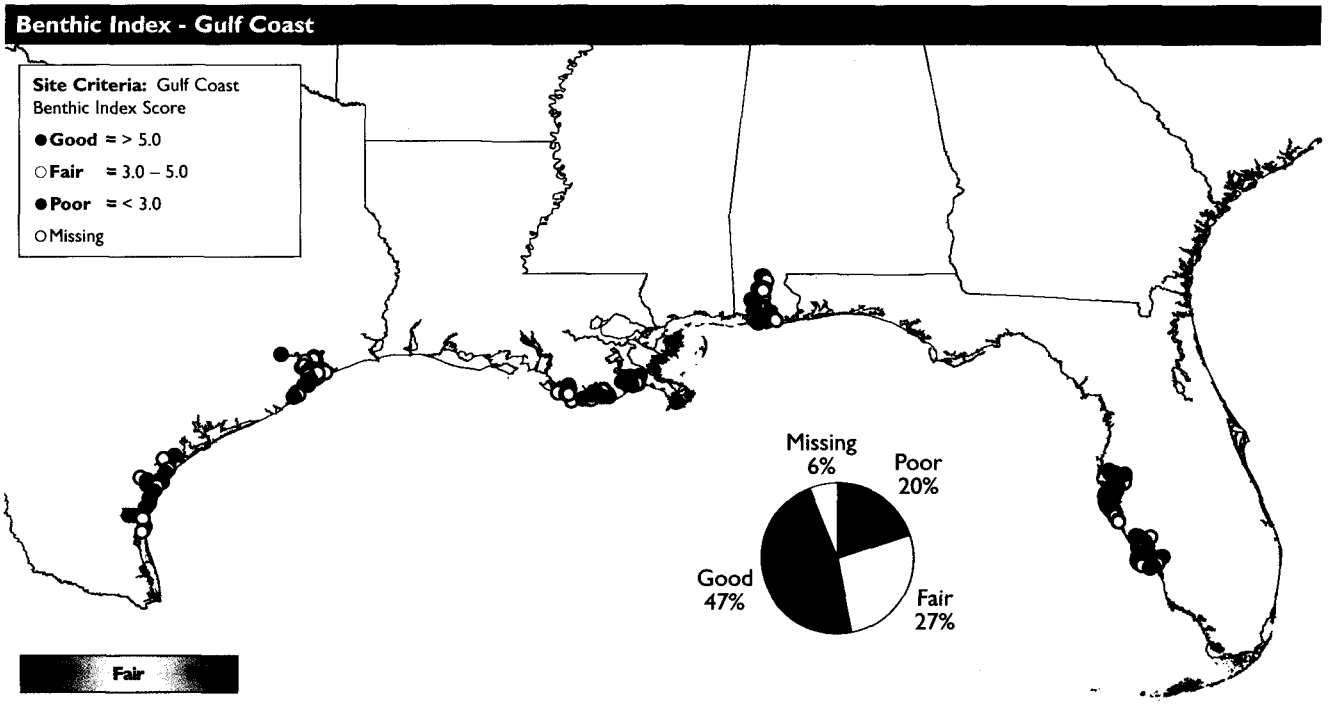


Figure 5-7. Benthic index data for the Gulf Coast NEP estuarine area, 2000–2002 (U.S. EPA/NCA).

A great blue heron looking for its next meal (CBBEP).

Fish Tissue Contaminants Index

The fish tissue contaminants index for the Gulf Coast NEP estuarine area is rated good to fair. It should be noted that fish tissue contaminants were measured in only four of the seven Gulf Coast NEP estuaries, and NCA fish tissue data were not collected for the three Florida estuaries (Charlotte Harbor, Sarasota Bay, and Tampa Bay). Figure 5-8 shows that 12% of all stations sampled where fish were caught exceeded the EPA Advisory Guidance values used in this assessment and were rated poor. The whole-fish contaminant concentrations measured in this survey can be higher or lower than the concentrations associated with fillets only; only those contaminants that have an affinity for muscle tissue (e.g., mercury) are likely to have higher fillet concentrations. Fillet contaminant concentrations for most other contaminants will likely be lower; however, for some populations that consume whole fish, these risk calculations are appropriate.

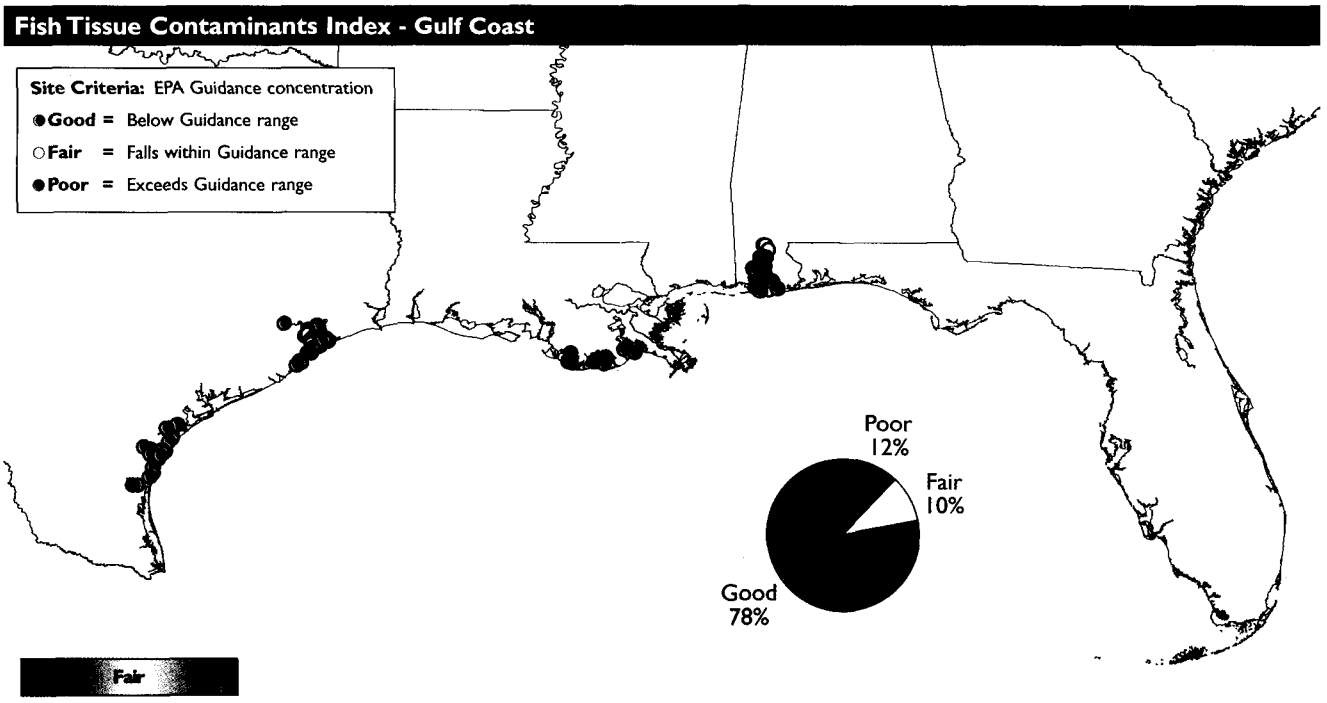


Figure 5-8. Fish tissue contaminants index data for the Gulf Coast NEP estuarine area, 2000–2002 (U.S. EPA/NCA).

NEP Estuaries and the Condition of the Gulf Coast Region

The purpose of the NEP is to identify, restore, and protect the nationally significant estuaries of the United States. Most of the seven NEP estuaries located in the Gulf Coast region need this extra protection, in part because their size and societal significance have led to intense human development; a diversity of uses, including municipal drinking water sources, industrial and agricultural production, and international commerce and shipping; and the associated environmental concerns throughout their watersheds. Does the condition of the Gulf Coast NEP estuaries accurately reflect the condition of all Gulf Coast estuaries (both NEP and non-NEP)? Based on the NCA survey results, the collective Gulf Coast NEP estuaries and all Gulf Coast estuaries combined are both rated fair for overall condition, with both groups receiving an overall condition score of 2.75 (Figure 5-9). Although the overall condition scores for the two groups of estuaries are the same, and both groups received similar ratings for the NCA estuarine indices, a comparison of NCA data reveals that the NEP estuaries had a greater percentage of area rated poor for almost every index than the non-NEP estuaries of the Gulf Coast region (Engle, 2004).

A comparison of NCA data for both groups of estuaries shows that the collective Gulf Coast NEP estuaries are rated fair for the water quality index; fair to poor for the sediment quality and benthic indices; and good to fair for the fish tissue contaminants index. In contrast, the group of all Gulf Coast estuaries combined are rated fair for the water quality, sediment quality, and fish tissue contaminants indices and fair to poor for the benthic index. In addition, the two groups of estuaries are rated comparably for most of the water quality and sediment quality component indicators, with both groups of estuaries rated good for DIN and dissolved oxygen concentrations, sediment toxicity, and sediment TOC and fair for DIP and sediment contaminant

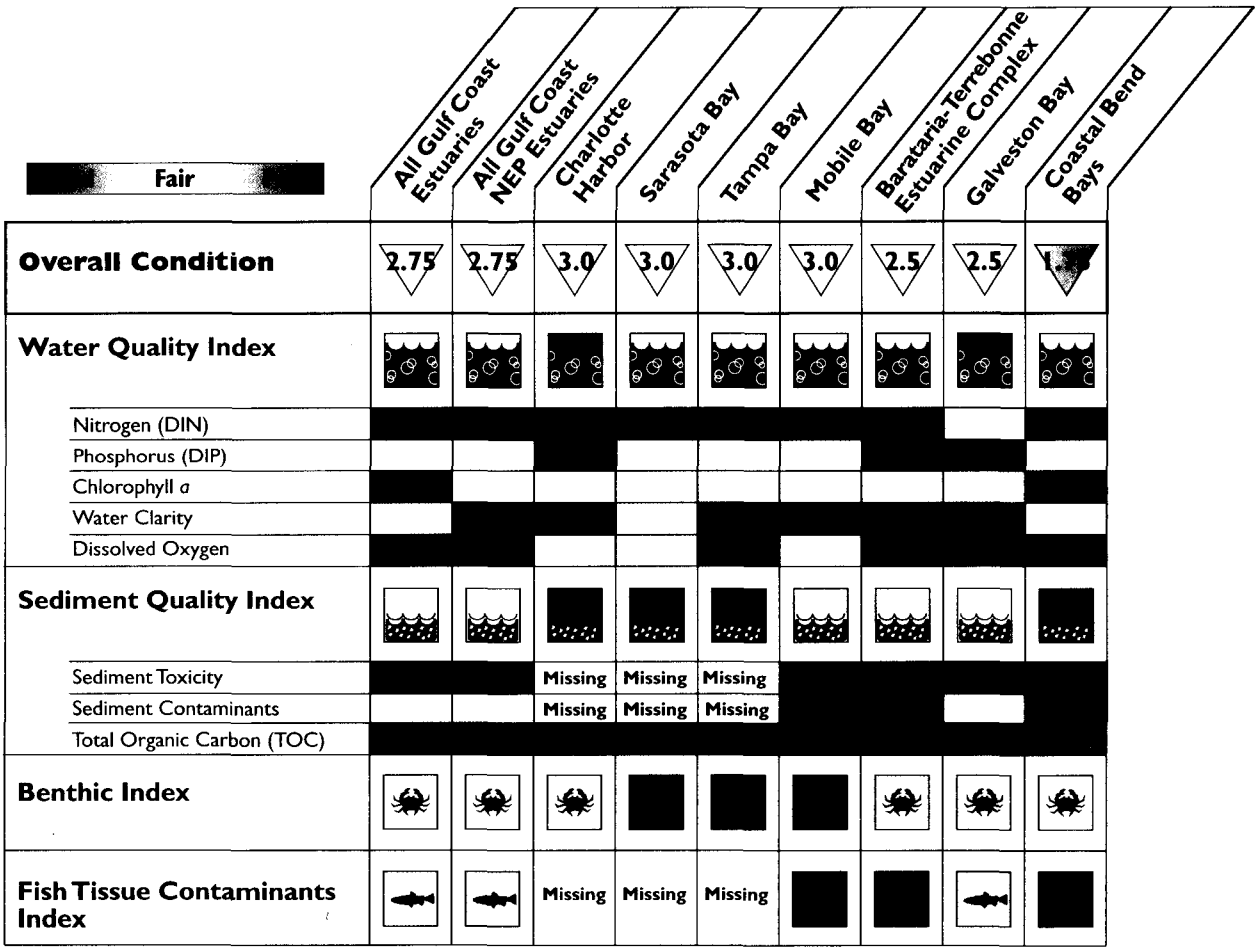


Figure 5-9. Comparison of NCA results for Gulf Coast NEP estuaries and all Gulf Coast estuaries (U.S. EPA/NCA).

concentrations. For the remaining two component indicators, the collective Gulf Coast NEP estuaries are rated fair for chlorophyll *a* concentrations and poor for water clarity, whereas the Gulf Coast estuaries combined are rated good and fair for these indicators, respectively.

With respect to the individual NEP estuaries, four of the seven estuaries received higher overall condition scores than the overall condition score for the collective Gulf Coast NEP estuaries (2.75, rated fair). These four estuaries are Charlotte Harbor (3.0), Sarasota Bay (3.0), Tampa Bay (3.0), and Mobile Bay (3.0) which are all rated fair. Galveston Bay (2.5, rated fair), the Barataria-Terrebonne Estuarine Complex (2.5, rated fair), and the Coastal Bend Bays (1.75, rated poor) received lower overall condition scores than the score for the collective Gulf Coast NEP estuaries.

A review of the NCA data for the water quality index and component indicators shows that the ratings vary between the individual Gulf Coast NEP estuaries. None of the NEP estuaries are rated good for the water quality index; Sarasota Bay, Mobile Bay, the Barataria-Terrebonne Estuarine Complex, and the Coastal Bend Bays are rated fair; Tampa Bay is rated fair to poor, largely driven by poor water clarity and fair concentrations of chlorophyll *a* and DIP; and Charlotte Harbor and Galveston Bay are rated poor, primarily due to poor DIP concentrations and poor water clarity ratings. All Gulf Coast NEP estuaries are rated good for DIN concentrations, except for Galveston Bay, which is rated fair. The Barataria-Terrebonne Estuarine Complex is rated good for DIP concentrations; Sarasota Bay, Tampa Bay, Mobile Bay, and the Coastal Bend Bays are rated fair; and Charlotte Harbor and Galveston Bay are rated poor. All the Gulf Coast NEP estuaries are rated fair for chlorophyll *a* concentrations, except for the Coastal Bend Bays, which are rated good for this component indicator. Although most Gulf Coast NEP estuaries (Charlotte Harbor, Tampa Bay, the Barataria-Terrebonne Estuarine Complex, and Galveston Bay) are rated poor for water clarity, Sarasota Bay and the Coastal Bend Bays are rated fair for this component indicator, and Mobile Bay is rated good. Four Gulf Coast NEP estuaries (Tampa Bay, the Barataria-Terrebonne Estuarine Complex, Galveston Bay, and the Coastal Bend Bays) are rated good for dissolved oxygen concentrations, but the three remaining NEP estuaries (Charlotte Harbor, Sarasota Bay, and Mobile Bay) are rated fair.

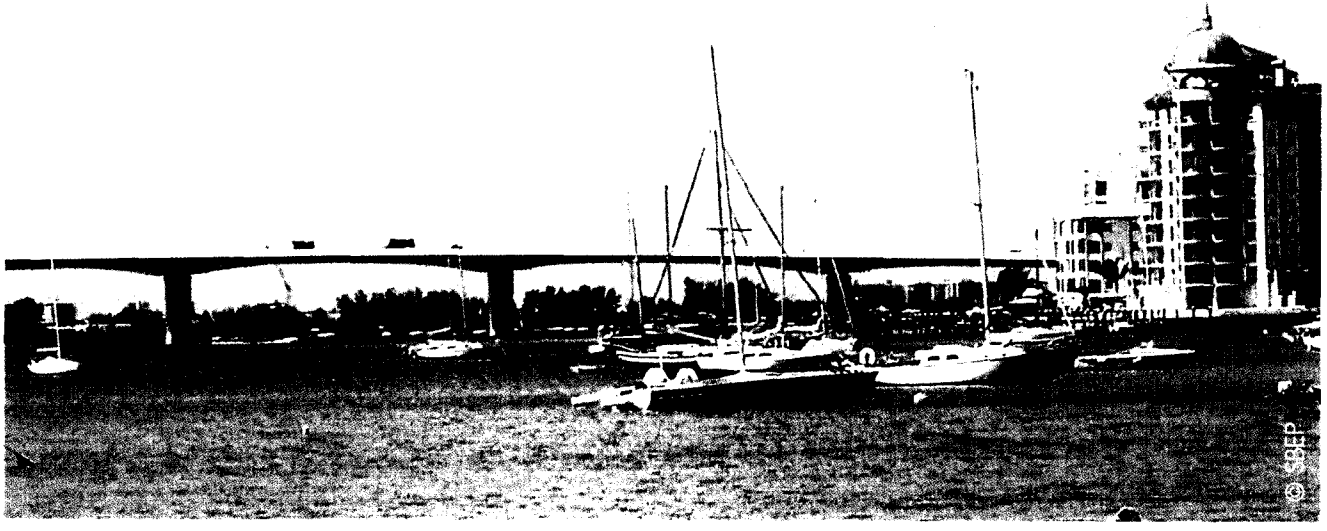
Kayaking is a popular pastime in Gulf Coast NEP estuaries (CBBEP).

The sediment quality index scores for the individual Gulf Coast NEP estuaries range from good to poor. For the three Florida NEP estuaries (Charlotte Harbor, Sarasota Bay, and Tampa Bay), the sediment quality index is rated good; however, it should be noted that NCA data on the sediment toxicity and sediment contaminants component indicators were not collected for these estuaries. For the remaining NEP estuaries, sediment quality index ratings decrease from east to west, with Mobile Bay and the Barataria-Terrebonne Estuarine Complex rated fair for sediment quality; Galveston Bay rated fair to poor; and the Coastal Bend Bays rated poor. Sediment toxicity is rated good for the Barataria-Terrebonne Estuarine Complex, Galveston Bay, and the Coastal Bend Bays and poor for Mobile Bay. Sediment contaminant concentrations are rated good for Mobile Bay and the Barataria-Terrebonne

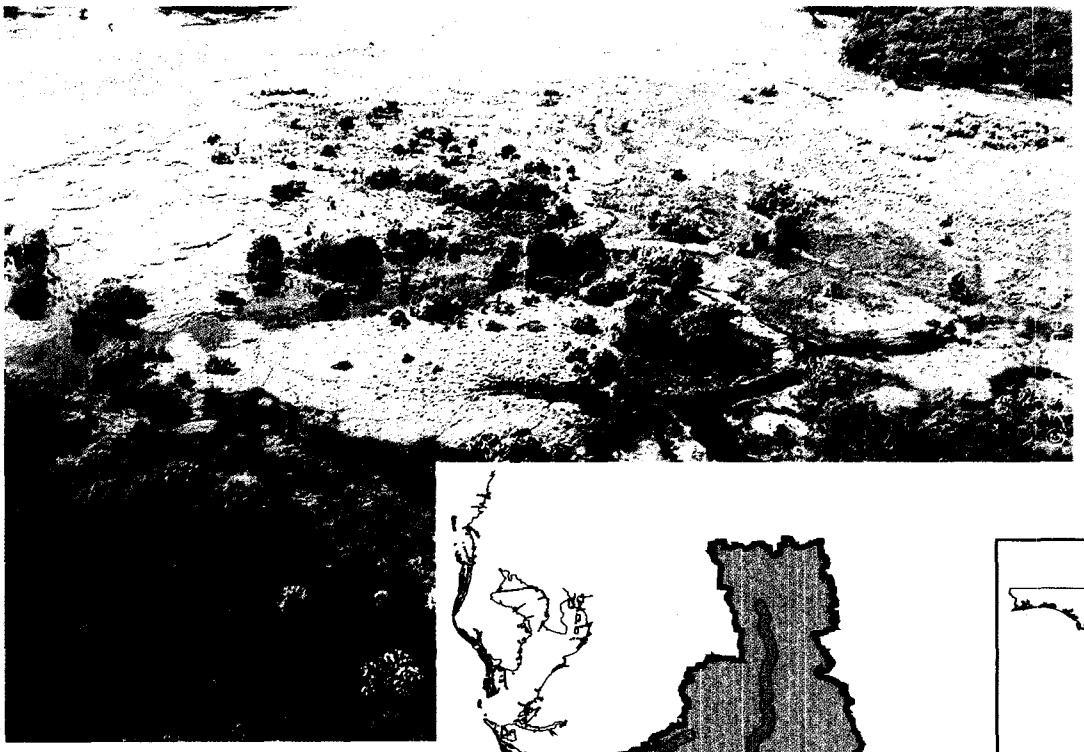
Estuarine Complex, fair for Galveston Bay, and poor for the Coastal Bend Bays. Sediment TOC content is rated good for all Gulf Coast NEP estuaries, both collectively and individually, as well as for all Gulf Coast estuaries combined.

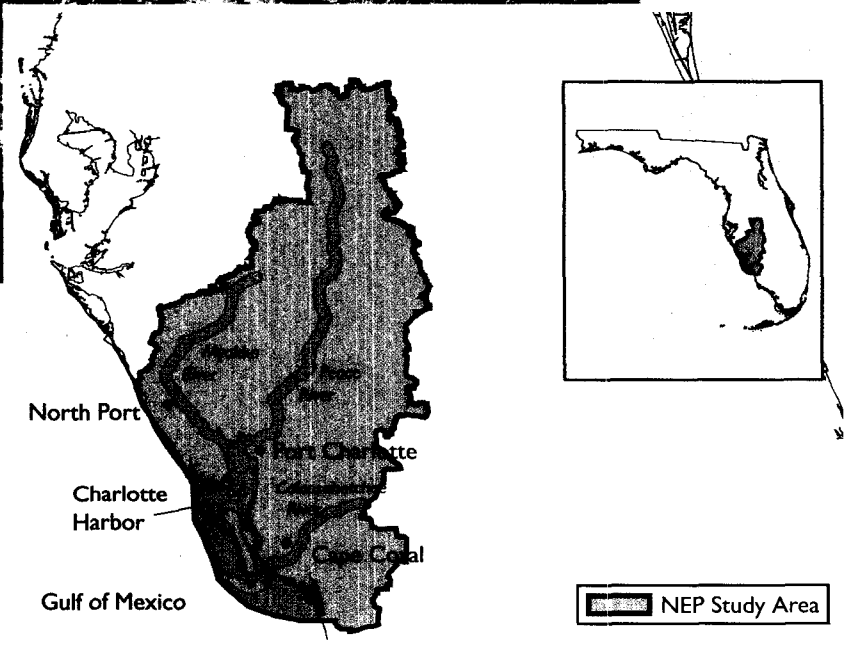
The benthic index scores for the individual NEP estuaries range from poor to fair. The benthic index is rated fair for Charlotte Harbor, the Barataria-Terrebonne Estuarine Complex, and Galveston Bay; fair to poor for the Coastal Bend Bays; and poor for Sarasota Bay, Tampa Bay, and Mobile Bay. The fish tissue contaminants index is rated good for Mobile Bay, good to fair for Galveston Bay, and poor for the Barataria-Terrebonne Estuarine Complex and the Coastal Bend Bays. NCA survey data on fish tissue contaminants were unavailable to evaluate any of the Gulf Coast NEP estuaries in Florida (Charlotte Harbor, Sarasota Bay, and Tampa Bay).

Nationally, the overall condition score for the collective NEP estuaries of the Gulf Coast region (2.75) is lower than the overall condition score for the collective NEP estuaries of the Southeast Coast region (4.0), comparable to the score for the West Coast region (2.5), and higher than the scores for the Northeast Coast (1.5) and Puerto Rico (1.5) regions. Population pressures, measured as population density (number of persons/mi^2), did not correlate well with the overall condition ratings for the individual Gulf Coast NEP estuaries. For example, the Coastal Bend Bays had the lowest population density of 53 persons/mi^2 in 2000, yet this estuary is rated poor for overall condition, with an overall condition score of 1.75. The two estuaries with the highest population densities in 2000, Galveston Bay (651 persons/mi^2) and Tampa Bay (640 persons/mi^2), are both rated fair for overall condition and received overall condition scores of 2.5 and 2.66, respectively. Mobile Bay (191 persons/mi^2), Charlotte Harbor (306 persons/mi^2), and Sarasota Bay (364 persons/mi^2), which had more intermediate population densities in 2000, each received an overall condition score of 3.0 and are rated fair for overall condition.



Charlotte Harbor National Estuary Program





www.chnep.org

Background

Located on the west coast of Florida's peninsula, Charlotte Harbor is created by the inflow and confluence of the Myakka, Peace, and Caloosahatchee rivers and empties into the Gulf of Mexico via Boca Grande, Gasparilla Pass, and San Carlos Bay. The fluctuations of river flow between the wet (summer) and dry (winter) seasons affect the Harbor's salinity and dissolved oxygen levels (NOAA, 1985). The Harbor itself is 30 miles long and 7 miles wide, with a total area of 270 mi^2 (CHNEP, 2005a). The Charlotte Harbor watershed is home to a highly diverse natural ecology, as well as to a growing human population and a variety of economic activities, including phosphate mining, residential development, tourism, intensive agriculture, and commercial fishing. Population growth is a major concern in the Charlotte Harbor watershed because county populations are projected to grow by more than 33% between 2000 and 2020 (CHNEP, 2000).

The estuarine area of the Charlotte Harbor NEP (CHNEP) contains waters listed as drinking water supplies (e.g., Shell and Horse creeks and parts of the Myakka River) and waters listed for shellfish propagation or harvesting (e.g., the tidal portion of the Myakka

and Peace rivers). The CHNEP estuarine area also includes most of the Peace River (U.S. EPA, 2005c). Those areas located within the Charlotte Harbor Aquatic and State Buffer Preserve and the Myakka River State Park have been designated as Outstanding Florida Waters. Charlotte Harbor and its contiguous coastal waters serve as a home, feeding ground, or nursery area for more than 270 resident, migrant, and commercial fish species of the Gulf of Mexico (CHNEP, 2005a). For numerous species, the most critical use of Charlotte Harbor is as a protected nursery area for both larval and juvenile stages of fish. Mangrove trees line the Harbor's shore and provide important habitat for plants, fish, birds, and other wildlife, such as manatees, sea turtles, wood storks, and dolphins.

Environmental Concerns

The environmental concerns of highest priority in Charlotte Harbor are hydrologic alterations, water quality degradation, and habitat loss. Management challenges for the CHNEP include protecting mangrove habitats; protecting seagrass areas from boat damage and water pollution; securing new water supply sources for the watershed's growing human populations and businesses; managing waste generated by septic tanks and sewer outfalls; protecting wetland areas for water retention, groundwater recharge, and wildlife habitat; and improving the overall efficiency of freshwater usage. Hydrologic alterations have occurred in the Harbor's three major tributary rivers, adversely effecting the location, timing, and volume of freshwater flows to this estuary (CHNEP, 2003a). The major causes of habitat loss in Charlotte Harbor include the degradation and elimination of headwater streams and other habitats by commercial development; the conversion of natural shorelines; the cumulative impacts of dock construction and boating; the invasion of exotic species; and other cumulative and future impacts of population growth (CHNEP, 2005a). In general, dissolved oxygen levels and surface water quality have declined in several areas of the Harbor's southern basins, including the Cape Coral peninsula south of Interstate 75, the north shore of the Caloosahatchee River, the coastal bays near Pine Island, and the Estero Bay watershed. Water quality in other areas of Charlotte Harbor is stable or improving (CHNEP, 2003b).

Population Pressures

The population of the 10 NOAA-designated coastal counties (Charlotte, Collier, DeSoto, Glades, Hardee, Hillsborough, Lee, Manatee, Polk, and Sarasota) coincident with the CHNEP study area increased by 251% during a 40-year period, from 0.8 million people in 1960 to 3.0 million people in 2000 (Figure 5-10) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the CHNEP study area was almost double the growth rate of 133.3% for the collective Gulf Coast NEP-coincident coastal counties and was the second-highest rate of growth of all NEPs in the Gulf Coast region, behind Sarasota Bay. In 2000, the population density of these 10 coastal counties was 306 persons/mi^2, slightly higher than the population density of 287 persons/mi^2 for the collective Gulf Coast NEP-coincident coastal counties (U.S. Census Bureau, 2001). Development and population pressures are especially strong in NEP study areas that serve as major shipping ports and as centers for commercial and recreational fisheries and other activities.

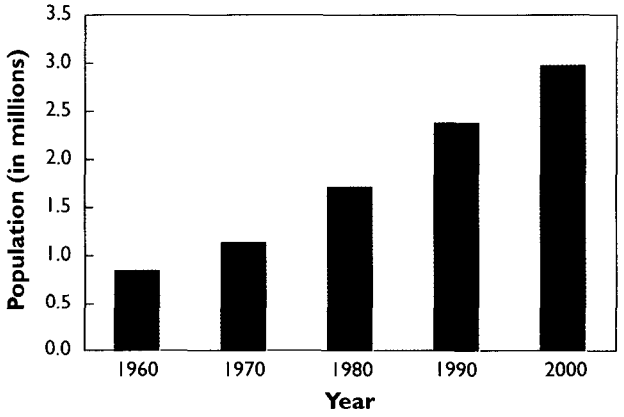


Figure 5-10. Population of NOAA-designated coastal counties of the CHNEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

Charlotte Harbor National Estuary Program

NCA Indices of Estuarine Condition—Charlotte Harbor

The overall condition of Charlotte Harbor is rated fair based on three of the four indices of estuarine condition used by the NCA (Figure 5-11). The water quality index is rated poor, the sediment quality index is rated good, and the benthic index is rated fair; NCA data were unavailable to calculate a fish tissue contaminants index for Charlotte Harbor. Figure 5-12 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 collected by the Florida Fish and Wildlife Research Institute, in partnership with the NCA, from 30 sites sampled in the CHNEP estuarine area in 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.

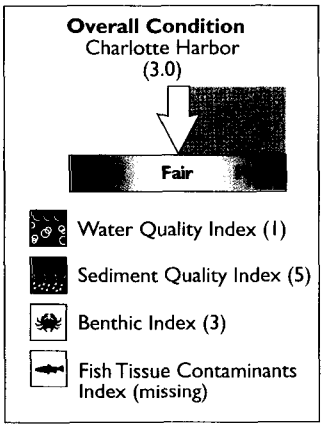


Figure 5-11. The overall condition of the CHNEP estuarine area is fair (U.S. EPA/NCA).

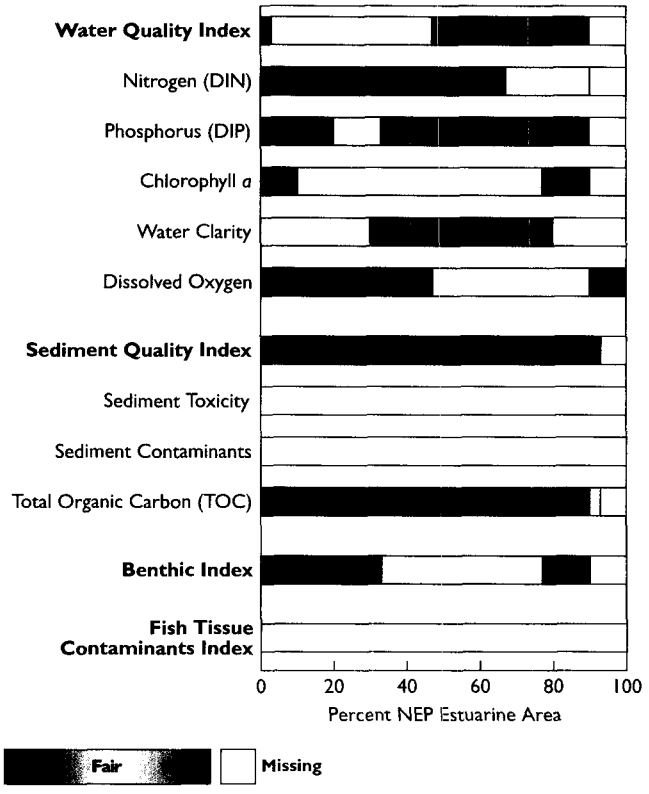


Figure 5-12. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Charlotte Harbor (U.S. EPA/NCA).

Water Quality Index

The water quality index for Charlotte Harbor is rated poor (Figure 5-13). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Elevated DIP concentrations and poor water clarity contributed to the Harbor's poor water quality condition. The NOAA's Estuarine Eutrophication Survey listed Charlotte Harbor as having low-to-high DIN concentrations, high DIP concentrations, and medium-to-hypereutrophic chlorophyll *a* levels (NOAA, 1997).

Dissolved Nitrogen and Phosphorus | The Charlotte Harbor is rated good for DIN concentrations. None of the estuarine area was rated poor for this component indicator, 23% of the area was rated fair, and 67% of the area was rated good. NCA data on DIN concentrations were unavailable for 10% of the CHNEP estuarine area. In contrast, DIP concentrations are rated poor for Charlotte Harbor; however, it should be noted that phosphorus levels in Charlotte Harbor are naturally high because of a commercially mined phosphate deposit, the Bone Valley deposit. Fifty-seven percent of the estuarine area was rated poor for DIP concentrations, 20% of the area was rated good, and 13% of the area was rated fair.

Chlorophyll a | Chlorophyll *a* concentrations in Charlotte Harbor are rated fair. Thirteen percent of the estuarine area was rated poor for this component indicator, 67% of the area was rated fair, and 10% was rated good. NCA data on chlorophyll *a* concentrations were unavailable for 10% of the CHNEP estuarine area.

Water Clarity | Water clarity in Charlotte Harbor is rated poor. Water clarity was rated poor at a sampling site if light penetration at 1 meter was less than 20% of surface illumination. Expectations for water clarity are high for Charlotte Harbor because one of the CHNEP's goals is to maintain SAV coverage and quality at levels of natural variability. Fifty percent of the estuarine area was rated poor for water clarity, 30% of the area was rated fair, and none of the area was rated good. NCA data on water clarity were unavailable for the remaining 20% of the CHNEP estuarine area.

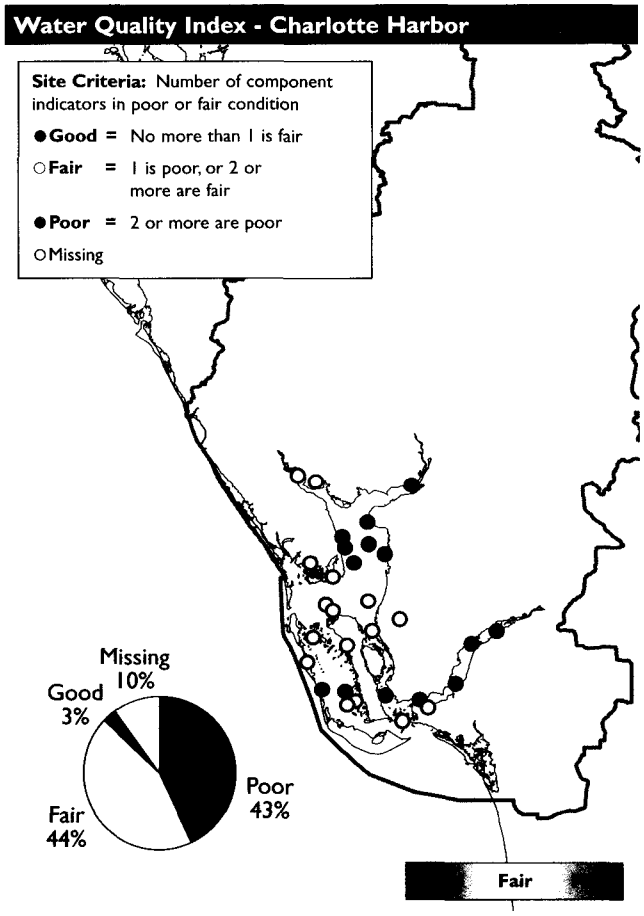


Figure 5-13. Water quality index data for Charlotte Harbor, 2002 (U.S. EPA/NCA).

Dissolved Oxygen | The Charlotte Harbor is rated fair for dissolved oxygen concentrations. NCA estimates show that only 10% of the CHNEP estuarine area was rated poor for this component indicator, 43% of the estuarine area was rated fair, and 47% of the area was rated good.

Sediment Quality Index

The sediment quality index for Charlotte Harbor is rated good; however, this rating is based on measurements of sediment TOC only (Figure 5-14). Ninety-three percent of the estuarine area was rated good for sediment quality, with NCA data unavailable for 7% of the CHNEP estuarine area.

Sediment Toxicity | The NCA did not collect sediment toxicity data for Charlotte Harbor in 2002; therefore, sediment toxicity in the Harbor has not been rated for this report.

Sediment Contaminants | The NCA did not collect sediment contaminants data for Charlotte Harbor in 2002; therefore, sediment contaminant concentrations in the Harbor have not been rated for this report.

Total Organic Carbon | Charlotte Harbor is rated good for TOC concentrations, with 90% of the estuarine area rated good and 3% rated fair for this component indicator. NCA data on TOC concentrations were unavailable for 7% of the CHNEP estuarine area.

Benthic Index

The condition of benthic invertebrate communities in Charlotte Harbor is rated fair based on the Gulf Coast Benthic Index and data from the NCA. Benthic index estimates indicate that 13% of the Harbor's estuarine area was rated poor for benthic condition, 44% was rated fair, and 33% was rated good (Figure 5-15).

Fish Tissue Contaminants Index

The NCA did not assess the level of fish tissue contaminants in the CHNEP estuarine area in 2002; therefore, a fish tissue contaminants index for Charlotte Harbor was not developed for this report.

Charlotte Harbor National Estuary Program Indicators of Estuarine Condition

The major indicators of estuarine condition used by the CHNEP are species composition and coverage of SAV; coverage and quality of fish and wildlife habitat; quantity and timing of freshwater flows and groundwater levels; and water quality conditions that lead to or are indicative of eutrophication. The CHNEP manages an interagency monitoring program that collects data on a variety of parameters, including Secchi disk, temperature, salinity, specific conductance, dissolved oxygen, pH, color, turbidity, total suspended solids, chlorophyll *a*, total nitrogen, total Kjeldahl nitrogen, total ammonia nitrogen, total nitrite+nitrate nitrogen, dissolved orthophosphate, total phosphorus, and TOC.

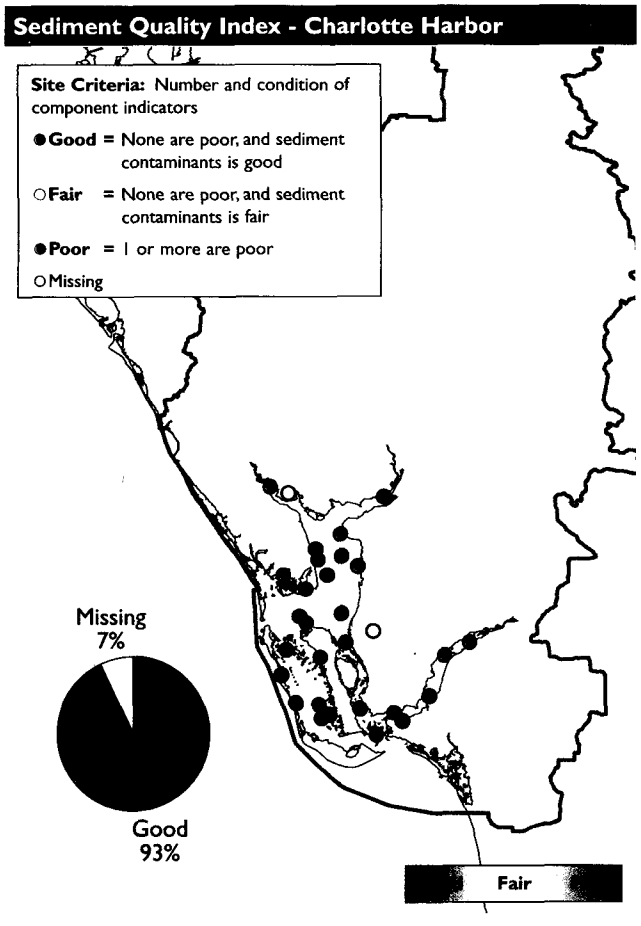


Figure 5-14. Sediment quality index data for Charlotte Harbor, 2002 (U.S. EPA/NCA).

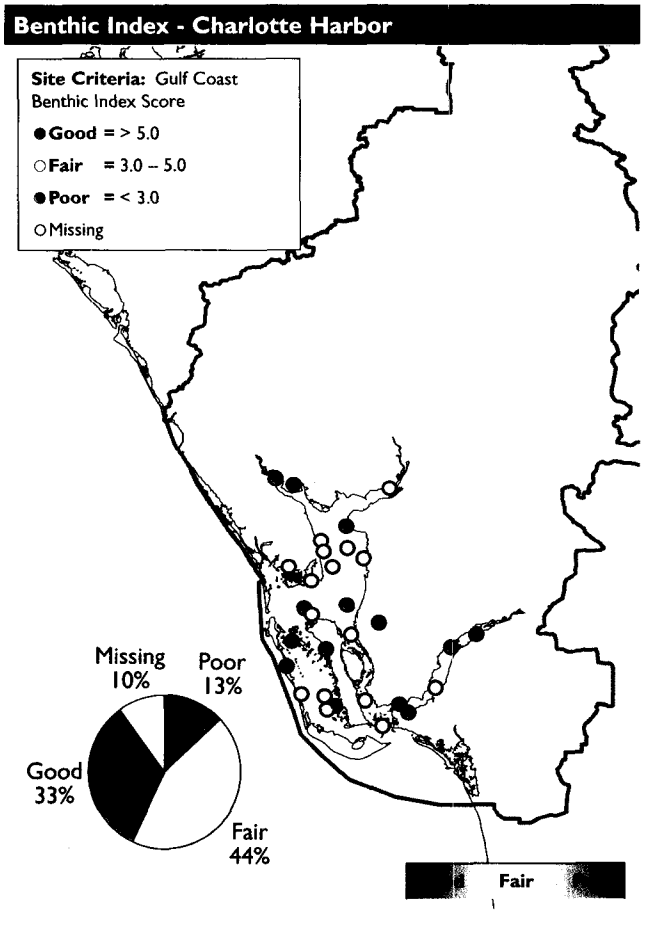


Figure 5-15. Benthic index data for Charlotte Harbor, 2002 (U.S. EPA/NCA).

The results from this monitoring program can be found at the following NEP-supported Web sites: http://www.checflorida.org and http://ws13.ipowerweb.com/checflor/chec/waterquality_home.htm.

Water and Sediment Quality

The presence of algal blooms; high concentrations of DIN, DIP, and chlorophyll *a*; and low levels of dissolved oxygen are the key indicators of potential eutrophic conditions in Charlotte Harbor. In recent decades, population growth, stormwater runoff from residential and commercial development, agricultural and industrial practices, and the burning of fossil fuels have been major sources of increased inputs of nutrients to Charlotte Harbor. Results from March 2004 show elevated levels of DIN and slightly higher than normal DIP concentrations in the Harbor, but normal chlorophyll *a* levels. Dissolved oxygen and turbidity values were rated better than normal by the CHNEP. The Caloosahatchee River basin has ongoing water quality problems, with excess nutrients, low dissolved oxygen, and noticeable increases in levels of copper and lead (CHNEP, 2005a). Recent maps of water and sediment quality indicators, as reported by the CHNEP on a monthly basis, can be found at http://www.chnep.org.

Declines in dissolved oxygen levels and worsening surface water quality were observed in the southern basins of Charlotte Harbor. Overall, there have been major increases in total suspended solids in the entire southern portion of the CHNEP estuarine area, including the full extent of Charlotte Harbor. Florida surface water standards have been exceeded frequently for dissolved oxygen (both instantaneous readings and daily average readings) and ammonia in many basins, and to a lesser extent, for chlorophyll *a* and bacteria levels (CHNEP, 2003b).

Habitat Quality

The natural habitats of the Charlotte Harbor estuarine area span a wide range of environments, from xeric oak scrubs to subtidal soft-bottoms to mangrove forests. Mangrove forests provide habitat for more than 2,300 species of animals, including at least 42 federally listed and state-listed endangered or threatened animal species, such as the Florida black bear, manatee, bald eagle, wood stork, Florida scrub jay, and American crocodile. In Charlotte Harbor, the acreage, type, and health of seagrass systems are monitored as one of the major indicators of estuarine condition. Informal habitat indicators monitored by the CHNEP include shellfish-area closures, number of fish kills, presence of fish lesions, acres of stable seagrass areas, and presence or lack of HABs (red tides). Some other useful response indicators include the effectiveness of riprap under docks, the effectiveness of artificial reefs in enhancing habitat value along seawalls, the length of shoreline restored, and the effectiveness of exotic vegetation removal (CHNEP, 2005a).

Seagrasses within the northern portion of the CHNEP study area have been found to be stable, and analysis is still being conducted on the southern portion of the area (CHNEP, 2005a). Seagrass habitats exist throughout all of the riverine and estuarine regions of the CHNEP study area, providing food sources, solid foundations, and protective structures for living resources. Historically, dredge-and-fill activities within coastal bottom and wetland areas have reduced the extent of these habitats. One specific goal of the CHNEP is to reduce propeller damage to SAV by 2010 (CHNEP, 2000). At the present time, the CHNEP's data is sufficient to evaluate significant losses of SAV acreage due to direct impacts, such as water management (e.g., losses in the Caloosahatchee River's *Vallisneria americana*) and channel and causeway island construction (e.g., losses in IntraCoastal Waterway and Sanibel Causeway). Dissolved and suspended matter within the water column, rather than chlorophyll *a*, largely limit light availability for seagrass beds in Charlotte Harbor, and water clarity in the Harbor increases with salinity and distance from the tributaries (McPherson and Miller, 1987; McPherson and Miller, 1994; Dixon and Kirkpatrick, 1999; Doering and Chamberlain, 1999; Tomasko and Hall, 1999); thus, seagrass coverage shows inter-annual variability largely due to inter-annual freshwater flow changes (Corbett et al., 2005). In some areas of Charlotte Harbor, unrestricted development has resulted in large losses of habitats, such as high marshes and salterns.

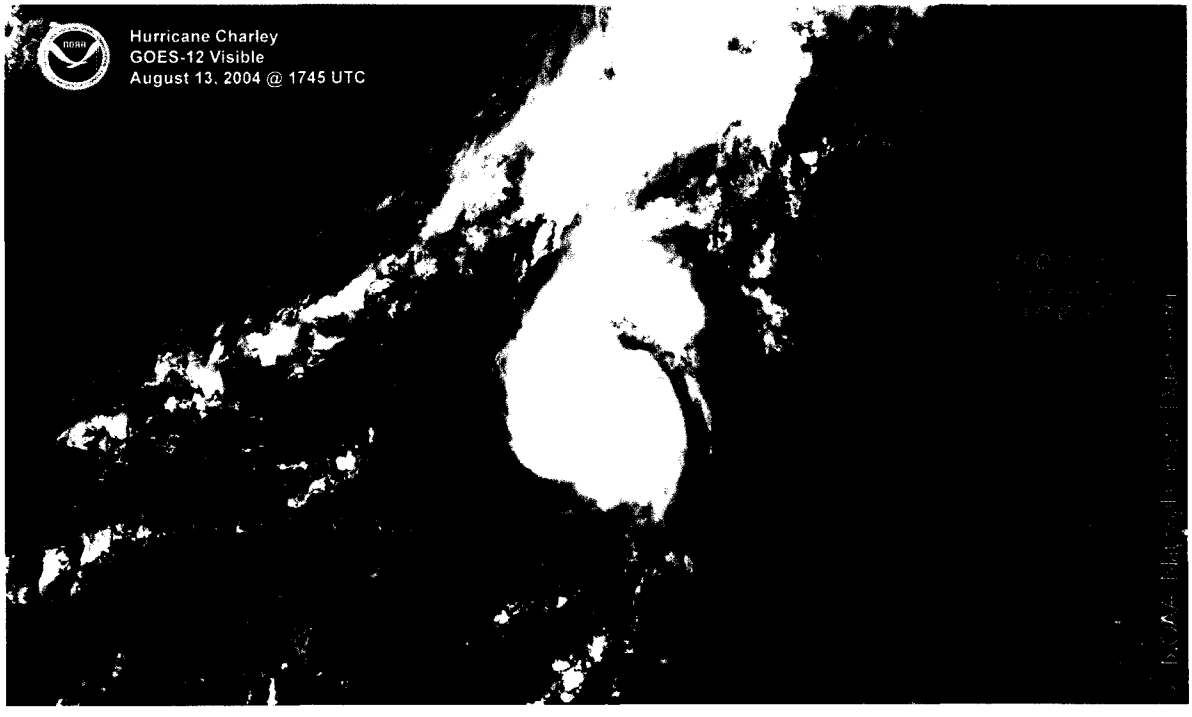
Charlotte Harbor National Estuary Program

HIGHLIGHT

Hurricanes and Hypoxia in 2004

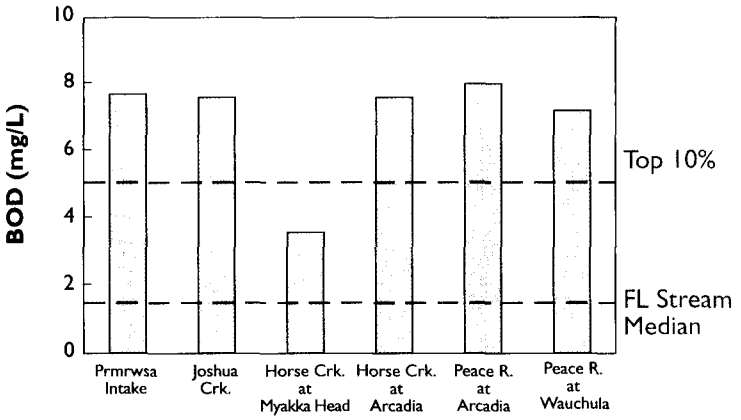
Over a two-month period in 2004, four major hurricanes and five named tropical storms battered Florida, with three hurricanes directly impacting the CHNEP study area (CHNEP, 2005b; Everham 2005). On August 13, 2004, Hurricane Charley—the strongest hurricane to hit the United States since Hurricane Andrew in 1992—passed through the heart of Charlotte Harbor (Pasch et al., 2005). The destruction from Hurricane Charley was not limited to the land and homes of the Charlotte Harbor watershed, but included damage to the Harbor and its rivers, creeks, and tributaries. Many of Charlotte Harbor's local islands, man-made canals, tributaries, and other waterways are lined with homes and boat docks. In calm weather, these settings provide an idyllic existence and magical vistas; however, the scenario changed in the face of Hurricane Charley, as waterways were made impassable by fallen trees, uprooted vegetation, and enormous quantities of debris (Fletcher, 2005).

One week after Hurricane Charley moved through Florida, state agencies began receiving complaints of foul-smelling water, prompting an unscheduled sampling effort that measured low dissolved oxygen levels for many areas of the estuary. Although the sampling found that turbidity and total suspended solid values for the estuary were not unusual, and that color was typical of values normally found during the wet season the biological oxygen demand (BOD) for the estuary was very high. The low dissolved oxygen values in Charlotte Harbor were associated with the decomposition of large amounts of dissolved organic matter that resulted in the high levels of BOD (see bar graph) (Tomasko et al., 2005b). Although hypoxia is a normal, wet season phenomenon in the Harbor (Camp Dresser & McKee, 1998) and a hypoxic zone was apparent in Charlotte Harbor two weeks after Hurricane Charley passed through the area (see map), hypoxia has never been recorded over such an extensive area of the Charlotte Harbor watershed (Tomasko et al., 2005b).

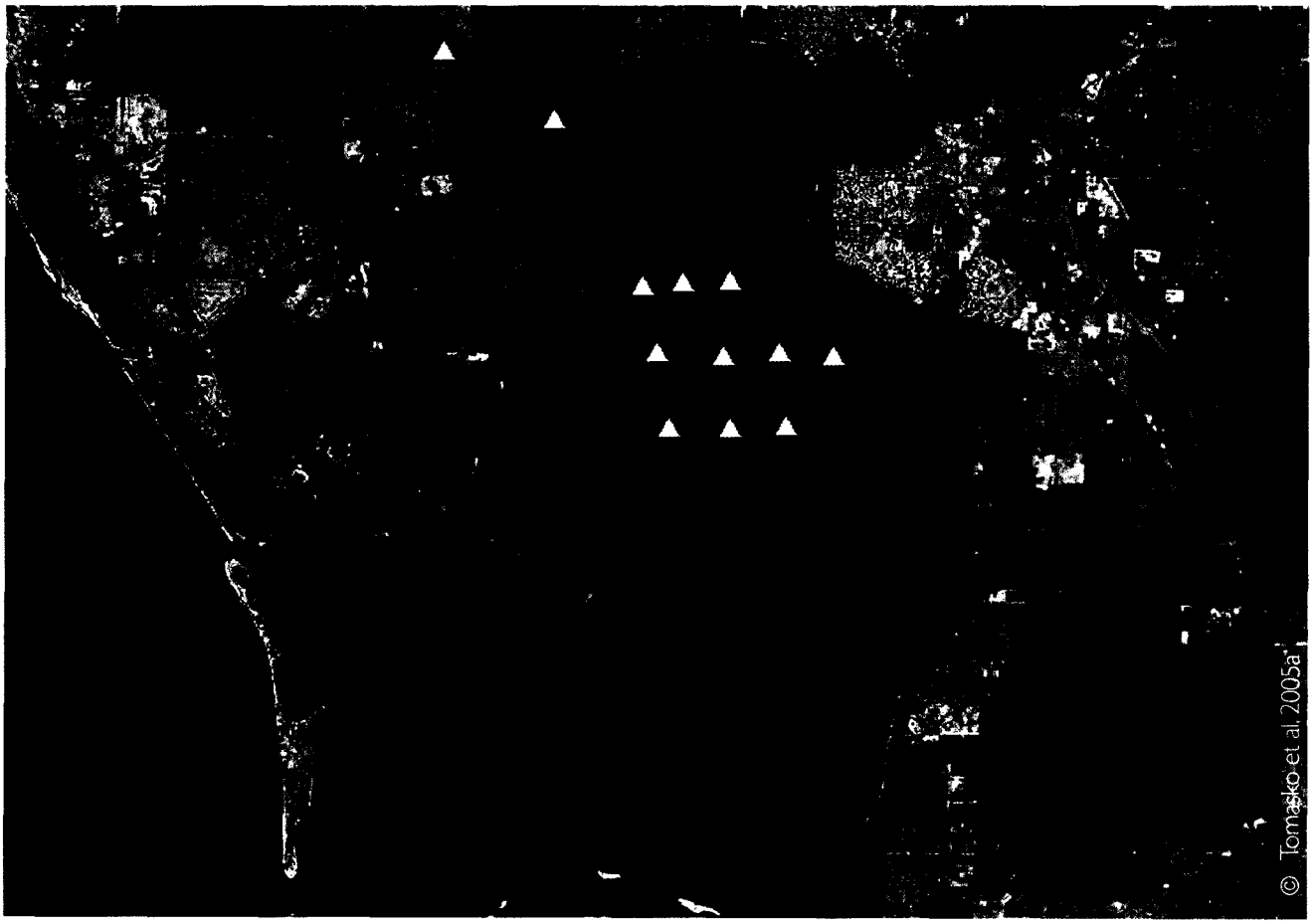


Satellite image of Hurricane Charley at landfall (NOAA National Climatic Data Center).

Subsequently, Hurricane Frances passed through Florida over the Labor Day weekend. Three weeks later, on National Estuary Day, Hurricane Jeanne followed Frances over the Peace River basin. The impacts of this string of hurricanes on the water quality of Charlotte Harbor were felt for months following the storms. Water quality characteristics in Charlotte Harbor, such as dissolved oxygen and water clarity, were degraded into the fall of 2004, but were showings signs of recovery by 2005 (Beever, 2005).



Five-day BOD values one week after Hurricane Charley (Tomasko et al., 2005a).



Large hypoxic zone (ca. 30 mi^2) apparent two weeks after Hurricane Charley. BLUE TRIANGLE: Sites with no hypoxia (DO < 2 mg/L) in surface or bottom waters. RED TRIANGLE POINTING UP: Sites with hypoxia in bottom waters only. RED TRIANGLE POINTING DOWN: Sites with hypoxia in both bottom and surface waters. YELLOW TRIANGLE: Sites not visited due to an oncoming storm. The red line delimits area believed to exhibit hypoxia for this event, based on event data and historical monitoring data demonstrating that hypoxia is associated with flows out of the Peace River and along the western "wall" of Charlotte Harbor. Some smaller areas (unknown in size) exhibited hypoxia in both bottom and surface waters (Tomasko et al., 2005a).

Living Resources

Charlotte Harbor provides habitat for 39 species of mammals, 331 species of birds, 67 species of reptiles, 27 species of amphibians, and 452 species of fish (CHNEP, 2005a); however, the growing human population and increasing urban development have resulted in habitat loss throughout the study area. This loss of habitat can negatively affect plant communities and wildlife. For example, since the 1920s, pine flatwoods habitat acreage has decreased; communities of pines, wax myrtle, and saw palmetto have been lost; and animals, including pileated woodpeckers, American kestrels, sandhill cranes, black bears, panthers, indigo snakes, and gopher tortoises, have been displaced (CHNEP, 2000).

Shellfish are a reliable measure of the environmental health of an estuary. Because they feed by filtering estuary water, shellfish assimilate and concentrate the materials carried in the water in their tissues. More than 275 species of shellfish are found throughout the waters of Charlotte Harbor. People have been harvesting shellfish in the area since the Calusa Indians of southwest Florida gathered enormous amounts of shellfish by digging canals and constructing immense shell mounds. In the more recent past, oysters, clams, and scallops have been harvested commercially and recreationally throughout Lemon Bay, Gasparilla Sound, Charlotte Harbor, and Pine Island Sound. The height of the shellfish industry in the Charlotte Harbor area occurred during the 1940s, and the commercial harvest of shellfish has declined since that time (CHNEP, 2000).

Environmental Stressors

Adverse changes in the location, timing, and volume of freshwater flows; overall function of flood plain systems; and natural river flows are the major hydrologic concerns in Charlotte Harbor. Man-made canals and waterfront lots are two major developments that alter surface water hydrology and degrade estuarine conditions in Charlotte Harbor. The construction of drainage channels for transportation, agricultural activities, urbanization, and hurricane flood relief have been just as prevalent. Although changes to groundwater systems in the Charlotte Harbor watershed have been less obvious, the increased drainage of surface systems reduces recharge to groundwater, altering the general flow of underground aquifers. Saltwater intrusion is an indicator of these changes.

Hydrologic alterations have occurred in many regions of the Charlotte Harbor area. For example, the Caloosahatchee River was channelized and artificially connected to Lake Okeechobee in the late 1800s and early 1900s to provide flood protection, serve as a navigational channel, and supply water for agricultural and

Prop roots of mangrove trees below the water surface provide substrate for many other organisms (CHNEP)

urban use. Three locks and dams have been constructed along the Caloosahatchee River, one of which artificially truncates the river's estuarine system by blocking the natural gradient of fresh water to salt water that historically had extended upstream during the dry season. The flow through this river is highly manipulated because water management juggles the often conflicting needs of estuary resources, public water supply, and agricultural uses (CHNEP, 2003a). In addition, the upper Peace River has changed from a gaining stream with flow all year long to a losing stream with river flows being lost in sinkholes along the upper Peace River. Kissingen Springs, located along the upper Peace River, ceased flowing in the early 1950s, which is a sign of a lowered groundwater table in the Charlotte Harbor watershed (Corbett, 2003). The Myakka River flows have been artificially augmented because of the overland surface flow of groundwater pumped for agricultural use in the dry season. Also, the upper Myakka River demonstrates an increasing trend in specific conductivity (sulfate and calcium levels), and an extensive tree die-off has occurred in this area due to hydrologic stress (CHNEP, 2003b; Minnis, 2003).

Current Projects, Accomplishments, and Future Goals

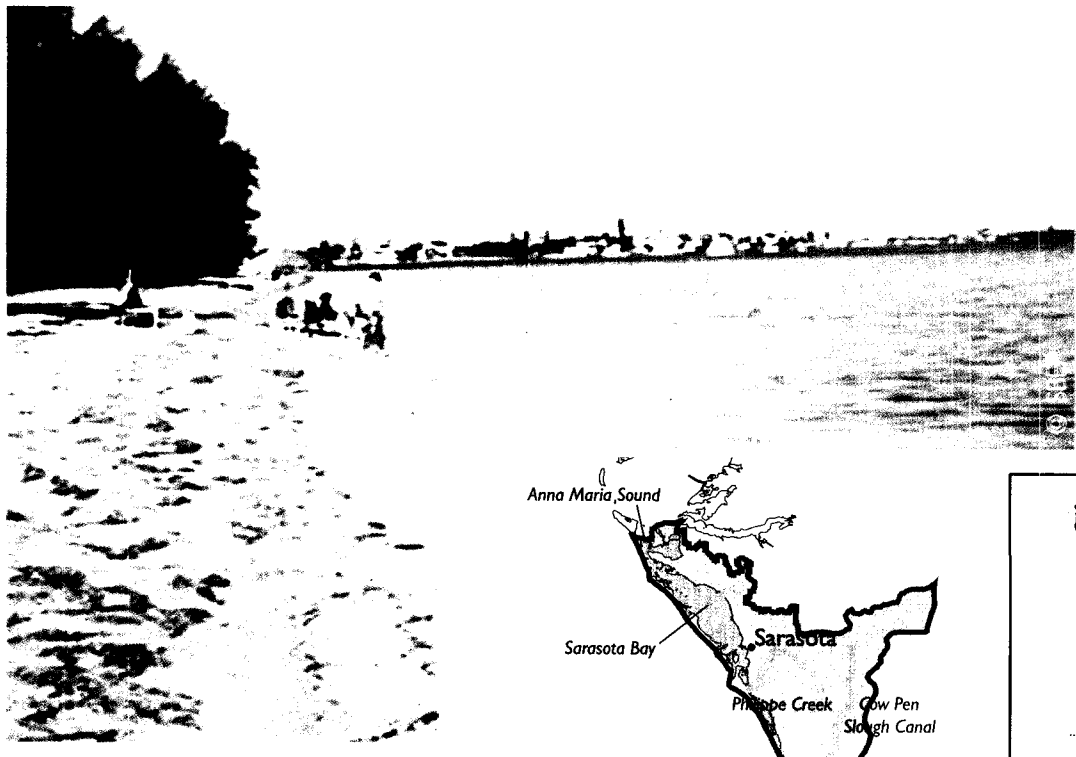
The CHNEP set a variety of goals in *Committing to Our Future: A Comprehensive Conservation and Management Plan for the Greater Charlotte Harbor Watershed, Volume 1* (CHNEP, 2000). A goal of the CHNEP is to increase conservation, preservation, and stewardship lands by 25% by the year 2018. To combat hydrological alterations, the CHNEP plans to improve waterbodies affected by artificial structures by the year 2020. To help improve water quality, the program will gather information for the State of Florida to use in developing TMDLs (except for mercury) for high-priority, 303(d)-listed water segments by 2004 and for all remaining 303(d) waters in the CHNEP estuarine area by 2009. The CHNEP also plans to develop a sense of stewardship by providing information on living resources and water quality to the public, as well as by maintaining environmental education efforts with partners (CHNEP, 2000).

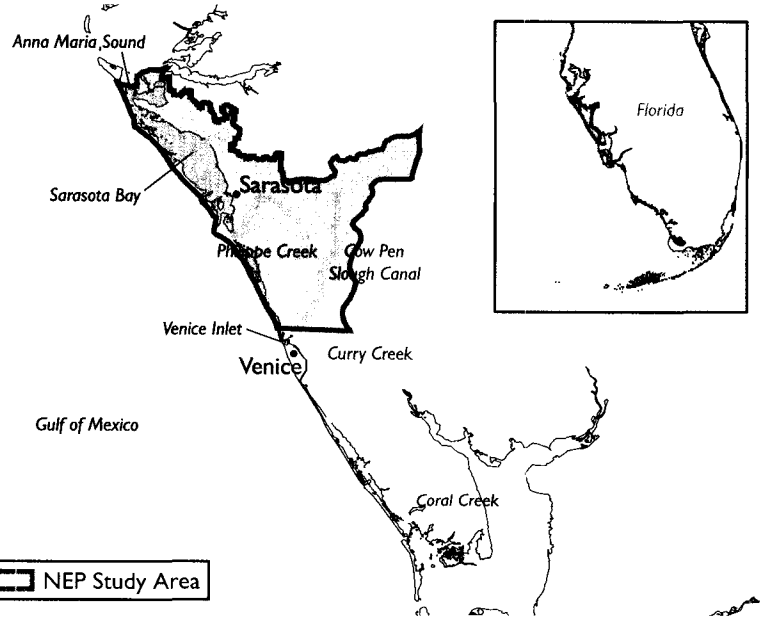
Conclusion

Urban development in the Charlotte Harbor study area has been rapid and has contributed to water quality degradation, habitat loss, and hydrologic changes. In addition, there have been ongoing declines in water quality in many of the Charlotte Harbor basins. NCA data classify the overall condition of Charlotte Harbor as fair. Water quality in the Harbor is rated poor, with DIN concentrations rated good; chlorophyll *a* and dissolved oxygen concentrations rated fair; and DIP concentrations and water clarity rated poor. Sediment quality in the Harbor is rated good; however, this rating is based only on measurements of one sediment quality component indicator (sediment TOC). The benthic index is rated fair, and 2002 NCA data were unavailable to develop a fish tissue contaminants index for Charlotte Harbor.

A young student conducts water quality tests in Charlotte Harbor (CHNEP).

Sarasota Bay Estuary Program





SARASOTA BAY
ESTUARY PROGRAM
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Background

Sarasota Bay is a small, subtropical estuary that is located on the southwestern coast of Florida and covers 52 mi^2 of surface water area. The Bay's watershed spreads across Manatee and Sarasota counties and covers 150 mi^2 of land area. This watershed extends from Venice Inlet to Anna Maria Island and includes the barrier islands and mainland east to Interstate 75 (SWFWMD, 2002). Sarasota Bay is classified as an Outstanding Florida Water Body and was classified as an Estuary of National Significance in 1987 (SBNEP, 2000; FDEP, 2005). The Sarasota Bay Estuary Program (SBEP) estuarine area includes Sarasota, Roberts, Little Sarasota, and Blackburn bays, which are characterized by stretches of barrier islands. The Bay region is home to a wide variety of marine life, including dolphins, manatees, black mullet, red drum, spotted sea trout, snook, blue crab, stone crab, bait shrimp, and the endangered loggerhead sea turtle. Common birds in this region include the great blue heron, cattle egret, great egret, white ibis, brown pelican, osprey, wood stork, yellow-crowned night heron, bald eagle, and the endangered Florida scrub jay.

Sarasota Bay proper is the largest and deepest bay between Tampa Bay and Charlotte Harbor. The Bay is well flushed by three passes (Big Sarasota, New, and Longboat), and its water is much clearer than the waters of the smaller bays to the south (Roberts, Little Sarasota, and Blackburn bays) (Florida Center for Community Design and Research, 2004). Improved drainage levels in the urban watersheds around Sarasota Bay provide more fresh water than historical levels, and numerous improvements have been made in the Bay's water quality, seagrass coverage, and natural habitat areas. Most of the waterbodies in the SBEP estuarine area are designated as recreational-use waters, which means that waters should be fishable and swimmable. Some waterbodies, including Palma Sola Bay and parts of Sarasota Bay, are suitable for shellfish propagation or harvesting (U.S. EPA, 2005c). Of all of the Gulf Coast NEP estuaries, the Sarasota Bay watershed has the greatest percentage of urban land use.

The tourism industry is the largest industry in Sarasota County and the second-largest industry in Manatee County. Seasonal residents are estimated to represent up to 25% of the study area's total population and more than 70% of the population on the barrier islands. Although this multi-million dollar industry helps to raise the revenue used to fund monitoring and conservation efforts, tourism and recreational activities can also take a toll on the water quality, habitat, and wildlife of Sarasota Bay. Human activities, including the management of waste and the operation of automobiles and watercraft, can contribute nitrogen and other contaminants to Sarasota Bay and degrade the Bay's water quality. In addition, dredging has been conducted in the area to create navigable waterways and new home sites and has destroyed habitat and reduced the populations of fish and shellfish in the Bay (SBNEP, 2000). Tourism and recreational activities can also directly harm wildlife; for example, more than 30% of the annual manatee deaths in Sarasota Bay are caused by collisions with boats (Sarasota Dolphin Research Program, 2005).

Environmental Concerns

Population increases and the accompanying development around Sarasota Bay between 1930 and 1990 resulted in the loss of historic seagrass habitat and mangrove wetlands (SBNEP, 2000). For example, 2,495 acres of tidal wetlands were lost between 1950 and 1990 due to dredge-and-fill activities, construction, and invasive species (SBNEP, 1992). Over time, loss of habitat areas has been accompanied by declines in marine life, fish, birds, and shellfish. Increased development has also resulted in excess nitrogen pollution and stormwater runoff, both priority concerns of the SBEP. Nitrogen is the major pollutant of concern in Sarasota Bay, with nitrogen loads transported to the Bay through baseflow, wastewater, stormwater, and atmospheric deposition (Figure 5-16) (SBNEP, 2000). In 1990, nitrogen loadings were approximately 300% of the levels that existed prior to development of the region (U.S. EPA, 2005b), and loadings are projected to increase by another 8% during the next 20 years and by 16% when the area is fully developed according to existing plans. Tributaries to Sarasota Bay act as pipelines for dispensing stormwater and suspended matter into the estuary. Although the overall trophic status index for Sarasota Bay is good, the Bay segments that receive water from the tributaries have the poorest water quality. Chlorinated pesticides, PAHs, and metals have been found in tributary sediments; those tributaries with the highest levels of these contaminants are Hudson Bayou, Cedar Hammock Creek, and Whitaker Bayou (Lowrey et al., 1992).

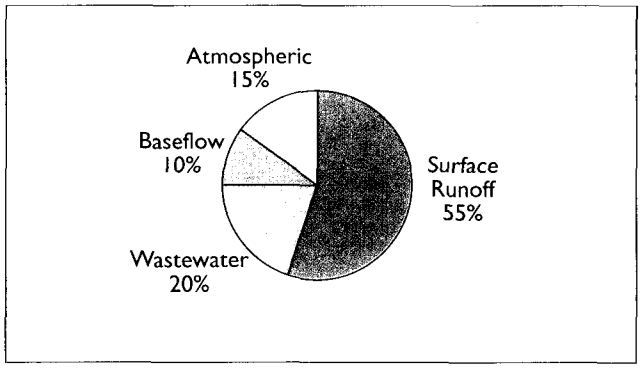


Figure 5-16. Percentages of nitrogen distributed to Sarasota Bay (SBNEP, 2000).

Sarasota Bay Estuary Program

Population Pressures

The population of the 2 NOAA-designated coastal counties (Manatee and Sarasota) coincident with the SBEP study area increased by 304% during a 40-year period, from 0.14 million people in 1960 to 0.59 million people in 2000 (Figure 5-17) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the SBEP study area substantially exceeded the population growth rate of 133.3% for the collective NEP-coincident coastal counties of the Gulf Coast region and was the highest rate of population growth for any of the individual Gulf Coast NEPs. In 2000, the population density of these 2 coastal counties was 447 persons/mi^2, significantly higher than the population density of 287 persons/mi^2 for the collective NEP-coincident coastal counties of the Gulf Coast region (U.S. Census Bureau, 2001). Development and population pressures are especially strong in NEP study areas that serve as major shipping centers for commercial and recreational activities.

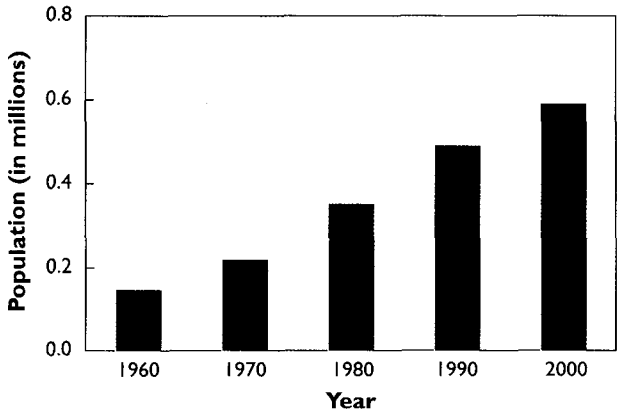


Figure 5-17. Population of NOAA-designated coastal counties of the SBEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Sarasota Bay

The overall condition of Sarasota Bay is rated fair based on three of the four indices of estuarine condition used by the NCA (Figure 5-18). The water quality index for Sarasota Bay is rated fair, the sediment quality index is rated good, and the benthic index is rated poor; no data were available to calculate a fish tissue contaminants index for this estuary. Figure 5-19 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 collected by the Florida Fish and Wildlife Research Institute, in partnership with the NCA, from 20 stations sampled in the SBEP estuarine area in 2000. 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.

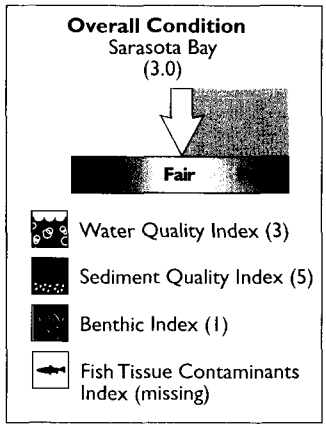


Figure 5-18. The overall condition of the SBEP estuarine area is fair (U.S. EPA/NCA).

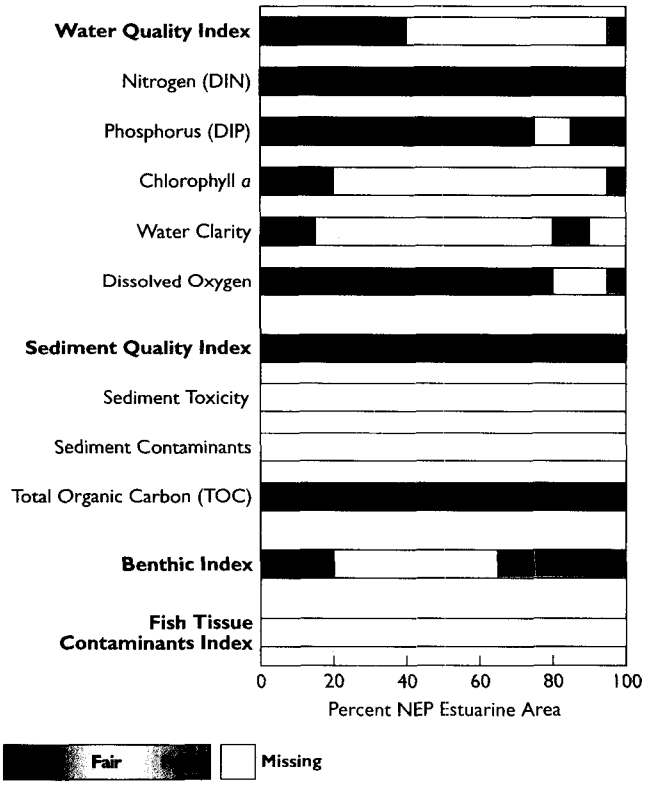


Figure 5-19. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Sarasota Bay (U.S. EPA/NCA).

Water Quality Index

Based on NCA survey results, the water quality index for Sarasota Bay is rated fair (Figure 5-20). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. In NOAA's Estuarine Eutrophication Survey, Sarasota Bay was listed as having medium DIN concentrations, high DIP concentrations, and high chlorophyll *a* levels (NOAA, 1997). Results from the 2000 NCA survey show some improvement over the previous study, with low DIN, moderate DIP, and moderate chlorophyll *a* concentrations measured.

Dissolved Nitrogen and Phosphorus | Sarasota Bay is rated good for DIN concentrations, with 100% of the estuarine area rated good for this component indicator. NCA data for Sarasota Bay were collected in the summer, when elevated DIN concentrations are less likely to occur because freshwater inputs are low and dissolved nutrients are more rapidly utilized by phytoplankton populations. Sarasota Bay is rated fair for DIP concentrations, with 15% of the estuarine area rated poor, 10% of the area rated fair, and 75% of the area rated good for this component indicator.

Chlorophyll a | Chlorophyll *a* concentrations in Sarasota Bay are rated fair. Although only 5% of the estuarine area was rated poor for this component indicator, 75% was rated fair, and 20% was rated good.

Water Clarity | Water clarity in Sarasota Bay is also rated fair; however, expectations for water clarity are high because one of the goals of the SBEP is to re-establish SAV. Water clarity in Sarasota Bay was rated poor at a sampling site if light penetration at 1 meter was less than 20% of surface illumination. Ten percent of the estuarine area was rated poor for water clarity, 15% of the area was rated good, and 65% of the area was rated fair. NCA data on water clarity were unavailable for 10% of the SBEP estuarine area.

Dissolved Oxygen | Dissolved oxygen conditions in Sarasota Bay are rated fair. NCA estimates show that 5% of the estuarine area was rated poor for dissolved oxygen concentrations, 15% of the area was rated fair, and 80% of the area was rated good.

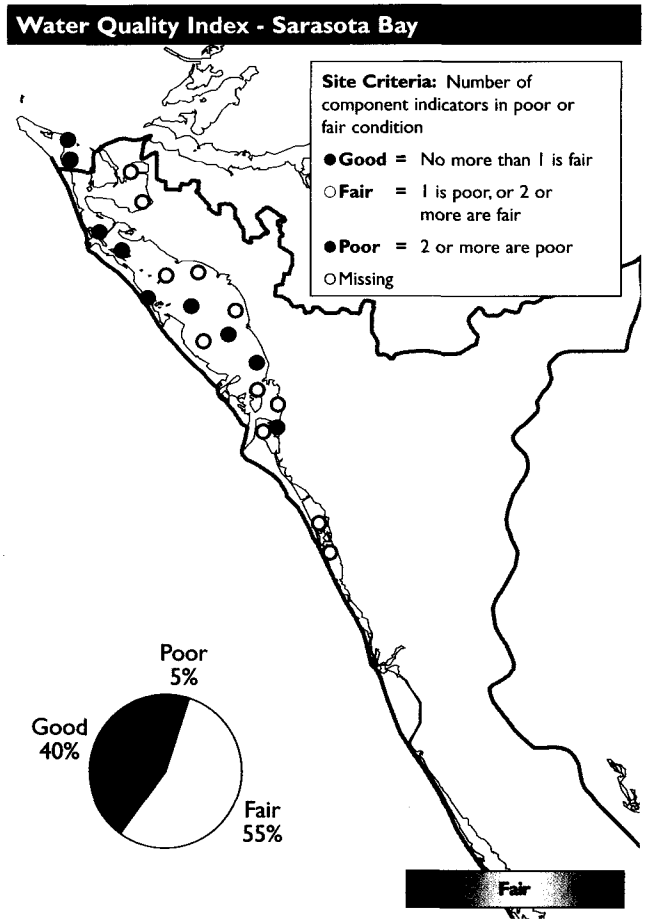


Figure 5-20. Water quality index data for Sarasota Bay, 2000 (U.S. EPA/NCA).

Sediment Quality Index

The sediment quality index for Sarasota Bay is rated good; however, this rating is based on measurements of sediment TOC only (Figure 5-21). Sediment quality was rated good in 100% of the Bay's estuarine area.

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

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

Total Organic Carbon | Sediment TOC concentrations were the only sediment quality component indicator monitored in Sarasota Bay by the NCA in 2000. TOC concentrations in Sarasota Bay sediments are rated good, with 100% of the estuarine area rated good for this component indicator.

Benthic Index

The condition of benthic invertebrate communities in Sarasota Bay is rated poor, based on the Gulf Coast Benthic Index and data from the NCA. Benthic index estimates indicate that 35% of the estuarine area in Sarasota Bay has degraded benthic resources and is rated poor (Figure 5-22).

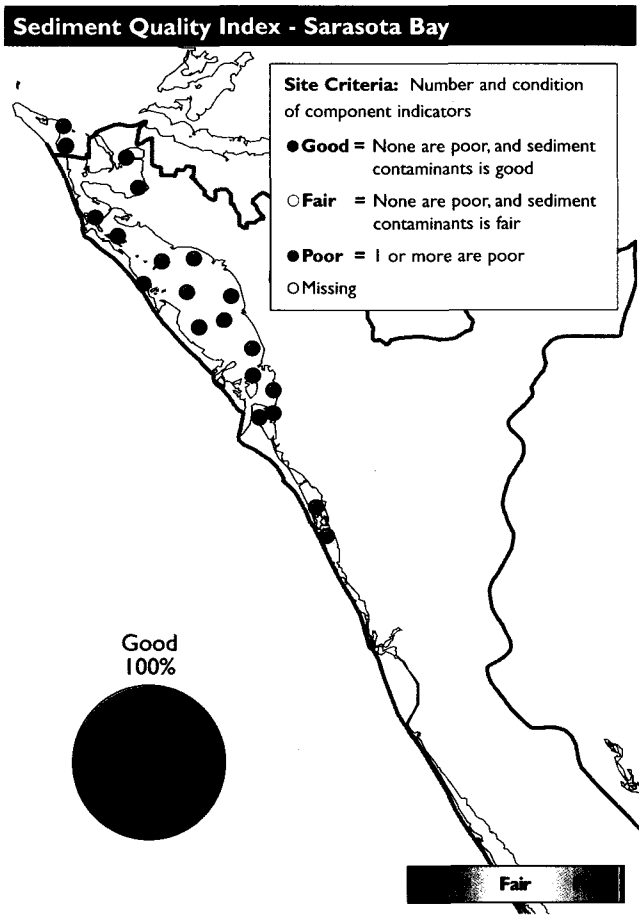


Figure 5-21. Sediment quality index data for Sarasota Bay, 2000 (U.S. EPA/NCA).

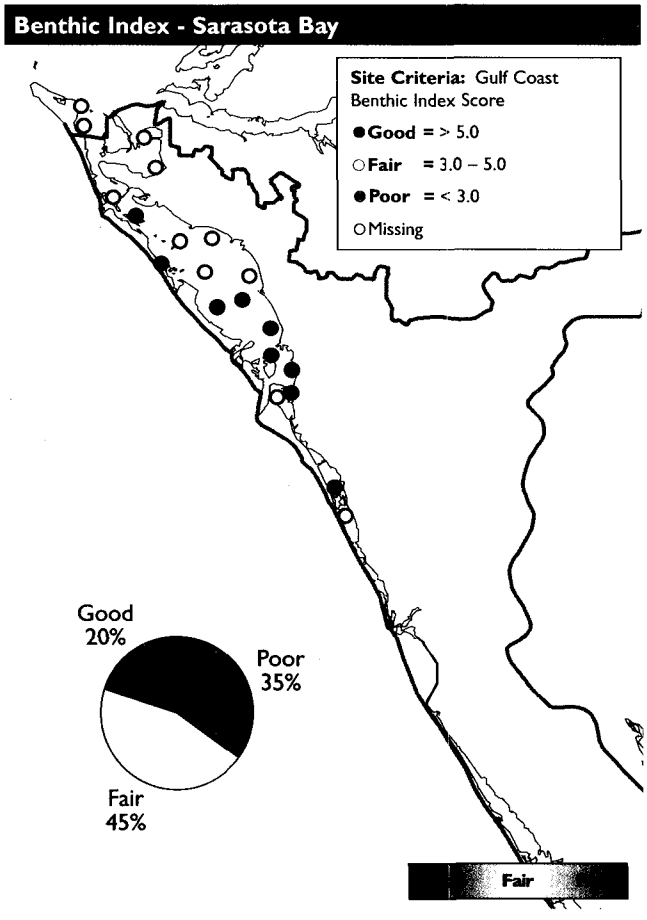


Figure 5-22. Benthic index data for Sarasota Bay, 2000 (U.S. EPA/NCA).

Fish Tissue Contaminants Index

The NCA did not assess the level of fish tissue contaminants in the SBEP estuarine area in 2002; therefore, a fish tissues contaminants index for Sarasota Bay was not developed for this report.

Sarasota Bay Estuary Program Indicators of Estuarine Condition

Water and Sediment Quality

The SBEP's specific indicators for measuring water quality in Sarasota Bay are the following:

- Chlorophyll *a*
- Nitrogen (e.g., DIN levels, total nitrogen levels, nitrogen load)
- Inorganic phosphorus
- Transparency (as measured using Secchi depth).

In general, water quality trends for Sarasota Bay have shown improvements with time. Data from 1968 through 1991 indicate that nutrient and chlorophyll *a* levels are decreasing in the Bay, and Secchi depths are increasing over time. For northern Sarasota Bay, regional trends in chlorophyll *a* levels, inorganic nitrogen, organic nitrogen, total nitrogen, and inorganic phosphorus have been declining since 1980; however, Manatee County data have shown significant increases in these parameters. The middle portion of Sarasota Bay has displayed declining trends similar to those observed in the northern portion of the Bay, with the exception of chlorophyll *a* and total phosphorus concentrations, which were increasing. SBEP data for the southern portion of Sarasota Bay indicate a regional increase in both chlorophyll *a* and ammonium nitrogen levels. Other significant improvements observed in the trend analysis for the southern portion of the Bay were long-term declines in nitrate-nitrite, total nitrogen, and inorganic phosphorus. The transparency of Sarasota Bay waters is measured by Secchi depth and can be used to help indicate overall water quality or the effects of erosion and increased rainfall. Data from 1968 to 1991 show that Secchi depth has increased (greater water transparency) in all segments that demonstrated significant trends (Lowrey et al., 1992), and recently collected monthly data show that Secchi depth generally fluctuates between 4 and 8 feet (Florida Center for Community Design and Research, 2004). Trend analyses that examined data from 1980 to 2002 suggest that inorganic nitrogen and chlorophyll *a* levels have declined during the long term; inorganic phosphorus levels have also declined, although increases were noted in total phosphorus, particularly from 1995 to 2002 (Dixon, 2003).

In addition to the SBEP's formal indicators, other water quality parameters monitored for the Bay include salinity, temperature, dissolved oxygen, pH, *Enterococci*, and fecal coliform. Salinity in the Bay has increased over time, except for the period from 1995 to 1998, when salinity declined (Dixon, 2003). Beach water samples are collected every 2 weeks at 14 different beach sites in Sarasota County and are analyzed for *Enterococci* and fecal coliform bacteria (Florida Center for Community Design and Research, 2004).

A great egret (*Ardea alba*) hunts in the waters of an SBEP restoration site (SBEP).

Sarasota Bay Estuary Program

HIGHLIGHT

Improving Water Quality in the Sarasota Bay Watershed

Reducing nitrogen inputs to Sarasota Bay has been recognized as a primary water quality concern since the 1980s. A central tenet of these reduction efforts has been to address all contributors to water quality degradation in the restoration of Sarasota Bay. Nutrient loads in Sarasota Bay in 1988 were approximately 400% higher than those expected from a pristine, undeveloped watershed (SBNEP, 2000). By comprehensively addressing the sources of nitrogen and other pollutants, the water quality throughout most of Sarasota Bay has steadily improved during the past decade.

The SBEP and its partners have been working with the community to cost-effectively limit and control the amount of nitrogen entering Sarasota Bay. The integration of different water quality improvement components that address wastewater, stormwater, groundwater, and atmospheric deposition as a whole is an important step to ensure that issues of timing, cost, and effectiveness are considered.

The widespread implementation of advanced wastewater treatment, required by federal legislation in 1990, resulted in reductions of more than 80% of nitrogen loadings from wastewater to Sarasota Bay. At the present time, stormwater from all areas is the primary source of nitrogen pollution, with stormwater from residential areas estimated to contribute more than

Urban stormwater runoff deposits large amounts of sediments and other pollutants into Sarasota Bay through drainage ditches (above) and tributaries (Gary Raulerson, SBEP).

one-third of the total nitrogen load to Sarasota Bay. Currently, an unquantified number of stormwater pipelines that discharge directly into Sarasota Bay or its tributaries do not receive any type of wastewater treatment (SBNEP, 2000). Beginning in September 2005, a new SBEP project will identify and prioritize water quality control retrofits for urban stormwater, especially in direct-discharge locations. Information to be gained will include project price, maintenance accessibility, and a receiving water of high resource value. This information can be used by local, state, and federal agencies to help determine where to direct resources to continue the restoration of Sarasota Bay.

The Florida Yards and Neighborhoods (FYN) Program was developed in 1993 to promote environmentally friendly landscaping using plants suited to the southwest Florida climate, natural conditions, and wildlife. Using FYN's principles, homeowners can reduce fertilizer and pesticide use, thereby helping to maximize the quality of stormwater runoff. Improvements in stormwater conveyance and treatment systems also impact water quality. Designed primarily for flood and sediment control, these systems have an important effect on toxic loading, as well as a smaller, but significant impact on nutrients.

The SBEP is also pursuing other management strategies, including septic tank replacement (such as that currently underway within the Phillippi Creek watershed). This strategy is being pursued primarily from a public health perspective, but should also reduce nitrogen loadings to Sarasota Bay. Regionally instituted water conservation policies can also help improve the water quality of Sarasota Bay. Through the creation and implementation of a master reuse plan, the discharge of wastewater to the Bay is being substantially reduced. At the same time, this wastewater is offsetting withdrawals from the Floridian aquifer.

Human-related atmospheric deposition (from auto emissions, industry, and other sources) plays a role within the Sarasota Bay watershed; however, this role is not as large as previously believed. Although nitrogen emissions from automobiles and other mobile sources (such as lawn mowers) may not be as great as originally thought, this may become an important area for further reductions.

Sarasota Bay Estuary Program

Habitat Quality

The following indicators are used to evaluate habitat quality in Sarasota Bay:

- Freshwater wetlands coverage
- SAV (seagrass) coverage
- Intertidal habitat coverage
- Abundance of juvenile fish in restored areas vs. abundance in natural areas
- Effectiveness of artificial reef construction.

Freshwater wetlands have declined 16% since 1975, and non-forested freshwater wetlands have declined by 35% (U.S. EPA, 2005b). Since 1950, the area of saltwater wetlands in Sarasota Bay has declined 39%, and seagrass acreage has generally declined by 30%, mainly due to nitrogen pollution and dredging impacts (SBNEP, 2000). Seagrass coverage in the Bay is an indicator of the success or failure of restoration activities and the area of suitable habitat, as well as an indirect indicator of the effects of water quality changes, sediment contamination, or other human-induced impacts on the ecosystem.

Approximately every 2 years, the Southwest Florida Water Management District (SWFWMD) uses aerial photography to analyze seagrass communities in waterbodies (including Sarasota Bay) located within its watershed. The SWFWMD's analysis distinguishes between patchy seagrass beds (less than 75% coverage within a given area) and continuous seagrass beds (greater than 75% coverage within a given area). Since 1988, approximately 600 new acres of seagrasses have appeared in the Sarasota Bay estuarine area. Additionally, the amount of continuous seagrass beds in Sarasota Bay has increased by more than 120% (SBEP, 2006). Figure 5-23 illustrates the percent changes in seagrass coverage in Sarasota Bay (from the Anna Maria Sound at State Road 64 to Venice Inlet), both for continuous and patchy distributions of seagrass.

At least 15 artificial reefs are being established in Sarasota Bay to help create additional juvenile fish habitat (U.S. EPA, 2005b). To help monitor the abundance of fish species in natural areas in comparison with fish abundance in restored areas, the SBEP continues to study the effectiveness of artificial structures in providing juvenile fish nursery habitat. The SBEP, with funding from EPA and the Florida Department of Environmental Protection (FDEP), has sponsored the development of inexpensive seawall modules to attract larval, juvenile, and adult fish. An early pilot project demonstrated the potential benefit of deploying artificial reefs along hardened seawalls, with some types of structures showing fish abundances more than 100 times that of nearby areas without artificial reefs (SBNEP, 2000). In a recent shoreline survey, researchers found that more than 200 miles of armored and altered shoreline exist in Sarasota Bay (U.S. EPA, 2003); altered shorelines typically do not provide enough complex or suitable habitat for fish.

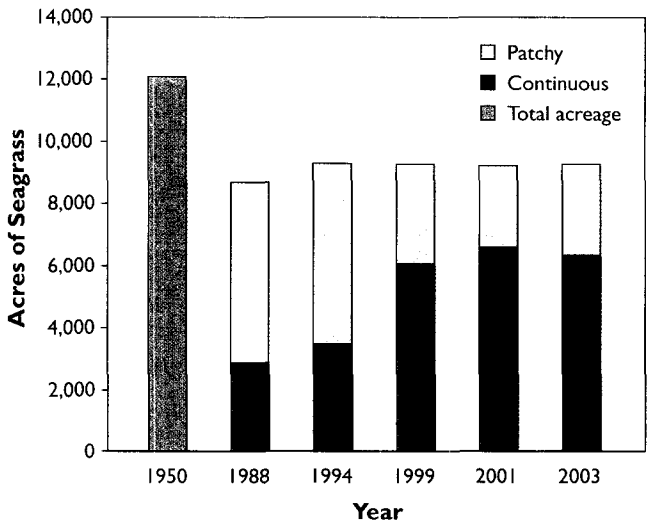


Figure 5-23. Changes in continuous, patchy, and total seagrass coverage areas in Sarasota Bay (SBEP, 2006).

Living Resources

Sarasota Bay is home to a variety of fish and wildlife, including the great blue heron, cattle egret, bald eagle, Florida scrub jay, red drum, spotted seatrout, flounder, blue crab, manatee, and bottlenose dolphin. The SBEP and other organizations monitor the populations of fish and wildlife in the SBEP study area.

Aerial surveys used to monitor manatee populations in Sarasota Bay indicate that the number of manatees in the Bay has increased since the early 1990s (Florida Center for Community Design and Research, 2004). Manatees are typically found along the fringes of the Bay from April to December, with seasonal migration patterns reducing the number of manatees in the Bay between January and February.

The bottlenose dolphins that use Sarasota Bay have been monitored since the 1970s, and mark-recapture estimates in 1976 and 1983 indicated that about 100 dolphins were present on a regular basis. Since 1984, researchers have monitored individual dolphins using distinctive dorsal fin features. The bottlenose dolphin population in Sarasota Bay has increased since the mid-1990s due to the dolphin immigration from other areas, seasonal migration patterns of dolphins from Tampa Bay, and high birth rates of native dolphins. These increases correlate with presumed fish stock increases since the net ban, but cause-effect relationships have not been conclusively established (Florida Center for Community Design and Research, 2004).

Current Projects, Accomplishments, and Future Goals

Much of Sarasota Bay's habitat for young fish was recently destroyed when the natural mangrove shoreline was replaced by concrete seawalls during the development of waterfront communities. As a result, the SBEP is embarking on an artificial habitat enhancement and wetland restoration strategy to increase its young fish population and overall fishery production. A recent study by the SBEP indicated that intertidal restoration sites less than 10 years old provide habitat for more than 68,000 fish per acre (Serviss and Sauers, 2003). Because most of the seawalls cannot be removed without causing severe damage to homes, the SBEP seeks to convert them into an asset for the Bay rather than a liability. Four different styles of small artificial reefs attached to seawalls are being tested for their ability to provide a home for young fish (SBNEP, 2000). Early results show more than 400 young fish living near these artificial reefs (U.S. EPA, 2006d), whereas only a few young fish have been seen in similar areas without reefs.

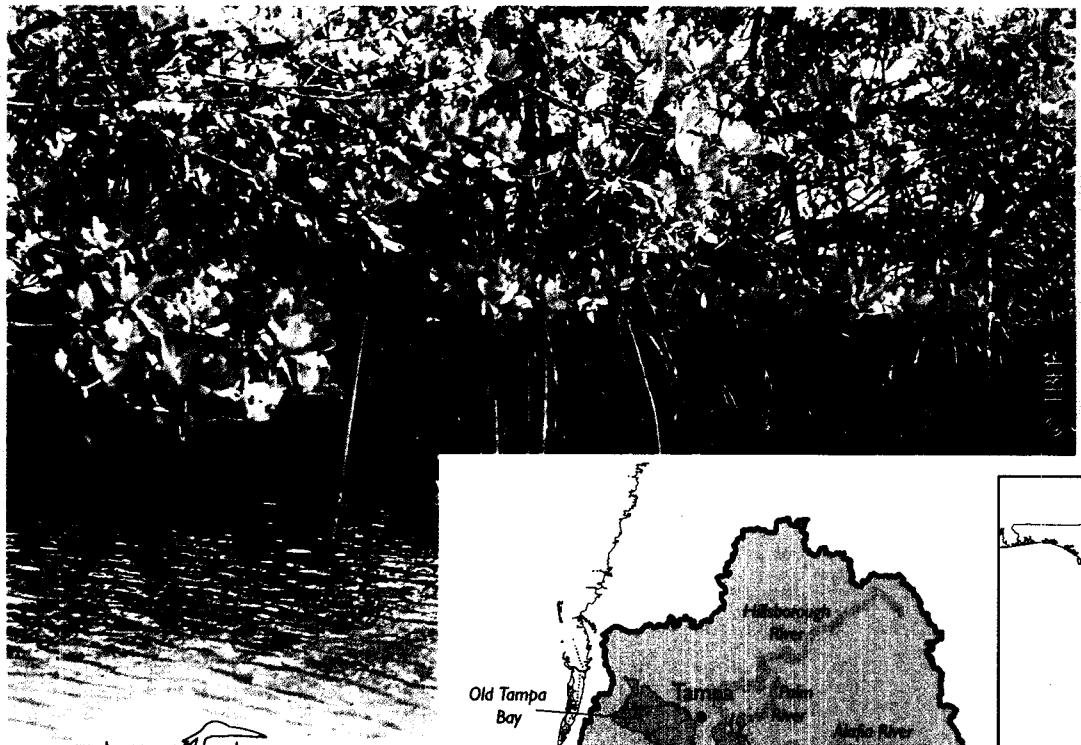
EPA plans to restore or create at least 18 acres of intertidal wetlands and 11 acres of non-forested, freshwater wetlands per year, as well as to increase the quantity, improve the quality, and protect the diversity of freshwater and saltwater wetlands in the Sarasota Bay watershed (U.S. EPA, 2005b). Twenty-one wetland-enhancement projects have been proposed and funded since 1989, and 13 significant habitat-restoration initiatives have been completed, with 12 more initiatives currently in the design phase (SBNEP, 2000; U.S. EPA, 2005b). In addition, new channel markers are being installed in Sarasota Bay (with artificial reefs built on each) to protect seagrass beds. The SBEP and the surrounding community has achieved a number of environmental success stories:

- Nitrogen pollution to the Bay has been reduced by 47% since 1990
- Seagrass habitat has increased by 7% (592 acres) since 1988
- More than 200 acres of intertidal wetland habitat have been restored since 1990
- More than 20 artificial reef projects have been permitted and constructed
- The Bay supports an estimated 110 million more fish, 71 million more crabs, and 330 million more shrimp than it did in 1988
- Several urban watershed areas around Sarasota Bay have been retrofitted for improved stormwater management
- Scallops have been reintroduced to the Bay to re-establish stocks
- SBEP policies have been integrated into local government CCMPs (SBNEP, 2000; SBEP, 2006).

Conclusion

Based on NCA survey results, the overall condition of Sarasota Bay is rated fair. SBEP analyses have shown that although temporal trends by segment indicate that water quality in Sarasota Bay is improving, water quality problems still exist in the tributaries and the Bay segments receiving water from the tributaries. Seagrass coverage in Sarasota Bay has improved substantially in the past few years, with declines in SAV occurring at a much slower rate. Although there is no substitute for natural habitat with respect to the diversity and productivity of organisms, engineering options for some environments (e.g., dredge holes, canal communities, and channel markers) exist to create artificial habitats for juvenile and adult finfish, shellfish, and other invertebrates.

Tampa Bay Estuary Program



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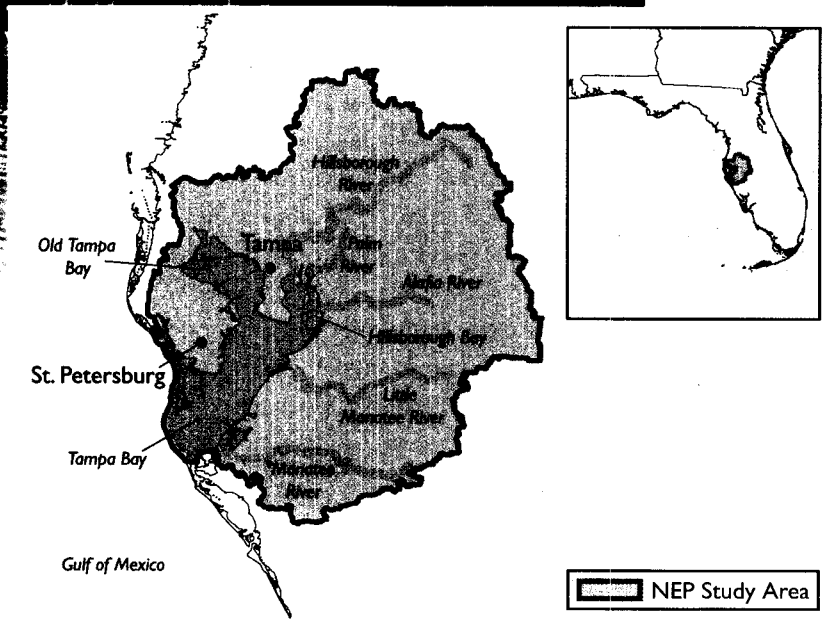


Background

Tampa Bay, Florida's largest open-water estuary, spans almost 400 mi^2 and drains 2,300 mi^2 of land (TBEP, 2003). The Tampa Bay watershed extends north of the Bay to the upper reaches of the Hillsborough River, east to the headwaters of the Alafia River, and south to the headwaters of the Manatee River. The Bay receives freshwater inflow from the Lake Tarpon Canal and the Hillsborough, Palm, Alafia, Little Manatee, and Manatee rivers. Tampa Bay empties into the Intracoastal Waterway via Boca Ciega Bay and into the Gulf of Mexico via the Southwest Channel and Passage Key Inlet.

Tampa Bay is an important nursery for young fish, shrimp, and crabs, and provides habitat for many other types of wildlife, including wading birds, dolphins, sea turtles, and manatees. In addition to its ecological diversity, Tampa Bay boasts three major seaports and contributes more than $5 billion annually from trade, tourism, development, and fishing (TBEP, 2005). More than 100,000 boats are registered to anglers and sailing enthusiasts in the Tampa Bay area, and more than 2 million people live in the Bay's watershed, with the population expected to grow 10% to 20% during the

next 10 years (U.S. Census Bureau, 2001; TBEP, 2005). Developing a plan to deal with the region's growth and the associated pollution and stress on natural habitats is the primary mission of the Tampa Bay Estuary Program (TBEP) (TBEP, 2005).

Environmental Concerns

Habitat loss, declines in living resources, and the atmospheric deposition of nitrogen are major concerns for the TBEP. Since population growth began to soar in 1950, nearly half the Bay's marshes and 40% of its seagrass areas have disappeared (TBEP, 2005). Although the abundance of many Bay species has increased in recent years, populations of other native species have declined as their habitats have shrunk. For example, the destruction of vital seagrass meadows caused a rapid decline in spotted seatrout and other fish populations in the Bay from the early 1970s through the 1980s (Murphy, 2003). In addition, atmospheric deposition of total nitrogen directly to the surface of Tampa Bay accounts for about one-quarter of the nitrogen loadings to the Bay (about 780 tons/year) (Poor et al., 2001). This estimate does not include total nitrogen from atmospheric sources deposited in the watershed and washed to the estuary as stormwater. When both direct and indirect pathways are considered, more than half of the total nitrogen loading originates from atmospheric sources (Poe et al., 2005a). The prevention of future nitrogen loading to the Bay will continue to be a challenge because population growth in the Bay area is projected to continue at a high rate.

Population Pressures

The population of the 6 NOAA-designated coastal counties (Hillsborough, Manatee, Pasco, Pinellas, Polk, and Sarasota) coincident with the TBEP study area increased by more 190% during a 40-year period, from 1.2 million people in 1960 to 3.3 million people in 2000 (Figure 5-24) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the TBEP study area exceeded the population growth rate of 133.3% for the collective NEP-coincident coastal counties of the Gulf Coast region and was the third-highest growth rate for all of the Gulf Coast NEPs. In 2000, these 6 counties had a population density of 640 persons/mi^2, more than double the density of 287 persons/mi^2 for the collective NEP-coincident coastal counties of the Gulf Coast region (U.S. Census Bureau, 2001). Development and population pressures are especially strong in NEP study areas that serve as major shipping centers for commercial and recreational activities.

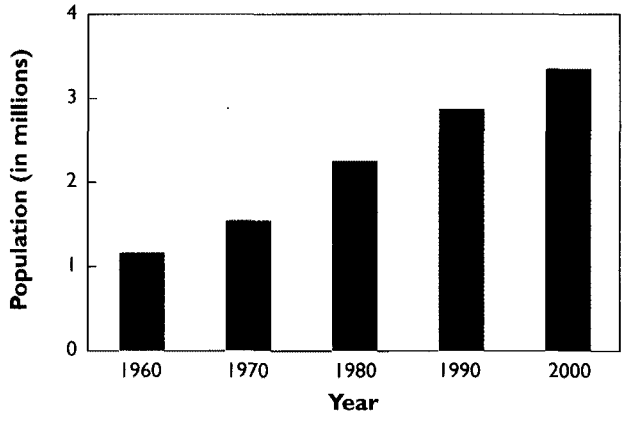


Figure 5-24. Population of NOAA-designated counties of the TBEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

Rare white-phase reddish egret. Tampa Bay boasts about 60 nesting pairs of reddish egrets, the largest population in Florida (Gerold Morrison).

Tampa Bay Estuary Program

NCA Indices of Estuarine Condition—Tampa Bay

The overall condition of Tampa Bay is rated fair based on three of the four indices of estuarine condition used by the NCA (Figure 5-25). The water quality index for Tampa Bay is rated fair, the sediment quality index is rated good, and the benthic index is rated poor; no data were available to calculate a fish tissue contaminants index for Tampa Bay. Figure 5-26 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 collected by EMAP from 25 NCA stations sampled in the TBEP estuarine area in 2000. 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.

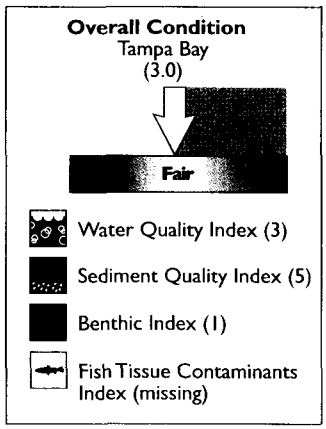


Figure 5-25. The overall condition of the TBEP estuarine area is fair (U.S. EPA/NCA).

Water Quality Index

The water quality index for Tampa Bay is rated fair (Figure 5-27). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. In NOAA's Estuarine Eutrophication Survey, Tampa Bay was listed as having medium-to-very-high chlorophyll *a* levels and medium-to-high DIN and DIP concentrations (NOAA, 1997). Results from the 2000 NCA survey show some improvements over the previous study, with low DIN, moderate DIP, and moderate chlorophyll *a* concentrations measured.

Dissolved Nitrogen and Phosphorus | Tampa Bay is rated good for DIN concentrations, with concentrations rated good throughout the TBEP estuarine area. Elevated DIN concentrations are not expected to occur during the summer in Gulf Coast waters because freshwater input is lower and dissolved nutrients are more rapidly utilized by phytoplankton during this season. Tampa Bay is rated fair for DIP concentrations, with 12% of the estuarine area rated poor for this component indicator, 72% of the area rated fair, and 16% of the area rated good.

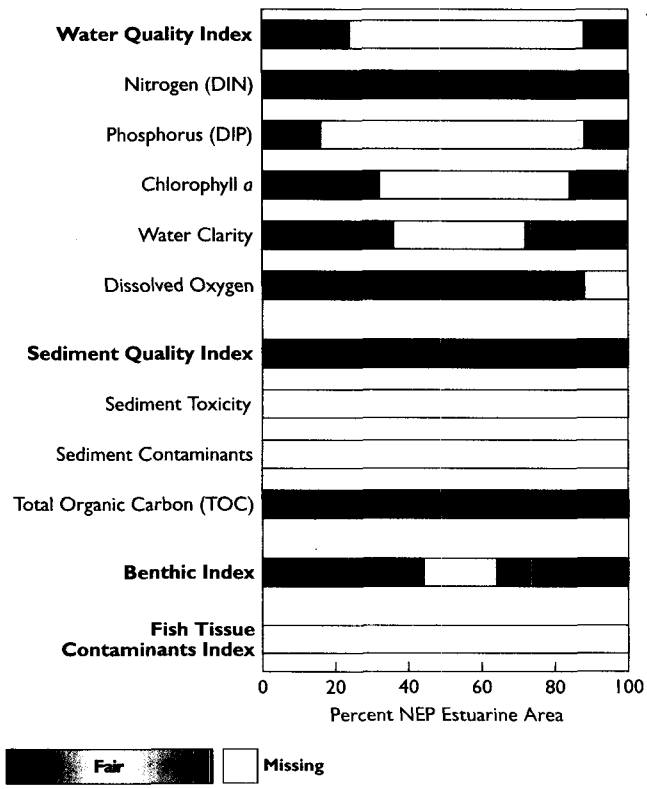


Figure 5-26. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Tampa Bay (U.S. EPA/NCA).

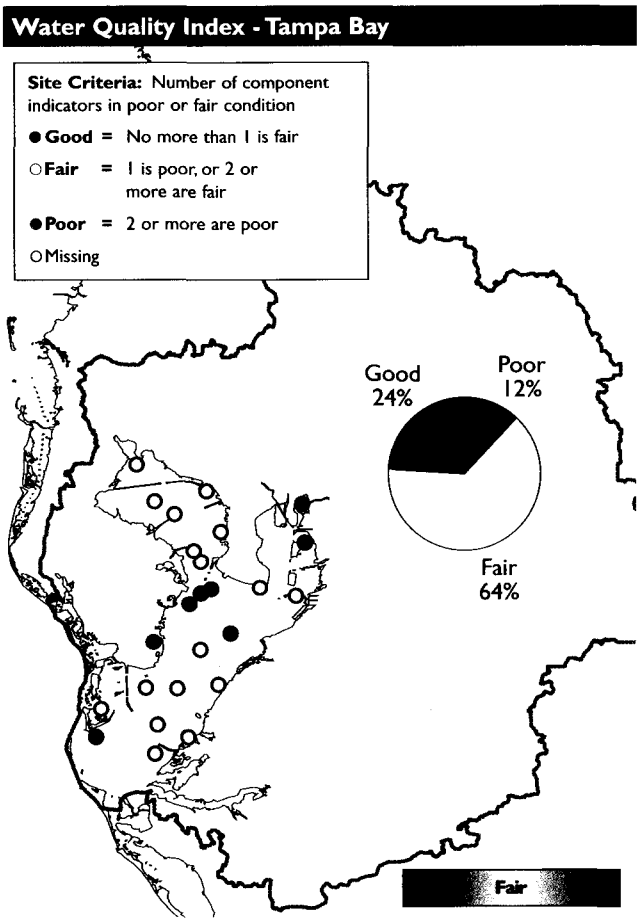


Figure 5-27. Water quality index data for Tampa Bay, 2000 (U.S. EPA/NCA).

Chlorophyll a | Tampa Bay is rated fair for chlorophyll *a* concentrations, with 16% of the estuarine area rated poor for this component indicator, 52% of the area rated fair, and 32% of the area rated good.

Water Clarity | Water clarity in Tampa Bay is rated poor. Water clarity was rated poor at a sampling site if light penetration at 1 meter was less than 20% of surface illumination. Expectations for water clarity are high because one of the TBEP's goals is to re-establish SAV. Twenty-eight percent of the TBEP estuarine area was rated poor for water clarity, 36% of the area was rated good, and 36% of the area was rated fair.

Dissolved Oxygen | Dissolved oxygen conditions in Tampa Bay are rated good. NCA estimates for Tampa Bay show that none of the Bay's bottom waters exhibited hypoxia in late summer. Twelve percent of the estuarine area was rated fair for dissolved oxygen concentrations, and 88% of the area was rated good.

Sediment Quality Index

The sediment quality index for Tampa Bay is rated good; however, this index is based on measurements of sediment TOC only (Figure 5-28). One-hundred percent of the TBEP estuarine area was rated good for sediment quality.

Sediment Toxicity | The NCA did not collect sediment toxicity data for Tampa Bay in 2000; therefore, sediment toxicity in the Bay has not be rated for this report.

Sediment Contaminants | The NCA did not collect sediment contaminants data for Tampa Bay in 2000; therefore, sediment contaminant concentrations in the Bay have not been rated for this report.

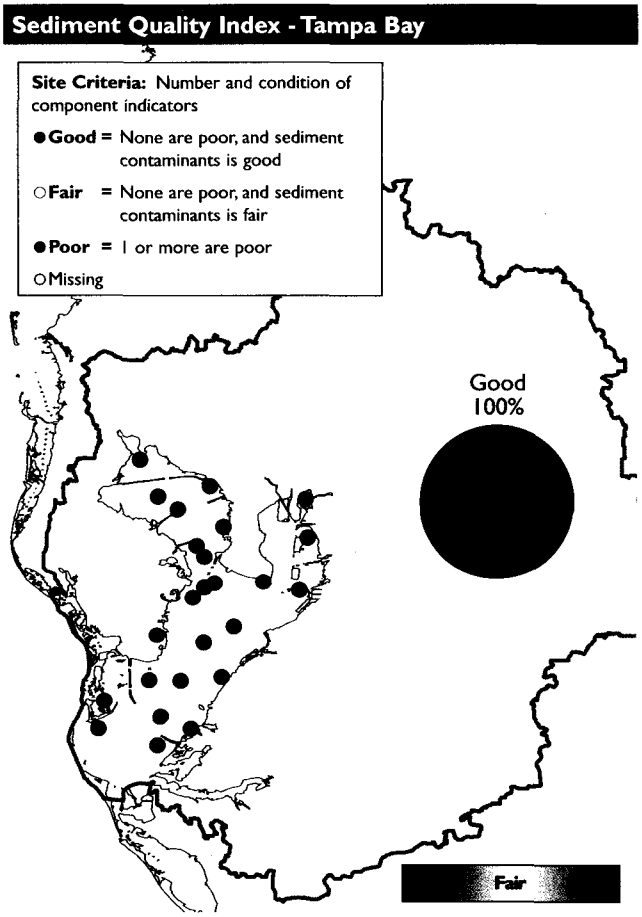


Figure 5-28. Sediment quality index data for Tampa Bay, 2000 (U.S. EPA/NCA).

Total Organic Carbon | TOC concentrations in Tampa Bay sediments were rated good throughout 100% of the TBEP estuarine area; therefore, Tampa Bay is rated good for sediment TOC.

Benthic Index

The condition of benthic invertebrate communities in Tampa Bay is rated poor, based on the Gulf Coast Benthic Index and data collected by the NCA. Benthic index estimates indicate that 36% of the estuarine area has degraded benthic resources (Figure 5-31).

Fish Tissue Contaminants Index

The NCA did not assess the level of fish tissue contaminants in the TBEP estuarine area in 2000; therefore, a fish tissue contaminants index for Tampa Bay was not developed for this report.

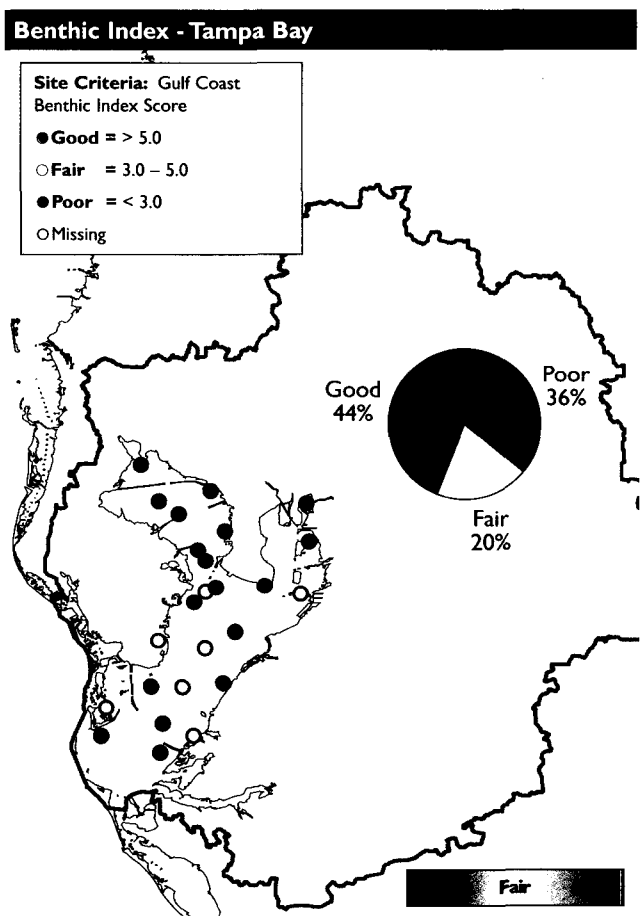


Figure 5-31. Benthic index data for Tampa Bay, 2000 (U.S. EPA/NCA).

Tampa Bay Estuary Program Indicators of Estuarine Condition

The Tampa Bay resource management community has developed monitoring programs and environmental indicators to measure progress towards adopted measurable goals for three major areas of concern: (1) water and sediment quality; (2) habitat restoration and protection; and (3) fish and wildlife protection. In many cases, the TBEP also uses target indicators to help assess progress towards these goals. Although some of these indicators are similar to those evaluated by the NCA, other indicators have been customized to suit the ecology and ecosystems that are unique to Tampa Bay. The TBEP's major indicators are chlorophyll *a* concentrations, water clarity, nitrogen loading (tons/year), acres of seagrass, and habitat restoration and protection (acres of oligohaline/brackish habitat). The TBEP also monitors other indicators, including bacteria; metals; organochlorine pesticides and other organic chemicals; benthic resources; boater compliance with posted speed zones; and trends in fishery stocks.

Local high school students plant marsh grass as part of a habitat restoration project coordinated by Tampa Bay Watch (Tampa Bay Watch).

Water and Sediment Quality

Chlorophyll *a* concentrations and light attenuation data help the TBEP track its progress toward improving water clarity to meet seagrass habitat goals for Tampa Bay. The TBEP calculates that sufficient water clarity will be maintained for the desired level of seagrass recovery if average annual chlorophyll *a* concentrations can be maintained at levels adequate to support seagrass recovery to depths observed in 1950 and equal to those measured between 1992 and 1994 (TBEP, 2003; Greening and Janicki, 2006). Similarly, light attenuation (a measure of water clarity) goals that are needed to maintain a minimum of 20% light to target depths have been adopted for seagrass recovery. Although this is the same light attenuation level used by the NCA, the TBEP uses the average annual estimate from monthly measurements taken throughout the year rather than the summertime index period used by the NCA. Based on the most recent assessment by the TBEP, all four major Bay segments met target levels for chlorophyll *a* concentrations in 1999 through 2002, and three of four segments met these targets in 2003 and 2004; however, none of the segments met chlorophyll *a* targets during the El Niño year (1998). Figure 5-29 shows that mean annual chlorophyll *a* concentrations in the Bay have generally declined during the past 20 years. From 1998 to 2001, light attenuation did not meet target levels in three of the four major Bay segments (Figure 5-30). This indicates that particles in the water, including non-chlorophyll particles, were preventing enough light from reaching seagrass growing on the Bay's floor, likely hindering the growth and expansion of seagrass beds (Poe et al., 2005b). These data correlate well with the NCA component indicator ratings of poor for water clarity and fair for chlorophyll *a* concentrations. The TBEP has been able to track the trends in these conditions because the program collects data from multiple seasons and for multiple years, rather than the snapshot approach used by the NCA.

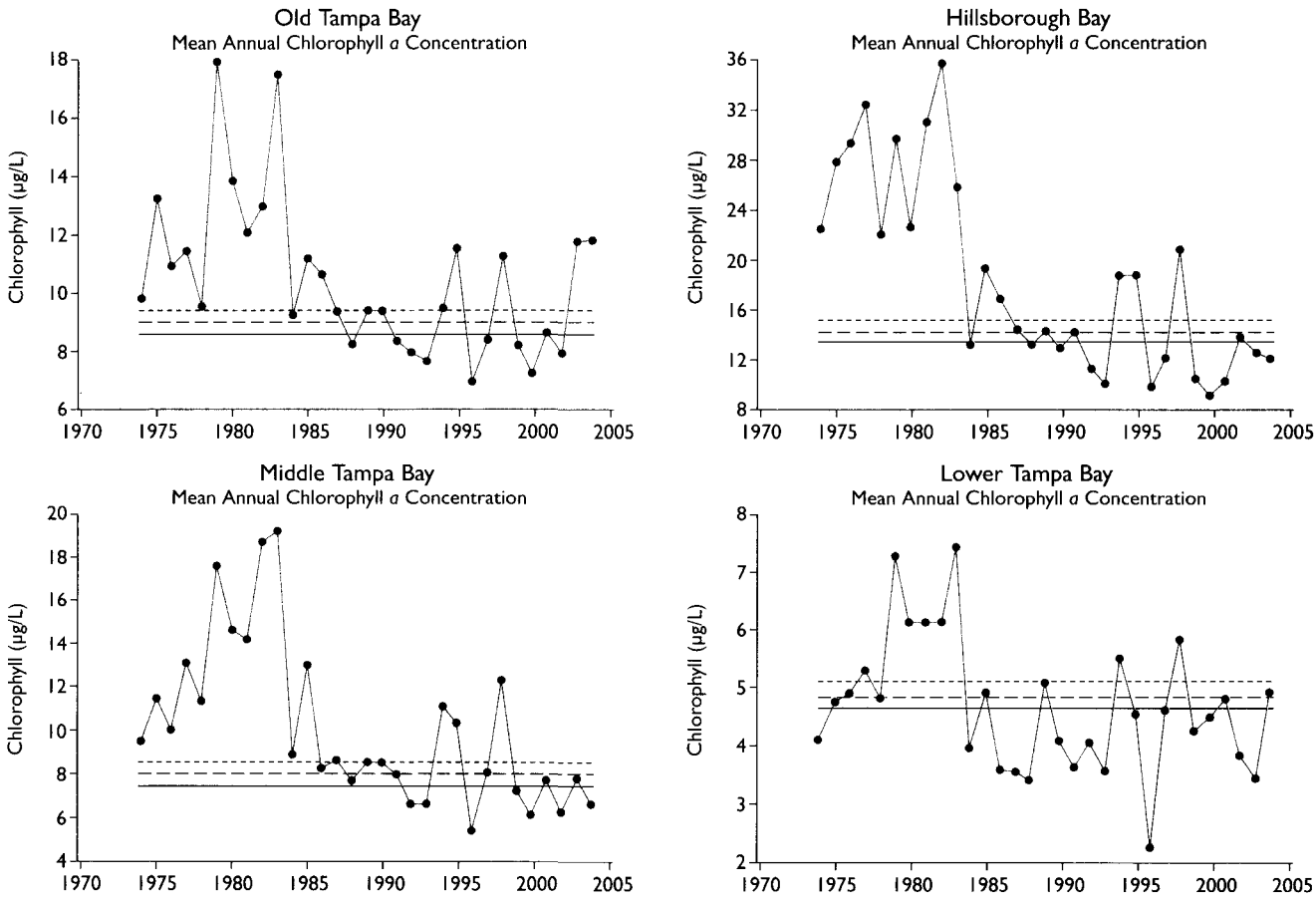


Figure 5-29. Mean annual chlorophyll *a* concentrations have generally declined over the past 20 years. The solid line indicates adopted target levels, with ± 1 and 2 standard deviation (dashed lines) (Poe et al., 2005b).

Tampa Bay Estuary Program

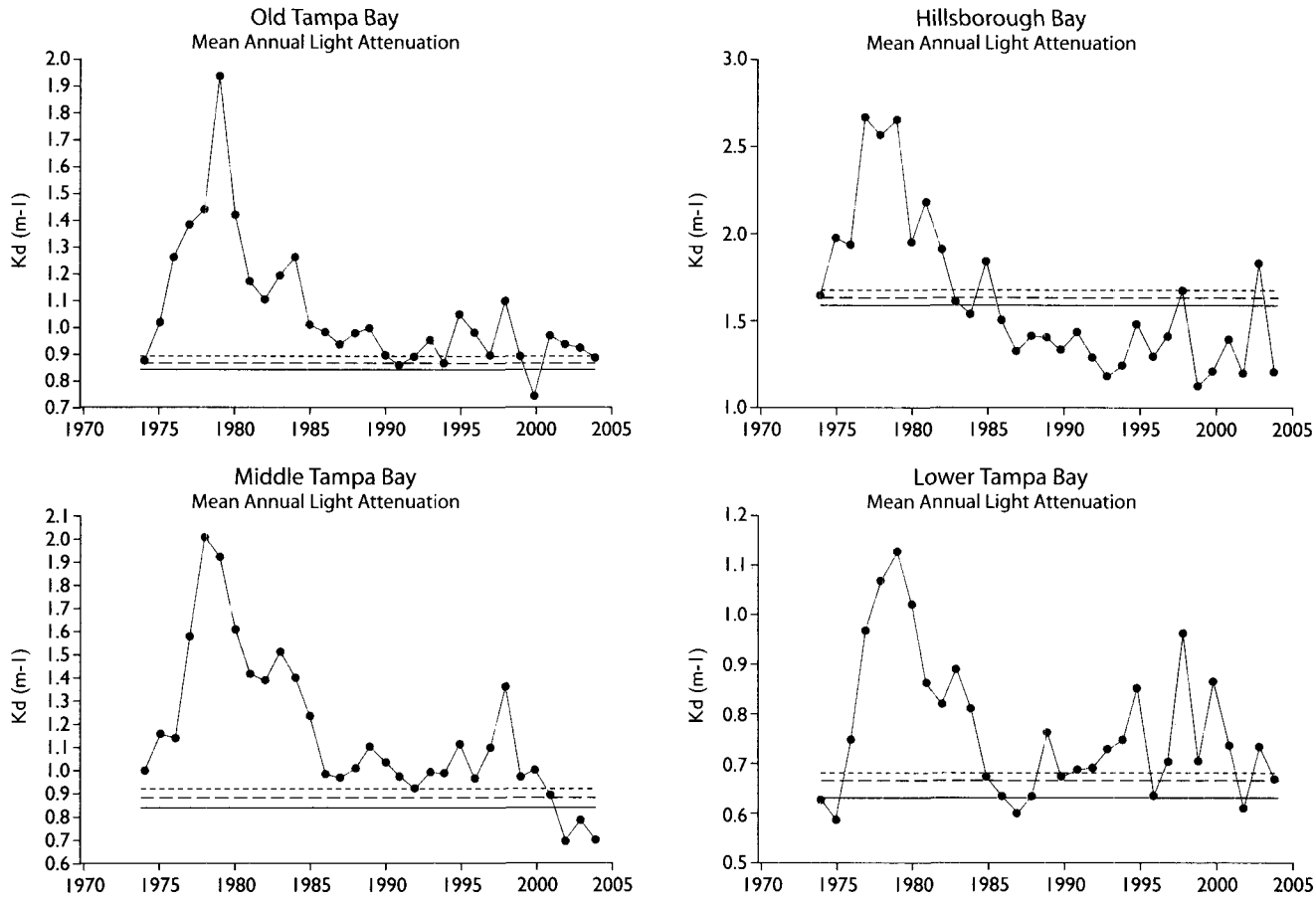


Figure 5-30. Light attenuation indicators met target levels only in one major Bay segment (Middle Tampa Bay). The solid line indicates light attenuation targets for each major Bay segment; dashed lines indicate 1 and 2 standard deviation (Poe et al., 2005b).

The TBEP uses nitrogen loading as an indicator of overall water quality because excess nitrogen can lead to algal blooms and decreased water clarity. The TBEP's goal is to prevent increases in the Bay's nitrogen loading to maintain levels measured between 1992 and 1994. The TBEP's estimates showed that nitrogen loading from 1995 to 2003 was higher than for the previous period (1985–1994), primarily due to heavy rains and runoff associated with El Niño in 1997–1998; however, when adjusted for rainfall, nitrogen loadings showed no change since 1985 (Poe et al., 2005a).

Elevated levels of bacteria in Tampa Bay waters can result from septic system malfunctions and stormwater runoff, especially during rainfall events. These elevated levels are a potential public health concern to people who use Tampa Bay for recreational swimming and boating activities. In 2000, the Healthy Beaches Tampa Bay one-year survey showed that the human health risk from bacterial contamination was low throughout the Bay; however, samples from 2 of the 22 sites around the Bay and its beaches consistently exceeded suggested guidelines for human health (Rose et al., 2001). Although the TBEP has not yet finalized specific indicators for tracking changes in bacterial contamination levels, it is considering several indicators, including fecal coliform bacteria and *Enterococci*. For areas where identifying the source of contamination is important, the TBEP is considering conducting multiple antibiotic resistance (MAR) tests for fecal coliform bacteria. Bacteria develop patterns of resistance to antibiotics that they are exposed to by their host organisms, and MAR tests can identify the source of the bacteria based on

these patterns of resistance. When the source of contamination is known, it becomes easier to target specific areas for cleanup and pollution prevention.

To improve sediment quality, the TBEP's goal is to reduce toxic chemicals in contaminated sediments and to protect clean areas. Despite the input of chemical contaminants, including metals, organochlorine pesticides, and the organic chemicals PCBs and PAHs, TBEP data show that the overall benthic condition of the Bay is good, with elevated contaminant levels typically found in only a few areas (TBEP, 2003). NCA data on sediment contaminants and sediment toxicity were not collected for Tampa Bay.

Both the TBEP and NCA collected monitoring data on the condition of benthic resources. During the past 10 years, TBEP partners and a national advisory group have worked together to implement a probabilistic benthic monitoring program based on EPA's EMAP design and to develop narrative and numerical sediment quality targets for key indicators of sediment quality. The newly developed Tampa Bay Benthic Index (TBBI) classifies sediments as healthy or degraded based on the diversity and abundance of the observed benthos. Using the TBBI, "hot spots" of contaminated sediments have been found to occur in relatively concentrated areas around large marinas, ports, and urban stormwater outfalls (Malloy et al., in press) (Figure 5-32). No trends in sediment quality have been observed since monitoring was initiated in 1993 (Karlen, 2003). Although the TBEP collected more sediment samples than the NCA, both programs used the same benthic index method to determine the health of the benthic community.

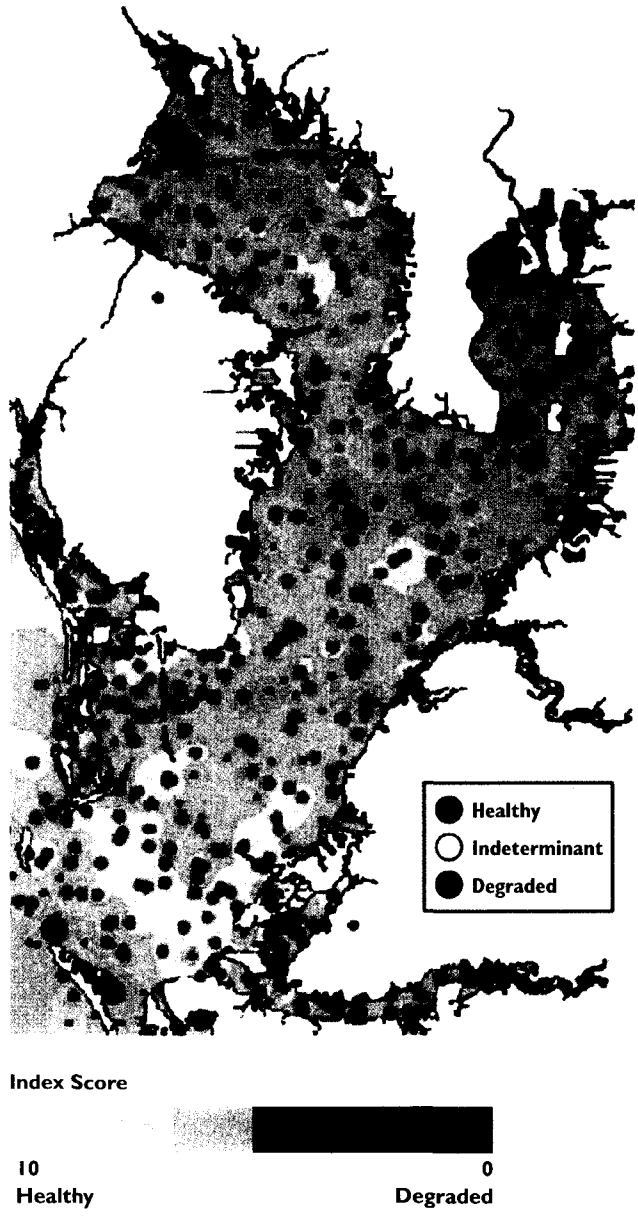


Figure 5-32. Tampa Bay Benthic Index classification (David Wade, Janicki Environmental, Inc.).

Tampa Bay Estuary Program

Summary: Tampa Bay Habitat Restoration/Protection Master Plan

TBEP participants have agreed to the implementation of a watershed strategy for coastal habitat restoration and protection, with a focus on preventing habitat "bottlenecks" for the survival and growth of estuarine-dependent fauna. Since the 1950s, more than 20% of Tampa Bay's saltwater marsh and mangrove habitat has been lost to development, and more than 50% of the shoreline has been altered by seawalls, dredge-and-fill, or other hardening activities (Lewis and Robison, 1995).

Step 1: Identify Estuarine-dependent "Indicator" Faunal Guilds

Although the TBEP Technical Advisory Committee (TAC) attempted to identify indicator species and their habitat requirements, the group was not comfortable with selecting individual species to drive this process. A total of 38 species were identified as potential indicators, ranging from filter-feeding zooplankton species to manatees —an unmanageable number for determining specific habitat requirements. Each species was considered to be a critical indicator by at least one TAC member, and determining the relative importance of one species over another proved an impossible task within the group (Lewis and Robison, 1995).

To address this problem, members of the TAC agreed on 10 faunal guilds (based roughly on trophic guilds and taxonomic groups) in which all the potential indicator species could be grouped. Several species were separated into different guilds, depending upon life stage. For example, larvae of some fish may be classified as open-water filter feeders, but then reclassified as shallow-water forage fish as they mature. The 10 adopted Tampa Bay guilds were the following:

- Open-water filter feeders
- Shallow-water forage fish
- Recreational/commercial finfish and shellfish
- Subtidal invertebrates
- Intertidal invertebrates
- Estuarine mollusks
- Estuarine-dependent birds
- Estuarine-dependent birds requiring freshwater forage areas
- Estuarine reptiles
- Marine mammals (Lewis and Robison, 1995).

Step 2: Identify Habitats Critical to Support Guilds

Based on the habitat requirements of each of the 10 guilds, 6 habitat types were identified as critical to support the full suite of guilds:

- Open estuarine water
- Oligohaline (low-salinity) marsh
- Mangrove/*Spartina*
- Salt barrens
- Associated uplands
- Freshwater "frogponds" (Lewis and Robison, 1995).

Step 3: Compare Historic and Existing Extent of Habitats

In 1950, Tampa Bay coastal areas were flown to collect aerial photographs to examine the potential for draining coastal wetlands with mosquito ditches to combat an ongoing malaria epidemic at that time. Using these historic aerial photographs, the areal extents of each of three target habitat types (mangrove/marsh, oligohaline marsh, and salt barren) in 1950 were estimated. Current areal estimates for each of these habitat types were similarly constructed using 1995 aerial photographs (Lewis and Robison, 1995).

Change in Acres of Mangrove/Marsh, Oligohaline Marsh, and Salt Barren Habitat between 1950 and 1995 (Lewis and Robison, 1995)

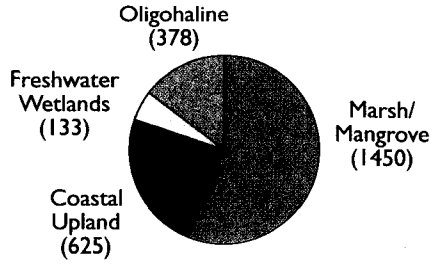
Habitat Type	1950 Acres	1950 Percent	1995 Acres	1995 Percent	Net Change (Acres)	Net Change (Percent)
Mangrove/marsh	15,894	67%	13,764	73%	-2,130	-13%
Oligohaline marsh	6,621	28%	4,117	22%	-2,504	-38%
Salt barren	1,371	5%	877	5%	-494	-36%
Total	23,886	100%	18,758	100%	-5,128	-21%

The table compares the acreage of these three target habitats in 1950 and 1995. Although a total of 21% of the total acreage for these three habitats was lost between 1950 and 1995, oligohaline habitat and salt barren acreage losses were approximately 38% and 36% of the 1950s acreage, respectively. Marsh and mangrove acreage loss was approximately 13% of the 1950s acreage. If mangrove/marsh habitat acreage remains constant, an increase of 1,800 acres of oligohaline habitat would be necessary to restore the historic balance of coastal habitats to support estuarine-dependent faunal guilds in Tampa Bay (Lewis and Robison, 1995).

Step 4: Focus Efforts on Restoring the Balance

Existing habitat-restoration efforts by agencies and local governments in Tampa Bay from 1990 to 1995 were successful in procuring funds for the restoration of 86 acres of coastal habitat. It was expected in 1995 that some additional funds would be available through 2005. Based on the results of this analyses and the recognized need for a reasonable expectation of funding sources, a target of restoring 100 acres of oligohaline habitat every 5 years was considered equivalent to the current rate of restoration. Thus, it was not assumed that additional funds would be available, but rather that funds be directed toward oligohaline marsh where possible. Mangrove/marsh habitat restoration has continued on an opportunity basis when appropriate sites are available and public support and funding exist (Lewis and Robison, 1995).

Between 1995 and 2003, the TBEP partners met and exceeded the adopted goal to restore at least 100 acres of oligohaline habitat every 5 years. A total of 2,357 acres of estuarine habitat was restored through 2003, including 378 acres of oligohaline habitat (see figure) (Greening et al., 2005).



Total acres of Tampa Bay estuarine habitat restored between 1995 and 2003 (Greening et al., 2005).

Tampa Bay Estuary Program

Habitat Quality

The TBEP monitors Bay acreage and changes in acreage over time to assess the quality of coastal wetland, salt marsh, and mangrove and seagrass habitats in the study area. The preservation of salt marsh and mangrove habitats in Tampa Bay is focused on 28 priority sites. These 28 sites were given the highest priority for Florida's Save Our Rivers and Preservation 2000 land-acquisition programs conducted by the SWFWMD. A total of 11,494 acres of estuarine habitat was preserved through direct land acquisitions between 1996 and 2003 (Figure 5-33) (Greening et al., 2005).

The area of historical seagrass coverage in Tampa Bay has been reduced as a result of excessive nitrogen loading and dredge-and-fill activities. To track and quantify changes in the seagrass beds, aerial photographs and mapping have been conducted every 2 years since 1988 to assess recovery trends. As shown in Figure 5-34, seagrass acreage in Tampa Bay declined between 1950 and 1982. Figure 5-35 illustrates the areas of seagrass cover lost between 1950 and 1990. Since 1992, overall seagrass acreage in the Bay has been increasing at a average rate of about 500 acres per year. Data from the 2004 survey show an increase in Bay-wide seagrass coverage by 2,183 acres between 1999 and 2004 (Tomasko et al., 2005c). One exception is the Old Tampa Bay area, which has experienced a 24% loss of seagrass during this time period and sustained previous losses between 1994 and 1996, suggesting a more serious condition could exist in this area. In addition to aerial photography and interpretation every 2 years, the Seagrass Condition Monitoring Program (70 transects Bay-wide) is conducted to better assess seagrass changes in the Bay (Avery and Johansson, 2004).

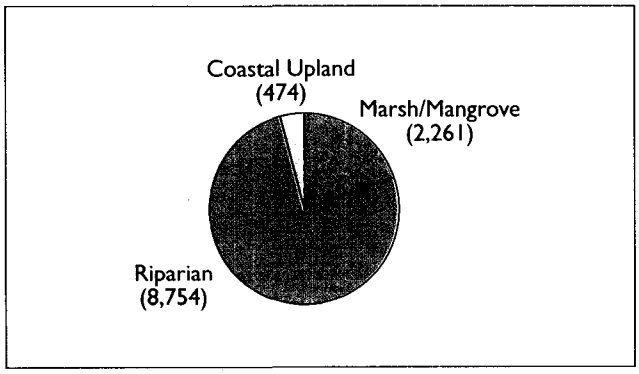


Figure 5-33. Total acres of habitat acquired through land acquisitions from 1996–2003 (Greening et al., 2005).

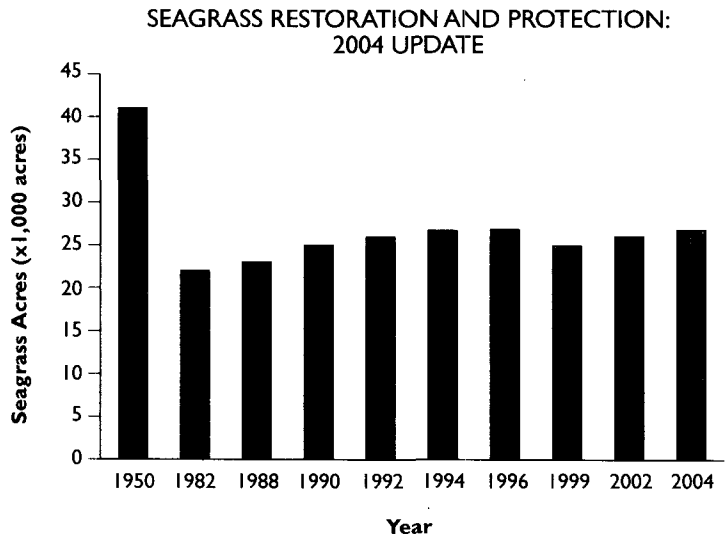


Figure 5-34. Decline in seagrass acreage in Tampa Bay between 1950 and 1982 and restoration after 1982 (Tomasko et al., 2005c).

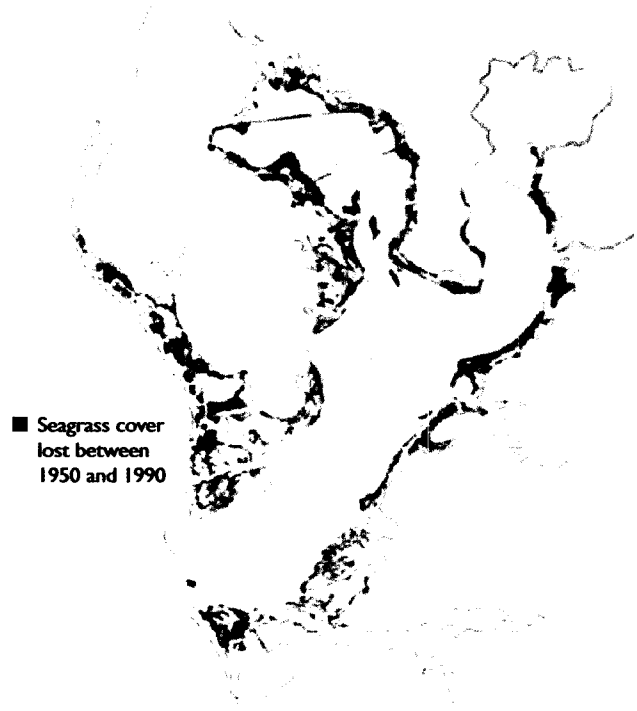


Figure 5-35. Seagrass cover lost between 1950 and 1990 in Tampa Bay (Janicki et al., 1994).

Living Resources

The TBEP has been working to protect manatees and ensure healthy fishing stocks in Tampa Bay. The program uses boater compliance with posted speed zones and trends in fishery stocks as indicators for monitoring the success of these activities.

Manatees, which graze on seagrass beds, are often injured or killed by power boats in shallow areas of Tampa Bay. Boater-education efforts and a number of different manatee-protection efforts, such as signs marking mandatory and voluntary "go slow" areas, may reduce the number of manatee deaths each year. The TBEP's Manatee Awareness Coalition (MAC) has developed intensive boater-education programs aimed at protecting manatees and the seagrass habitats they depend upon. The MAC has also assisted in the development of federal, state, and local boating speed zones in Tampa Bay. The success of these efforts is being assessed by monitoring the numbers of boaters complying with posted speed zones, including both voluntary and mandatory compliance.

The TBEP is also interested in ensuring that healthy fishery stocks are maintained in the Bay. Although no target population levels have been designated, fish and shellfish population estimates, as measured by the Florida Wildlife Commission's Fisheries Independent Monitoring Program, have shown species-specific patterns in fish abundance since 1989. The results of monitoring efforts have documented the Bay's yearly fluctuations in major fish species and have not recorded any overall declining trends in the fishery stocks of Tampa Bay (Matheson et al., 2005).

Current Projects, Accomplishments, and Future Goals

Since the Tampa Bay master plan was first adopted in 1996, the TBEP has made aggressive strides toward defining goals and taking actions for the restoration and protection of Tampa Bay. The program has set goals for water quality, habitat restoration and protection, and fish and wildlife.

The TBEP's goals for water quality are to reduce nitrogen loadings, improve water quality in the Bay for recreation, and improve water clarity for the protection of seagrass habitat. The TBEP is measuring its progress toward these goals through the monitoring of water clarity and bacteria, chlorophyll *a*, and nitrogen concentrations. The TBEP also aims to gain a better understanding of atmospheric deposition and to identify sources of air pollution that are adding excess nitrogen to the Bay (Poor et al., 2001). To learn more, the TBEP plans to continue supporting the careful monitoring needed to identify and track any changes in atmospheric deposition to the Bay.

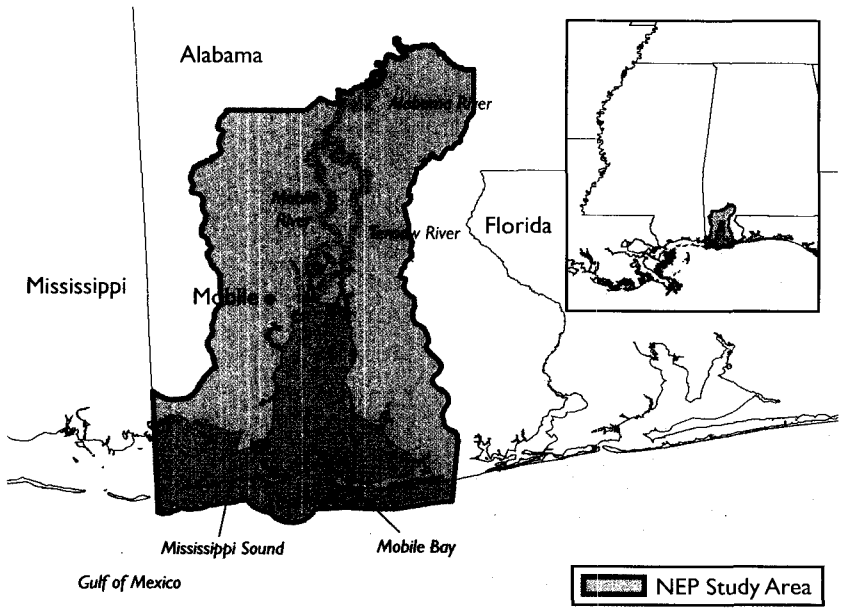
Habitat restoration and protection goals for Tampa Bay are directed primarily toward restoring the historic balance of coastal wetland habitats, preserving the Bay's salt marsh and mangrove acreage, and protecting and restoring the Bay's seagrass beds. The primary indicators of success toward these goals involve tracking the acreage of each habitat and the changes in acreage over time. In some cases, the TBEP has set specific goals for habitat preservation. For example, one of the program's estuarine habitat protection goals is to preserve the Bay's 18,800 acres of salt marsh and mangrove habitat (TBEP, 2003).

Fish and wildlife goals for Tampa Bay are directed primarily toward developing recommendations for local manatee protection zones and improving on-water enforcement of fishing and environmental regulations. The improvement of on-water enforcement was greatly facilitated by the merger of the Florida Fish and Wildlife Commission and the Florida Game and Freshwater Fish Commission. This merger increased the on-water presence in Tampa Bay.

Conclusion

The overall condition of Tampa Bay is rated fair based on three indices of estuarine condition used by the NCA. The TBEP has taken strong actions to establish short- and long-term goals for the protection and restoration of this estuary. NCA and TBEP monitoring data show that many aspects of environmental quality in the Bay are improving, such as nitrogen load and chlorophyll *a* levels and seagrass coverage. Attaining the TBEP's ambitious goals will require continued strong scientific involvement through monitoring, research, and pollution management, as well as the cooperation and dedication of a wide spectrum of stakeholders, including the public.

Mobile Bay National Estuary Program



www.mobilebaynep.com

Background

Mobile Bay is a submerged river valley that acts as a coastal transition zone between the Mobile Bay watershed and the Gulf of Mexico. The Mobile Bay watershed covers approximately 44,600 mi^2, including two-thirds of Alabama and portions of Mississippi, Georgia, and Tennessee (NOAA, 1985; Mobile Bay NEP, 2002a). It is the nation's fourth-largest watershed in flow volume and the sixth-largest river system in area (Mobile Bay NEP, 2002a).

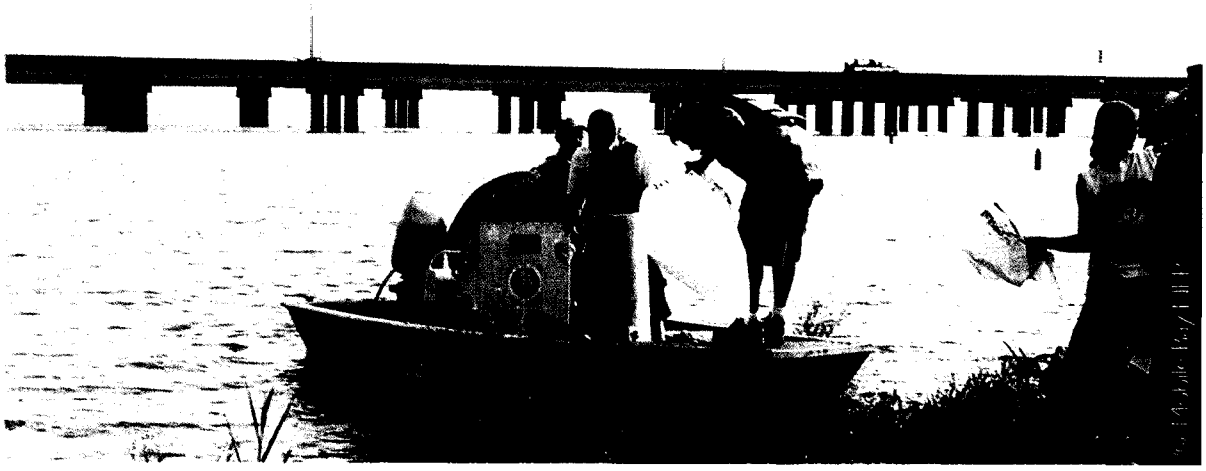
Although the Mobile Bay watershed covers a vast area, the Mobile Bay NEP study area is limited to the portions of the watershed in Baldwin and Mobile counties in Alabama. The study area also includes Mobile Bay, the Mobile-Tensaw Delta, the surface waters between the Mississippi Sound and Alabama-Mississippi state line, and the Alabama state marine waters in the north-central portion of the Gulf of Mexico, which extend three miles south of Dauphin Island and the Fort Morgan Peninsula. The surface waters of Mobile Bay cover 409 mi^2, and the average depth of the Bay is about 10 feet, which is very shallow for a bay of this size (NOAA, 1985; Mobile Bay NEP, 2002a). Fresh water flows into the Bay through the Mobile-Tensaw, Blakely,

Apalachee, Dog, Deer, Fowl, and Fish rivers. The Bay's primary opening to the Gulf of Mexico is the Main Pass, located between Dauphin Island and the Fort Morgan Penninsula. The Mobile-Tensaw River Delta is the largest intact delta in the United States and covers approximately 289 mi^2 of marsh, swamp, and forested wetlands (Wallace 1994; Auburn University, 2004). The Bay basin is characterized by barrier islands, tidal marshes, cypress swamps, bottomland hardwoods, and oyster reefs. The Mobile Bay NEP study area is home to 49 species of mammals, 126 species of reptiles and amphibians, 337 species of freshwater and saltwater fish, and 355 species of birds (Mobile Bay NEP, 2002a). Portions of Mobile Bay and the Mobile-Tensaw Delta, including the Tennessee-Tombigbee Waterway and the Port of Alabama, are subject to a number of human uses with national implications, such as commercial fisheries, industry, tourism and recreation, and coastal development.

An estimated 4.85 million metric tons of sediment enter this estuary annually, with 33% being deposited in the Mobile-Tensaw Delta, 52% in Mobile Bay, and the remainder flowing through to the Gulf of Mexico (Mobile Bay NEP, 2002a). Mobile Bay's salinity regime is complex. At times, the predominant influence is freshwater inflow from the large Mobile Bay watershed; however, salinity levels are highly variable in Mobile Bay because winds and tidal regimes affect the inflow of salty Gulf of Mexico waters into the Bay from the south. A recent hydrologic study indicated that salinity also varies with depth in the Bay and in the major river channels, shallower embayments, and stream channels of the Mobile-Tensaw Delta (Braun and Neugarten, 2005).

Environmental Concerns

Habitat loss is a high-priority environmental concern for the Mobile Bay NEP. Development, natural erosion processes, sedimentation, dredge-and-fill practices, exotic species, and hydrologic modifications are some of the causes of habitat loss in the Mobile Bay NEP study area (Mobile Bay NEP, 2002a). Between the mid-1950s and the late 1970s, 34% of the wetlands in northern Mobile Bay were lost, compared to the national and southeastern wetland loss average of 8% (U.S. EPA, 1998). Loss of habitat can result in a decreased number and/or diversity of faunal species in the Bay, increased flooding, and impaired water quality (Mobile Bay NEP, 2002a). For example, the Mobile Bay Causeway, a major hydrologic modification in the Mobile-Tensaw Delta, was built in the 1920s and acts as an unintentional barrier between the Delta waters to the north and the saline waters to the south. Recent studies indicate that the causeway has significantly impacted the ecological function of the lower Mobile-Tensaw Delta and may also have impacted the region's biodiversity (Mobile Bay NEP, 2002a; Valentine et. al., 2004).



Coastal cleanup along the Mobile Bay Causeway (Mobile Bay NEP).

Mobile Bay National Estuary Program

Population Pressures

The population of the 2 NOAA-designated coastal counties (Baldwin and Mobile) coincident with the Mobile Bay NEP study area increased by 49% during a 40-year period, from 0.36 million people in 1960 to 0.54 million people in 2000 (Figure 5-36) (U.S. Census Bureau, 1991; 2001). This population growth rate for the Mobile Bay NEP study area was less than half the population growth rate of 133.3% for the collective NEP-coincident coastal counties of the Gulf Coast region. The population density of these two counties in 2000 was 191 persons/mi^2, which was about one-third less than the population density of 287 persons/mi^2 for the collective Gulf Coast NEP-coincident coastal counties (U.S. Census Bureau, 2001). Development and population pressures are especially strong in NEP study areas that serve as major shipping centers for commercial and recreational activities.

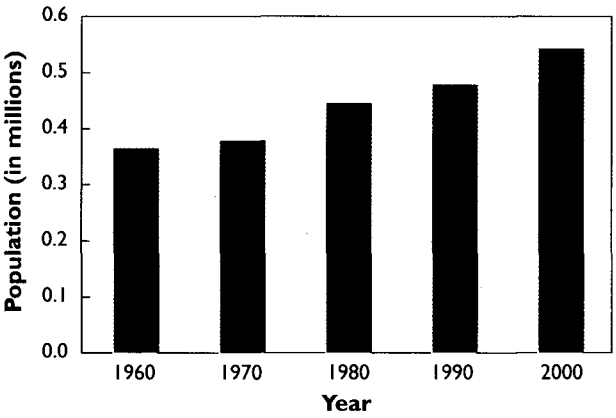


Figure 5-36. Population of NOAA-designated counties of the Mobile Bay NEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Mobile Bay

The overall condition of Mobile Bay is rated fair based on the four indices of estaurine condition used by the NCA (Figure 5-37). The water quality and sediment quality indices are rated fair, the benthic index is rated poor, and the fish tissue contaminants index is rated good. Figure 5-38 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 collected by the Alabama Department of Environmental Management (ADEM), in partnership with the NCA, from 66 sites sampled in the Mobile Bay 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.

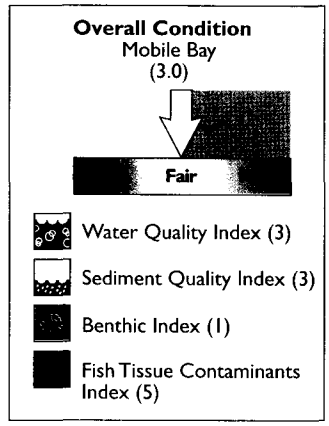


Figure 5-37. The overall condition of the Mobile Bay NEP estuarine area is fair (U.S. EPA/NCA).

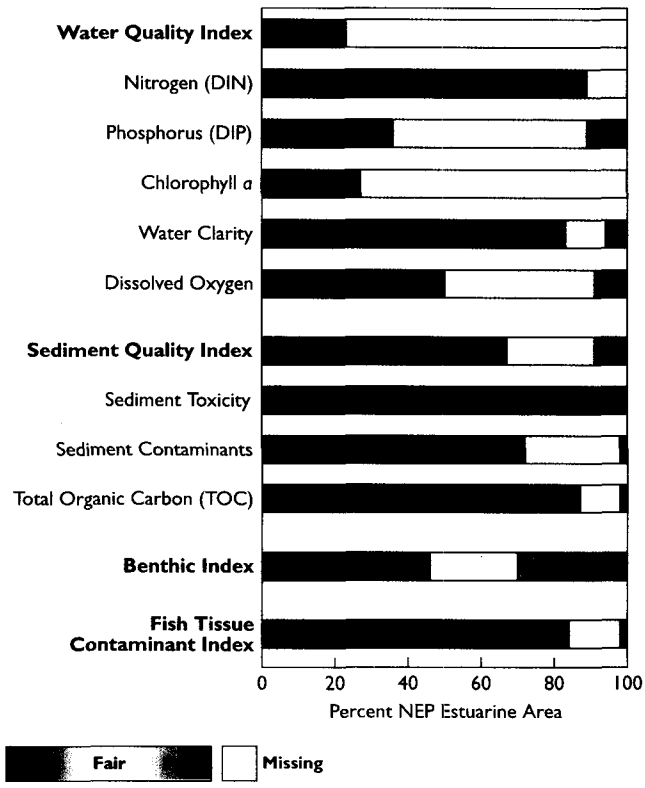


Figure 5-38. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Mobile Bay (U.S. EPA/NCA).

Water Quality Index

Based on NCA survey results, the water quality index for Mobile Bay is rated fair (Figure 5-39). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. In NOAA's Estuarine Eutrophication Survey, Mobile Bay was listed as having medium levels of chlorophyll *a* and medium-to-low DIN and DIP concentrations (NOAA, 1997).

Dissolved Nitrogen and Phosphorus | DIN concentrations in Mobile Bay are rated good, whereas DIP concentrations are rated fair. Concentrations of DIN were rated good in 89% of the estuarine area and fair in the remaining 11%. Eleven percent of the estuarine area was rated poor for DIP concentrations, 53% of the area was rated fair, and 36% of the area was rated good.

Chlorophyll a | Chlorophyll *a* concentrations in Mobile Bay are rated fair. Although no poor chlorophyll *a* conditions occurred in Mobile Bay, 73% of the estuarine area was rated fair, and the remaining 27% of the area was rated good for this component indicator.

Water Clarity | Water clarity in Mobile Bay is rated good. Expectations for water clarity in Mobile Bay are low due to high river flow and naturally high turbidity. Water clarity was rated poor at a sampling site if light penetration at 1 meter was less than 5% of surface illumination. Water clarity was rated poor in only 6% of the estaurine area, 11% of the area was rated fair, and 83% of the area was rated good.

Dissolved Oxygen | Dissolved oxygen conditions in Mobile Bay are rated fair. NCA estimates show that 9% of the estuarine area was rated poor for this component indicator, 41% of the area was rated fair, and 50% of the area was rated good.

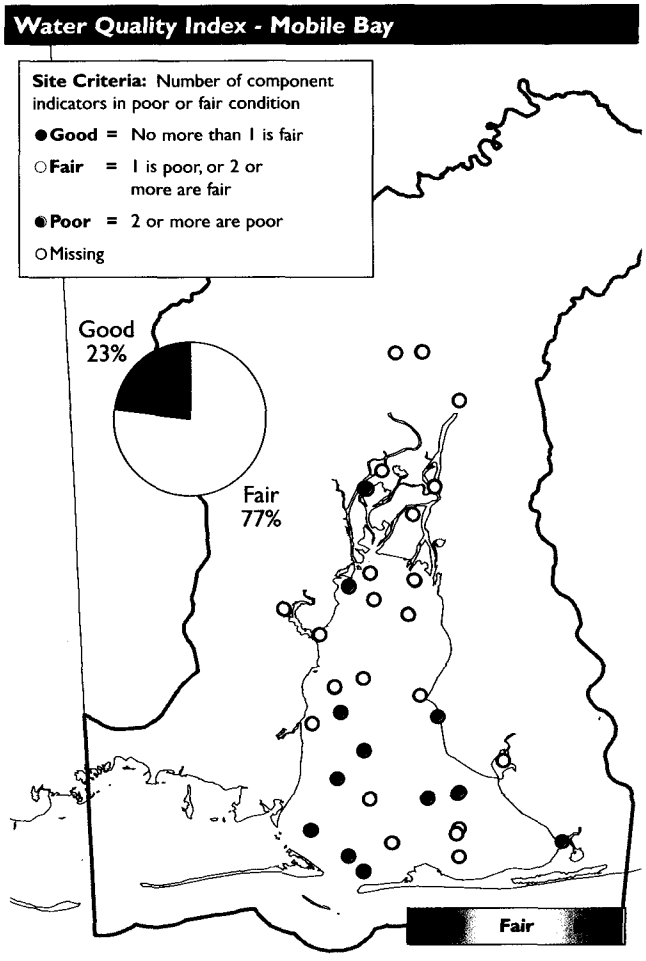


Figure 5-39. Water quality index data for Mobile Bay, 2000–2001 (U.S. EPA/NCA).

Throwing a cast net for bait fish, shrimp, and mullet is a popular local tradition (Mobile Bay NEP).

Sediment Quality Index

The sediment quality index for Mobile Bay is rated fair because 9% of the estuarine area was rated poor for sediment quality (Figure 5-40). This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC.

Sediment Toxicity | Mobile Bay is rated poor for sediment toxicity because 6% of the estuarine area was rated poor for this component indicator.

Sediment Contaminants | Only 2% of the estuarine area was rated poor for sediment contaminant concentrations; therefore, this component indicator is rated good for Mobile Bay.

Total Organic Carbon | Mobile Bay is rated good for sediment TOC. Eighty-seven percent of the estuarine area was rated good for this component indicator, 11% of the area was rated fair, and only 2% of the area was rated poor.

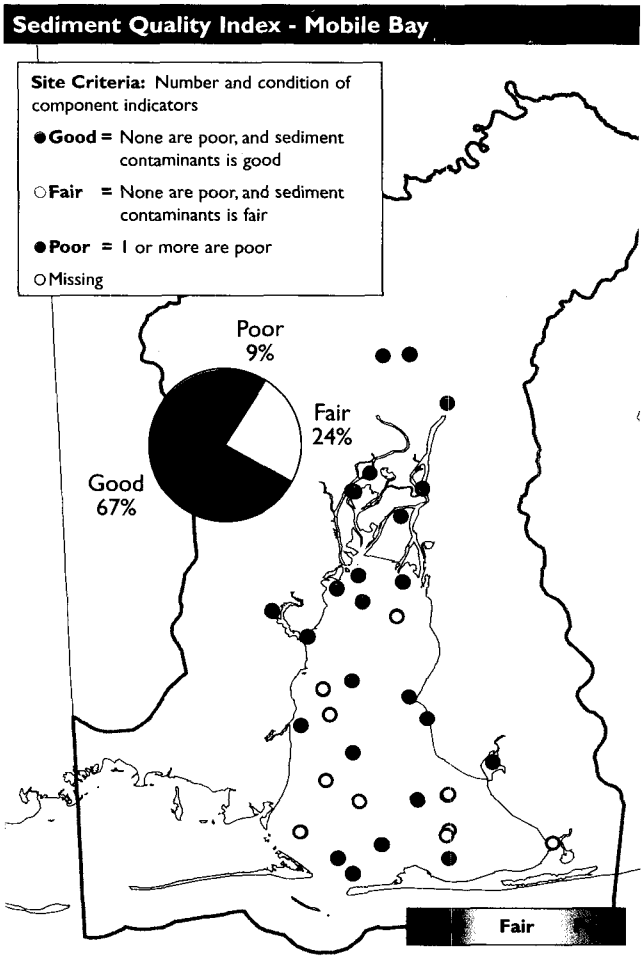


Figure 5-40. Sediment quality index data for Mobile Bay, 2000–2001 (U.S. EPA/NCA).

Navy Cove along Fort Morgan Peninsula, Alabama (Mobile Bay NEP).

Benthic Index

Based on the Gulf Coast Benthic Index and data from the NCA, the condition of benthic invertebrate communities in Mobile Bay is rated poor. Benthic index estimates indicate that 30% of the estuarine area has degraded benthic resources and another 24% of the area is rated fair (Figure 5-41).

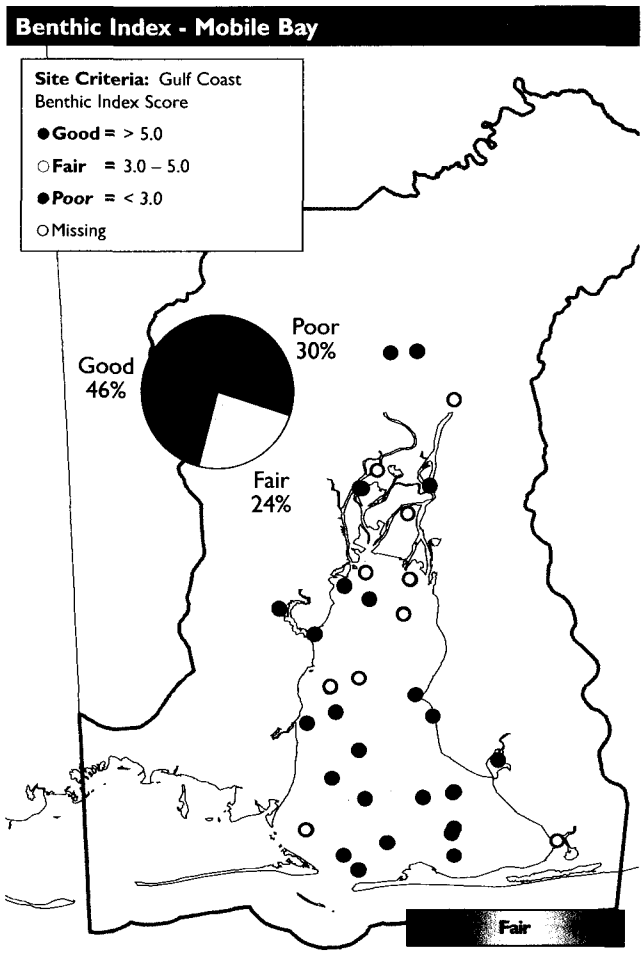


Figure 5-41. Benthic index data for Mobile Bay, 2000–2001 (U.S. EPA/NCA).

Fish Tissue Contaminants Index

The fish tissue contaminants index for Mobile Bay is rated good, based on concentrations of contaminants in fish tissues (whole fish). Figure 5-42 shows that 2% of all stations sampled where fish were caught exceeded the EPA Advisory Guidance values used in this assessment and were rated poor.

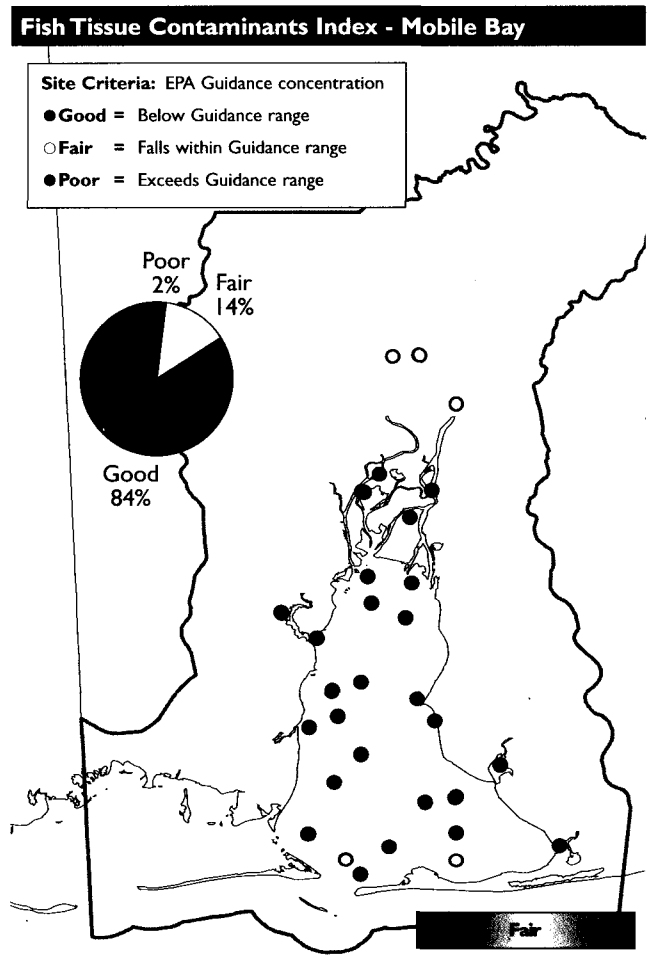


Figure 5-42. Fish tissue contaminants index data for Mobile Bay, 2000–2001 (U.S. EPA/NCA).

Mobile Bay National Estuary Program

HIGHLIGHT

Invasive Species of Coastal Alabama and Mississippi

The invasion of non-indigenous aquatic species is recognized as one of the five most-critical environmental issues facing the ocean's marine life (NRC, 1995). Broad efforts are underway nationwide to combat the entry of new species into our country and to effectively control and manage those that have already made their way here. This is particularly important in Gulf Coast waters because numerous vectors exist for the introduction of non-native aquatic plant and animal species in this region. These invasive species pose ecological, economic, and even human health threats.

Identifying these "alien" species was the goal of the newly formed Alabama-Mississippi Rapid Assessment Team (AMRAT) during the largest coast-wide rapid assessment of living resources ever held in the Gulf of Mexico. This team carried out rapid assessment surveys of non-native plant and animal species in Mobile Bay over several days in September 2003, as well as along the Mississippi coast in August and September 2004. The result was a "snapshot" inventory of coastal species from which potentially invasive or nuisance species could be identified. Such surveys offer an opportunity for the early detection of newly introduced non-native species, can result in early actions to curb the spread of invasive species, and provide insight into the ways these plants and animals arrive in a region. The assessments can also serve as a basis for the development of management plans to deal with potential nuisance species. The data collected provides a baseline against which future status and trends in non-native populations can be assessed (Mobile Bay NEP, 2005).

During the assessment surveys, researchers used a variety of sampling techniques to collect and identify as many different non-native organisms as possible. These techniques included aerial surveys, diving, electroshocking, plankton and algae sampling, trawling, seine netting, hand netting, hand picking, and scraping fouling organisms from surfaces. Ballast water was also sampled from ships in port and analyzed for pathogens by an FDA laboratory. Collectively, more than 120 researchers, technicians, and support personnel from 22 state, federal, and research institutions and agencies took part in these intensive field and laboratory efforts (Mobile Bay NEP, 2005).

The AMRAT is a continuing effort led by a unique partnership between co-founders Harriet Perry, Director of the Center for Fisheries Research and Development at the University of Mississippi's Gulf Coast Research Laboratory (GCRL), and David Yeager, Director of the Mobile Bay NEP. The team was founded is based on the premise that few individual organizations have all the resident scientific expertise or logistical ability to carry out a survey of this scale. The AMRAT partnership represents an innovative way to provide this capability. The surveys were coordinated with the Gulf and South Atlantic Regional Panel on Aquatic Invasive Species. The Gulf States Marine Fisheries Commission administers this panel and manages the data from the surveys.

More than 730 samples were collected during the AMRAT assessment surveys (Yeager and Perry, 2004). Many native and non-native animals and plants were classified and accessioned into the GCRL museum to serve as type specimens and aid in future study and identification. The surveys validated the presence of previously identified or suspected non-native plants and animals and added some new information. New arrivals include a population of Nile tilapia (*Oreochromis niloticus*) and the wild taro plant (*Colocasia antiquorum*), both noted in Mississippi, and the Asian clam (*Corbicula fluminea*), noted in both Alabama and Mississippi. In addition, two new state records for molluscs in Alabama were established: a marine snail (*Turbonila puncta*) and a bicolor purse-oyster (*Isognomon bicolor*). Changes in the distribution of certain native plants such as smooth cord grass (*Spartina alterniflora*) and their replacement by an invasive, *Phragmites*, were also noted. This was also the first time seaweeds and benthic algae in Alabama coastal waters were cataloged.

A researcher collects samples during AMRAT 2004 (Pam Fuller, USGS).

The AMRAT assessment surveys were unqualified successes and were highly acclaimed by participants, observers, and reviewers. In 2006, the AMRAT program was awarded a first place Gulf Guardian Award by EPA's Gulf of Mexico Program. The survey is identified by the Gulf and South Atlantic Regional Panel on Aquatic Invasive Species in their current strategic plan as a model for Gulf–wide assessment efforts, and other areas of the Gulf Coast are considering implementing similar programs. Current plans for coastal Louisiana surveys, led by the Louisiana Sea Grant Program and the Barataria-Terrebonne NEP (BTNEP), are using the lessons learned from AMRAT. Discussions also are underway to extend the AMRAT surveys into areas of the Florida panhandle as early as 2006. Additional information about AMRAT and a full list of its partners and participants is available from the following Web sites: http://www.mobilebaynep.com, http://nis.gsmfc.org, and http://www.gsmfc.org.

Mobile Bay National Estuary Program Indicators of Estuarine Condition

The Mobile Bay NEP has not yet finalized indicators for tracking the health of Mobile Bay, but will complete this task in 2006. Several successful public participation workshops resulted in a preliminary list of indicators that may be used to easily communicate the ecological condition of the Bay to the public. These indicators are either currently monitored or considered sufficiently important to warrant additional monitoring. Progress has also been made in developing status and trends data in preparation for a future report on the five issue areas identified in the Mobile Bay NEP *Comprehensive Conservation and Management Plan, Volume I—A Call to Action* (Mobile Bay NEP, 2002a). This progress includes initiating a new sub-estuary water quality monitoring project; instituting a continuous Bay-wide time series monitoring project; performing rapid assessments to monitor invasive species; analyzing more than 20 years of collected fish population data to evaluate trends; performing the first comprehensive modern survey of SAV and a comparison with historical data; establishing a completely updated NWI wetland survey and upland habitat survey for Mobile and Baldwin counties; utilizing a land-use cover map for Baldwin County; and performing other baseline data collection to provide a solid scientific basis for evaluating status and trends.

Water and Sediment Quality

The Mobile Bay NEP has established explicit goals and objectives for Mobile Bay and its subbasins, including developing allowable water quality-based loadings sufficient to maintain water quality standards (or TMDLs) for pathogens, nutrients, toxic chemicals, and other pollutants. Water quality indicators for Mobile Bay include chlorophyll *a*, total phosphate, ammonia, nitrates+nitrites, dissolved oxygen, salinity, pH, biochemical oxygen demand, turbidity, and water temperature. ADEM also monitors the Bay for several toxic chemicals, including mercury, cadmium, chromium, DDT, and PAHs (Hutchings and Yokel, 2000).

Portions of some rivers in the Mobile Bay NEP study area do not fully support their current or proposed water-use classifications because of nutrient enrichment and/or low dissolved oxygen levels; however, dissolved oxygen standards were actually achieved in 95% of the coastal waters across the Bay (Baya et al., 1998). Nutrient levels in the Bay are affected by point and non-point sources of nitrogen and phosphorus, rainfall levels, freshwater flows in the Mobile Bay River Delta, and a variety of cycling processes between the sediment and water column. Data collected between 1993 and 1995 show that more than 55% of Mobile Bay had bottom dissolved oxygen levels below 4 mg/L and that 30% of the Bay had levels below 2 mg/L, indicating poor conditions for dissolved oxygen (Mobile Bay NEP, 2002a). Eight percent of the sites monitored by the Alabama Monitoring and Assessment Program (ALAMAP) indicated dissolved oxygen deficiencies (below the 5-mg/L criteria) (ADEM, 2004).

ADEM's pathogen indicators for Mobile Bay are fecal coliform and *Enterococci*. Existing pathogen data have been deemed insufficient for developing a true status and trends relationship because these data have focused on short time frames and narrow geographic regions. In 1996, 412 of 451 mi^2 (91%) of shellfish waters in the study area did not fully support their intended use classifications due to pathogen indicators (Mobile Bay NEP, 2002a). The 2002 303(d) list of impaired stream segments in the Mobile Bay NEP study area indicates that, of the 23 stream segments listed, 11 were listed in part due to pathogen contamination (ADEM, 2002).

Metals and chemicals that are slow to break down in the environment accumulate in Mobile Bay sediments over time, and the Mobile Bay NEP uses a variety of indicators to assess the Bay's sediment quality. These indicators include analyzing sediments for metals and pesticides, monitoring human activities such as fuel spills and pesticide use, and assessing shellfish contamination levels (Mobile Bay NEP, 2002b). Of the 23 303(d)-listed streams located in the Mobile Bay NEP study area, 8 were impaired, in part due to mercury contamination (ADEM, 2002).

Habitat Quality

The Mobile Bay NEP monitors indicators of habitat quality and habitat loss, including upland habitat extent and conversion. Changes in SAV habitat acreage, wetland areas, beach and dune extent, and shoreline habitats are all indicators that have been monitored to evaluate habitat loss in the Mobile Bay system (Hutchings and Yokel, 2000). Probable impacts of habitat loss include population declines and/or the extinction of native species. More than 50% of Alabama's wetland acreage was lost between 1780 and 1980 (Mobile Bay NEP, 2002a). In 2002, the Mobile Bay NEP used aerial photography and GIS technology to assess the extent of SAV in Mobile Bay. The study showed that Mobile Bay's SAV acreage decreased by more than 55% in Mobile County (1940–2002) and by more than 88% in Baldwin County (1955–2002) (Barry A. Vittor &

The brown pelican population has made a remarkable recovery on Gaillard Island (Mobile Bay NEP).

Associates, Inc., 2005). In light of this trend, the relationship between water quality (including nutrient loading and water clarity) and SAV loss is a subject for further evaluation by the Mobile Bay NEP and its partners.

Living Resources

Indicators for monitoring living resources include distribution, diversity, and composition of benthic assemblages; distribution and diversity of native fishes; abundance of exotic species; number of rare listed species by year and habitat acreage; and other measures. The population of many wildlife species in the Mobile Bay NEP study area have been diminished due to overharvesting, pollution, and habitat loss. The Bay and coastal waters of the study area are home to many rare and endangered species of wildlife, including five species of sea turtles; the West Indian manatee; sperm whales; bottlenose dolphins; and the American bald eagle. Thirty-six of the Bay's 337 fish species are listed as at risk (Mobile Bay NEP, 2002a).

More than 350 species of birds can be found in the Mobile Bay NEP study area each year. Some of the birds are year-round residents, whereas others pass though the area during migrations or reside in the area for part of the year. These birds include waterfowl, colonial wading birds, and seabirds. Gaillard Island supports the only nesting colonies of the brown pelican, laughing gull, Caspian tern, and sandwich tern in Alabama. Nests of brown pelicans on the island increased from 4 in 1983 to 4,597 in 1997 (Stout et al., 1998).

Although there are no fish advisories specific to Mobile Bay, the State of Alabama has issued a statewide advisory for mercury in king mackerel from all estuarine/coastal Alabama waters (U.S. EPA, 2005a). The State of Alabama currently employs the FDA standards set for the sale of seafood in issuing fish consumption advisories based on mercury contamination. Discussion is underway to adopt the stricter EPA standards for fish tissue contamination. Using EPA standards would significantly expand the number of streams in Alabama with fish consumption advisories based on mercury contamination (Bouma, 2005).

Environmental Stressors

A variety of human activities are used as indicators to help evaluate environmental stressors in Mobile Bay. These indicators include population growth, sanitary waste per capita, changes in land use and land cover, increase in impervious surfaces, the number and type of development permits, the number of boating and fishing licenses, the number of municipal sewage violations, and the air pollution index for Mobile Bay. Indicators of hydrologic modification are also monitored and include the acres of floodways impacted by development, extent of bulkheading, areal extent of dredging activities, areal extent of wetland filling and excavation, linear extent of stream and creek channelization, shoreline loss and erosion, and other parameters (Hutchings and Yokel, 2000).

Current Projects, Accomplishments, and Future Goals

Major goals of the Mobile Bay NEP include attaining and maintaining water and sediment quality that is sufficient to support healthy aquatic communities and designated human uses; providing optimum fish and wildlife habitat; and restoring historic plant and animal populations. The Mobile Bay NEP is also concerned with providing consistent and enforceable land- and water-use management that ensures smart growth for sustainable development. High-priority issues of the Mobile Bay NEP are habitat loss, rapid coastal growth and development and attendant nonpoint source pollution, water quality, growth management, municipal treatment facilities, public education, and industrial impacts on the Bay. Several of the Mobile Bay NEP's current projects and accomplishments are described below:

- The Mobile Bay NEP, in partnership with the Dauphin Island Sea Lab, the University of South Alabama's Center for Estuarine Studies, and the Weeks Bay NERR, has established the first long-term network of real-time, continuous time-series water monitoring stations in Mobile Bay. This project provides basic data from three new sites in Mobile Bay and links an established site at the Weeks Bay NERR. The most recent addition to the network, the site at Middle Bay, is unique in that its vertical water-profiling system provides information throughout the water column. The measured meteorological and hydrographic parameters include wind speed and direction, air temperature, barometric pressure, solar radiation, quantum radiation, precipitation, water temperature, water height, salinity, dissolved oxygen, and turbidity.
- A major GIS study and water monitoring program is now underway to identify the sources of pathogen introduction into one of the local 303(d)-listed streams, with an aim toward taking necessary remediation or corrective actions.
- Two major habitat-restoration grants have been awarded to local organizations by the Mobile Bay NEP. The first grant helped eliminate the world's second-most invasive weed, cogon grass, on a portion of a 2,400-acre site bordering the Tensaw River. The second grant provides for purchase and further restoration of an 8-acre marsh on Mon Luis Island.
- A SAV restoration manual has been completed and printed, and a SAV restoration project involving numerous volunteers is in progress (Turner et al., 2005).
- In concert with the USACE and other partners, several restoration projects are in the planning stages, including the use of dredge material to restore nesting habitat on a barrier island; the creation of additional oyster bottom, emergent marsh, and SAV habitat; and the examination of the feasibility of increased public access.
- In partnership with the Nature Conservancy, the Mobile Bay NEP has completed an assessment of habitat-protection needs and identified priority sites for acquisition and conservation protection, as well as other priority sites for restoration efforts. The first efforts toward implementing these goals are underway. In addition, a database is being created in partnership with the Mississippi-Alabama Sea Grant to catalogue restoration and acquisition efforts on the Mississippi and Alabama coasts and to help better direct and refine efforts in this area.

- The Mobile Bay NEP facilitated discussions and planning between conservation, recreational, and commercial interests through a public process. These activities resulted in the closure of a portion of the upper reaches of Mobile Bay to shrimp trawling, thereby reducing the impacts of bycatch on juvenile finfish and of trawling on SAV habitat.
- The Mobile Bay NEP is partnering with the City of Mobile and the State Lands Division on the creation of a significant public access site and the restoration of its adjoining marsh area.
- A preliminary report has been prepared concerning the probable impacts of the Mobile Bay Causeway on freshwater and saltwater hydrology in the Mobile-Tensaw River Delta, as well as its attendant impact on aquatic living resources (Valentine et al., 2004).
- Since 2001, the Mobile Bay NEP has helped to conduct an Oyster Gardening Program. This program has many purposes, including collecting data on oysters, improving water quality through oyster filtration, protecting young oysters by improving their conditions, creating habitat for other marine species that form the base of the food chain, and educating the community about oysters.

Conclusion

Based on data collected by the NCA, the overall condition of Mobile Bay is rated fair. The Mobile Bay NEP has not yet finalized its indicators for tracking the health of Mobile Bay, but this task will be completed in 2006. The preliminary list of indicators includes a variety of parameters used to assess water, sediment, and habitat quality; habitat loss; living resources; hydrologic modifications; and the effects of human activities on the estuary. Several of these parameters are currently being monitored in the study area, and the Mobile Bay NEP is making progress towards developing status and trends data for these indicators.

Barataria-Terrebonne National Estuary Program

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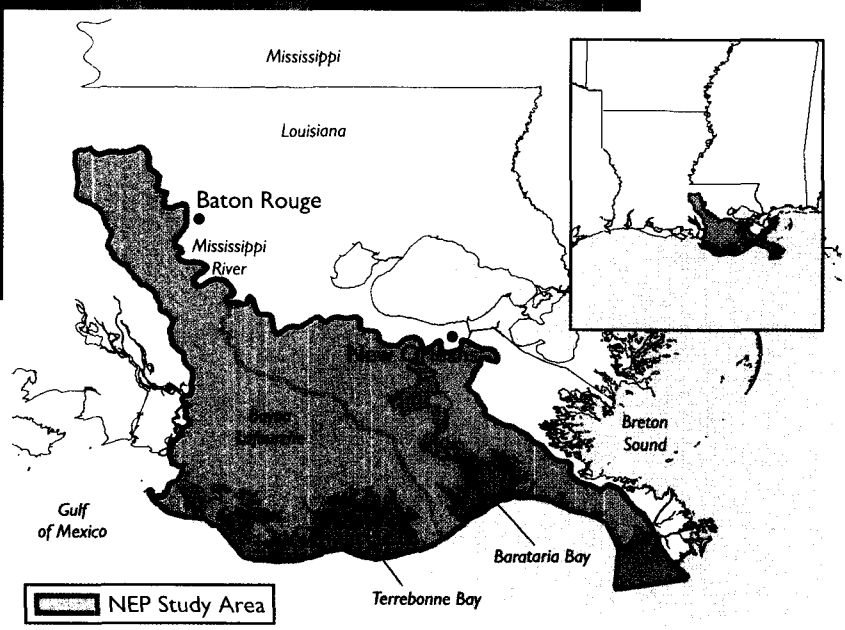


Background

The study area of the Barataria-Terrebonne National Estuary Program (BTNEP) is located between the Mississippi and Atchafalaya rivers in southern Louisiana and covers approximately 6,500 mi^2 (Caffey and Breaux, 2000). Bayou Lafourche separates this area into two basins: Barataria Basin to the east and Terrebonne Basin to the west. The integration of salt water and fresh water begins offshore, where water, sediment, nutrients, and pollutants from the Mississippi River mix with the salt water of the Gulf of Mexico. Approximately 735 species of birds, finfish, shellfish, reptiles, amphibians, and mammals spend all or part of their life cycle in the estuary, with several of these species categorized as either threatened or endangered (BTNEP, 2005).

Significant industrial and municipal effluents enter the Mississippi River between Baton Rouge and New Orleans, contributing to nutrient and contaminant loadings in the estuary system. Several natural and man-made waterways transect the estuary system, including the Gulf Intracoastal Waterway and the Barataria Waterway. Open water and wetlands are the predominant land-use classifications in the region and have been

increasing in area since 1956 (Figure 5-43). More than three quarters of the BTNEP study area (3.2 million acres) is classified as open water or wetlands, leaving approximately one million acres for urban and agricultural uses (Moore and Rivers, 1996).

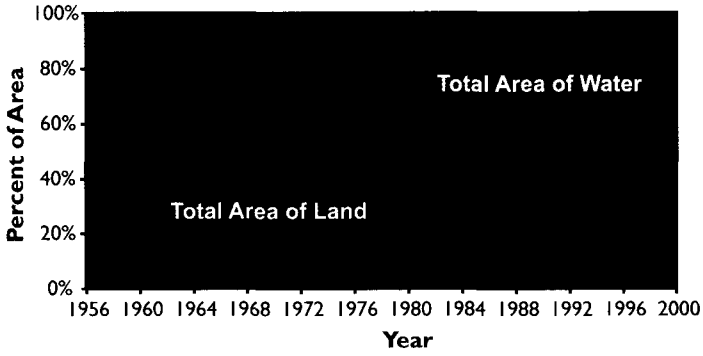


Figure 5-43. Change in the total area of water in the BTNEP estuarine area between 1956 and 2000 (BTNEP, 2002).

Environmental Concerns

The priority issues affecting the BTNEP study area include habitat loss, hydrological modification, reduced sediment flows (reduction in sediment inputs), eutrophication, pathogen contamination from untreated sewage and stormwater discharges, toxic substances, and declines in living resources (Battelle, 2003). Sediment loss (depletion), in conjunction with the subsidence (sinking) of marshes, is the most significant problem in the Barataria-Terrebonne Estuarine Complex. The construction of levees to protect human communities from floods has eliminated vital inputs of fresh water and sediments from reaching the estuaries; these inputs are needed to keep the marshes above water. Sea-level rise, erosion, canal dredging, and the construction of navigation and oil-exploration channels further contribute to this problem. The impacts of hydrological modifications in the BTNEP study area are numerous; man-made canals create paths for waters of higher salinity to intrude inland, destroying freshwater plants and forcing animals either to adapt or to relocate. Each year, about 15 mi^2 of wetlands in the study area are lost, and a half-acre of the Complex's coastal wetlands turns to open water every 15 minutes (BTNEP, 2002; Focazio, 2006b). Because this coastal marsh habitat provides a considerable buffer from the flooding, storms, and hurricanes that threaten the Louisiana coastline, this loss of habitat is detrimental to the health of fish and wildlife populations and to human development. Many species that depend on habitat in the Barataria-Terrebonne Estuarine Complex are either threatened or endangered, including the American bald eagle, brown pelican, piping plover, least tern, Louisiana black bear, and American alligator.

Population Pressures

The population of the 16 NOAA-designated coastal parishes coincident with the BTNEP study area increased by 28% during a 40-year period, from 1.3 million people in 1960 to 1.6 million people in 2000 (Figure 5-44) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the BTNEP study area was the lowest growth rate of any of the Gulf Coast NEPs and constitutes less that one-fourth of the population growth rate of 133.3% for the collective NEP-coincident coastal counties of the Gulf Coast region. In addition, the population density of the BTNEP study area in 2000 was 184 persons/mi^2, the second-lowest density of the Gulf Coast NEPs and about one-third less than the population density of the region's collective NEP-coincident counties (287 persons/mi^2) (U.S. Census Bureau, 2001). Development and population pressures are moderate in this study area, which serves as a major center for commercial fishing and shellfish, the petrochemical industry, and recreational activities.

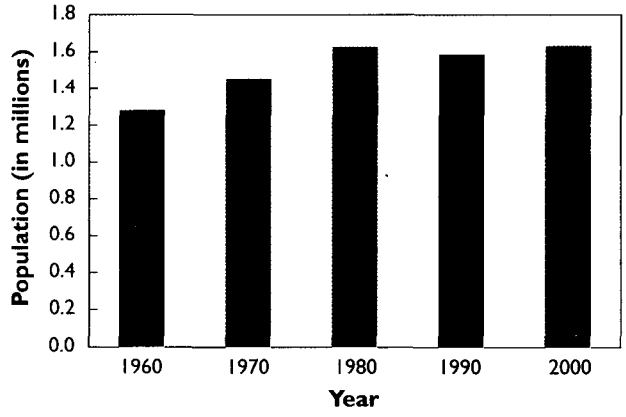


Figure 5-44. Population of NOAA-designated counties of the BTNEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Barataria-Terrebonne Estuarine Complex

The overall condition of the Barataria-Terrebonne Estuarine Complex is rated fair based on the four indices of estuarine condition used by the NCA (Figure 5-45). The water quality, sediment quality, and benthic indices are rated fair, and the fish tissue contaminants index is rated poor. Figure 5-46 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 collected by the State of Louisiana and the NCA from 25 stations sampled in the BTNEP 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.

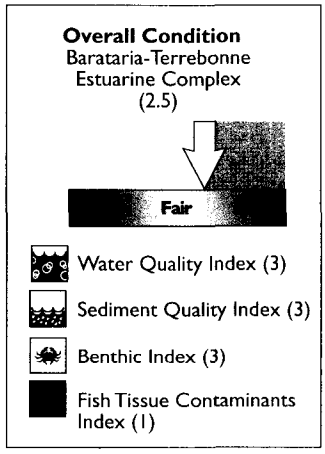


Figure 5-45. The overall condition of the BTNEP estuarine area is fair (U.S. EPA/NCA).

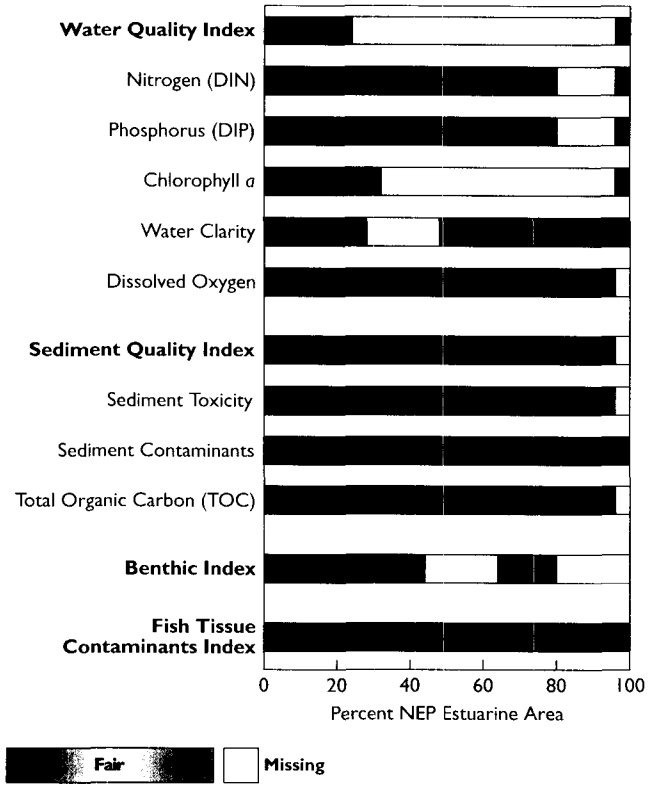


Figure 5-46. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Barataria-Terrebonne Estuarine Complex (U.S. EPA/NCA).

Water Quality Index

Based on NCA survey results, the water quality index for the Barataria-Terrebonne Estuarine Complex is rated fair (Figure 5-47). This water quality index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. In NOAA's Estuarine Eutrophication Survey, Barataria Bay was listed as having high to hypereutrophic chlorophyll *a* concentrations and high DIN and DIP concentrations (NOAA, 1997). In the same report, the Terrebonne and Timbalier bays were listed as having high chlorophyll *a* and DIP concentrations and moderate DIN concentrations.

Dissolved Nitrogen and Phosphorus | DIN and DIP concentrations in the BTNEP estuarine area are rated good. For both component indicators, 4% of the estuarine area was rated poor, 16% of the area was rated fair, and 80% of the area was rated good.

Chlorophyll a | Chlorophyll *a* concentrations in the Barataria-Terrebonne Estuarine Complex are rated fair. Although only 4% of the estuarine area was rated poor for chlorophyll *a* concentrations, 64% of the area was rated fair, and 32% of the area was rated good.

Water Clarity | Water clarity in the BTNEP estuarine area is rated poor. Expectations for water clarity are low due to high river flow and naturally high turbidity for these estuaries. Water clarity was rated poor at a sampling site if light penetration at 1 meter was less than 5% of surface illumination. Fifty-two percent of the estuarine area was rated poor for water clarity, 20% of the area was rated fair, and 28% of the area was rated good.

Dissolved Oxygen | Dissolved oxygen conditions in the BTNEP estuarine area are rated good. NCA estimates show that none of the estuarine area was rated poor for this component indicator, 4% of the estuarine area was rated fair, and 96% of the area was rated good.

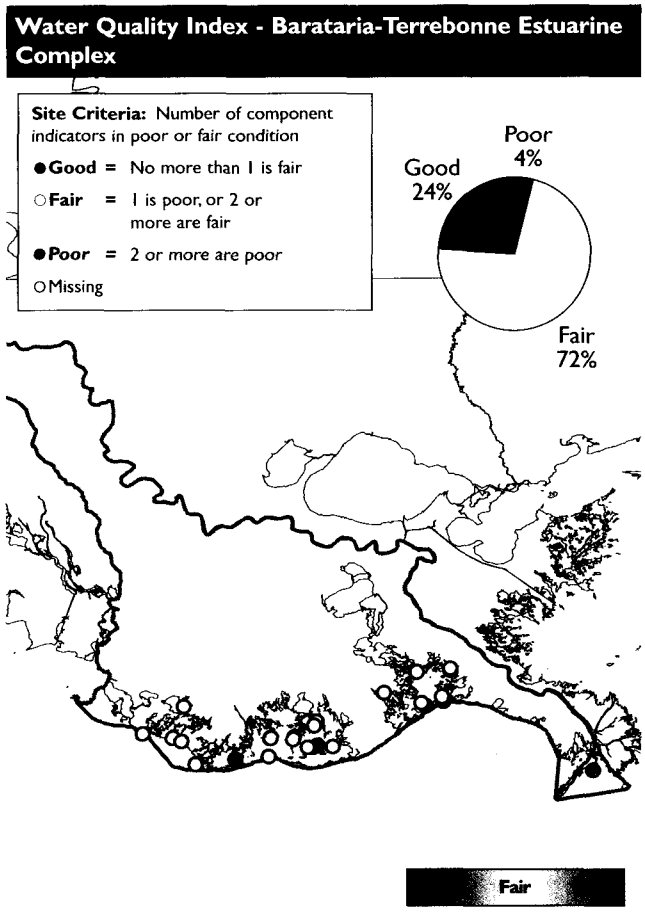


Figure 5-47. Water quality index data for the Barataria-Terrebonne Estuarine Complex, 2000–2001 (U.S. EPA/NCA).

Sediment Quality Index

The sediment quality index for the Barataria-Terrebonne Estuarine Complex is rated fair. This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC. Although all three component indicators received good ratings for the Barataria-Terrebonne Estuarine Complex, the index is rated fair because greater than 5% of the estuarine area was rated poor for sediment quality (Figure 5-48).

Sediment Toxicity | Sediment toxicity is rated good for the BTNEP estuarine area because none of the area was rated poor for this component indicator.

Sediment Contaminants | Only 4% of the BTNEP estuarine area was rated poor for sediment contaminant concentrations; therefore, the Complex is rated good for this component indicator.

Total Organic Carbon | Sediment TOC is rated good for the BTNEP estuarine area. Eighty-eight percent of the estuarine area was rated good for this component indicator, and only 8% of the area was rated poor. NCA data on TOC concentrations were unavailable for 4% of the BTNEP estuarine area.

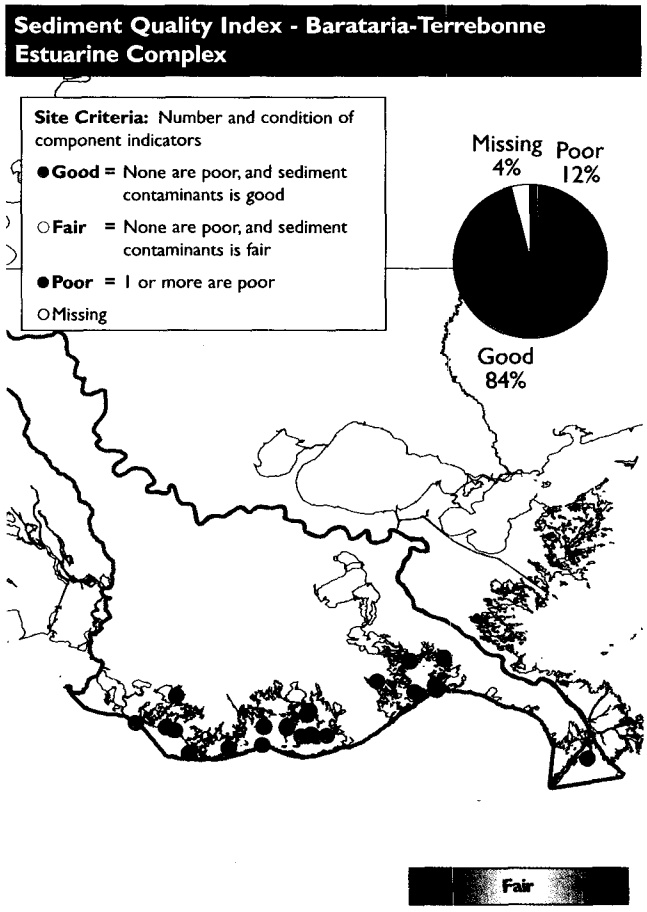
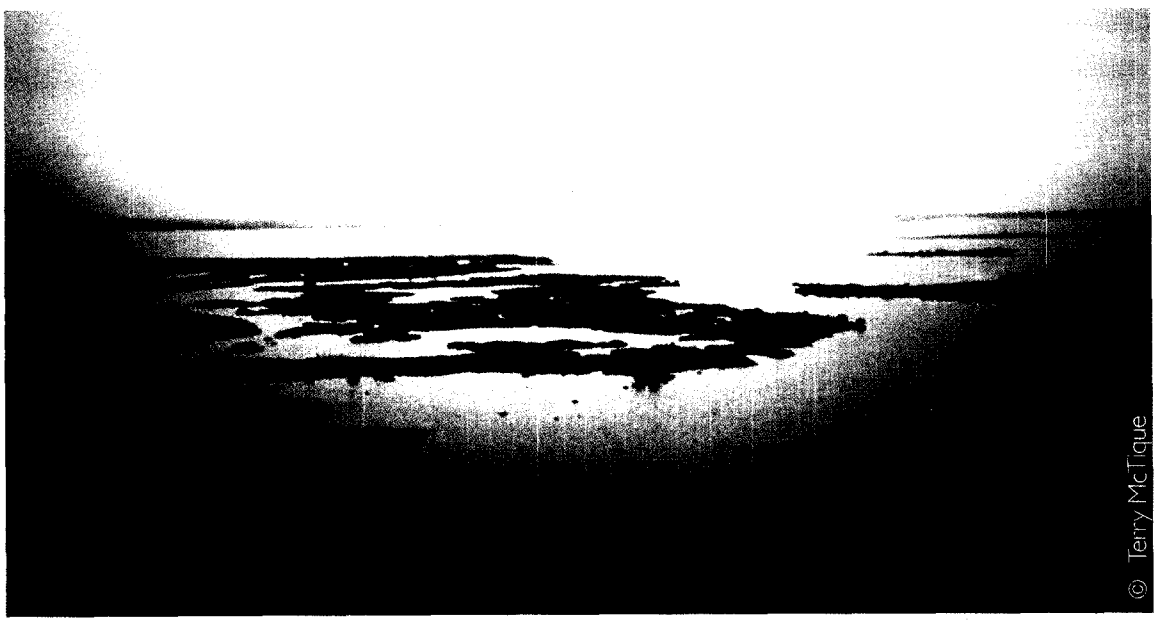


Figure 5-48. Sediment quality index data for the Barataria-Terrebonne Estuarine Complex, 2000–2001 (U.S. EPA/NCA).



Eroding marsh peninsula between Bayous Perot and Rigolettes, Barataria Basin (Dr. Terry McTigue, NOAA, NOS, ORR).

Benthic Index

Based on NCA survey data and the Gulf Coast Benthic Index, the condition of benthic invertebrate communities in the Barataria-Terrebonne Estuarine Complex is rated fair. Benthic condition index estimates indicate that 16% of the area had degraded benthic resources, and NCA data on benthic condition were unavailable for 20% of the BTNEP estuarine area (Figure 5-49).

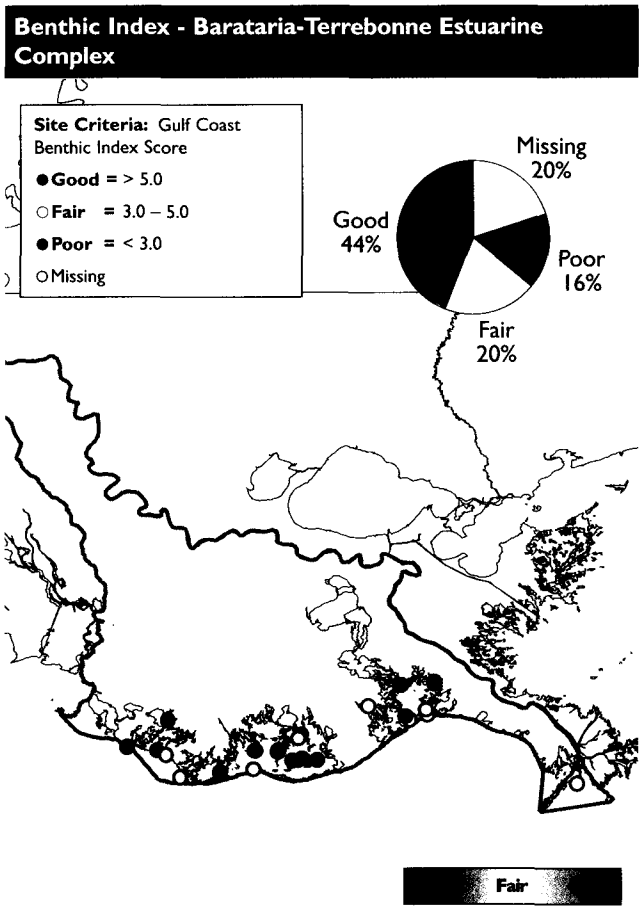


Figure 5-49. Benthic index data for the Barataria-Terrebonne Estuarine Complex, 2000–2001 (U.S. EPA/NCA).

Fish Tissue Contaminants Index

The fish tissue contaminants index for the Barataria-Terrebonne Estuarine Complex is rated poor. Figure 5-50 shows that 27% of all stations sampled where fish were caught exceeded the EPA Advisory Guidance values used in this assessment and were rated poor.

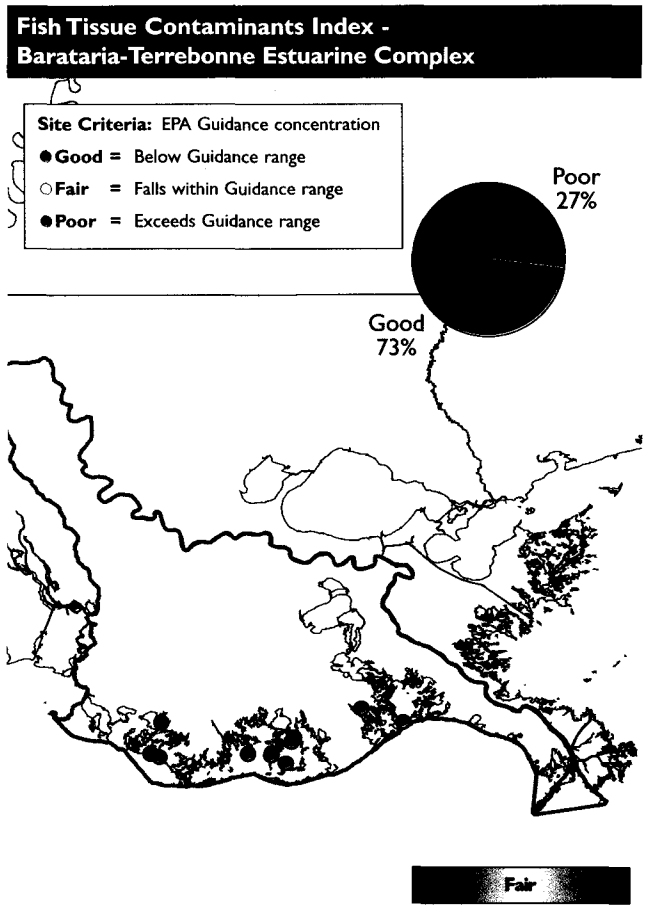


Figure 5-50. Fish tissue contaminants index data for the Barataria-Terrebonne Estuarine Complex, 2000–2001 (U.S. EPA/NCA).

Barataria-Terrebonne National Estuary Program

HIGHLIGHT

Maritime Forest Ridge and Marsh Restoration at Port Fourchon, Louisiana

The Maritime Forest Ridge and Marsh Restoration (MFRMR) at Port Fourchon, LA, is a vital migratory bird habitat-restoration project that is intended to serve as an example for similar coastal ridge restoration work and to provide useful scientific data for future coastal restoration projects. To achieve these goals, the BTNEP has offered its assistance in many capacities. For example, the BTNEP and its Migratory Bird Action Plan Team worked as liaisons between the bird-watching community and the Greater Lafourche Port Commission to encourage the project. The BTNEP has also served as a liaison between the Greater Lafourche Port Commission and various federal and state agencies during the permitting process.

The project's vision includes plans to restore a historic maritime forest ridge that has eroded and subsided since the 1950s; vegetate the ridge with woody plant species that provide excellent habitat for migratory birds; and eventually add boardwalks, trails, and an interpretive center.

More than 60 acres each of salt marsh and maritime forest ridge have been created. The construction phase of this project involved grading the land to transform a linear mound into a sloped ridge habitat, with a elevation gradient ranging from marsh elevation at 1.6 feet above sea level in the tidal zone to 8 feet above sea level at the peak of the ridge. Future phases of the MFRMR project development include plans to extend the project area linearly by several thousand feet over the next few years. Funding for the initial conceptualization and construction phase came from several sources, including $100,000 of direct project support from the Louisiana Department of Natural Resources (LDNR); a $100,000 grant from the Shell Oil Company; and $45,000 in project support from various project partners (Personal communication, Blanchard, 2005). The partners for this phase of the project listed below.

Partners for Restoring the Historic Maritime Forest Ridge	
Barataria-Terrebonne National Estuary Program	Barataria-Terrebonne Estuary Foundation
Greater LaFourche Port Commission	Gulf of Mexico Foundation
Gulf of Mexico Program	The Louisiana Nature Conservancy
Louisiana Department of Natural Resources	Natural Resource Conservation Service
National Oceanic and Atmospheric Administration	Orleans Audubon
Shell Oil Company	Terrebonne Bird Club

Now that this phase of the MFRMR project is nearing completion, the BTNEP is working closely with another group of partners (e.g., NOAA, the Gulf of Mexico Partners) to vegetate and monitor the MFRMR project area. The newly formed BTNEP Volunteer Program has hosted three volunteer planting events at the MFRMR project area. These events involved more than 150 volunteers who planted nearly 11,000 plants (Personal communication, Blanchard, 2005). Because of the logistics involved in transporting people and plants to the MFRMR site, project partners were needed to ferry materials and volunteers to the site by boat, as well as to provide lunches, drinks, and T-shirts to the volunteers. Partners who contributed to the volunteer efforts on the ridge include the BTNEP, Barataria-Terrebonne Estuary Foundation, Greater Lafourche Port Commission, USDA NRCS Plant Materials Center, ES&H Environmental Safety Consulting, Inc., Louisiana Department of Wildlife and Fisheries (LDWF), and Lafourche Parish Coastal Zone Management (CZM). Groups that volunteered their efforts for the different planting events on the ridge include the Lockport Middle School, Bayou Lafourche Marine Institute, Boy Scouts of America, Shell Oil Company Summer Interns, and University of New Orleans PIES Camp students. The efforts of these volunteers are important because the vegetation helps to stabilize the shoreline and slopes of this restored habitat against hurricanes. A future large-scale volunteer effort is also planned, where volunteers will plant woody trees and shrubs on the crown of the ridge.

The BTNEP recognizes that any efforts to restore the rapidly vanishing coastal lands of south Louisiana not only require sound scientific footing, but also the full support and involvement of the citizens who live, work, and play in the lands and waterways of coastal Louisiana. By engaging residents through volunteerism, the BTNEP not only forges new community partnerships and fosters public support for coastal restoration, but it also puts a face on the efforts to save this landscape by allowing citizen volunteers to work shoulder-to-shoulder with the biologists, geologists, engineers, and other scientists who work on the immense problems faced by the coastal Louisiana region. Additional information about the MFRMR and other restoration projects in the BTNEP study area is available by contacting the BTNEP or by visiting the program's Web site at: http://www.btnep.org.

BTNEP volunteers plant marsh plants to restore vegetation to the ridge site (BTNEP).

Barataria-Terrebonne National Estuary Program Indicators of Estuarine Condition

Water and Sediment Quality

The following water and sediment quality indicators are used by the BTNEP to assess estuarine condition:

- Eutropic conditions and nutrient levels
- Hypoxia (i.e., area of dead zone)
- Pathogens (e.g., fecal coliform at swimming and shellfish-harvesting areas)
- Levels of toxic substances in water and sediment
- Oyster bed closures.

Eutrophic conditions and nutrient levels in the Barataria-Terrebonne Estuarine Complex are monitored at a series of 15 sites within the region, and trend studies show that all sites have been classified as having either medium or high nutrient conditions under EPA/NOAA's guidelines for evaluating nutrient concentrations. Measurements of chlorophyll *a* levels during the past 20 years provide strong evidence that eutrophication is occurring in this system because many sites show an increase in chlorophyll *a* concentrations over time (Rabalais et al., 1995).

The extent of mid-summer hypoxia (dissolved oxygen levels below 2.0 mg/L) in bottom waters often affects up to 8,000 mi^2 of the Louisiana and Texas continental shelf and has been associated with large fish kills in the Barataria-Terrebonne Estuarine Complex (Battelle, 2003). Hypoxic events are good indicators for monitoring nutrient pollution loads associated with wastewater treatment and agricultural runoff. Over time, nearshore bottom dissolved oxygen concentrations have typically varied from 4 to 8 mg/L in the Complex, with sampling results indicating that persistent hypoxia tends to occur from mid-May to mid-September (Rabalais et al., 1995). Overall, data on dissolved oxygen in bottom waters are limited, but research has shown that hypoxic conditions (area of dead zone) in the Complex are most likely to occur in poorly flushed areas, deeper channels, and areas receiving organic loading from sewage or other wastewater outfalls.

Pathogens from sewage pollution in the Complex are associated with illnesses in humans who swim in contaminated waters or who eat contaminated oysters. To help reduce the consumption of pathogen-contaminated oysters, the Louisiana Department of Heath and Hospitals Molluscan Shellfish Program monitors fecal coliform bacteria levels in surface waters on a monthly basis in the oyster bed areas of the Barataria-Terrebonne Estuarine Complex (Battelle, 2003). Fecal coliform in the Complex comes from a variety of sources, including poorly functioning on-site septic systems, pasture land runoff, and waste from marsh animals, nutria, and waterfowl.

The presence of toxic substances in BTNEP waters can be measured by testing the surface water and sediment or by testing the fish that feed in these waters. Atrazine is a concern in the surface waters of the BTNEP study area and is measured through the direct testing of these waters. Concentrations of atrazine in the surface waters of the Upper Terrebonne basin have exceeded the EPA maximum contaminant level (MCL) of 3 ppb for drinking water (Battelle, 2003). Copper, lead, arsenic, chromium, and cadmium concentrations have declined since the 1980s, whereas mercury levels have remained fairly constant. Although contamination is fairly widespread in scope, the areas of most concern are on the periphery of the Complex, such as Oyster Bayou and Tiger Pass. Other contaminants have been detected in fish or shellfish, which accumulate toxic substances from the food they eat and from the surrounding water and sediments. Toxics detected in fish and crustaceans of the Barataria-Terrebonne Estuarine Complex include pesticides, metals, volatile organic compounds (VOCs), and PCBs (Rabalais et al., 1995).

Habitat Quality

The LDNR, NRCS, and other programs collectively monitor the number of acres of salt marshes and oligohaline (low salinity) habitat that have been restored in the BTNEP study area since 1986; however, the data needed to make actual assessments of habitat quality and functionality on a Complex-wide basis do not yet exist (Battelle, 2003). A large number of data sets specific to individual restoration projects are available, but these data sets can not be readily combined to

report on status and trends for habitat restoration across the entire Barataria-Terrebonne Estuarine Complex. The Louisiana Coastwide Reference Monitoring System has been proposed to help make large restoration efforts a possibility. This effort requires collecting estuary-wide information, including land/water ratios; vegetation composition and cover; frequency of flooding; salinity; and sedimentation and erosion.

Living Resources

The following list of indicators is used by the BTNEP to measure changes in living resources:

- Endangered or threatened species (e.g., abundance and nesting success of brown pelican and American bald eagle)
- Waterfowl (e.g., abundance of mottled duck)
- Density of alligator nests
- Invasive species (e.g., acres of marsh damaged by invasive nutria)
- Number of fish consumption advisories and mercury levels in fish tissue.

Both the bald eagle and the brown pelican populations show signs of recovery following near extinction in the area due to reproductive failures associated with pesticide exposures. Today, Louisiana's brown pelicans occur throughout their historic range, and this reintroduction program is a success story in Louisiana's conservation efforts. The number of successful nests in the Barataria-Terrebonne Estuarine Complex has risen from 675 in 1990 to more than 6,500 in 2001 (BTNEP, 2002). Bald eagles are monitored for the number of successful nests, active nests, and fledglings produced (Battelle, 2003).

Status and trend reports indicate that 35 species of waterfowl have been reported in the Complex, which is of international significance as a wintering ground for migratory waterfowl species. Drought, marsh loss, commercial development, and predation all affect the Complex's duck population on an annual basis and can provide information about degradation or loss of habitat (Condrey et al., 1995). The Audubon Society's Christmas bird count is another indicator used by the BTNEP, and monitoring the abundance of shorebird species has been suggested as a priority indicator need.

The density of alligator nests in the Barataria-Terrebonne Estuarine Complex is directly indicative of population size and indirectly indicative of the abundance of fresh marsh habitats. The LDWF has been conducting an annual nest survey since 1991 to establish quotas, measure abundance, and assess productivity. The number of alligator nests is often affected by drought conditions and salinity levels (Battelle, 2003).

The growth of invasive species and the resultant damage they cause is another priority concern of the BTNEP. Among the most serious invasive species found in the Barataria-Terrebonne Estuarine Complex are water hyacinth, water spangle, Eurasion watermilfoil, *Hydrilla*, alligatorweed, Chinese tallow tree, and zebra mussel. The LDWF spends about $1.5 million annually on non-native aquatic plant control (BTNEP, 2002) and also collects data on the damage caused by nutria herbivory using periodic aerial surveys over brackish marsh areas (Figure 5-51). Nutria are a concern because they damage agricultural crops and irrigation dikes and consume the roots of marsh plants, thereby accelerating land loss. Damage and control costs for zebra mussels is also a good indicator of the magnitude of this invasive species problem.

The number of fish consumption advisories issued in the Barataria-Terrebonne Estuarine Complex is an indicator of the overall human health risk associated with toxic contaminants in seafood. Fish sampling is conducted by the Louisiana Department of Environmental Quality near facilities that have experienced chemical spills or demonstrated poor waste management practices. There are no waterbody-specific fish consumption advisories within the BTNEP study area; however, Louisiana has issued a statewide mercury advisory for king mackerel in all coastal waters, which includes BTNEP estuarine waters (U.S. EPA, 2005a).

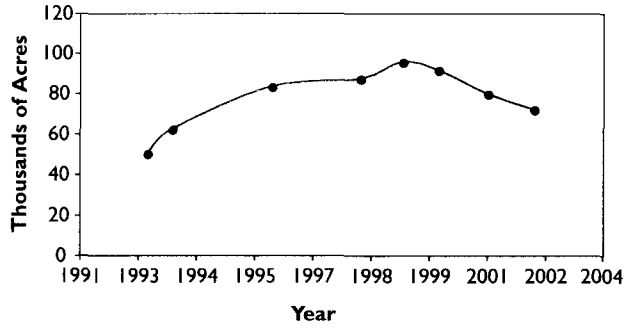


Figure 5-51. Estimated acreage damaged by nutria herbivory (BTNEP, 2002).

Environmental Stressors

In coastal Louisiana, more than 160,000 registered recreational vessels share the water with thousands of commercial vessels. Dumping sewage overboard can contaminate surface waters, sediments, and fishery stock with pathogens and was the suspected cause of at least two outbreaks of illness due to the consumption of contaminated oysters in the 1990s. To reduce instances of overboard dumping, many marinas offer boat pump-out stations for the collection of sewage from recreational and commercial vehicles. The cumulative number of boat pump-out stations in the Barataria-Terrebonne Estuarine Complex is another indicator tracked by the LDWF, and the number of stations has risen considerably at both commercial and recreational marinas since the early 1990s. The availability of these stations is critical to reducing overboard discharge of sewage to swimming and oyster-growing areas in the region and to controlling outbreaks of gastroenteritis that have been associated with Norwalk viruses and site closures since 1982 (Battelle, 2003).

Current Projects, Accomplishments, and Future Goals

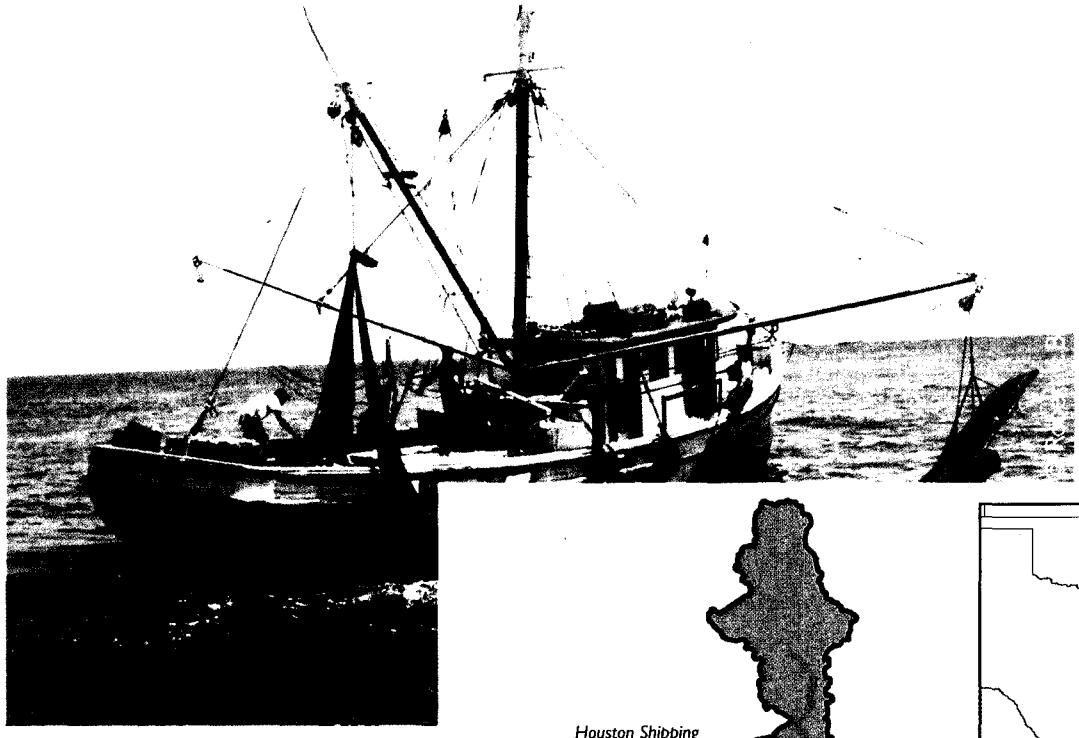
The BTNEP has produced videos, posters, brochures, booklets, and presentations and has made them available to teachers and other educators through their Web site. Materials are available for kindergarten through 12th grade and feature a range of media, including coloring books, videos, slides, and posters. The BTNEP has also created Action Plan Teams to implement its CCMP, *The Estuary Compact: A Public Promise to Work Together to Save the Barataria and Terrebonne Basins* (Moore and Rivers, 1996), in each of five different areas: Water Quality, Habitat, Living Resources, Cultural Heritage, and Economic Development. The BTNEP is actively implementing a large habitat-restoration program, which includes numerous projects to rebuild wetlands, ridges, barrier islands, and other habitats, such as the following:

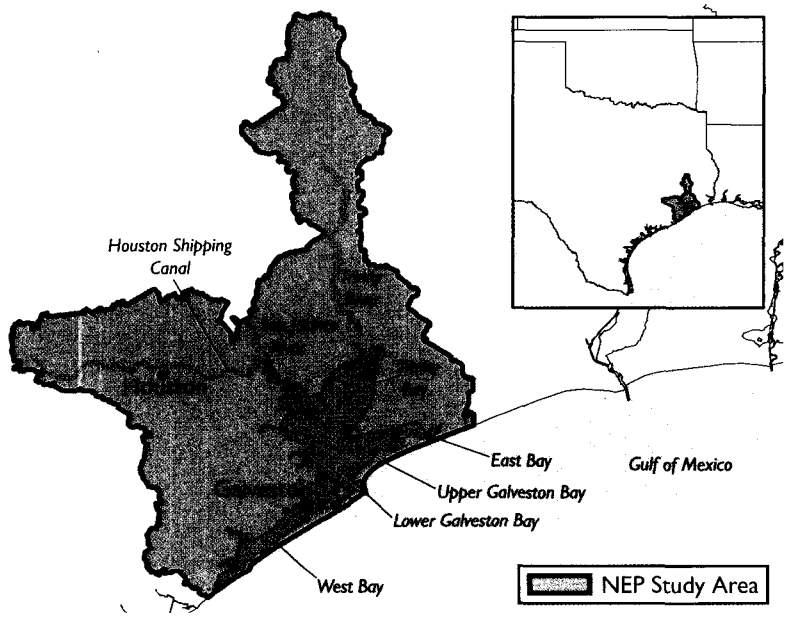
- **Point Aux Chenes stormwater redirection** – This pilot-scale restoration project is diverting stormwater discharge into the Point Aux Chenes wetlands. These discharges are expected to reduce salinity, stimulate the growth of emergent vegetation, and encourage sedimentation in the wetland.
- **SAV research** – The BTNEP is working to assess the habitat value and to develop new methods for restoring various SAV throughout the Complex.
- **Invasive species workshops** – These workshops educate the public about which invasive species have infiltrated the BTNEP study area, how these species impact the region's ecosystem, and what steps government agencies and individuals need to take to combat these invasive species.

Conclusion

The data from the NCA suggest that the overall condition of the BTNEP study area is rated fair and that water quality is rated fair. Water quality indicators used by the BTNEP show that eutrophication is a continuing concern across the Complex and will require ongoing monitoring of nutrient and dissolved oxygen concentrations. In addition, the monitoring of chlorophyll *a* levels helps provide the more conclusive data needed to support future analyses of eutrophic conditions. Although the NCA's dissolved oxygen measurements show that none of the Complex's bottom water areas exhibited hypoxia, these measurements were made during a relatively short time period and provide only a snapshot of the summer dissolved oxygen concentrations. The BTNEP's partner agencies conduct monitoring on a year-round basis rather than during a single summer-sampling period, as is used by the NCA. The more intensive year-round monitoring allows researchers to evaluate more subtle changes and trends that may only be discernable when comparing data over a more extensive period of time. For example, NCA sampling may not have occurred during one of the periods of hypoxia that often occur in the Complex during late summer; however, these hypoxic events are sometimes detected when more frequent monitoring intervals are used by the BTNEP. The BTNEP's indicators also demonstrate that pathogens are an issue within the estuarine system. Sediment quality tests have provided limited information, but indicate contamination around discharge areas in the estuary basin.

Galveston Bay Estuary Program





GALVESTON BAY ESTUARY PROGRAM

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Background

Galveston Bay is a subtropical estuary located on the southeastern shore of the upper Texas Gulf coast. The Bay is composed of five major subbays: Trinity, Upper Galveston, Lower Galveston, East, and West bays. The combined area of the five subbays is 384,000 acres (600 mi^2), surrounded by 1,171 miles of shoreline (GBEP, 2005; HARC, 2005b). The estuary is fed by two major rivers (Trinity and San Jacinto rivers) and is bordered by low-lying wetlands, two barrier islands, and a peninsula. The waters of Galveston Bay can be characterized as well mixed and quite shallow (averaging 7 feet) and are made shallower in some places by extensive oyster reefs (GBEP, 2005). The Bay has increased in volume during the past 50 years due to natural and anthropogenic subsidence, as well as sea level rise and dredging operations (Lester and Gonzalez, 2003). Major habitats in the Bay include estuarine and freshwater marsh, mudflats, seagrass beds or SAV, oyster reefs, and open water.

Galveston Bay is used extensively for recreational and commercial activities, and the potential for large-scale human impacts is great. Galveston Bay is one of the

largest sources of seafood for Texas, as well as one of the major oyster-producing estuaries in the country. The oysters, crabs, shrimp, and finfish harvested from Galveston Bay are worth a combined $19 million annually (Sage and Gallaway, 2002). One-third of the state's commercial fishing income and more than half of the state's recreational fishing expenditures are derived from Galveston Bay (GBEP, 2005). The Port of Houston is the second-largest port in the United States in tonnage and the eighth-largest port in the world (Sage and Gallaway, 2002). Along with the ports of Texas City and Galveston, the Port of Houston supports the region's petrochemical industries, which are the largest in the nation and the second-largest in the world (Port of Houston Authority, 2006). These industries combine to produce one-half of the nation's chemicals and one-third of the nation's petroleum refining (U.S. EPA, 2002a).

Extending back from the river mouths, the entire Galveston Bay watershed covers 33,000 mi^2, includes the metropolitan areas of Houston-Galveston and Dallas-Ft. Worth, and is home to nearly half of the population of Texas (GBEP, 2005). The surrounding watershed is composed of a variety of habitats, ranging from open prairies and coastal wetlands to riparian hardwoods and pine-dominant forests, and these habitats support numerous plant, fish, and wildlife species.

To increase public awareness and help address negative trends in wetland loss, habitat degradation, and non-point source pollution, the Galveston Bay Estuary Program (GBEP) was formed in 1989. Efforts of the GBEP are concentrated in the 4,200-mi^2 lower watershed, which is demarked by the dams that form Lake Houston on the San Jacinto River and Lake Livingston on the Trinity River. Following the establishment of its CCMP, *The Galveston Bay Plan: The Comprehensive Conservation and Management Plan for the Galveston Bay Ecosystem*, the GBEP now continues its work as part of the Texas Commission on Environmental Quality (TCEQ) (GBNEP, 1995).

Environmental Concerns

With Galveston Bay in the shadow of the nation's fourth-largest city, the environmental concerns of highest priority for the GBEP are wetland loss and habitat degradation, point and non-point source pollution, and chemical and petroleum product spills from barges and industry (Sage and Gallaway, 2002). Non-point source pollution in Galveston Bay is attributed to a variety of sources, including runoff from thousands of gas stations, residential lawns, failing septic systems, driveways, parking lots, industries, farms, and other sources. Accidental spills and the deliberate dumping of oil and other contaminants potentially harm the habitat and living resources of Galveston Bay. Other priority issues for Galveston Bay include new and existing introductions of aquatic and terrestrial exotic nuisance species, contaminated runoff from urbanized areas, and the increasing and often competing demands for fresh water. Additionally, sediment in the Houston Ship Channel exceeds levels of concern for a number of hazardous chemicals, including PCBs, DDT, dioxin, and heavy metals.

Population Pressures

The population of the 7 NOAA-designated coastal counties (Brazaria, Chambers, Fort Bend, Galveston, Harris, Liberty, and Waller) coincident with the GBEP study area increased by 182% during a 40-year period, from 1.6 million people in 1960 to 4.4 million people in 2000 (Figure 5-52) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the GBEP study area exceeded the population growth rate of 133.3% for the collective NEP-coincident coastal counties of the Gulf Coast region. In 2000, the GBEP-coincident coastal counties had a population density of 651 persons/mi^2 (the highest of all the Gulf Coast NEPs).

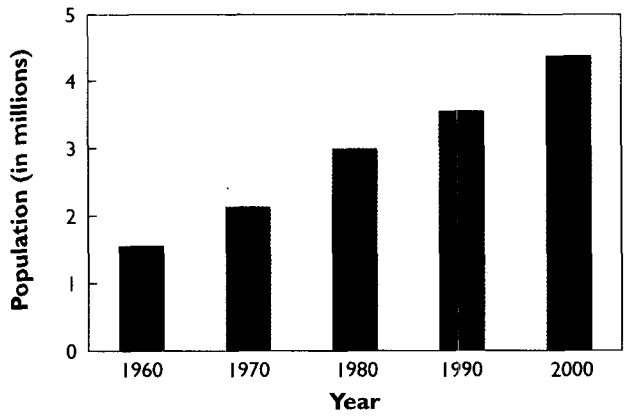


Figure 5-52. Population of NOAA-designated counties of the GBEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

This density was more than double the density of 287 persons/mi^2 for the collective NEP-coincident coastal counties of the Gulf Coast region (U.S. Census Bureau, 2001). Development and population pressures are especially strong in this NEP because it serves as a major center for international commerce; oil refinery and other petrochemical industries; commercial fish and shellfishing operations; and recreational activities for these coastal communities.

NCA Indices of Estuarine Condition—Galveston Bay

The overall condition of Galveston Bay is rated fair based on the four indices of estuarine condition used by the NCA (Figure 5-53). The water quality index is rated poor, the sediment quality index is rated fair to poor, the benthic index is rated fair, and the fish tissue contaminants index is rated good to fair. Figure 5-54 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 collected by the Texas Park and Wildlife Department (TPWD) and NCA from 28 stations sampled in the GBEP 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.

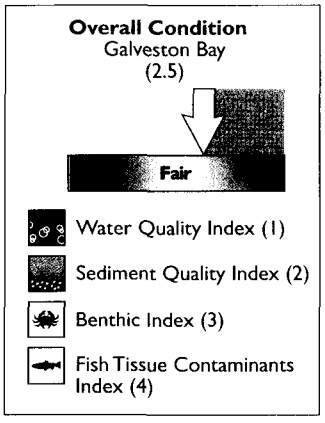


Figure 5-53. The overall condition of the GBEP estuarine area is fair (U.S. EPA/NCA).

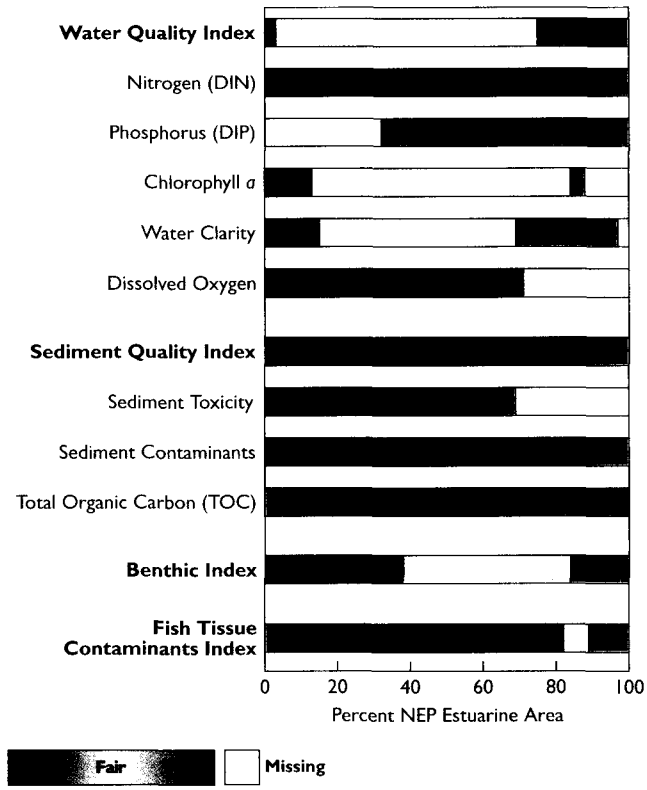
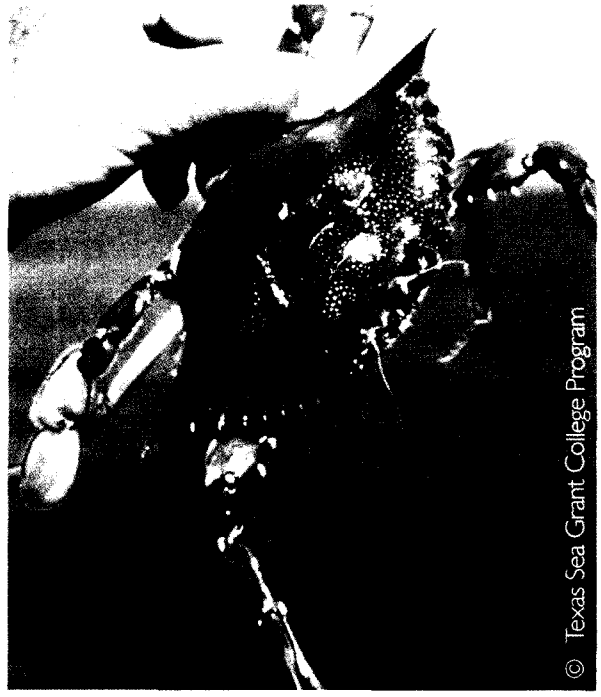


Figure 5-54. Percentage of NEP estuarine area achieving each rating for all indices and component indicators — Galveston Bay (U.S. EPA/NCA).



Significant declines in the number of blue crabs have been noted in the West Bay (Texas Sea Grant College Program).

Galveston Bay Estuary Program

Water Quality Index

Based on NCA survey results, the water quality index for Galveston Bay is rated poor (Figure 5-55). This water quality index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. In NOAA's Estuarine Eutrophication Survey, Galveston Bay was listed as having medium chlorophyll *a* and medium-to-low DIN and DIP concentrations, with elevated concentrations occurring in tidal freshwater areas (NOAA, 1997).

Dissolved Nitrogen and Phosphorus | Galveston Bay is rated fair for DIN concentrations and rated poor for DIP concentrations. Thirteen percent of the estuarine area was rated poor for DIN concentrations, whereas 68% of the estuarine area was rated poor for DIP concentrations. As discussed later in this profile, the GBEP also monitors nutrients in the bays and tributaries of the GBEP estuarine area.

Chlorophyll a | Galveston Bay is rated fair for chlorophyll *a* concentrations. Although only 4% of the estuarine area was rated poor for chlorophyll *a* concentrations, 71% of the area was rated fair, and 13% of the area was rated good. NCA data on chlorophyll *a* concentrations were unavailable for 12% of the GBEP estuarine area.

Water Clarity | Water clarity in Galveston Bay is rated poor because 28% of the estuarine area was rated poor. Expectations for water clarity are similar to those for normally turbid estuaries, with water clarity rated poor at a sampling site if light penetration at 1 meter was less than 10% of surface illumination.

Dissolved Oxygen | Dissolved oxygen conditions in Galveston Bay are rated good. Seventy-one percent of the estuarine area was rated good for dissolved oxygen concentrations, 29% of the area was rated fair, and none of the area was rated poor.

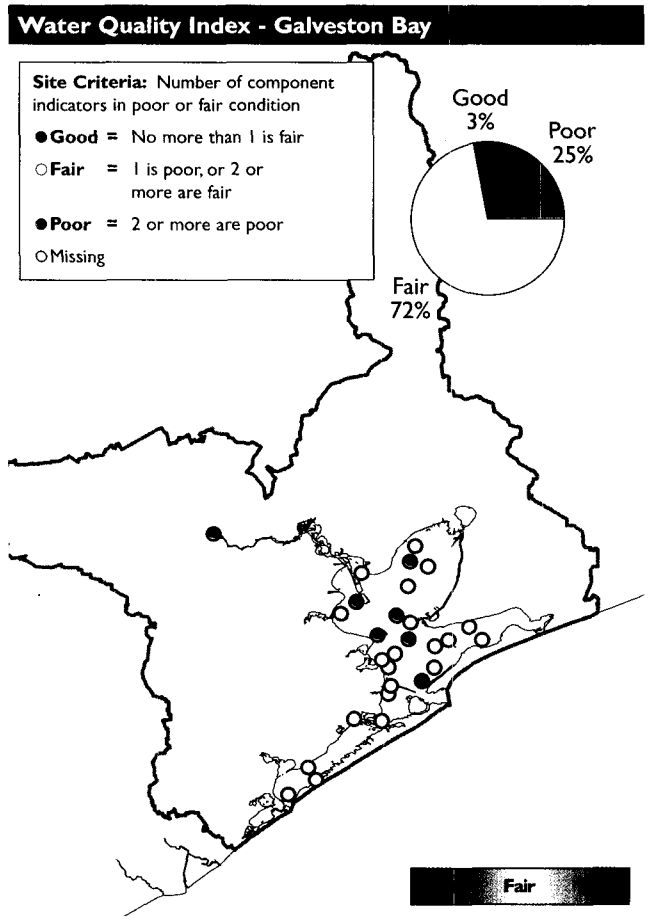


Figure 5-55. Water quality index data for Galveston Bay, 2000–2001 (U.S. EPA/NCA).

Sediment Quality Index

The sediment quality index for Galveston Bay is rated fair to poor because greater than 5% of the estuarine area was rated poor for sediment quality (Figure 5-56). This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC.

Sediment Toxicity | Sediment toxicity is rated good for Galveston Bay because only 3% of the estuarine area was rated poor; however, NCA data on sediment toxicity were unavailable to evaluate 31% of the GBEP estuarine area.

Sediment Contaminants | Sediment contaminant concentrations were rated poor in 10% of the GBEP estuarine area; therefore, this component indicator is rated fair.

Total Organic Carbon | TOC concentrations in Galveston Bay sediments were rated good in 100% of the estuarine area; therefore, Galveston Bay is rated good for this component indicator.

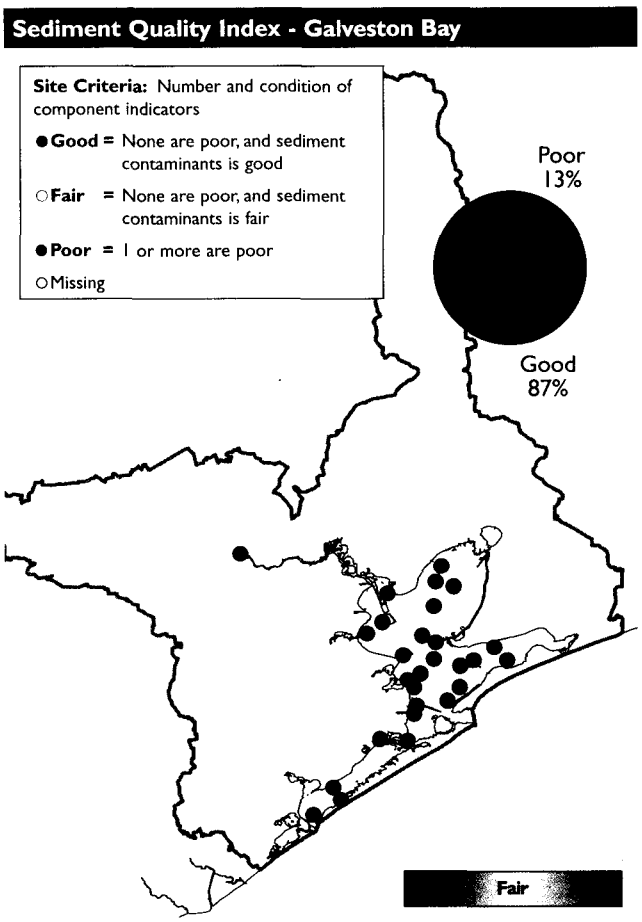


Figure 5-56. Sediment quality index data for Galveston Bay, 2000–2001 (U.S. EPA/NCA).

Benthic Index

Based on NCA survey data and the Gulf Coast Benthic Index, the condition of benthic invertebrate communities in Galveston Bay is rated fair. Benthic index estimates indicate that 16% of the estuarine area had degraded benthic resources (Figure 5-57).

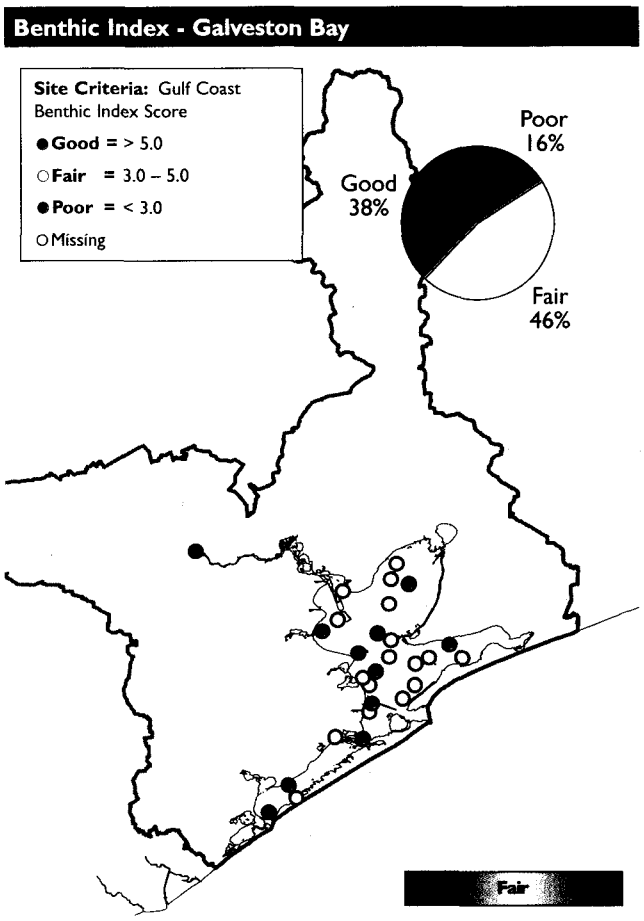


Figure 5-57. Benthic index data for Galveston Bay, 2000–2001 (U.S. EPA/NCA).

Fish Tissue Contaminants Index

The fish tissue contaminants index for Galveston Bay is rated good to fair. Figure 5-58 shows that 11% of all stations sampled where fish were caught exceeded the EPA Advisory Guidance values used in this assessment and were rated poor.

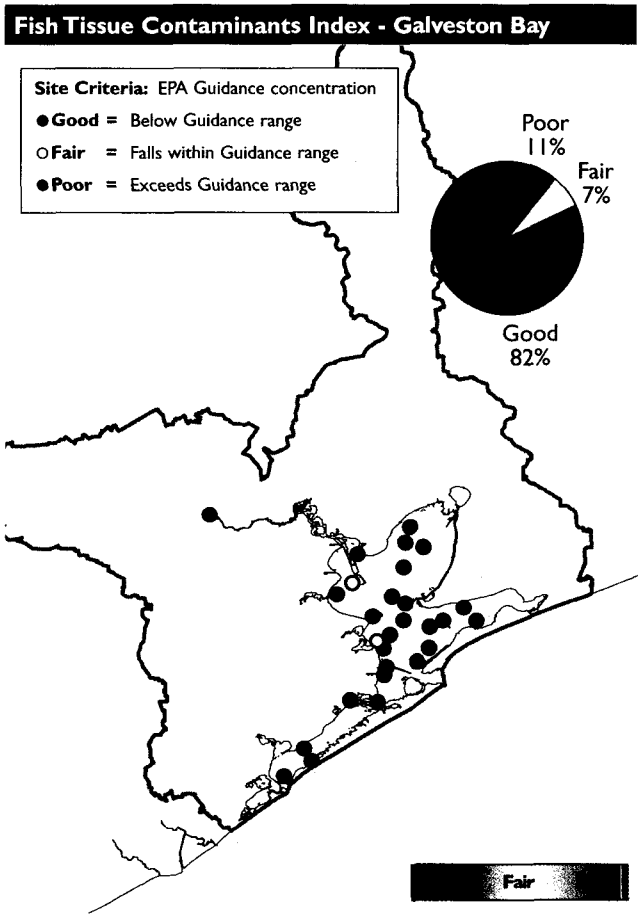


Figure 5-58. Fish tissue contaminants index data for Galveston Bay, 2000–2001 (U.S. EPA/NCA).

Galveston Bay Estuary Program Indicators of Estuarine Condition

The GBEP implements a regional monitoring program to foster effective cooperation by all agencies that participate in monitoring activities for Galveston Bay and to help prevent duplication of effort. Through the coordination of monitoring efforts, the GBEP's regional monitoring program ensures that data are available to assess trends in ecological condition and provides online access to this data at http://www.gbep.state.tx.us. The GBEP partners include the TCEQ Surface Water Quality Monitoring Program, which collects data describing surface water quality, sediment quality, and benthic organisms; the Texas Clean Rivers Program (administered locally by the Houston-Galveston Area Council), which collects water quality data; and the TPWD, which collects fishery independent and dependent data, as well as data on fish tissue contamination, water quality, and sediment quality in conjunction with the NCA. Other monitoring data tracked by the GBEP include oil spill incidents (Texas General Land Office [GLO]), colonial nesting bird counts (FWS), freshwater inflows (Texas Water Development Board), and fish advisories, oyster harvest area closures, and illnesses related to seafood consumption (Texas Department of State Health Services [DSHS]).

Water and Sediment Quality

The GBEP's formal indicators for monitoring water quality conditions in the estuary include dissolved oxygen, nitrogen (e.g., nitrate, nitrite, ammonia), total phosphorus, chlorophyll *a*, total suspended solids/turbidity, salinity, water temperature, pH, pathogens (e.g., *Enterococci*, fecal coliform), BOD, and TOC. Of the five subbays in the GBEP study area, only Christmas Bay exhibited a slightly increasing trend in dissolved oxygen concentrations, which rose from 7.0 to 8.0 mg/L between 1969 and 2001 (Lester and Gonzalez, 2003).

To help measure changes in nutrient levels over time, the TCEQ monitors ammonia, total nitrogen, and total phosphorus. Declines in annual average ammonia levels have been observed in several areas of Galveston Bay, with the most dramatic decline seen in the Houston Ship Channel. For the most part, annual average concentrations remain below screening levels. Nitrate-nitrite concentrations were highest in the Houston Ship Channel, which demonstrated an increasing trend from about 0 mg/L in 1969 to 1.75 mg/L in 2001. The Intracoastal Waterway East exhibited a significant declining trend in nitrate-nitrite, and the Trinity River had a significant declining trend in phosphorus (since 1969), which has slowed in recent years. None of the five subbays of Galveston Bay showed trends exceeding

the estuarine screening levels for nutrients (Lester and Gonzalez, 2003).

Annual average concentrations of chlorophyll *a* have declined across all Galveston Bay subbays and tributaries since 1969, with the largest decreasing trend in chlorophyll *a* concentrations found in the Houston Ship Channel, San Jacinto River, and Texas City Ship Channel. Monthly average concentrations of chlorophyll *a* did not show a significant trend in any of the five subbays in Galveston Bay. NCA data collected in 2000 and 2001 for the West Bay region had annual averages similar to those of the TCEQ data, but chlorophyll *a* concentrations were slightly higher in this region (Lester and Gonzalez, 2003).

The Galveston Bay Indicators Project rates the area's subbays and tributaries based on the percentage of data samples that exceed the state's screening criteria (Figure 5-59). Using water quality screening levels developed by the TCEQ and indicator criteria developed specifically for Galveston Bay, the project rates Galveston Bay water quality (for nutrients and chlorophyll *a*) in the subbays as moderate to good for the period 1990–2003, as compared to the poor rating based on NCA survey data for 2000–2001 (Lester and Gonzalez, 2005). It should be noted that the DIN and DIP criteria used by the NCA survey are much more stringent than those used by the State of Texas; TCEQ estuarine screening levels for nitrogen and phosphorus are 0.26 and 0.22 mg/L, respectively. In addition, NCA sampling does not differentiate between criteria levels for Bay versus tributary waters. Nutrients in Galveston Bay proper remain fairly constant during the year; however, nutrient concentrations in Galveston Bay tributaries are highest in the summer months, when NCA data are collected. In the Galveston Bay Indicators Project evaluation, the tributary Buffalo Bayou was the only Bay segment to receive a poor rating for nutrients and chlorophyll *a* data because it exceeded the screening level more than 30% of the time between 2000 and 2003. It is also worth noting the improving trend overall for Galveston Bay since the 1970s (Lester and Gonzalez, 2005); however, the TCEQ is currently reviewing its estuarine nutrient criteria, which might change the results for this indicator.

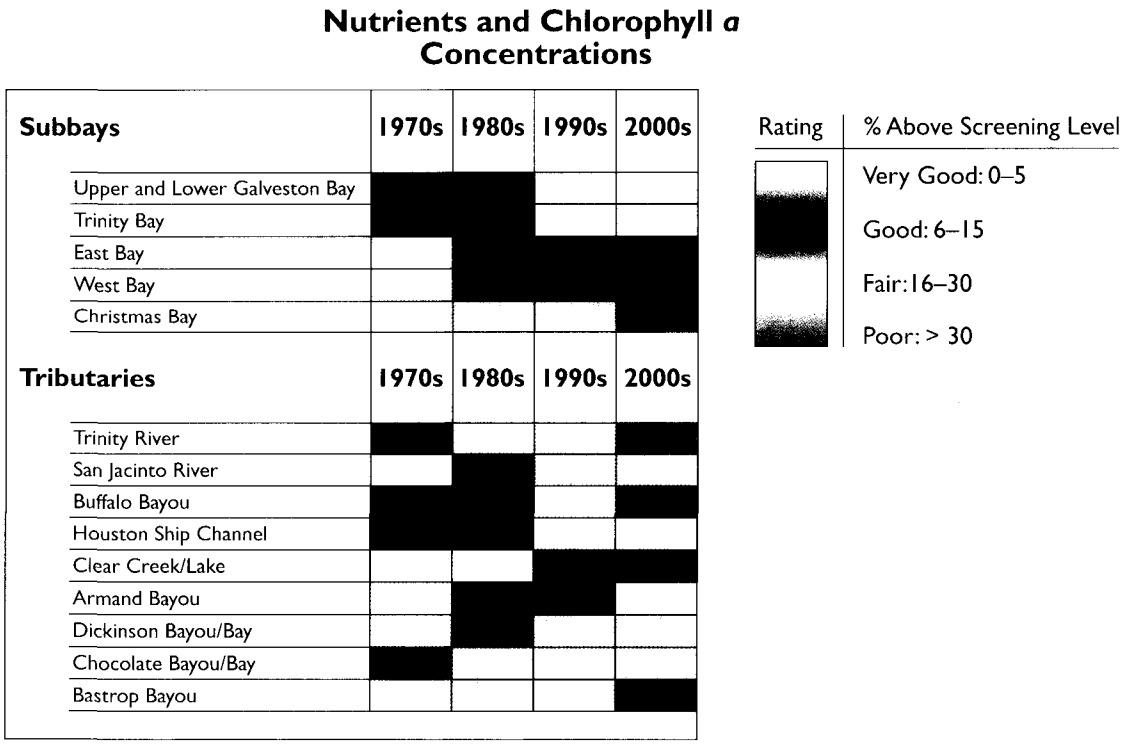


Figure 5-59. TCEQ water quality ratings for Galveston Bay nutrients and chlorophyll *a* concentrations (Lester and Gonzalez, 2005).

Galveston Bay Estuary Program

Case Study on Changes in Freshwater Wetland Habitat

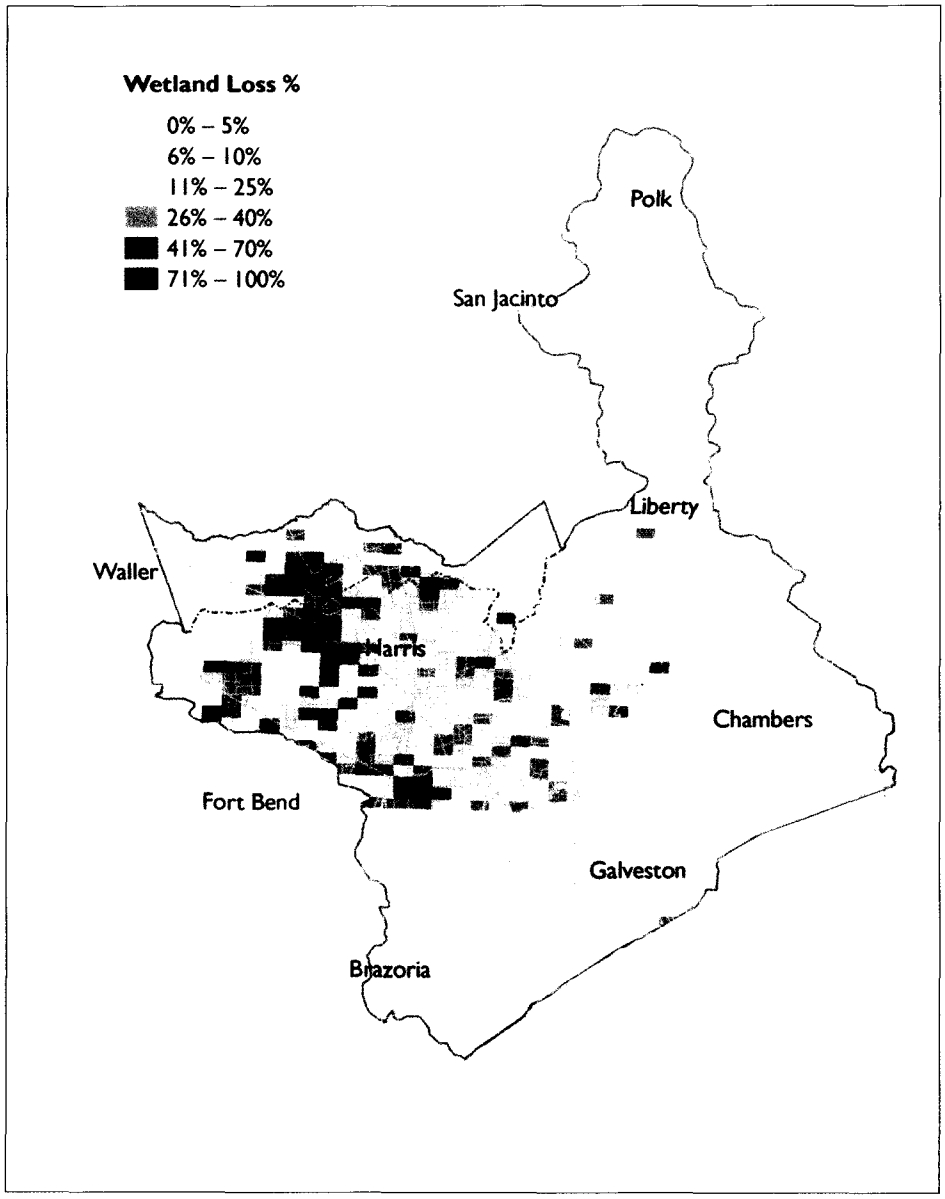
The Galveston Bay region is attracting a growing urban and industrial sector, and the region's population is expected to double to approximately 8 million by 2025 (Sage and Gallaway, 2002; H-GAC, 2003). The Galveston Bay watershed contains a wealth of unique freshwater wetland complexes that provide critical human and ecological services, including attenuation of water pollution, floodwater retention, wildlife habitat, and recreational opportunities. The GBEP recognizes that preserving these valuable resources requires a better understanding of the status and trends of the wetland habitat; therefore, the GBEP partnered with the Texas Coastal Watershed Program of the Texas Cooperative Extension in 2003 to determine the status and trends in the wetlands of Galveston Bay.

To perform a wetlands analysis, the partners conducted an inventory that was similar to the FWS's NWI program. The last FWS NWI for the Galveston Bay region was completed in 1992; however, the 1992 data are not directly comparable to those gathered during the new wetland inventory. The methods of identifying wetland areas have improved since the 1992 NWI, and the new inventory might identify areas that were missed in 1992. To account for this, the GBEP and Texas Cooperative Extension chose to consider the 1992 NWI data as a subset of the wetlands in the region at the time. To analyze changes in the wetlands, these data were directly compared to aerial photographs of the same areas taken in 2000 or 2002 as part of the new inventory.

Coastal prairie wetlands in Texas (Dr. John Jacobs, Texas Cooperative Extension/ Texas Sea Grant).

In 1992, the Galveston Bay watershed contained 294,556 acres of freshwater, non-tidal wetlands (e.g., palustrine, lacustrine, riverine). The new inventory results showed that 285,432 acres remained in the subset, representing a loss of 9,124 acres or 3.1%. These losses were attributed to industrial, commercial, and residential development (70%); fill activities (26%); and open-water development, such as man-made ponds and lakes (3%). These loss estimates are conservative figures, and resource experts believe that actual losses are much higher due to the wetland areas that were likely missed in the 1992 NWI. Consistent with the pattern of urban growth spreading into more rural areas, the greatest wetland losses (13%) occurred in Harris County, which includes the city of Houston (see figure) (Jacob and Lopez, 2005).

The results of the GBEP/Texas Cooperative Extension inventory study will be used to educate citizens on the implications of wetland loss, as well as to work with local governments and others to identify key parcels for preservation.



Wetland loss due to urban growth (Jacob and Lopez, 2005).

Galveston Bay Estuary Program

Total suspended solids showed declining trends in annual average concentrations across all subbays and tributaries of the Galveston Bay system, with the exception of Upper Galveston Bay, Lower Galveston Bay, and Cedar Bayou (Lester and Gonzalez, 2003). Galveston Bay is naturally turbid because of its shallow depth and fine sediments; however, dredging activities, commercial fisheries, and natural and man-made erosion assist in promoting this turbid nature.

The pathogen indicators monitored by the TCEQ in Galveston Bay are *Enterococci*, *E. coli*, and fecal coliform, with concentrations of fecal coliform sampled since 1973. According to the 2005 Galveston Bay Indicators Project, the areas of Galveston Bay with the greatest number of TCEQ criteria-level exceedences for fecal coliform bacteria are Buffalo Bayou, the Houston Ship Channel, Clear Creek, and Dickinson Bayou (Figure 5-60). In addition, Buffalo Bayou, White Oak Bayou, and Dickinson Bayou are the subjects of ongoing TMDL studies (Lester and Gonzalez, 2005). A declining trend in fecal coliform was found in the East Intracoastal Waterway area, but the other four major subareas of the Bay did not show a significant trend for fecal coliform. Elevated concentrations of fecal coliform in the middle reach of Bastrop Bayou have drawn considerable attention from the public in the past. The areas with the highest concentrations of *Enterococci* were the Houston Ship Channel, East Intracoastal Waterway, San Jacinto River, and Trinity Bay, whereas areas with the lowest concentrations were the Galveston Channel, Texas City Channel, Christmas Bay, Bastrop Bayou Complex, Dickinson Bayou/Dickinson Bay, and East Bay (Lester and Gonzalez, 2003).

Organic matter content in Galveston Bay is measured as TOC, and annual average TOC concentrations have declined in all subbays and tributaries of Galveston Bay since 1973. The TCEQ also reports five-day BOD to help measure the breakdown and decomposition of organic matter in the Bay. Sufficient data only exist for three of the five subbays in Galveston Bay, and none of these subbays exhibited significant trends for BOD (Lester and Gonzalez, 2003). This finding aligns with NCA data, which found Galveston Bay to be in good condition for TOC concentrations.

In Galveston Bay, sediments, metals, and commonly measured organic compounds appear to follow the same general spatial distribution, as do most of the other water quality parameters. Elevated concentrations of these contaminants occur in regions of runoff, freshwater inflow, and waste discharges, and lower, relatively

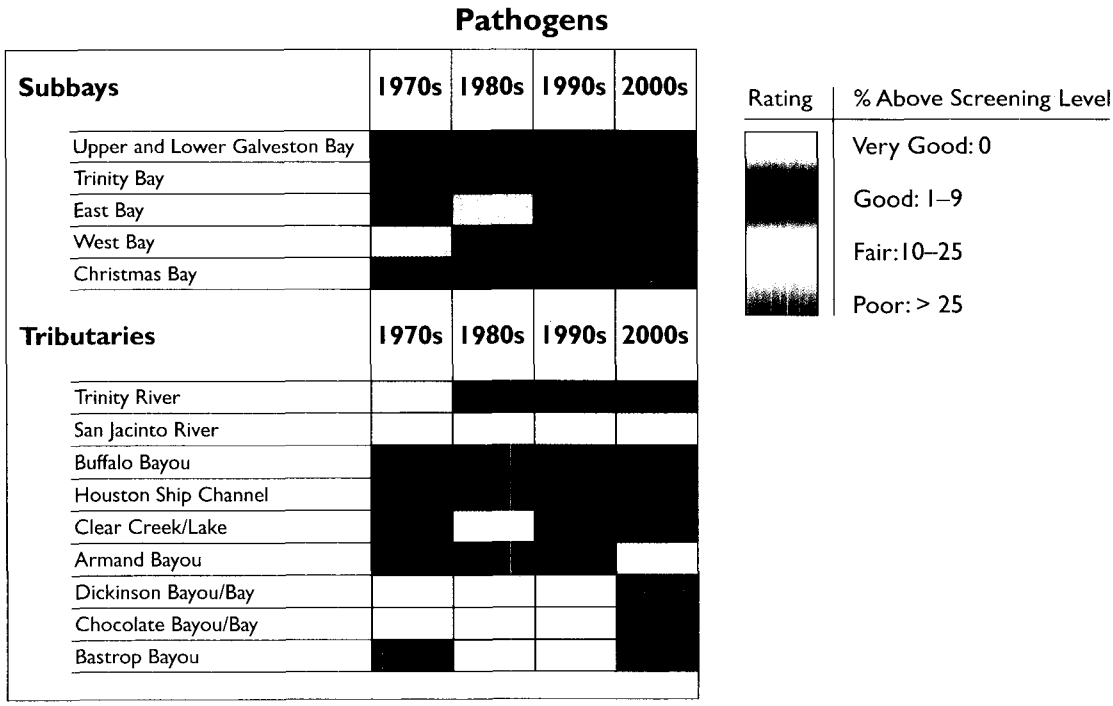


Figure 5-60. TCEQ water quality ratings for Galveston Bay pathogens (Lester and Gonzalez, 2005).

uniform concentrations occur in the open bay. The upper Houston Ship Channel generally has the maximal concentration of these contaminants (Lester and Gonzalez, 2005).

Habitat Quality

Wetland loss and declines in SAV are of significant concern for the GBEP, but support from federal, state, and local agencies; area non-profit organizations; and industry activities are slowly helping to mitigate losses through restoration and preservation. *The Galveston Bay Plan* calls for the restoration of 8,600 acres of estuary marsh and 1,400 acres of SAV (GBNEP, 1995).

Wetland loss between 1950 and 1989 has been estimated to be between 700 and 1,000 acres a year, or a net loss of over 30,000 acres (White et al., 1993). The total acreage of wetlands lost to dredge-and-fill activities over time has increased to 20% of the net losses estimated for Galveston Bay (Sage and Gallaway, 2002). A recent estuarine wetland inventory indicated that more than 1,181 of the 118,072 acres of emergent marsh identified in 1995 were lost by 2002. The loss of approximately 830 of these acres was induced by human activities (Webb, 2005). The GBEP continues to work with its partners to monitor trends in wetlands loss.

Salinity, turbidity, and rainfall patterns seem to be the controlling factors for natural seagrass growth in Galveston Bay. In the 1950s, SAV was estimated at 2,500 acres; in 1989, SAV was estimated to be approximately 700 acres—more than a 70% decline. Since 1989, evidence suggests a rebound, with new areas being established adjacent to wetland restoration sites in West Bay (Sage and Gallaway, 2002).

Living Resources

The GBEP uses several indicators to measure trends in living resources. Data are collected from a variety of sources, including the TPWD, Texas DSHS, and FWS. These indicators are the following:

- Abundance of selected colonial waterbird species (e.g., great blue heron, white ibis)
- Abundance of selected finfish species (i.e., measured from bag seine, shrimp trawl, or gill net)
- Episodes of seafood contamination and issuance of advisories (e.g., oyster harvest-area closures, fish consumption advisories, and elevated chemical contaminant levels in fish tissue).

Figure 5-61 shows 20-year population trends for several bird and finfish species monitored in the GBEP study area. Of the 19 species of colonial nesting water birds tracked between 1973 and 2001, 9 exhibit negative trends, whereas others appear stable or are

BIRDS

Feeding Guild	Species	20-Year Trend
Marsh Feeders	Great Blue Heron	Declining
	Reddish Egret	Declining
	Roseate Spoonbill	Stable
	Snowy Egret	Stable
	Tricolored Heron	Declining
	White Ibis	Stable
Open-Water Feeders	Black Skimmer	Declining
	Brown Pelican	Declining
	Least Tern	Stable
	Royal Tern	Stable
	Sandwich Tern	Stable

FISH

Species	20-Year Trend
Black Drum	Stable
Red Drum	Stable
Sand Seatrout	Stable
Southern Flounder	Stable
Spotted Seatrout	Declining

Increasing
Stable
Declining

Figure 5-61. Bird and finfish population trends in Galveston Bay (Lester and Gonzalez, 2005).

increasing. As with other parts of the country, brown pelicans have been a success story in returning from the brink of extinction (HARC, 2005a). Significant declines in blue crab numbers have been noted in West Bay. Gulf killifish have demonstrated a significant decline in the estuary and could indicate a declining quantity of fringing wetlands. Bay anchovy have demonstrated a significant increasing trend in West Bay, and pink shrimp have demonstrated a significant increasing trend in Upper and Lower Galveston Bay (Lester and Gonzalez, 2003). For areas of the Houston Ship Channel and Upper Galveston Bay, the Texas DSHS has issued several seafood consumption advisories for contaminants, including PCBs and dioxins, in species such as blue crab, catfish, and speckled trout (Figure 5-62) (Lester and Gonzalez, 2005).

Environmental Stressors

The GBEP's regional monitoring program also uses human activities as indicators to assess the health of the estuary. The Texas GLO has monitored the amount, type, date, and location of 11 petroleum products spilled into the waters of 4 counties in the Galveston Bay watershed (Brazoria, Chambers, Galveston, and Harris). Between 1998 and 2002, a total of 262,010 gallons of petroleum products were spilled into the waters of Galveston Bay (Lester and Gonzalez, 2003).

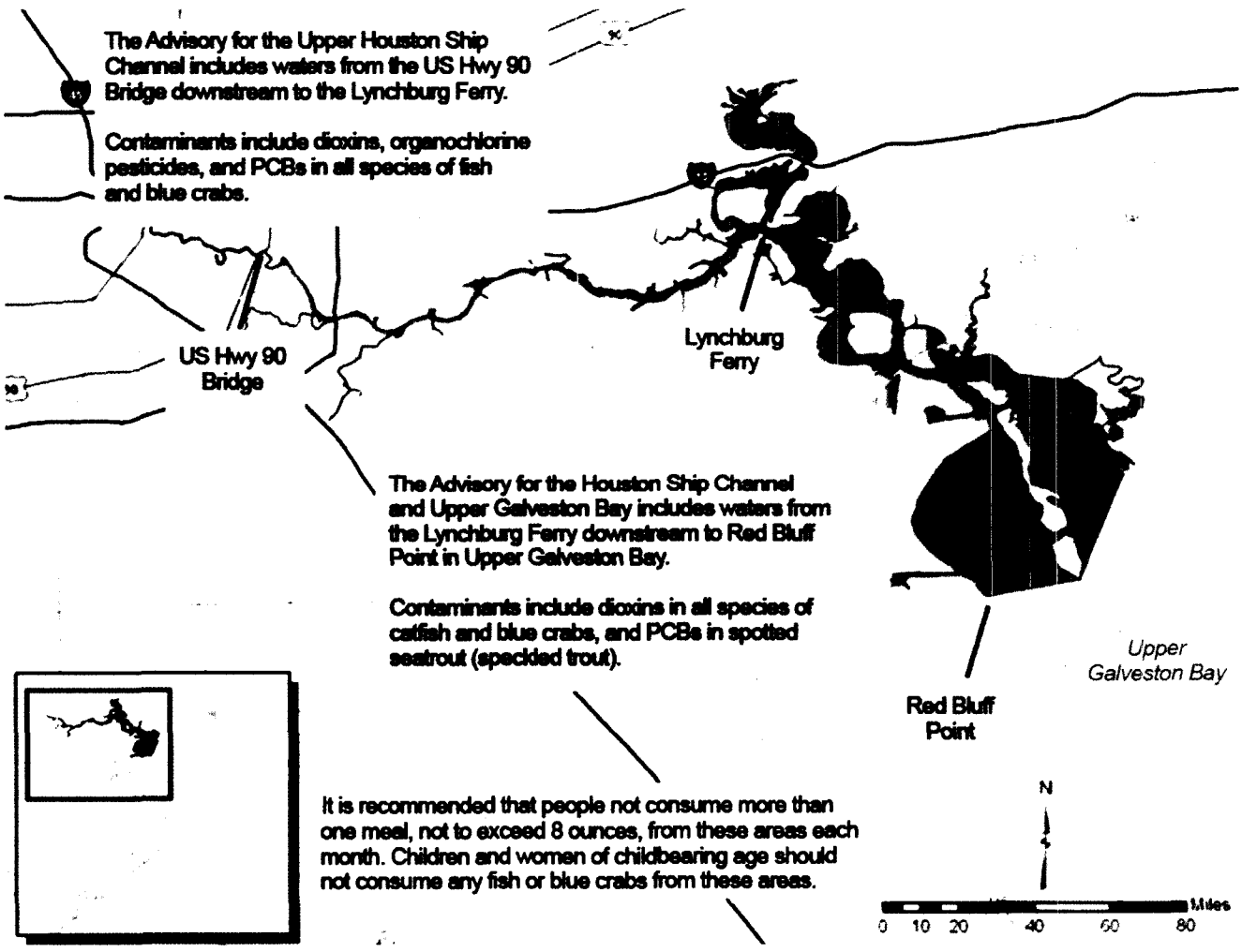


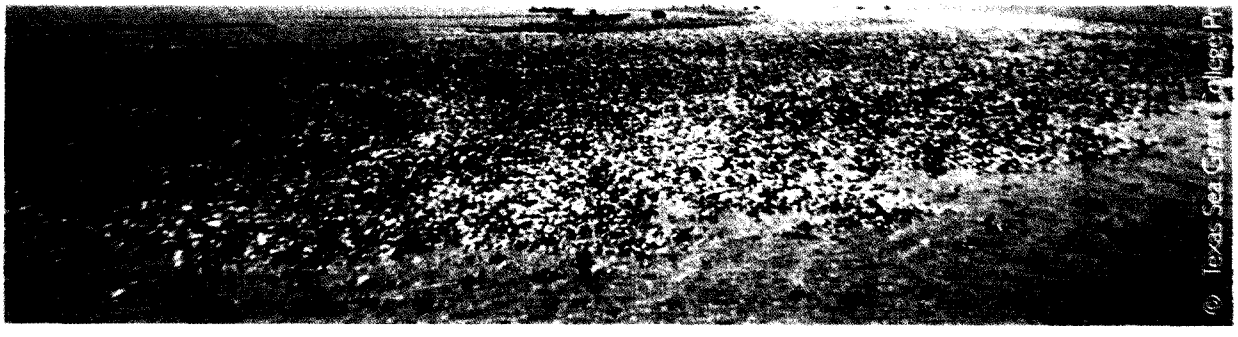
Figure 5-62. Seafood consumption advisory areas designated in 1990, 2001, and 2005 (Lester and Gonzalez, 2005).

Current Projects, Accomplishments, and Future Goals

To protect and restore wetland habitats, the GBEP is encouraging better use of dredge material. When disposed of improperly, dredge materials can adversely modify wetland habitats; however, these materials also can be beneficial if used to create, restore, or enhance estuary habitats (e.g., bird rookery islands). The efforts of the GBEP and its partners have led to the restoration of 8,000 acres of habitat (Personal communication, Johnston, 2006). The GBEP is also working with local governments toward increasing wetland and habitat conservation through the promotion of water quality, recreation, and flood-control benefits and by assisting with grant writing and the development of stormwater management plans. Other priorities of the GBEP include controlling harmful exotic species; promoting water conservation, stormwater management, and technical assistance programs; assessing the safety of consuming seafood from Galveston Bay; and assisting septic system owners and small WWTP operators. Some of the invasive species of highest ecological concern in Galveston Bay include Chinese tallow, giant salvinia, *Hydrilla*, red imported fire ant, Brazilian pepper, water hyacinth, and channeled apple snail.

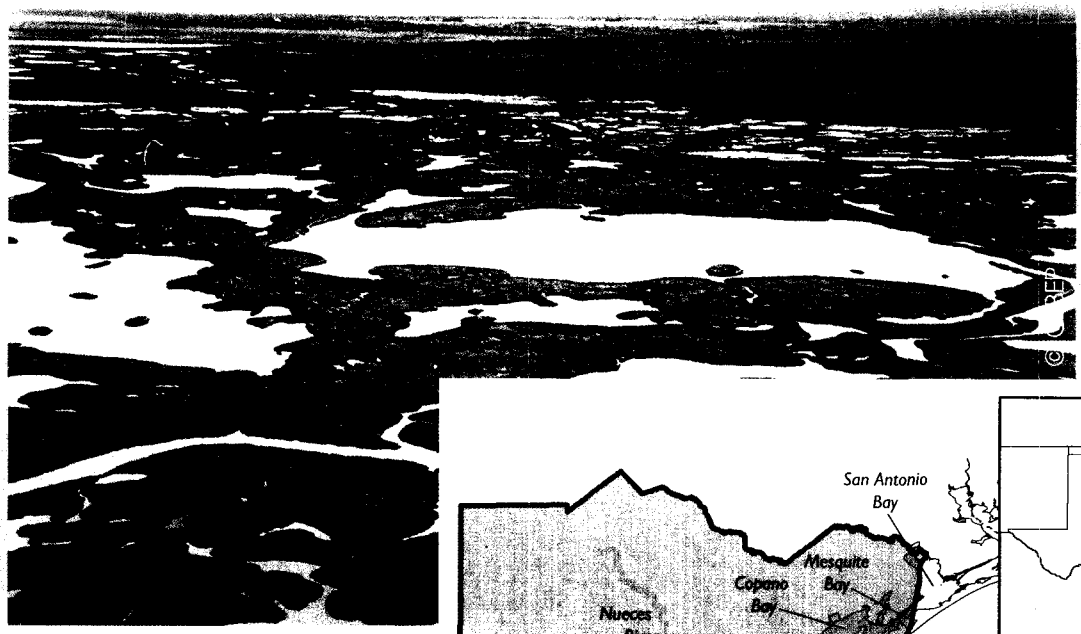
Conclusion

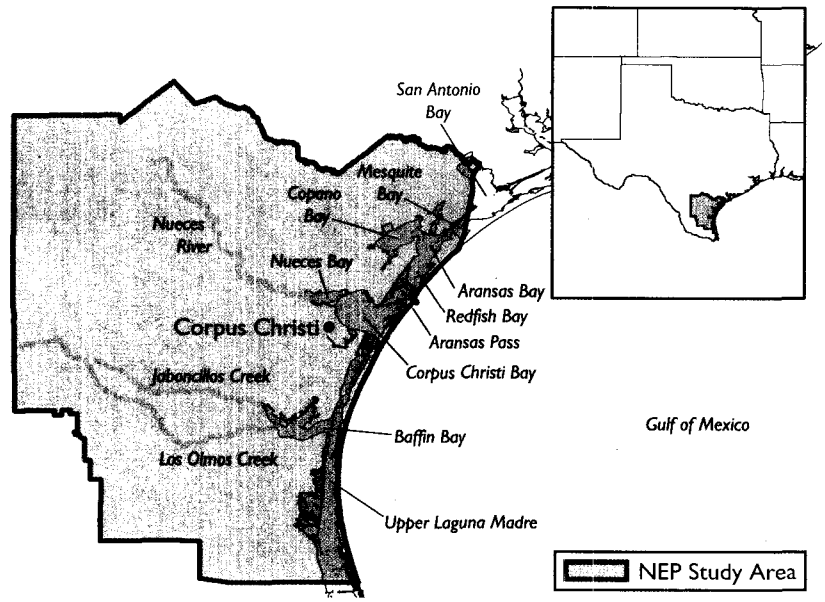
Based on data from the NCA estuarine survey, the overall condition of Galveston Bay is rated fair. Data from the GBEP and its partners indicate that, in spite of the large human population and increasing resource demands, Galveston Bay remains productive and, for the most part, healthy. The Bay as a whole is not threatened by eutrophication, and nutrient concentrations are decreasing in many areas of this estuary. Several aquatic species exhibit stable trends in abundance. Galveston Bay is not rapidly degrading in terms of increasing concentrations of toxic or organic pollutants; rather, trends in pollution are mixed. Concentrations of contaminants are decreasing in the most polluted areas of the Bay, but are rising in other areas. Even with these stable and, in some cases, improving trends, focus remains on strategic habitat conservation and pollution control as the region's population continues to expand and land-use patterns trend towards urbanization.



Extensive oyster reefs are found in Galveston Bay (Texas Sea Grant College Program).

Coastal Bend Bays and Estuaries Program





COASTAL BEND BAYS & ESTUARIES PROGRAM

www.cbbep.org

Background

The estuarine area of the Coastal Bend Bays and Estuaries Program (CBBEP) is located within an area known as the Coastal Bend and includes three of the seven estuaries found in Texas. The most northerly portion of the CBBEP study area encompasses the San Antonio, Mesquite, Redfish, Copano, and Aransas bays. The middle estuarine portion includes Nueces Bay and Corpus Christi Bay (the largest of the bays) and discharges into the Gulf of Mexico at Aransas Pass. The most southerly estuarine portion includes Upper Laguna Madre and Baffin Bay. The CBBEP study area includes 75 miles of Texas coastline and 515 mi^2 of water (CBBEP, 2005a). In addition to the tidal marshes and the barrier islands of the CBBEP estuarine area, this area also includes seagrass meadows, open bays, oyster and serpulid worm reefs, wind tidal flats, and freshwater marshes.

The CBBEP study area is an important resource for recreational, commercial, industrial, and residential uses. Popular for sportboat fishing, bird watching, and windsurfing, the Bays also support a commercial fishing industry that harvests, on average, more than 8 million pounds of finfish, shrimp, and crab from the area's

estuarine waters (Tunnell et al., 1996). This area contains 40% of the state's total seagrass acreage, which provides nursery areas for fish and shellfish and habitat for other wildlife, including birds, sea mammals, and marine turtles (CBBEP, 1998). Corpus Christi Bay is the nation's fifth-largest port and holds the third-largest refinery and petrochemical complex in the United States (CBBEP, 2005a). Although the region's population was 550,000 in 1995, it is projected to be nearly 1 million people by 2050 (CBBEP, 1998).

Environmental Concerns

Fresh water is in short supply in semi-arid southern Texas, and because of the state's ever-increasing coastal population and growing industry, there will always be competing demands for this limited resource. Residential and business water use in this region is expected to increase by 50% by 2050, and industrial demand is expected to double (CBBEP, 1998). Fresh water is not only vital to the survival of the human population, but it is also closely tied to the survival of the entire ecosystem. Fresh water inflows provide three vital functions essential to an estuary. First, inflows blend with Gulf seawater to create a range of salinities in the Bays' waters. Second, inflows of surface runoff carry nutrients (nitrogen, phosphorus, and decomposing organic matter) that are essential to the productivity of estuarine ecosystems. Phytoplankton and large plants need these nutrients to survive, multiply, and provide food and nursery areas for a multitude of aquatic and terrestrial species. Lastly, inflows bring sediment to the estuaries, and these sediments are deposited as river waters slow down upon entering the Bays. Without the replenishing of these sediments, wave action would eventually wash away the existing wetlands. The annual streamflow for the Nueces River demonstrated a declining trend from 1940–1996 due to the construction of the Choke Canyon Reservoir, evaporative loss from the surface of the reservoir, increased water use in the river basin, and a long-term regional drought.

Population Pressures

The population of the 11 NOAA-designated coastal counties coincident with the CBBEP study area increased by 36% during a 40-year period, from 0.40 million people in 1960 to 0.55 million people in 2000 (Figure 5-63) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the CBBEP study area was about one-fourth of the population growth rate of 133.3% for the collective Gulf Coast NEP-coincident counties and the second-lowest population growth rate of the Gulf Coast NEP study areas. In addition, the population density of these 11 coastal counties in 2000 was 53 persons/mi^2, which was the lowest density of any NEP study area in the Gulf Coast region (U.S. Census Bureau, 2001). Development and population pressures are less dramatic for this NEP study area, which serves as a center for commercial fishing and recreational activities for its coastal communities.

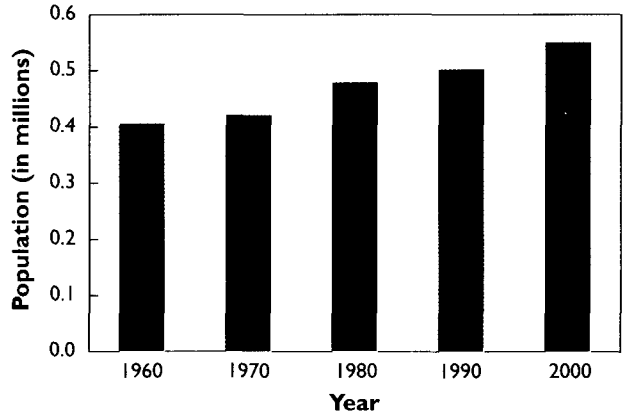


Figure 5-63. Population of NOAA-designated counties of the CBBEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Coastal Bend Bays

The overall condition of the Coastal Bend Bays is rated poor based on the four indices of estuarine condition used by the NCA (Figure 5-64). The water quality index is rated fair, the sediment quality and fish tissue contaminants indices are rated poor, and the benthic index is rated fair to poor. Figure 5-65 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 collected by the TPWD and NCA from 27 stations sampled in the Coastal Bend Bays 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.

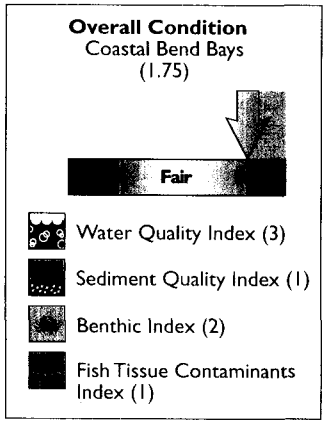


Figure 5-64. The overall condition of the CBBEP estuarine area is poor (U.S. EPA/NCA).

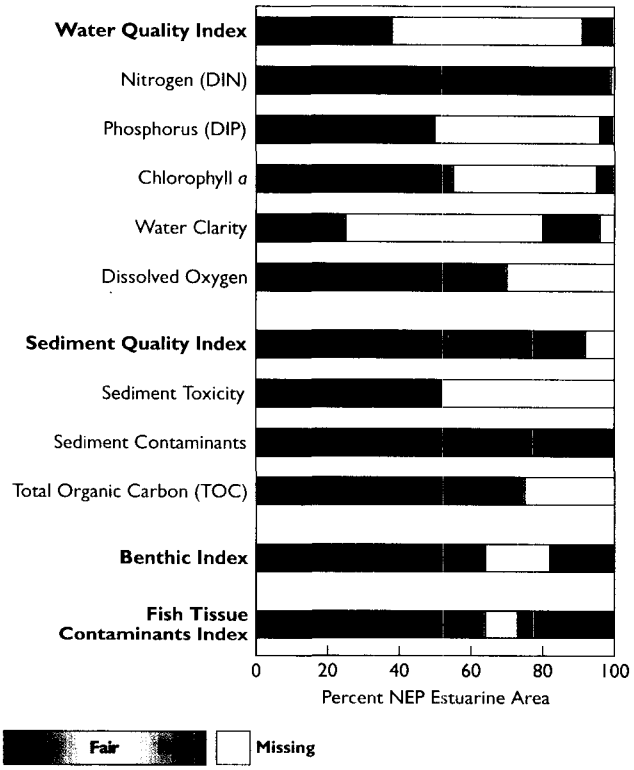


Figure 5-65. Percentage of NEP estuarine area achieving each ranking for all indices and component indicators — Coastal Bend Bays (U.S. EPA/NCA).

Water Quality Index

Based on NCA survey results, the water quality index for the Coastal Bend Bays is rated fair (Figure 5-66). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. In NOAA's Estuarine Eutrophication Survey, the Coastal Bend Bays were listed as having medium to hypereutrophic chlorophyll *a* levels and low to high DIN and DIP concentrations, with elevated concentrations occurring in tidal freshwater areas (NOAA, 1997).

Dissolved Nitrogen and Phosphorus | The Coastal Bend Bays are rated good for DIN concentrations, with 99% of the estuarine area rated good for this component indicator. The Bays are rated fair for DIP concentrations, with 4% of the estuarine area rated poor, 46% of the area rated fair, and 50% of the area rated good for this component indicator.

Chlorophyll a | Chlorophyll *a* concentrations in the Coastal Bend Bays are rated good. Although only 5% of the estuarine area exhibited poor chlorophyll *a* concentrations, 40% of the estuarine area was rated fair for this component indicator, and 55% of the area was rated good.

Water Clarity | Water clarity in the Coastal Bend Bays is rated fair because 16% of the estuarine area was rated poor for this component indicator. In Corpus Christi and Aransas bays, expectations for water clarity are similar to those for normally turbid estuaries, and water clarity was rated poor at a sampling site if light penetration at 1 meter was less than 10% of surface illumination. However, because one of the CBBEP's goals is to re-establish SAV beds in Upper Laguna

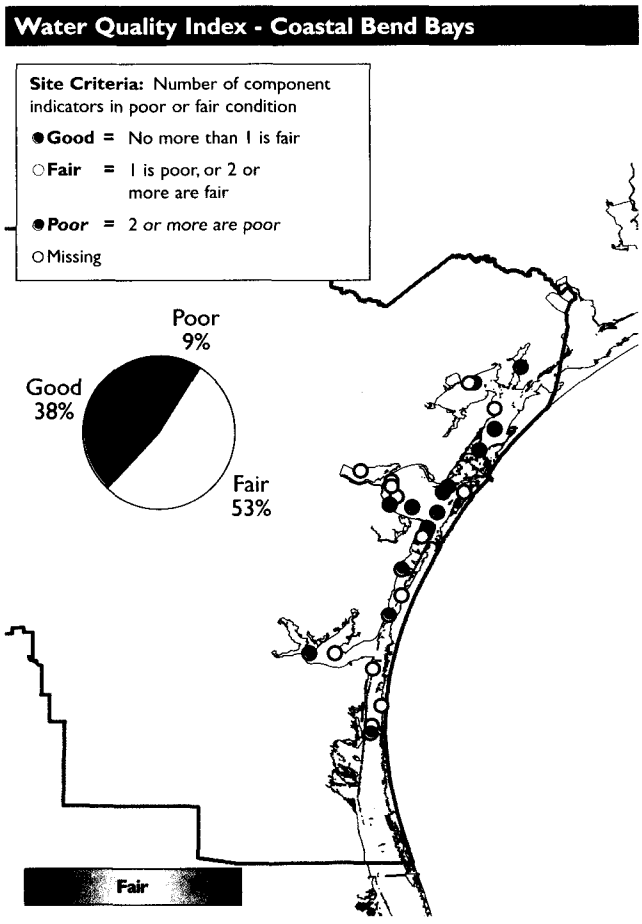


Figure 5-66. Water quality index data for the Coastal Bend Bays, 2000–2001 (U.S. EPA/NCA).

Madre and Baffin Bay, expectations for water clarity in these areas are high; therefore, water clarity was rated poor at a sampling sites in this area if light penetration at 1 meter was less than 20% of surface illumination.

Dissolved Oxygen | Dissolved oxygen conditions in the Coastal Bend Bays are rated good. NCA data show that 70% of the estuarine area was rated good for dissolved oxygen concentrations, 30% of the area was rated fair, and none of the area was rated poor.

Sediment Quality Index

The sediment quality index for the Coastal Bend Bays is rated poor because more than 15% of the estuarine area was rated poor for sediment quality (Figure 5-67). This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC.

Sediment Toxicity | Sediment toxicity is rated good for the Coastal Bend Bays because none of the estuarine area was rated poor for this component indicator; however, NCA data on sediment toxicity were unavailable for 48% of the CBBEP estuarine area.

Sediment Contaminants | The Coastal Bend Bays are rated poor for sediment contaminant concentrations because 38% of the estuarine area was rated poor for this component indicator.

Total Organic Carbon | The Coastal Bend Bays are rated good for sediment TOC concentrations. None of the estuarine area was rated poor for this component indicator, and 75% of the area was rated good. NCA data on TOC concentrations were unavailable for 25% of the CBBEP estuarine area.

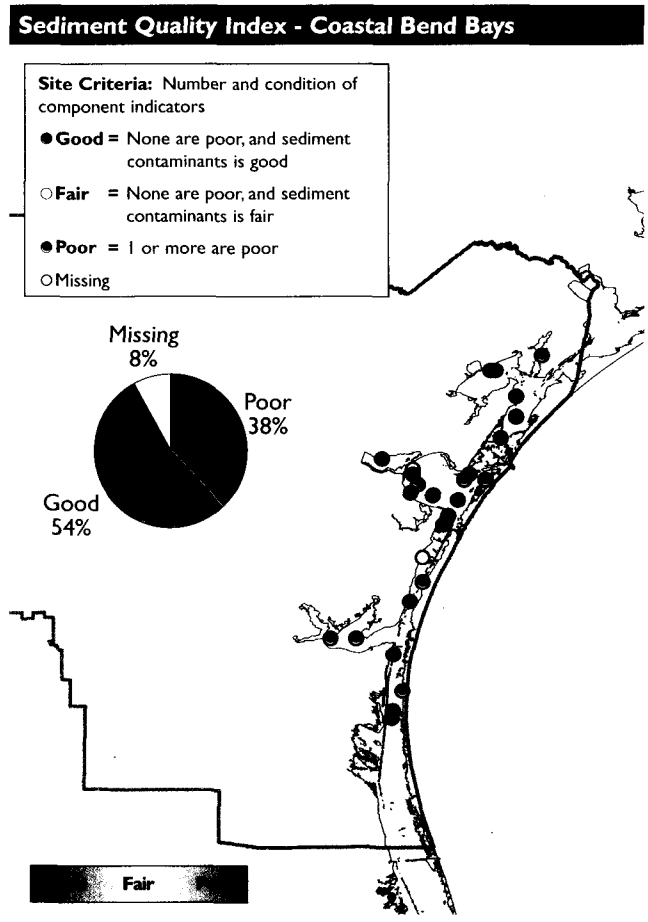


Figure 5-67. Sediment quality index data for the Coastal Bend Bays, 2000–2001 (U.S. EPA/NCA).

Benthic Index

Based on NCA survey data and the Gulf Coast Benthic Index, the condition of benthic invertebrate communities in the Coastal Bend Bays is rated fair to poor. Benthic index estimates indicate that 18% of the estuarine area had degraded benthic resources and was rated poor and another 18% was somewhat degraded and was rated fair (Figure 5-68).

Fish Tissue Contaminants Index

The fish tissue contaminants index for the Coastal Bend Bays is rated poor. Figure 5-69 shows that tissue concentrations exceeded the EPA Advisory Guidance values used in this assessment at 27% of all the stations sampled where fish were caught.

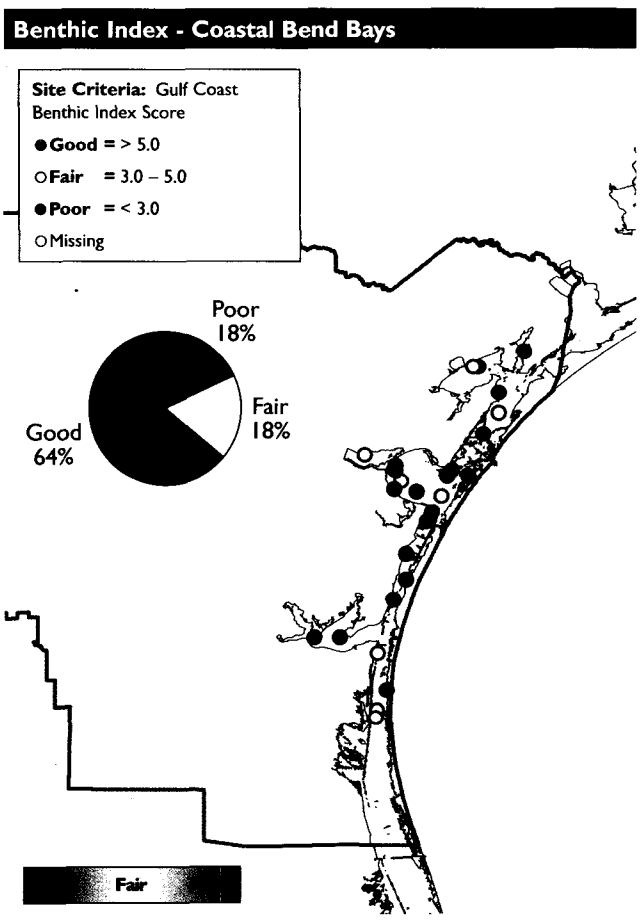


Figure 5-68. Benthic index data for the Coastal Bend Bays, 2000–2001 (U.S. EPA/NCA).

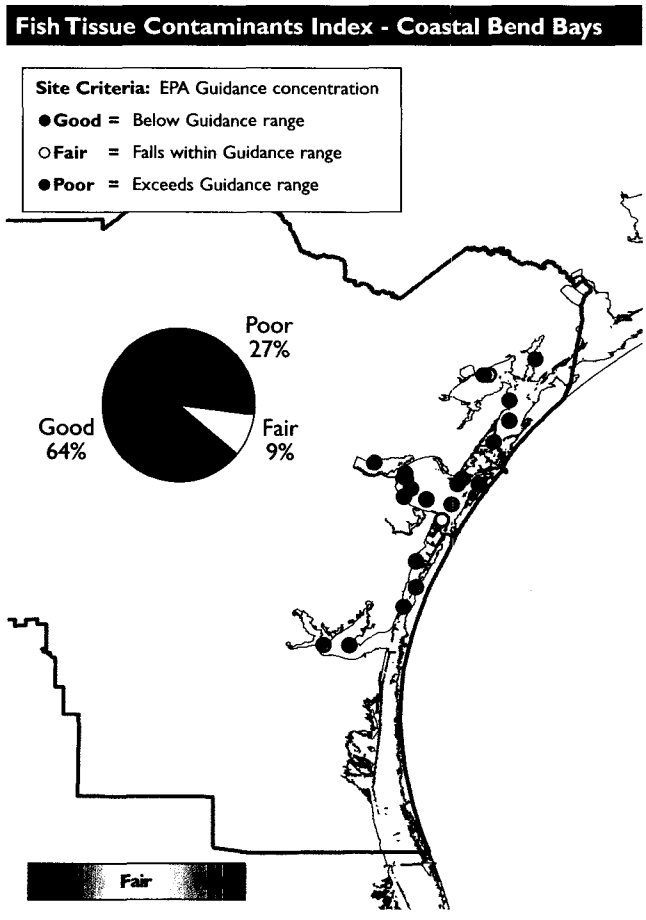


Figure 5-69. Fish tissue contaminants index data for the Coastal Bend Bays, 2000–2001 (U.S. EPA/NCA).

Coastal Bend Bays and Estuaries Program Indicators of Estuarine Condition

The CBBEP uses specific indicators to monitor the overall health of the estuarine area, and a scoring system is used to assign relative values for indicator measures. This system allows analysts to assess trends and identify the areas showing the greatest improvements. A summary of the key resources and the types of indicators used to monitor system-wide environmental trends is presented below.

Water and Sediment Quality

The CBBEP uses a number of indicators to monitor water quality in the study area, including temperature, salinity, dissolved oxygen, transparency, fluorescence, pH, nitrogen, ammonia, phosphorus, dissolved oxygen, sulfide, chlorophyll *a* and *b*, total suspended solids, and BOD. The program also tests waters for trace metals, organic compounds, and pathogens, including fecal coliform, *E. coli*, and *Enterococci*. The Inner Harbor, which is affected by wastewater discharges, exhibits high levels of several parameters, including ammonia nitrogen, organic compounds, TOC, metals, and fecal coliform. Other parameters, such as nitrate-nitrogen and phosphorus, are typically highest in regions affected by runoff and inflow. In general, levels of copper, nickel, and zinc are elevated throughout Corpus Christi Bay (Ward and Armstrong, 1997).

Hypoxic events have been documented every summer in the southeastern region of Corpus Christi Bay since 1988. When hypoxia occurs in the Bay, the low dissolved oxygen levels are limited to the waters within 3–6 feet of the Bay's bottom surface. Hypoxia is caused by a combination of respiration, low mixing potential, small tidal ranges, and high temperatures. The extent and intensity of hypoxic events in the Bays has been increasing over time, which corresponds to rising temperatures in the region during the past 20 years. These events are primarily due to the increase in temperature because nutrient levels in this area of the Bay have not increased (Morehead et al., 2002).

Freshwater flow affects the quality of surface waters in the estuary, and the CBBEP uses several freshwater-flow indicators to help assess water quality in the region. These indicators include the flux, volume, timing, and locations of freshwater flows (point and river sources) into the CBBEP area, as well as rainfall trends and freshwater demand. Annual precipitation rates range from 24 inches per year in the southern end of the study area to 40 inches per year in the northern end. Between 2% (at the southern end) and 10% (at the northern end) of this precipitation reaches the Bays as runoff. The non-point loadings of total nitrogen and total phosphorus to the Bays are largely driven by runoff from agricultural lands (Quenzer et al., 1998).

Sediment quality is also monitored in the CBBEP study area. The CBBEP assesses sediments for grain size, TOC, redox potential discontinuity, contaminant levels, and toxicity. The diversity of benthic communities and other benthic community indicators are also used to characterize sediment quality. Arsenic, cadmium, mercury, and zinc concentrations in Corpus Christi Bay sediments are generally elevated. The highest levels of common pesticides have been measured in Baffin and Copano bays (Ward and Armstrong, 1997). Elevated levels of PAHs, metals, pesticides, PCBs, and fecal coliform have also been measured in sediments collected near stormwater outfall sites and other areas of concern in the CBBEP study area (Carr et al., 1998).

Area fishermen participate in the Texas Abanded Crab Trap Removal Project by collecting derelict crab traps in area bays (CBBEP).

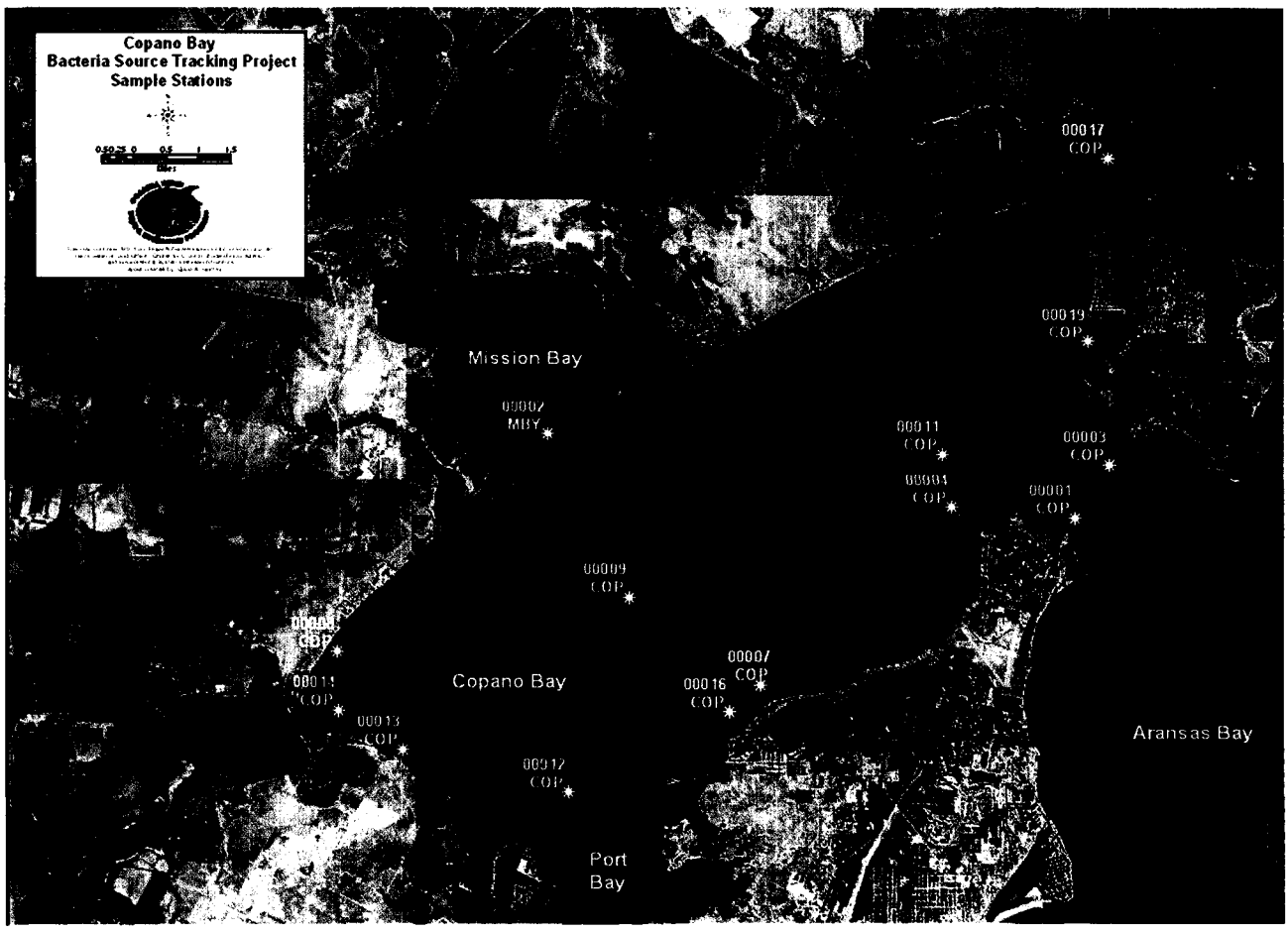
Coastal Bend Bays and Estuaries Program

HIGHLIGHT

CBBEP Bacteria Source Tracking in Copano Bay

In Copano Bay, there are a number of waterbody segments identified in Section 303(d) of the Clean Water Act that are listed as having high concentrations of coliform bacteria. The monitoring data used for this assessment are derived from various sources. The Texas DSHS collects data for use in assessing the health risks of exposure to bacteria in estuarine waters and for posting closures of shellfish harvesting areas. The TPWD and several academic research institutions, collect water quality monitoring data as contractors for the Regional Coastal Assessment Program. Monitoring data have shown that microbial contamination is occurring and that elevated concentrations of bacteria are usually present following heavy rainfall events; however, identifying the source or sources of the contamination is more difficult.

The CBBEP, TCEQ, the Texas DSHS, and Texas GLO are working with Dr. Joanna Mott at Texas A&M University/Corpus Christi, Center for Coastal Studies, to determine the source of bacterial contamination in Copano Bay through bacterial DNA source tracking and the development of a database of fecal samples collected from numerous animals within the watershed,



Copano Bay Bacteria Source Tracking Project sampling stations (CBBEP).

including humans. The University uses samples from 14 stations in Copano Bay that are part of the Texas DSHS Shellfish Sanitation Program. Filtration of these water samples yields isolated *E. coli* bacteria samples, which are then verified using BIOLOG. Isolates from these samples are also fingerprinted for their DNA by Pulse Field Gel Electrophoresis. In addition, antibiotic resistance profiling is also conducted on some of the *E. coli* samples. The goal of this sampling effort is to develop a screening tool that can be used to determine if the coliform bacteria are coming from human, domestic animal, or wildlife sources so that steps can be taken to reduce the contamination.

The results of this project will assist several state resource agencies in determining the source of bacteriological contamination to the Copano Bay area. The Texas DSHS can use this data to review needed changes to shellfish harvesting rules, and the TCEQ can use this same data to develop a TMDL for Copano Bay. In addition, a watershed model for coliform bacteria is being developed by the University of Texas, and data from the Copano Bay Source Tracking Project will be used to assist in model calibration. Since the project's inception in 2003, the two major rivers (Aransas and Mission rivers) discharging into Copano Bay have been added to the 303(d) list due to elevated levels of coliform bacteria. The CBBEP plans to extend this effort to identify and evaluate sources of coliform bacteria throughout the entire watershed with the hope of reducing microbial contamination of estuarine waters and protecting and maintaining healthy shellfishing resources.

Coastal Bend Bays and Estuaries Program

Habitat Quality

Eight major tidally influenced habitats are represented in the CBBEP study area, including coastal marshes, wind tidal flats, seagrass meadows, open bays, oyster and serpulid worm reefs, barrier islands, and freshwater marshes. Loss of habitat in the study area results from the following contributing factors: conversion to other land uses, dredge-and-fill activities, natural erosion, altered freshwater inflow, and degraded water quality (CBBEP, 1998).

The CCBEP monitors the acreage of each key habitat. Although losses and gains have been observed for specific habitat types, habitat acreage has been fairly stable over time. Wind tidal flats have suffered the most significant losses in the study area (CBBEP, 2002). More than 24,500 acres of wind tidal flats were converted to other habitat classes between the 1950s and 1979 due to rising sea levels and dredge-and-fill activities. The most extensive losses were observed on Mustang Island, San Jose Island, and Harbor Island, and in the upper portion of the Laguna Madre-Corpus Christi estuarine complex (CBBEP, 1998; Withers and Tunnell, 1998).

Dredge-and-fill activities also alter the region's habitat. Maritime commerce is important to the CBBEP's regional economy, and dredging is required to maintain the region's more than 175 miles of navigable waterways, including the Intracoastal Waterway and the Corpus Christi and La Quinta Ship channels (Tunnell et al., 1996). Between 1958 and 1994, dredging was part of construction and maintenance activities for the Intracoastal Waterway and other shipping channels in Redfish Bay. During this time frame, more than 950 acres of seagrass were lost due to channel impacts and the deposition of dredged materials on seagrass beds (Pulich et al., 1997; CBBEP, 1998). Habitat for nesting birds can also be created when dredged materials are stacked high enough to create islands. For example, Pelican Island was created from dredged material and is now the largest brown pelican nesting area in Texas (CBBEP, 1998).

The CBBEP also measures habitat quality to assess the overall health and productivity of the estuarine area. Habitat quality can be affected by a variety of factors, including changes in circulation patterns from freshwater inflow alterations, dredge-and-fill activities, shoreline alterations, road construction, point and nonpoint discharges, and activities associated with oil and gas exploration. For example, historical brine discharges have degraded habitat at White's Point in Nueces Bay (CBBEP, 1998). Some of the indicators used to monitor the habitat quality of SAV include maximum depth and width of vegetative growth, shoot density, patchiness, vegetative species composition, and percent cover (CBBEP, 2002). Preliminary assessment activities indicate that certain habitat types in the CBBEP study area are stressed or at risk (CBBEP, 1998).

Black skimmer chicks exploring while the mother is out foraging for food (CBBEP).

Living Resources

The CBBEP assesses the quality and quantity of the living resources within the study area. The program monitors the area's fisheries and several species of concern, including species of birds, marine mammals, and sea turtles. The fishery indicators include the relative abundance of fish and shellfish; standing crops versus fishing pressure; CPUE for several species, including spotted seatrout and blue crab; commercial fish landings by type from within the system areas; TPWD creel surveys data; catch-and-release data; contaminant concentrations in edible tissue of fish and shellfish; and bacteria levels in the waters where the fish live. The program also monitors the population size and

reproduction statistics for birds, colonial bird nesting pairs, number of rookery sites visited or vandalized, the numbers of strandings and mortalities of marine mammals, number of strandings and sea turtle condition, and numbers of nesting sea turtles and turtle nests.

The varied habitats across the CBBEP study area support a wide range of finfish and shellfish species that are of commercial and recreational value. The area is also home to many resident and migratory birds and to marine mammals such as the bottlenose dolphin. Although the study area is one of the richest fishery areas in Texas, particularly for finfish, shrimp, and crab, data suggest that some population declines have occurred in species such as Atlantic croaker, summer flounder, Gulf menhaden, white shrimp, and blue crabs (Lacson and Lee, 1997). Benthic communities in some bays (Corpus Christi, Baffin, and Nueces bays) are characterized by low diversity, a dominance of pioneer species, and a high variance of community and physical variables (Montagna et al., 1998). Although the CBBEP area supports almost 500 species of birds, the nesting populations of colonial waterbirds, with the exception of the brown pelican, have declined. The FWS is concerned about two issues that impact migratory species: rapid habitat loss in Latin and South American countries and the need to preserve wooded riparian corridors and coastal prairies along the Gulf Coast. Some evidence also suggests that there is an increasing trend in the number of dolphin strandings. This issue is of particular concern for bottlenose dolphins (Tunnell et al., 1996).

Environmental Stressors

The CBBEP monitors several human indicators in the study area, including the length, area, and location of hardened shoreline, bulkheads, and other hydrological modifications; the number of vessels and amount of cargo crossing the Bays; and the number of oil and chemical spills in the region. Almost 200 miles of CBBEP shoreline are protected by seawalls and other man-made structures, whereas 1,118 miles remain in their natural state (White et al., 1998). Approximately 80,000 vessels annually cross the Coastal Bend Bays, and recent analysis indicates that the amount of freight transported and the number of vessels in CBBEP waters is increasing (CBBEP, 1998). More than 90% of the region's maritime cargo tonnage is composed of oil and petrochemicals. Although the number of oil and chemical spills in the region has decreased since 1990, some spills do occur (CBBEP, 1998). These spills have the potential to impact the region's water, sediment, and habitat quality, as well as to injure or kill fish and wildlife.

Current Projects, Accomplishments, and Future Goals

The CBBEP and its partners are actively collecting data that will provide a system-wide assessment of the environmental trends in the Coastal Bend Bays resulting from the cumulative effects of action implementation. Several CBBEP projects and numerous partner projects are underway to quantify changes to habitat, water and sediment quality, freshwater resources, commercial and recreational fisheries, species of concern, and shoreline management; however, several factors limit the CBBEP's ability to report on system-wide progress at this time. Some projects are still in progress, and results may not be available for some time. In addition, significant resources are being directed toward water and sediment quality assessment projects to determine the statistical confidence of these data, and some partners have not submitted data to the program's information clearinghouse. For these reasons, reporting system-wide environmental changes as a result of CBBEP or partner action is premature.

A partnership between the CBBEP and the City of Corpus Christi will help restore freshwater flow to the Nueces River Delta and revitalize a wetland that is crucial to the Gulf Coast. The Nueces Delta Preserve is a dynamic ecosystem of highly productive wetlands, open water, islands, prairie, and river and bay shorelines. The river provides vital riparian habitat, whereas brackish wetlands are home to shrimp, crabs, juvenile fish, and birds. The uplands contain an attractive diversity of native vegetation that host a variety of wildlife. Approximately 3,000 acres of wetlands-associated uplands have been acquired for the purpose of habitat protection as part of a long-term regional water and land management plan to meet human and environmental needs for fresh water (CBBEP, 2005b).

The Delta provides highly productive wetlands and critical habitat for numerous shorebirds, as well as recreationally and commercially important fish and shellfish species (e.g., shrimp, crabs, and juvenile finfish). Part of the new Nueces Delta Preserve will be purchased by the City of Corpus Christi for use as an overflow channel and pipeline corridor to deliver much-needed fresh water directly to the upper Nueces River Delta.

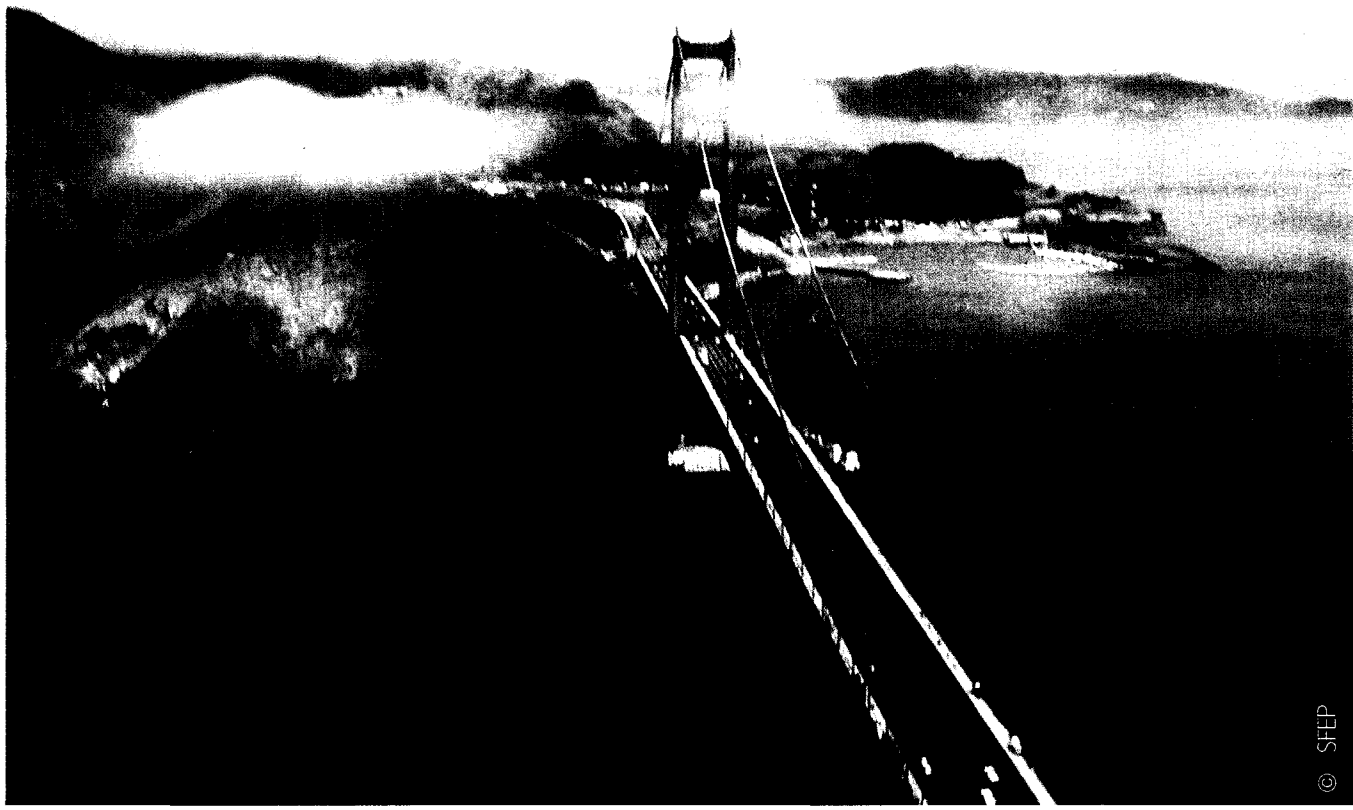
Conclusion

The CBBEP has taken actions to establish aggressive goals for the protection and restoration of the Coastal Bend Bays by obtaining consensus among a variety of different stakeholder groups. NCA monitoring data classify the Coastal Bend Bay's overall condition as poor. Because many of the CBBEP's own monitoring data are still being collected or evaluated, it is not known whether the comprehensive list of CBBEP indicators will show a pattern similar to the NCA data. Attaining the CBBEP's goals will require continued strong monitoring efforts, as well as comprehensive pollution and resource management. Projected population increases in the CBBEP area will require increasing cooperation among stakeholder groups in developing a strong regional water management plan that will balance the long-term environmental needs of the human inhabitants and living resources of the Coastal Bend Bays to maintain a sustainable freshwater system.

Outdoor enthusiasts getting ready to hit the waves in their catamarans on North Padre Island (CBBEP).

CHAPTER 6

WEST COAST NATIONAL ESTUARY PROGRAM COASTAL CONDITION



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CHAPTER 6

WEST COAST NATIONAL ESTUARY PROGRAM COASTAL CONDITION

Background

The West Coast region extends from the Mexican border north to the Canadian border and, due to its unique geological history, has the fewest estuaries of any coastal region of the United States. With the exception of parts of the Washington coast that have become coastal flats and islands due to the erosion of sedimentary rocks, the West Coast is characterized by uplifted, resistant rock. The proximity of coastal mountains to the shoreline in this region has restricted the area of coastal plain and rivers that flow to the sea (NOAA, 1985).

Within the West Coast region, there are six NEP estuaries: Puget Sound, the Lower Columbia River Estuary, Tillamook Bay, the San Francisco Estuary, Morro Bay, and Santa Monica Bay (Figure 6-1). The larger West Coast estuaries, Puget Sound and the San Francisco Estuary, were formed when sections of the coastline containing former river valleys sank below sea level during mountain-building processes (NOAA, 1985). Puget Sound was further deepened and elongated as a result of glacial activity, resulting in the development of a fjord that is narrow, deep, and steep-sided, with several internal sills. Both of these estuaries are dominated by tidal flow rather than by freshwater inputs. In contrast, the Lower Columbia River Estuary is heavily influenced by freshwater riverine discharge. During high river-flow periods, the Estuary is almost entirely composed of fresh water that is well connected to the ocean; however, during low-flow periods, discharge is insufficient to maintain a good connection with the ocean, and tidal action along the shoreline tends to affect the entrance to the Estuary.

Sediment loads delivered to West Coast estuaries vary considerably throughout the region, with high sediment loading in southern California, moderate loading in central California, and generally low loading from northern California to Washington due to extensive forested lands that help reduce sediment runoff (NOAA, 1985). However, historic logging activities, steep slopes, and heavy rainfall in some of the Northwest Coast estuaries combine to result in high levels of sediment and lower water clarity in some river systems.

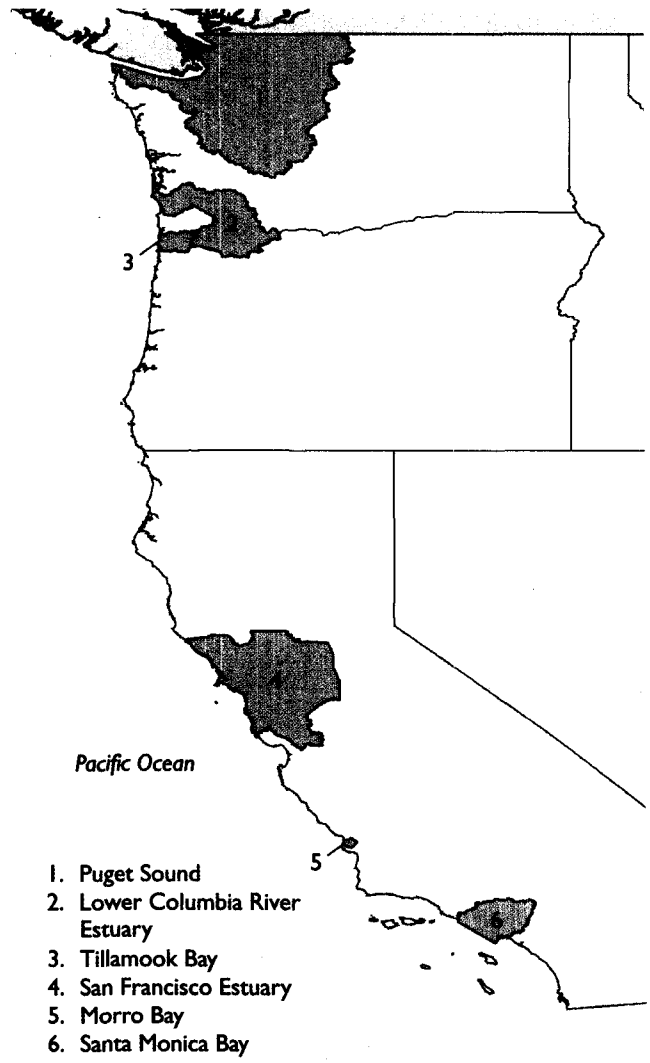


Figure 6-1. The West Coast region is home to six NEP estuaries.

Population Pressures

The population of the 41 NOAA-designated coastal counties coincident with the estuarine study areas of the West Coast NEPs increased by 100.3% during a 40-year period, from 14.7 million people in 1960 to 29.5 million people in 2000 (Figure 6-2) (U.S. Census Bureau, 1991; 2001). This growth resulted in a population density of 421 persons/mi^2 in 2000 for these NEP-coincident coastal counties; however, the population densities of the individual NEP study areas varied considerably, from a high of 844 persons/mi^2 for the San Francisco Estuary to a low of 22 persons/mi^2 for Tillamook Bay (U.S. Census Bureau, 2001). Development and population pressures are especially strong surrounding some of the West Coast NEP estuaries, which are centers of international commerce, major fishing ports, and recreational areas for these coastal communities.

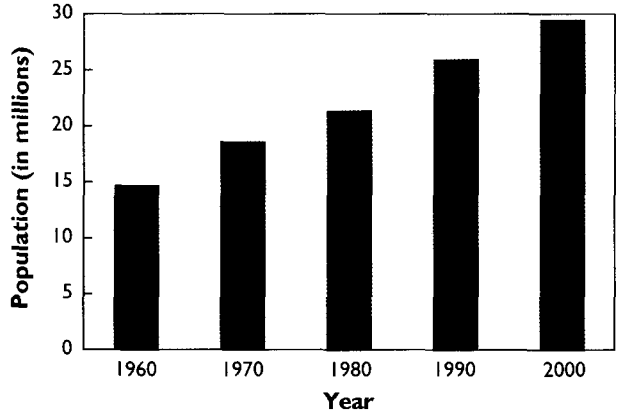


Figure 6-2. Population of the 41 NOAA-designated coastal counties of the West Coast NEP study areas, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—West Coast Region

Researchers with the Washington State Department of Ecology (WSDE), the Oregon Department of Environmental Quality (ODEQ), NOAA's NS&T Program, and the Moss Landing Marine Laboratories, under contract to the Southern California Water Resources Research Project, collected NCA data from 308 locations in the six West Coast NEP estuaries in 1999, 2000, and 2003. The NS&T Program also provided sediment contaminants data from some Puget Sound sites based on samples collected in 1997, 1998, and 1999. With the assumption that sediment contaminant concentrations will change slowly, these stations were incorporated into the 2000 sampling design and supplemented with water quality and biological data. The NS&T Program collected additional data during 2001 within the San Francisco Estuary, but these data have not been included in the current report. The Morro Bay and Santa Monica Bay estuarine areas were not sampled until 2003.

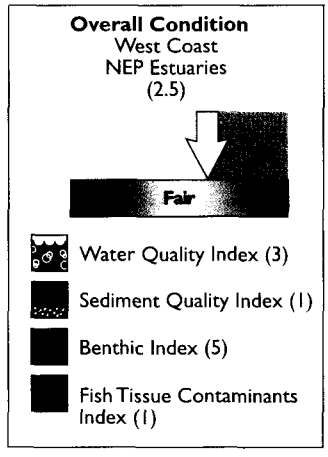


Figure 6-3. The overall condition of the West Coast NEP estuarine area is fair (U.S. EPA/NCA).

The following sections of this report discuss 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 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 assessments 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.

The overall condition of the collective West Coast NEP estuaries is rated fair based on the four indices of estuarine condition used by the NCA (Figure 6-3). The water quality index for the region is rated fair, the sediment quality and fish tissue contaminants indices are rated poor, and the benthic index is rated good. Figure 6-4 shows the percent of estuarine area rated good, fair, poor, or missing for each parameter considered. 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.

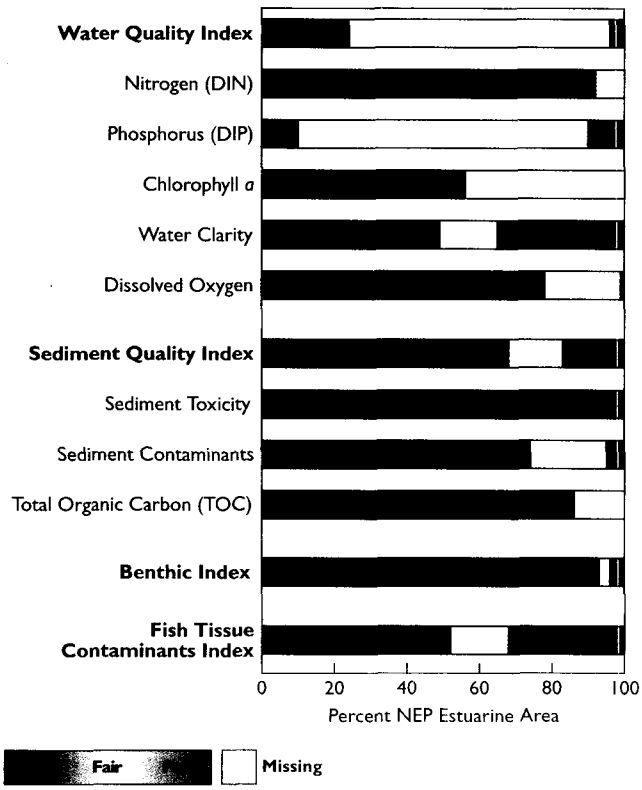


Figure 6-4. Percentage of NEP estuarine area achieving each ranking for all indices and component indicators — West Coast region (U.S. EPA/NCA).

Water Quality Index

Based on NCA survey results, the water quality index for the collective West Coast NEP estuaries is rated fair. This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Seventy-two percent of the estuarine area was rated fair for water quality because of limited water clarity and elevated levels of DIP (Figure 6-5).

Dissolved Nitrogen and Phosphorus | The West Coast region is rated good for DIN concentrations, with 92% of the NEP estuarine area rated good for this component indicator. The region is rated fair for DIP concentrations, with 10% of the NEP estuarine area rated poor and 80% of the area rated fair for this component indicator. It should be noted that the threshold for a West Coast site to be rated poor for DIN was a concentration in excess of 1 mg/L and for DIP was a concentration in excess of 0.1 mg/L. These values correspond to the levels used by the NOAA/EPA Team on Near Coastal Waters to indicate high nutrient levels in its report on the susceptibility of West Coast estuaries to nutrient discharges (NOAA/U.S. EPA, 1991). Along much of the West Coast, summer wind conditions result in an upwelling of nutrient-rich deep water, which enters the West Coast estuaries during flood tides (Landry et

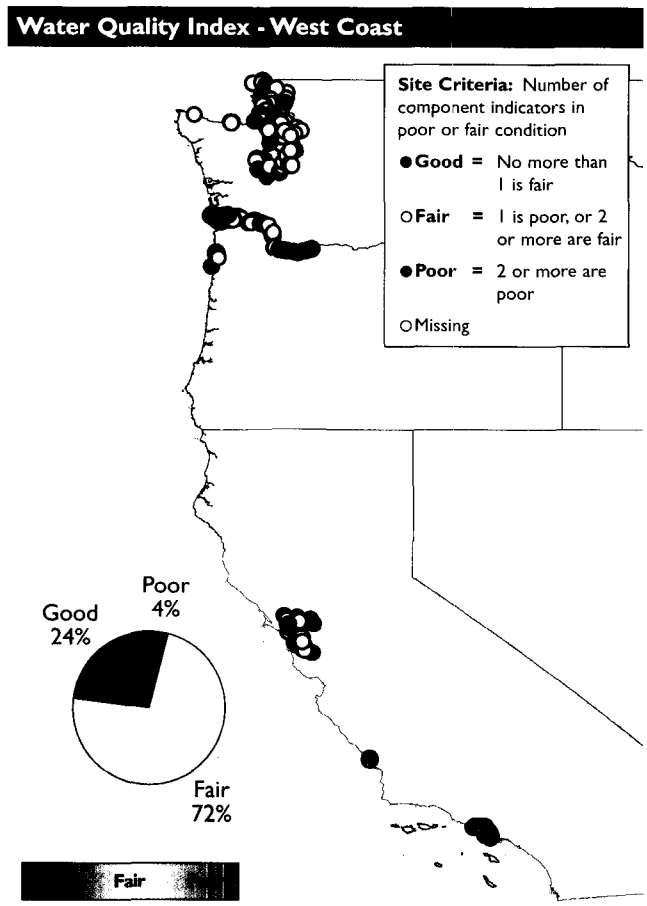


Figure 6-5. Water quality index data for the West Coast NEP estuarine area, 1999, 2000, and 2003 (U.S. EPA/NCA).

al., 1989) and constitutes a potentially important, natural source of nutrient inputs for many of these estuaries.

Chlorophyll a | Chlorophyll *a* concentrations for the West Coast region are rated good, with 44% of the NEP estuarine area rated fair for this component indicator and 56% of the area rated good. None of the West Coast region's NEP estuarine area was rated poor for chlorophyll *a* concentrations.

Water Clarity | NCA data show that water clarity in the NEP estuaries of the West Coast region is rated poor. For all of the West Coast NEP estuaries, water clarity was rated poor at a sample site if light penetration at 1 meter was less than 10% of surface illumination. Approximately 35% of the West Coast NEP estuarine area was rated poor for water clarity, and 16% of the area was rated fair. It should be noted that the West Coast typically experiences strong seasonal variations in freshwater flow between the wet conditions of winter and the dry conditions of summer. In interpreting water clarity for the West Coast NEP estuaries, the light penetration levels recorded represent water clarity only in late summer and do not represent high-flow, wet season conditions in the winter. In addition, the large tidal amplitude found in many estuaries along the West Coast may result in high natural levels of turbidity in the water column due to sediment suspension; however, phytoplankton and other particulate matter may also decrease water clarity. The NOAA Eutrophication Survey (NOAA, 1998) has previously reported high turbidity in the West Coast NEP estuarine areas and for the West Coast estuaries in general (20 of 38 estuaries surveyed).

Dissolved Oxygen | The West Coast region is rated good for dissolved oxygen conditions, with 78% of the NEP estuarine area rated good for this component indicator, 21% of the area rated fair, and only 1% of the area rated poor. Although conditions in West Coast NEP estuaries appear to be generally good for dissolved oxygen, measured values reflect daytime conditions, and some areas may still experience hypoxic conditions at night.

Sediment Contaminant Criteria (Long et al., 1995)

ERM (Effects Range Median)—Determined for each chemical as the 50th percentile (median) in a database of ascending concentrations associated with adverse biological effects.

ERL (Effects Range Low)—Determined for each chemical as the 10th percentile in a database of ascending concentrations associated with adverse biological effects.

Sediment Quality Index

The sediment quality index for the collective NEP estuaries of the West Coast region is rated poor, with 17% of the estuarine area exceeding thresholds for sediment toxicity, sediment contaminants, or sediment TOC (Figure 6-6). The sediment contaminants component of the sediment quality index for the West Coast NEP estuaries excluded phenanthrene (a PAH) and

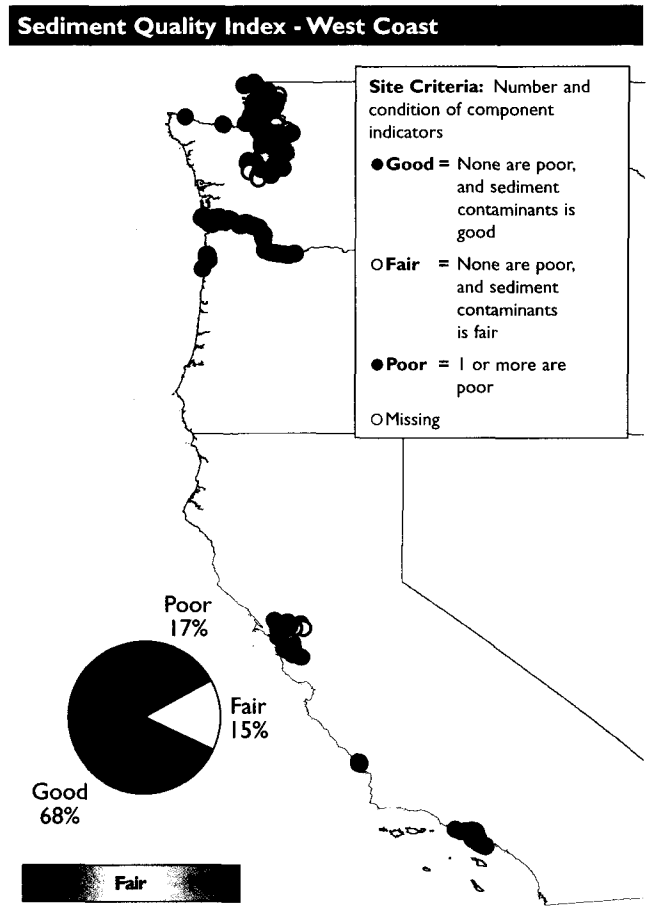


Figure 6-6. Sediment quality index data for the West Coast NEP estuarine area, 1997–2000, and 2003 (U.S. EPA/NCA).

nickel. Phenanthrene was excluded because concentrations were not available from all West Coast NEP estuaries, and nickel was excluded because its ERM value has a low reliability for West Coast conditions, where high natural crustal concentrations of nickel exist (Long et al., 1995).

Sediment Toxicity | The West Coast region is rated poor for sediment toxicity because 18% of the NEP estuarine area was rated poor for this component indicator. Toxicity was determined using a static 10-day acute toxicity test with the amphipods *Ampelisca abdita* or *Hyalella azteca*. Sediment toxicity was observed in all West Coast NEP estuaries except Tillamook Bay and the San Francisco Estuary.

Sediment Contaminants | The West Coast region is rated fair for sediment contaminant concentrations. Approximately 5% of the region's NEP estuarine area was rated poor for this component indicator, and 21% of the area was rated fair.

Total Organic Carbon | The West Coast NEP estuarine area is rated good for TOC concentrations because concentrations in sediment were rated good in 86% of the NEP estuarine area and fair in 14% of the area. None of the estuarine area was rated poor for this component indicator.

Benthic Index

Currently, there is no single benthic community index applicable to the entire West Coast region, although work on such an index is ongoing. In lieu of a West Coast Benthic Index, the deviation of species richness from an estimate of the expected species richness was used as an approximate indicator of the condition of the West Coast benthic community. The log10 transformed number of species per 0.1-square-meter grab sample was regressed on bottom salinity. The benthic condition of any station with fewer species than 75% of the lower 95% confidence limit of the mean from the regression was rated poor, whereas the condition of stations with 75% to 90% of the lower 95% confidence limit was rated fair.

The condition of the benthic invertebrate communities in the collective West Coast NEP estuaries is rated good based on deviations from the expected species richness (Figure 6-7). This analysis was based on a total of 245 benthic samples collected in 1999 and 2000 for the NEP estuarine areas of Tillamook Bay, Puget Sound, the San Francisco Estuary, and the Lower Columbia River Estuary, as well as in 2003 for Morro Bay and Santa Monica Bay.

A significant linear regression was found between salinity and the log of species richness that was moderately strong ($r^2 = 0.39$, $p < 0.01$). Based on this regression, 47 sites, representing 4% of the estuarine area, were rated poor, and another 36 sites, representing 3% of the area, were rated fair. Of the 47 sites rated poor, 25 sites (53%) were in the Lower Columbia River Estuary, which may reflect the naturally low diversity of this system, or potentially, the effects of stressors such as channel dredging on the benthic communities.

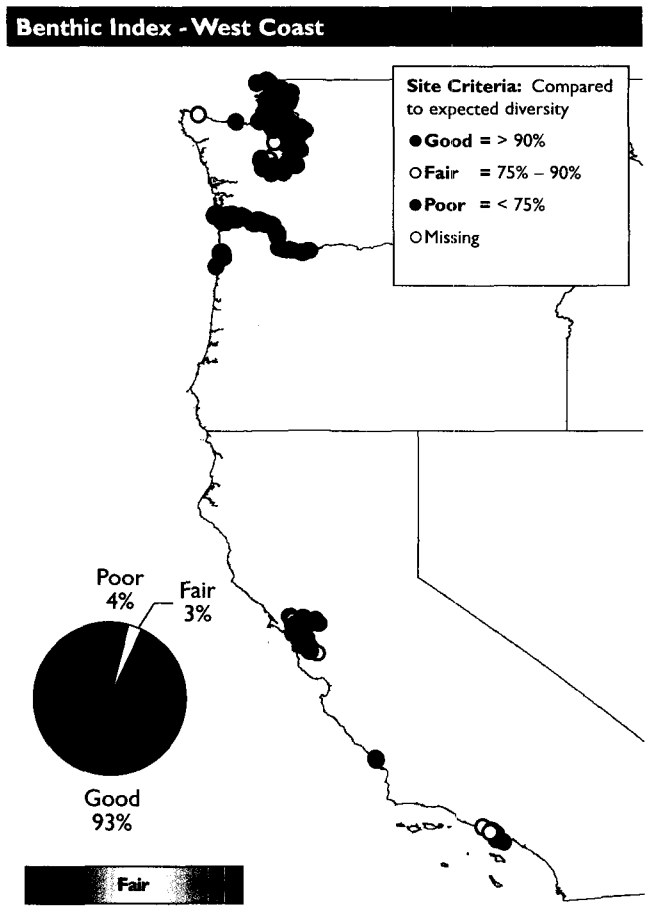


Figure 6-7. Benthic index data for the West Coast NEP estuarine area, 1999, 2000, and 2003 (U.S. EPA/NCA).

Fish Tissue Contaminants Index

The fish tissue contaminants index for the collective West Coast NEP estuaries is rated poor based on fish samples collected from 198 stations (Figure 6-8). Thirty-two percent of all stations sampled where fish were caught were rated poor for fish tissue contaminants, which most often included total PCBs, DDTs, and mercury.

Fish tissue contaminant levels were compared to EPA Advisory Guidance values using whole-fish contaminant concentrations. For populations that consume whole fish, these risk calculations are appropriate. Whole-fish contaminant concentrations can be higher or lower than the concentrations associated with fillets only. Only those contaminants that have an affinity for muscle tissue (e.g., mercury) are likely to have higher fillet concentrations. Fillet contaminant concentrations for most other contaminants will be lower than whole fish analyses. In contrast to the NEP estuaries of the Northeast, Southeast, and Gulf coasts, PAHs were not analyzed in fish tissue samples collected from the West Coast NEP estuaries.

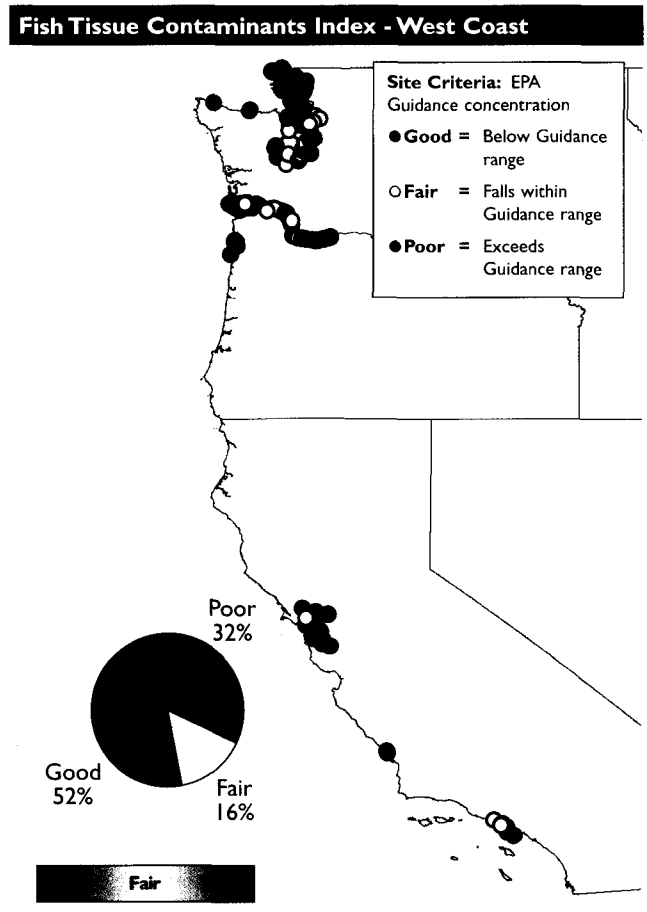


Figure 6-8. Fish tissue contaminants index data for the West Coast NEP estuarine area, 1999, 2000, and 2003 (U.S. EPA/NCA).

NEP Estuaries and the Condition of the West Coast Region

The purpose of the NEP is to identify, restore, and protect the nationally significant estuaries of the United States. The six West Coast NEP estuaries include a wide range of estuary types, from large estuaries, such as the San Francisco Estuary and Puget Sound, to much smaller estuaries, such as Tillamook Bay and Morro Bay. The larger estuaries are important to the nation as major centers of commerce and international trade, areas for commercial or recreational fisheries, and centers for coastal recreational activities; however, these diverse uses can create environmental stresses that may result in environmental degradation. Does the condition of the West Coast NEP estuaries accurately reflect the condition of all West Coast estuaries (both NEP and non-NEP)? Based on the NCA survey results, the collective West Coast NEP estuaries and all West Coast estuaries combined are both rated fair for overall condition, with the group of NEP estuaries receiving an overall condition score of 2.5, just slightly higher than the overall condition score of 2.25 for all West Coast estuaries (Figure 6-9). The overall condition scores for the two groups of West Coast estuaries were derived from estimates presented in the NCCR II and based on NCA data collected between 1999 and 2000 from all West Coast estuaries, except for Morro Bay and Santa Monica Bay, which were sampled in 2003. A higher overall condition score for the group of collective NEP estuaries has also been noted in some of the other regions outlined in this report.

A comparison of NCA data shows that the collective West Coast NEP estuaries are rated fair for the water quality index, poor for the sediment quality index, good for the benthic index, and poor for the fish tissue contaminants index. The group of all West Coast estuaries combined are rated fair for the water quality index, fair to poor for sediment quality index, fair for the benthic index, and poor for the fish tissue contaminants index. Both groups of estuaries are also rated comparably for almost all of the water and sediment quality component

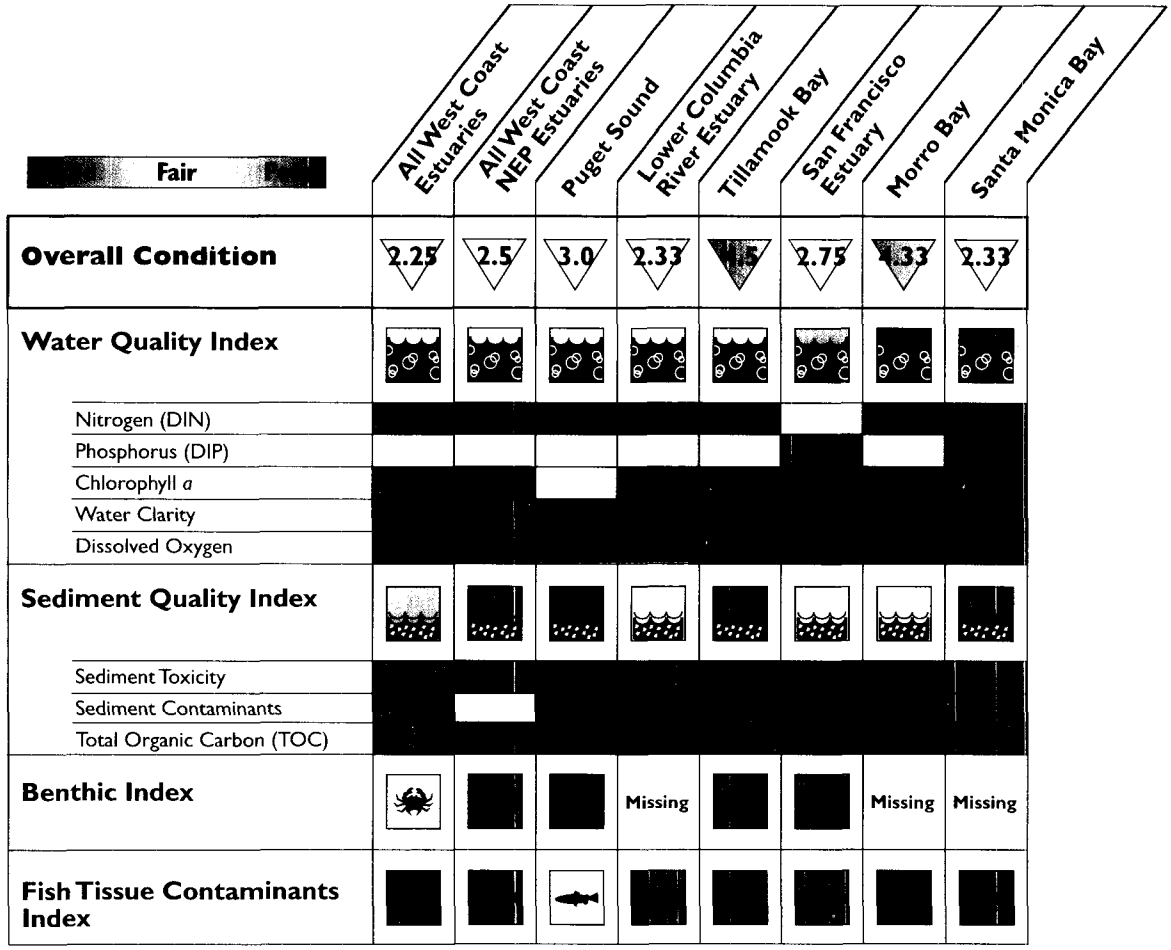


Figure 6-9. Comparison of NCA results for West Coast NEP estuaries and all West Coast estuaries (U.S. EPA/NCA).

indicators, with both groups rated good for DIN, chlorophyll *a*, dissolved oxygen, and TOC concentrations; fair for DIP concentrations; and poor for water clarity and sediment toxicity. However, the two groups of estuaries received different ratings for one sediment quality component indicator (sediment contaminants). The collective West Coast NEP estuaries are rated fair for sediment contaminant concentrations, whereas the group of all West Coast estuaries combined are rated good for this component indicator. Based on these ratings, the condition of the West Coast NEP estuaries is relatively representative of the condition of all West Coast estuaries, with the exception of sediment quality, where the group of all West Coast estuaries received better ratings.

With respect to the individual West Coast NEP estuaries, four of the six estuaries are rated higher for overall condition to the overall condition score for the collective West Coast NEP estuaries (2.5, rated fair). These NEP estuaries are Puget Sound (3.0, rated fair), Tillamook Bay (4.5, rated good), the San Francisco Estuary (2.75, rated fair), and Morro Bay (4.33, rated good). Only the Lower Columbia River Estuary (2.33) and the Santa Monica Bay (2.33), which are both rated fair, received overall condition scores below the overall condition score for the collective NEP estuaries of the West Coast region.

The water quality index is rated good for two of the six West Coast NEP estuaries (Morro Bay and Santa Monica Bay), both of which are located in the southernmost portion of the region. Three NEP estuaries (Puget Sound, the Lower Columbia River Estuary, and Tillamook Bay) are rated fair for the water quality index, whereas the San Francisco Estuary is rated fair to poor. With respect to the water quality component indicators, all of the West Coast NEP estuaries are rated good for DIN concentrations, except for the San Francisco Estuary, which is rated fair. The majority of

the NEP estuaries (Puget Sound, the Lower Columbia River Estuary, Tillamook Bay, and Morro Bay) are rated fair for DIP concentrations, although the San Francisco Estuary is rated poor and Santa Monica Bay is rated good for this component indicator. All the estuaries are rated good for chlorophyll *a* concentrations, except for Puget Sound, which is rated fair. Four of the six West Coast NEP estuaries (Puget Sound, the Lower Columbia River, Tillamook Bay, and the San Francisco Estuary) are rated poor for water clarity, whereas the remaining two estuaries (Morro Bay and Santa Monica Bay) are rated good. Finally, all six estuaries are rated good for dissolved oxygen concentrations.

The sediment quality index ratings for the individual West Coast NEP estuaries range from good to poor. The sediment quality index is rated good for Tillamook Bay; fair for the Lower Columbia River Estuary, San Francisco Estuary, and Morro Bay; and poor for Puget Sound and Santa Monica Bay. Sediment toxicity is rated good in Tillamook Bay and the San Francisco Estuary and poor in Puget Sound, the Lower Columbia River Estuary, Morro Bay, and Santa Monica Bay. Sediment contaminant concentrations are rated good for five of the West Coast NEP estuaries, but poor for Santa Monica Bay. Finally, sediment TOC is rated good in all West Coast NEP estuaries.

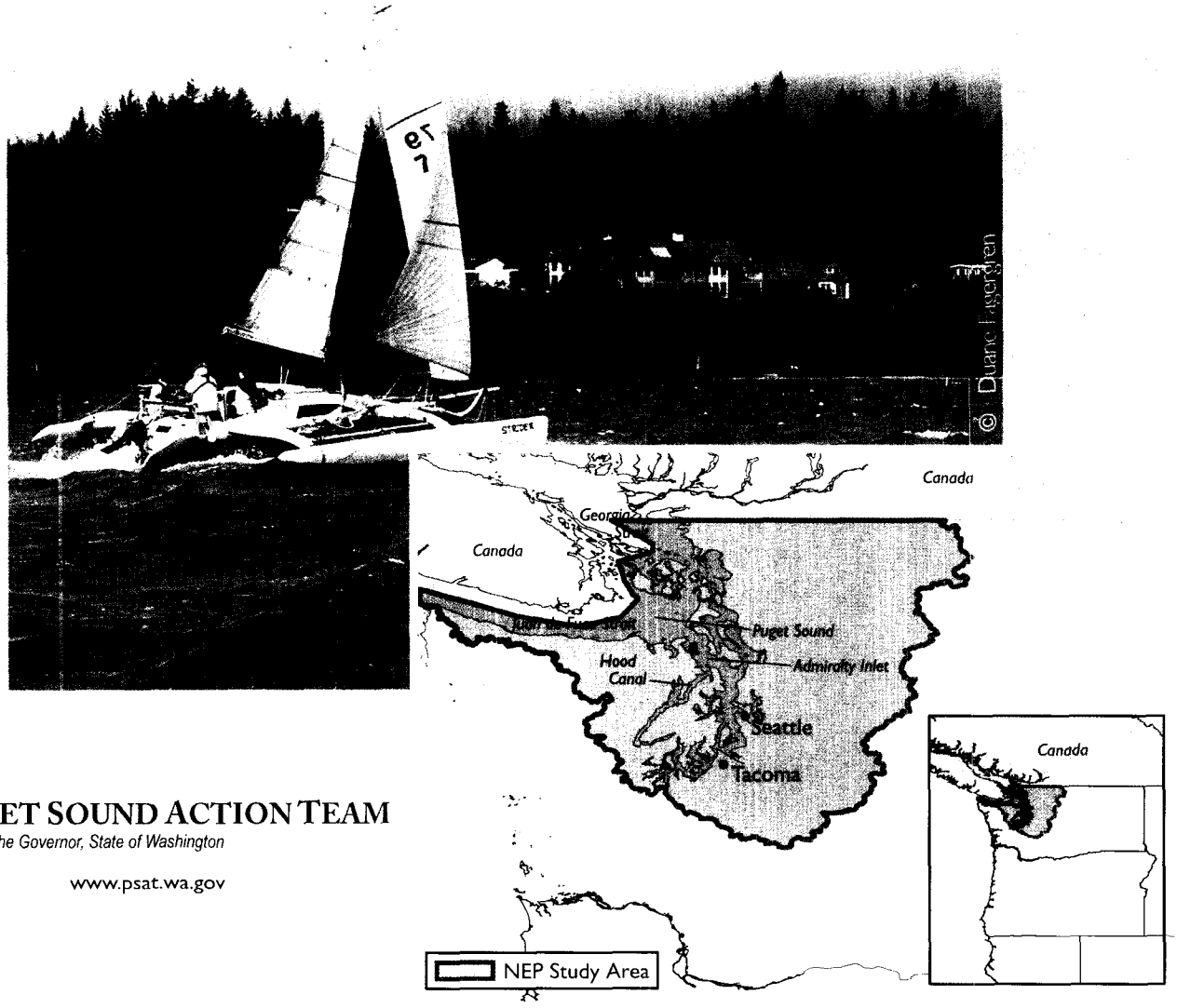
The benthic index is rated good for all West Coast NEP estuaries where a rating was applicable (Puget Sound, Tillamook Bay, and the San Francisco Estuary). Benthic index ratings were not applicable for the Lower Columbia River Estuary, Morro Bay, or Santa Monica Bay because the index used was based on deviations from the expected species richness. The benthic index methodology used by the NCA requires a significant regression between salinity and the log of species richness; however, a lack of significant regression existed for the two southernmost NEPs (Morro Bay and Santa Monica Bay) because of the small variation in salinity. For the Lower Columbia River Estuary, there was a lack of significant regression because of this area's low species richness, possibly associated with either dredging or naturally low species diversity.

The fish tissue contaminants index is rated good for Tillamook Bay and Morro Bay; fair for Puget Sound; and poor for the Lower Columbia River Estuary, San Francisco Estuary, and Santa Monica Bay.

Nationally, the overall condition score for the collective West Coast NEP estuaries (2.5) ranks higher than the overall condition scores for the Northeast Coast (1.5) and Puerto Rico (1.5) regions and lower than the overall condition scores for the Southeast Coast (4.0) and Gulf Coast (2.75) regions. Population pressures, measured as population density (number of persons/mi^2), correlated somewhat with the overall condition score for the West Coast NEP estuaries. For example, Morro Bay and Tillamook Bay had the lowest population densities of 75 and 22 persons/mi^2, respectively, and these estuaries had the highest overall condition scores of 4.33 and 4.5 (both rated good). The two largest estuaries with the highest population densities, San Francisco Estuary (844 persons/mi^2) and Puget Sound (205 persons/mi^2), were both rated fair for overall condition, with overall condition scores of 2.75 and 3.0, respectively. The Lower Columbia River Estuary and Santa Monica Bay had the lowest overall condition scores (both 2.33 and rated fair) of any of the six West Coast NEP estuaries and were intermediate in population density (138 and 533 persons/mi^2, respectively).

Harbor seals can be seen at sandy beaches, mudflats, bays, and estuaries along the West Coast (Jim Young).

Puget Sound Action Team



PUGET SOUND ACTION TEAM
Office of the Governor, State of Washington

www.psat.wa.gov

Background

Carved by glaciers, Puget Sound is a place where the salt water of the ocean meets fresh water flowing from about 10,000 rivers and streams (PSAT, 2003a). Together, these waters commingle to form a deep, complex system that provides invaluable habitat for fish and wildlife, including the region's renowned Pacific salmon and orca whales. The Sound covers 2,800 mi^2 of inland marine waters, with an average depth of 450 feet, and encompasses 2,500 miles of shoreline (PSAT, 2003a; 2006).

Much of the promise and potential of the Puget Sound estuarine area is based on natural resources and the industries these resources support, such as tourism, lumber, shellfish, and recreation. The region's natural resources and high quality of life have led to good economic growth, resulting in ever-increasing numbers of people who live and work in the counties surrounding Puget Sound. By 2020, the population in the Puget Sound basin is expected to be greater than five million people—almost 30% more people than the present population (PSAT, 2002). This region supports one of

the leading trade centers on the West Coast and is a gateway to some of the continent's busiest ports, including Seattle, Tacoma, Anacortes, Everett, Port Angeles, and Olympia. The port facilities within Puget Sound collectively handled more than 64 million tons of cargo during 2003 (PSAT, 2002; USACE, 2004b).

EPA declared Puget Sound to be an Estuary of National Significance in 1988, an action that included the Puget Sound in the NEP (PSAT, 2003a). Created in 1996, the Puget Sound Action Team (PSAT) is composed of state agencies and federal, tribal, and local governments. The federal government and the State of Washington have both adopted the *2000 Puget Sound Water Quality Management Plan* (PSAT, 2000) as the comprehensive plan to protect and restore Puget Sound. This partnership is leading efforts to implement the PSAT plan and to protect and restore Puget Sound (PSAT, 2003a).

Environmental Concerns

A growing human population means increasing stress on Puget Sound. Human development has modified significant portions of the Sound's shoreline, and stormwater runoff from developed areas is a substantial water pollution problem because of the contaminants from those surfaces. Toxic contamination, nearshore habitat modifications, habitat loss, declines in some fish and wildlife populations, Endangered Species Act listings of salmon and eight other species in the nearshore habitat, and shellfish bed closures remain among the primary concerns for Puget Sound. The Sound has experienced significant physical changes to its nearshore habitat, as well as population declines in some of its most important plant and animal species (PSAT, 2002).

Population Pressures

The population of the 14 NOAA-designated coastal counties coincident with the PSAT study area increased by about 120% during a 40-year period, from 1.8 million people in 1960 to 4.1 million people in 2000 (Figure 6-10) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the PSAT study area surpassed the population growth rate of 100.3% for the collective West Coast NEP-coincident coastal counties; however, the 2000 population density in the PSAT-coincident coastal counties remained fairly low at 205 person/mi^2, well below the West Coast NEP-coincident coastal county population density of 421 persons/mi^2 (U.S. Census Bureau, 2001). Development and population pressures are especially strong in NEP study areas that serve as major shipping centers for commercial, fishing industry, and recreational activities in their coastal communities.

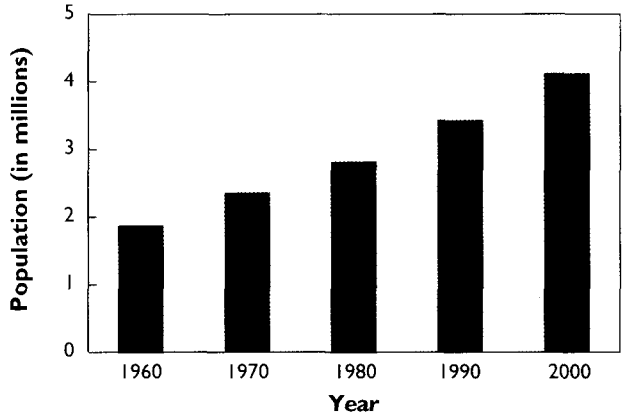


Figure 6-10. Population of NOAA-designated coastal counties of the PSAT study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Puget Sound

The overall condition of Puget Sound is rated fair based on the four indices of estuarine condition used by the NCA (Figure 6-11). The water quality and fish tissue contaminants indices are rated fair, the sediment quality index is rated poor, and the benthic index is rated good. Figure 6-12 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 collected by the WSDE, in collaboration with NOAA, from 73 sites sampled in the PSAT estuarine area between 1997 and 2000. 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.

Puget Sound Action Team

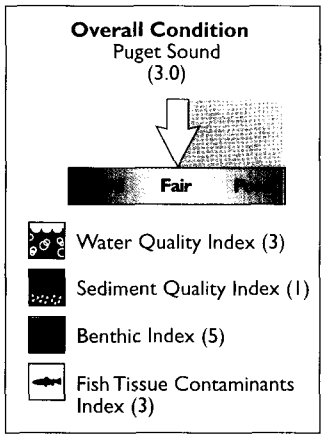


Figure 6-11. The overall condition of the PSAT estuarine area is fair (U.S. EPA/NCA).

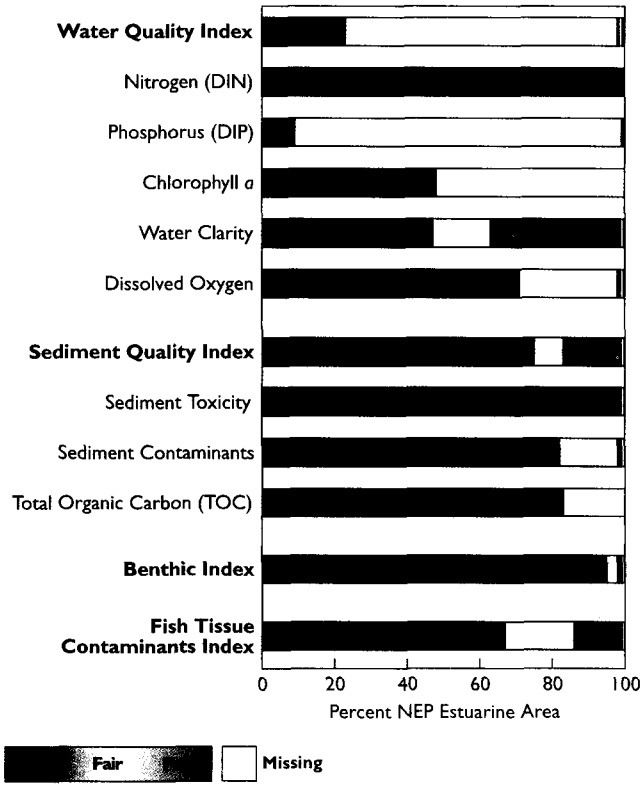


Figure 6-12. Percentage of NEP estuarine area achieving each ranking for all indices and component indicators — Puget Sound (U.S. EPA/NCA).

Water Quality Index

Based on NCA survey results, the water quality index for Puget Sound is rated fair. This index was developed using information from five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Most (75%) of the estuarine area received fair ratings for water quality, whereas 2% of the area was rated poor because of limited water clarity and moderate levels DIP and chlorophyll *a* (Figure 6-13).

Dissolved Nitrogen and Phosphorus | Puget Sound is rated good for DIN concentrations, but rated fair for DIP concentrations. Concentrations of DIN were rated good in 100% of the PSAT estuarine area. In contrast, fair DIP concentrations occurred in 90% of the estuarine area, and only 1% of the area was rated poor for this component indicator.

Chlorophyll a | Chlorophyll *a* concentrations in Puget Sound are rated fair. Fifty-two percent of the estuarine area was rated fair for this component indicator, and the remaining 48% of the area was rated good.

Water Clarity | Water clarity in Puget Sound is rated poor. Approximately 37% of the estuarine area was rated poor for water clarity, and 16% of the area was rated fair.

Dissolved Oxygen | Dissolved oxygen conditions in Puget Sound are rated good. Twenty-seven percent of the estuarine area was rated fair for this component indicator, and less than 2% of the estuarine area was rated poor, primarily for sites located in Hood Canal. Although dissolved oxygen conditions in Puget Sound appear to be generally good, measured values reflect daytime conditions, and some areas may still experience hypoxic conditions at night.

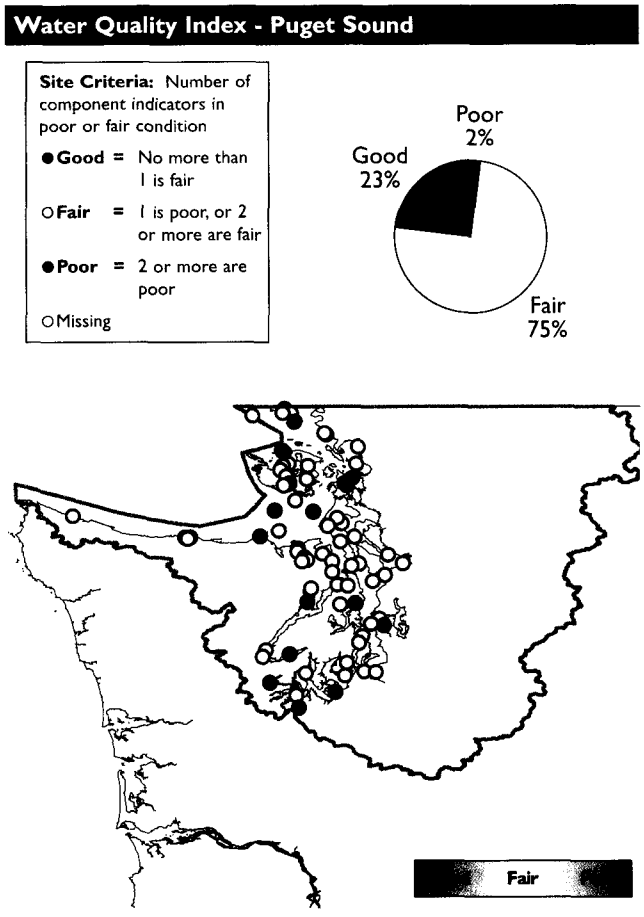


Figure 6-13. Water quality index data for Puget Sound, 1999–2000 (U.S. EPA/NCA).

Sediment Quality Index

The sediment quality index for Puget Sound is rated poor, with 17% of the area exceeding thresholds for one or more of the three component indicators—sediment toxicity, sediment contaminants, or sediment TOC (Figure 6-14).

Sediment Toxicity | Puget Sound is rated poor for sediment toxicity. Sediments in 21% of the estuarine area were rated poor; however, this percentage is based on poor ratings at only two sites, one of which had a 79% survival rate. The effect of these two sites on the area estimate of poor condition was augmented by the fact that both sites were located within the statistical stratum with the largest area and that only five other sites had acceptable sediment toxicity data within the stratum.

Sediment Contaminants | Puget Sound is rated good for sediment contaminant concentrations, with 2% of the estuarine area rated poor for this component indicator and 16% of the area rated fair.

Total Organic Carbon | Puget Sound is rated good for sediment TOC, with sediment concentrations rated good in 83% of the estuarine area and fair in 17% of the area. None of the PSAT estuarine area was rated poor for sediment TOC concentrations.

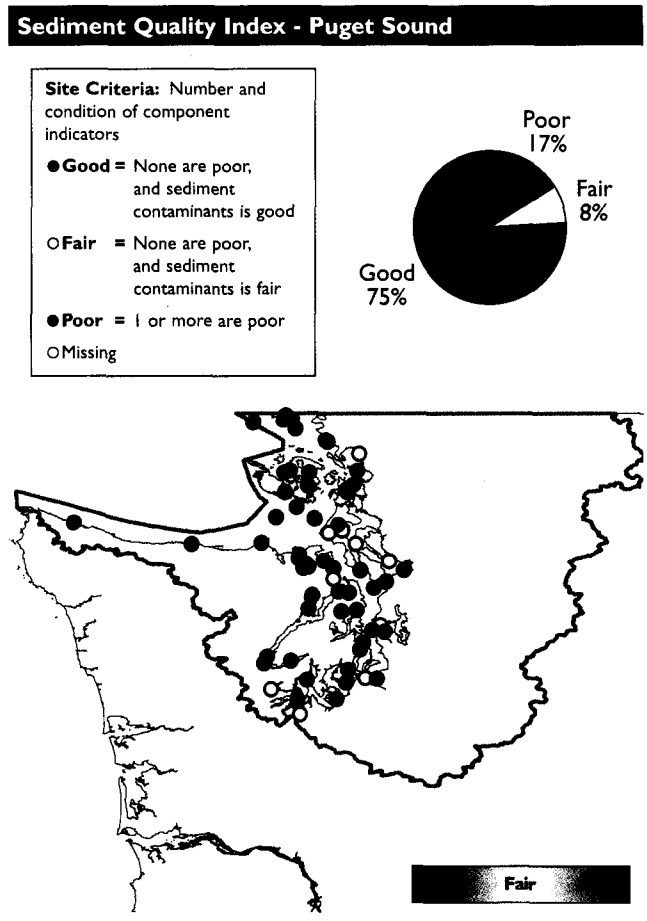


Figure 6-14. Sediment quality index data for Puget Sound, 1997–2000 (U.S. EPA/NCA).

Benthic Index

The benthic condition of Puget Sound is rated good based on deviations from the expected species richness (Figure 6-15). This analysis was based on 62 benthic samples collected in Puget Sound, including 8 samples collected in the embayments along the Strait of Juan de Fuca in 1999 and 54 from within Puget Sound proper in 2000.

A significant linear regression between log species richness and salinity was found in the Puget Sound estuary, although this regression was weak ($r^2 = 0.09$, $p < 0.01$). A potential reason for the weak relationship between species richness and salinity is that bottom salinity ranged only from 25.7 to 33.0 ppt among these sites. Using this regression, four sites (representing 2% of the estuarine area) were rated poor based on a lower-than-predicted species richness, and another four sites, representing 3% of the area, were rated fair. The remaining 95% of the estuarine area was rated good for benthic condition. The cause for the less-than-expected species richness at the sites rated poor is not readily apparent because all of these sites were rated good for sediment contaminant concentrations. In addition, sediment TOC was rated fair at three of the four sites surveyed, although a number of other sites with equivalent TOC measurements did not display depressed species richness.

Fish Tissue Contaminants Index

The fish tissue contaminants index for Puget Sound is rated fair. Fourteen percent of all stations sampled where fish were caught exceeded EPA Advisory Guidance values using whole-fish contaminant concentrations (Figure 6-16). For populations that consume whole fish, these risk calculations are appropriate. The contaminants found in fish tissues in Puget Sound most often included total PCBs.

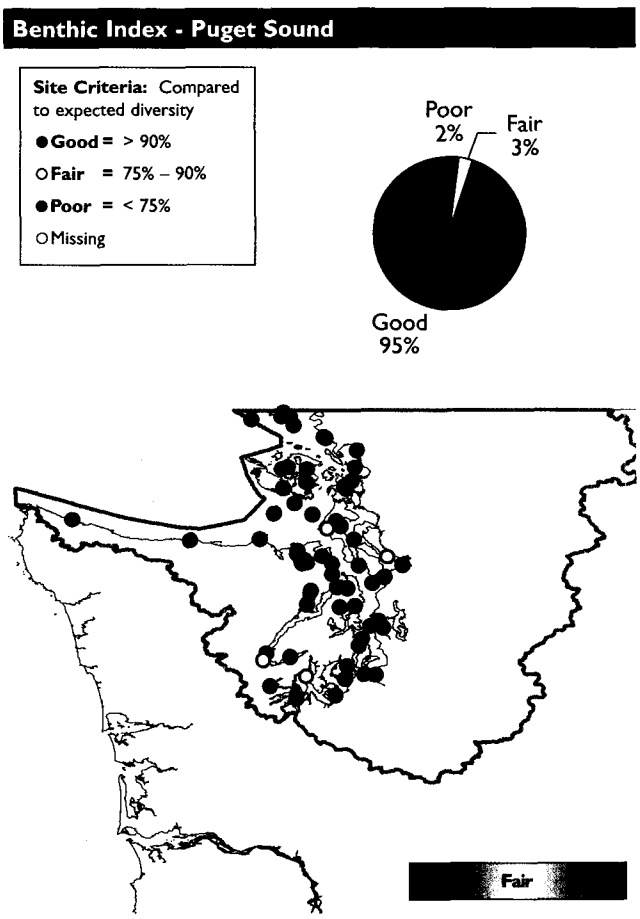


Figure 6-15. Benthic index data for Puget Sound, 1999–2000 (U.S. EPA/NCA).

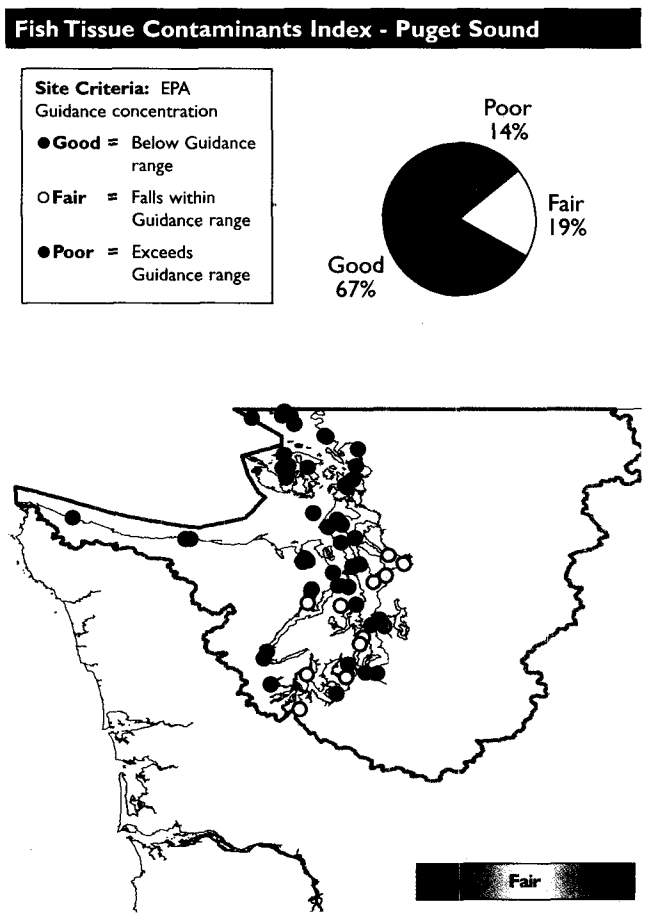


Figure 6-16. Fish tissue contaminants index data for Puget Sound, 1999–2000 (U.S. EPA/NCA).

Puget Sound Action Team

HIGHLIGHT

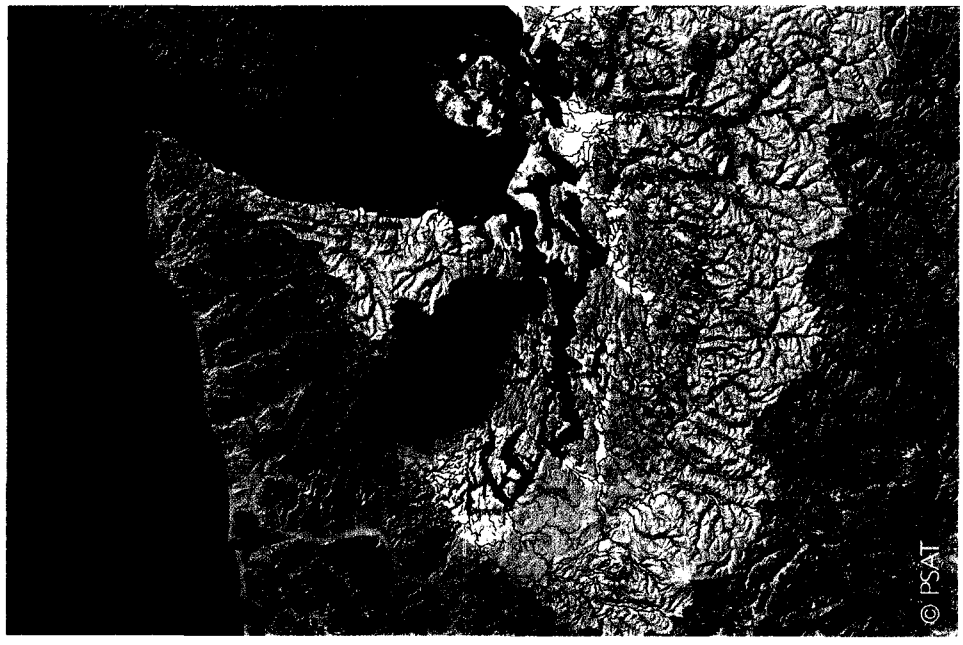
Efforts to Address Low Dissolved Oxygen Levels in Hood Canal, Washington

Hood Canal, a 60-mile-long, glacially carved fiord (see map), is one of the most scenic marine environments of Puget Sound, a region long renowned for its commercial and sport fishing and shellfish harvesting. Nestled between the Olympic Mountains and the central channel of Puget Sound, Hood Canal is experiencing increased growth and associated development. This activity may be at the heart of the reoccurring hypoxic conditions in Hood Canal, a problem that hit the spotlight in the spring of 2002 and again in the fall of 2003, when dead fish and other marine life washed up on Hood Canal's beaches. During 2004, the oxygen levels in Hood Canal dropped to all-time lows (PSAT, 2005a).

In 2005, the Washington State legislature acted on this problem, designating the PSAT as the state's lead agency for Hood Canal and the Hood Canal Coordinating Council as the local management board. The 2005 legislature charged both entities to work together to restore marine water quality and dissolved oxygen to levels adequate to support healthy marine life. The legislature also designated Hood Canal as the first Aquatic Rehabilitation Zone in Washington State. Most significantly, the legislature and Governor approved $22 million of new funds to scale-up corrective actions for Hood Canal (PSAT, 2005a).

Twenty-eight organizations, including state and federal agencies, universities, local and tribal governments, non-profit organizations, and research institutes, have formed a partnership to address low dissolved oxygen levels in Hood Canal and the effect of this problem on marine life. This partnership, the Hood Canal Dissolved Oxygen Program (HCDOP), will use data from monitoring, computer modeling, and demonstration projects to further develop and target the corrective actions designed to restore and maintain healthy levels of dissolved oxygen in Hood Canal (PSAT, 2005a).

For more information on the HCDOP's coordinated effort to recover Hood Canal, go to http://www.psat.wa.gov/Programs/hood_canal.htm.



Puget Sound Estuary and the Hood Canal (PSAT).

Puget Sound Action Team Indicators of Estuarine Condition

Factors such as water quality and the health of some marine animals signal improvements in the health of Puget Sound. Unfortunately, other environmental indicators warn of concerns for the Sound's overall ecosystem. In 2002, the PSAT issued its third biennial report on the health of Puget Sound, *Puget Sound's Health 2002* (PSAT, 2002). This report summarizes the condition of the Sound's marine waters, shoreline, 200 species of fish, 26 species of marine mammals, 100 species of sea birds, and thousands of species of marine invertebrates, using 19 indicators to determine whether the Sound's health is getting better or worse. As shown in Table 6-1, 8 of the 19 indicators classify Puget Sound's health as improving, 2 indicators classify the Sound's health as declining, 3 indicators show mixed results, 4 indicators document continued concerns about persistent toxic contamination problems, and 2 indicators are new indicators of nearshore habitat conditions. Additional information about recent conditions in Puget Sound and the PSAT's actions to restore the estuary is available at http://www.psat.wa.gov.

Water and Sediment Quality

Freshwater quality in the streams and rivers of the PSAT estuarine area is assessed using 8 parameters measured at 38 sites on a monthly basis. These eight parameters include measures of nutrients (e.g., total nitrogen, total phosphorus), pathogens (e.g., fecal coliform bacteria), and other physical parameters (e.g., water temperature, dissolved oxygen, pH, total suspended solids, and turbidity). Trend analysis for temperature based on data collected from 1995–2004 showed improvements in overall water quality index scores in all areas except the Stillaguamish River. The majority of rivers and streams monitored had good fecal coliform conditions (28 of 38 stations), the remainder of sites were rated fair, and none of the sites were rated poor for coliform conditions. The same percentage of sites were scored in good condition during wateryear 2005 as compared with wateryear 2000 (Personal communication, Brace, 2006).

Marine water quality monitoring in Puget Sound measures temperature, conductivity, salinity, density, dissolved oxygen, pH, light transmission, and nutrient (e.g., nitrate, nitrite, phosphate, silicate, and ammonium) and fecal coliform bacteria concentrations.

Table 6-1. Summary of Indicator Results from *Puget Sound's Health 2002* (PSAT, 2002)

Rating	Results
Improving	Area of commercial shellfish beds approved for harvesting
	Beaches used by recreational shellfish harvesters
	Water quality for recreation (measuring bacteria contamination)
	Size and frequency of major oil spills
	Reduced acreage of *Spartina* infestation, an aquatic nuisance plant species
	Freshwater habitat available to salmon (culverts allowing fish migration)
	Water temperature in rivers and streams
	Marine survival of Puget Sound wild coho salmon
Mixed	Harbor seal populations
	Herring populations
	Marine water quality
Declining	Scoter populations
	Rockfish populations
Persistent Toxic Contamination	Area of contaminated sediments (bottom of waterways)
	Contamination in mussels
	Contamination in harbor seals
	Occurrence of liver disease in English sole
New	Abundance and distribution of eelgrass beds
	Modifications to marine shorelines

Most of these parameters are monitored on a monthly basis. In general, regions of high concern with respect to marine water quality were located near urban areas or in poorly flushed areas such as Budd Inlet, Port Gardner, Bellingham Bay, Nisqually Reach, Carr Inlet, Case Inlet, and Henderson Inlet (Personal communication, Brace, 2006).

As of 2001, the WSDE had identified 112 contaminated sediment cleanup sites, representing an estimated 3,400 acres of marine sediments in Puget Sound (Figure 6-17) (WSDE, 2001; PSAT, 2002). Twenty-two of these sites have been cleaned up or require no further action. In 2002, cleanup activities were underway at 11 more sites. Action was still needed at an additional 79 sites, and 65 of these sites were in the investigation and design phases leading to cleanup. Between 1997 and 1999, 8,700 acres (1.5%) of soft sediment in Puget Sound (excluding the San Juan Islands and the Strait of Juan de Fuca) were contaminated, and approximately 83,000 acres were less severely contaminated. Long-term monitoring by the WSDE indicates that concentrations of some contaminants (e.g., naphthalene, low molecular-weight PAHs) have increased during the past few years, whereas concentrations of other contaminants (e.g., copper, mercury) have decreased (PSAT, 2002).

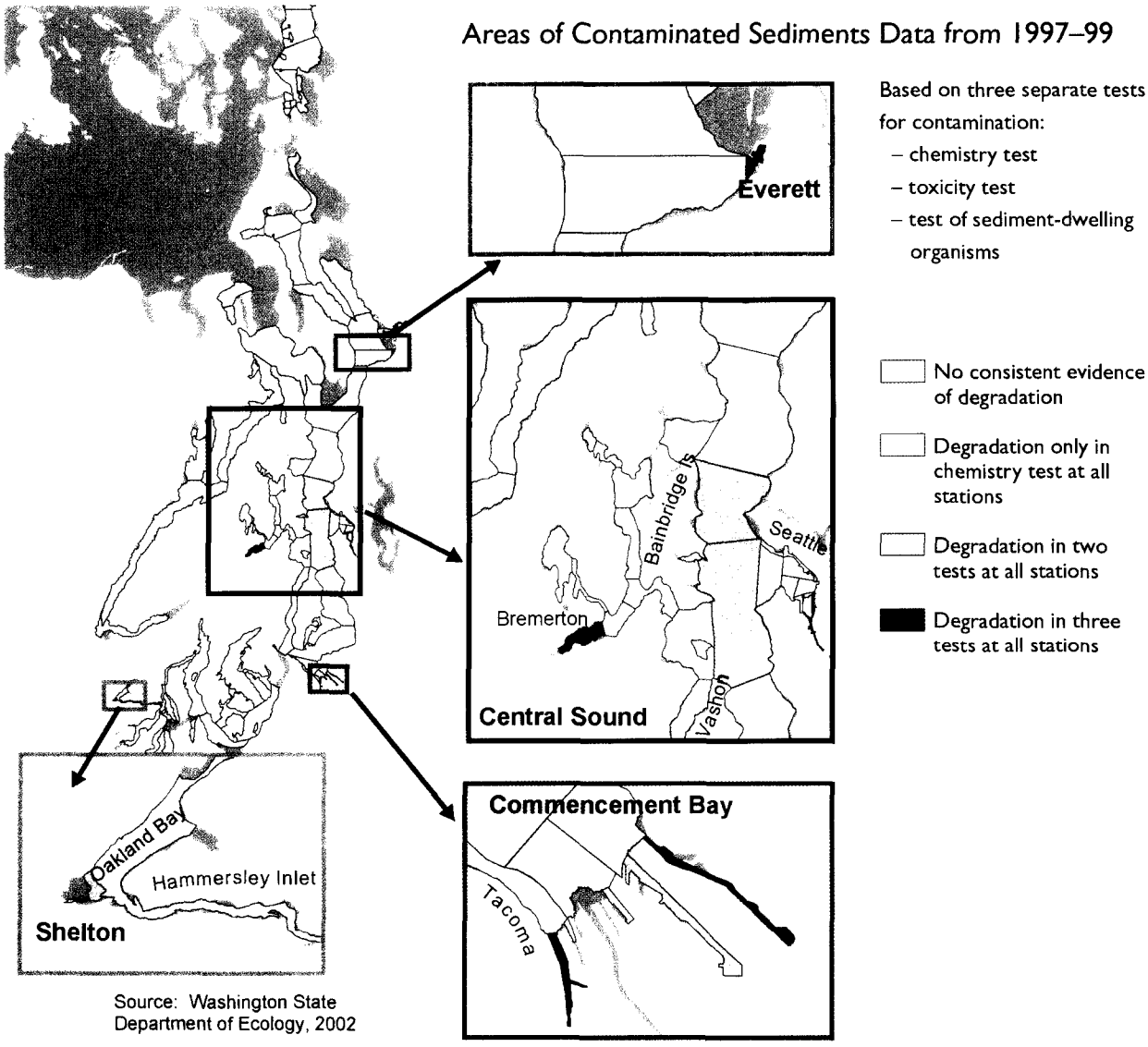


Figure 6-17. Sediment contamination map of Puget Sound (PSAT, 2002).

Puget Sound Action Team

Habitat Quality

Human development significantly alters the Puget Sound environment, and habitat loss and degradation are major threats to the health of the Sound's fish and wildlife. Protecting and restoring habitat is a key element of the strategy to recover wild salmon and a priority of the PSAT. Habitats at risk from direct human development and construction activities include freshwater habitat for salmon and other fish, as well as Puget Sound's fringe of shallow subtidal, intertidal, and shoreline habitats known as the marine nearshore. For example, infestations of *Spartina*, a salt marsh grass native to the eastern United States, can overtake native western grass species, making these habitats less useful to the area's fish, shellfish, and birds. Between 1999 and 2001, the Washington Department of Agriculture and its partners reduced *Spartina* infestations throughout most of the study area, except in Snohomish County (PSAT, 2002).

Eelgrass beds are also an environment of particular interest in considering habitat quality in Puget Sound. Based on the first year of a new eelgrass monitoring project, the Washington Department of Natural Resources (WDNR) estimates that Puget Sound is home to approximately 26,000 acres (or nearly 41 mi^2) of eelgrass. Eelgrass beds are divided into two habitat types. A significant amount of eelgrass occurs in flats, which can be large shallow bays or small pocket beaches, and close to one-fifth of all the eelgrass in Puget Sound grows in one large flat, Padilla Bay. Eelgrass also occurs in narrow fringing beds along steeper shorelines. These fringing beds are used as corridors for migrating salmon and other wildlife, and about one-half of all eelgrass in Puget Sound occurs in fringing beds. Eelgrass and other seagrass species are used as an indicator of estuary health because they respond to many natural and human-caused environmental variables, and changes in the abundance or distribution of this resource are likely to affect other species that depend on eelgrass habitat (PSAT, 2002).

Living Resources

A variety of living resource indicators are used to assess the health of Puget Sound. Population trends in fish and wildlife can provide insight into the state of the region's ecosystem. The extent of area open to shellfish harvesting is an indicator of the amount of contamination in the Sound. In addition, the PSAT examines the levels of several chemicals in the tissue of mussels and harbor seals to determine how these contaminants are behaving in the food chain. In general, the levels of pollutants in Puget Sound vary regionally, with higher levels found in marine life near urban areas. The effects of contaminants on the health of the area's wildlife is assessed by monitoring the occurrence of liver lesions in English sole (PSAT, 2002).

The PSAT uses the population trends and spawning potential of several key fish and wildlife species as indicators of estuary health. In 2000 and 2001, coho salmon appeared to be returning to Puget Sound in small but increased numbers compared with returns in the late 1990s. Rockfish, which can live for 80 to 100 years, are declining at an alarming rate, and the spawning potential for rockfish measured in 2000 was only 7% to 12% of the levels recorded in the late 1970s (PSAT, 2002; 2005b). Scientists believe that this decline, coupled with the decline of many other marine fish species, may point to significant problems with the entire Puget Sound ecosystem. A number of marine bird species have declined by 50% or more in the past 20 years. Populations of scoters, which are large black diving ducks with orange bills, have declined by 57% in the past 20 years. During the same period, 13 out of 18 other marine diving birds in Puget Sound have shown significant population declines. Some bird species, such as the marbled murrelets, have experienced population declines of more than 90% (PSAT, 2002).

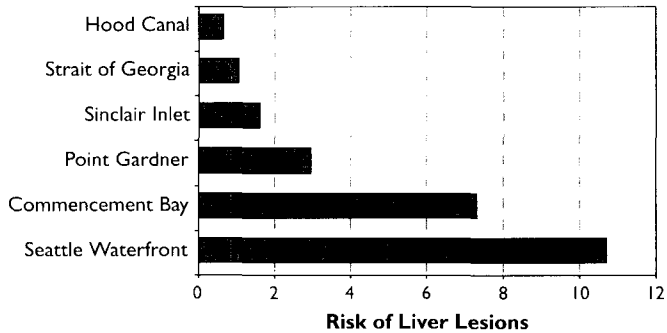
Washington is among the top shellfish-producing states in the nation, and the health of shellfish beds and the suitability of shellfish for consumption closely reflect conditions of the state's shellfish-growing environment. The Washington Department of Health (WDOH) classifies shellfish-growing areas to provide

information about the extent to which contamination restricts the ability to harvest shellfish, and changes in the classification of these areas can reflect problems related to how land is used and cared for in the nearby watersheds. Since 1980, nearly one-quarter of the approximately 140,000 acres available for direct commercial shellfish harvesting has been downgraded in classification because of bacterial contamination. During 2000–2001, the WDOH downgraded 849 acres and upgraded 1,540 acres. These areas were relatively small when compared to the approximately 33,000 acres that were downgraded in the 1980s; however, the net upgrade of 691 acres in 2000 and 2001 indicates that pollution-control efforts appear to be balancing increasing water quality threats (PSAT, 2002).

Mussels filter large quantities of water and can accumulate any toxic contaminants that are present in the water or adsorbed on phytoplankton. The NOAA National Mussel Watch Program data collected through 1998 demonstrated that multiple Puget Sound locations experienced long-term declining trends in the concentrations of banned pesticides (e.g., chlordane, DDT) and several metals (e.g., lead, mercury) in mussel tissue. However, it also appeared that PCB levels in mussels were no longer decreasing and possibly increasing during the mid- to late 1990s. NOAA scientists have used newly available data from 1999–2001 to construct a 16-year record of PCB levels and to identify three important patterns. First, concentrations of PCB in mussels have generally been declining during the two decades following the ban on most PCB uses in the 1970s. Second, the highest concentrations were consistently found in mussels from central Puget Sound sites, such as Four Mile Rock (north Elliott Bay) and adjacent areas, confirming that this urban area is a long-term source for PCBs. Finally, the long-term downward trend was interrupted in the mid-1990s by increases in PCB levels at many locations. Between 1999 and 2000, PCB concentrations in mussels began to decrease again. These patterns indicate that it is uncertain whether PCBs will continue to decline at the rates seen from the 1970s to early 1990s (PSAT, 2002).

Harbor seals feed relatively high in the food chain and accumulate contaminants from their food (primarily fish) in their fatty tissue. As a result of the widespread restrictions placed on PCB and DDT use in the early 1970s, there was a sharp decline in measured levels of these contaminants in Puget Sound harbor seals through the 1970s and afterwards. These declines have leveled off since the mid-1980s as contaminated land and sediments continue to release PCBs into the marine food chain (PSAT, 2002).

Scientists who routinely monitor English sole at six Puget Sound locations have found significantly elevated occurrences of liver lesions at two urban sites and one near-urban site (O'Neill et al., 2001). PAH concentrations in sediments were also elevated at these three sites. These results indicate that the health of bottom-dwelling fish in Puget Sound is worse in areas where sediments are contaminated (Figure 6-18). The risk of developing liver disease increased in English sole sampled along the Seattle waterfront between 1989 and 1998, but decreased in 1999 and remained low in 2000; no increasing or decreasing trends were evident at the other sites. The lower occurrence of liver lesions in English sole during 1999 and 2000 may have resulted from the numerous sediment-capping projects that have been completed to the north and south, as well as in the immediate vicinity of the Seattle waterfront, since 1989. Collectively, these projects may have lowered the PAH concentrations in sediments and reduced exposures to English sole feeding in this area (PSAT, 2002).



Source: Washington Department of Fish and Wildlife

Figure 6-18. Risk of liver disease in English sole based on geographical location (PSAT, 2002).

Environmental Stressors

Shoreline modifications, such as bulkheads or seawalls, tend to harm habitat through the conversion of tidelands to uplands. Modification also indirectly affects habitat by altering nearshore processes. The amount of modified shoreline in an area can be a useful indicator of the effect people have on the nearshore environment. In 2000, scientists with the Nearshore Habitat Program at the WDNR completed a statewide inventory to assess the extent of modification along saltwater shorelines (Berry et al., 2001). Approximately one-third of all saltwater shorelines in Washington have some kind of shoreline modification structure. In the PSAT study area, Snohomish and King counties have the most extensively modified shorelines (PSAT, 2002).

Current Projects, Accomplishments, and Future Goals

Protecting and restoring Puget Sound is a long-term commitment that requires continuing efforts by government, tribes, private industry, environmental and citizen groups, and individual residents throughout the region. Although progress has been made on many fronts, new challenges have emerged, and many existing problems persist as the region's population grows and the area of developed lands expands within the basin. The PSAT's partnership prepared the *Puget Sound Water Quality Work Plan: 2003–2005* (PSAT, 2003b) as the fourth biennial effort to specify and articulate actions to continue implementing the *2000 Puget Sound Water Quality Management Plan* (PSAT, 2000). The work plan outlines a 2-year strategy to achieve measurable progress in protecting Puget Sound. More specifically, the plan identifies ongoing issues (that require more than 2 years to address), as well as associated priorities and recommended actions to pursue during the biennium. These issues for the 2003–2005 work plan include the following:

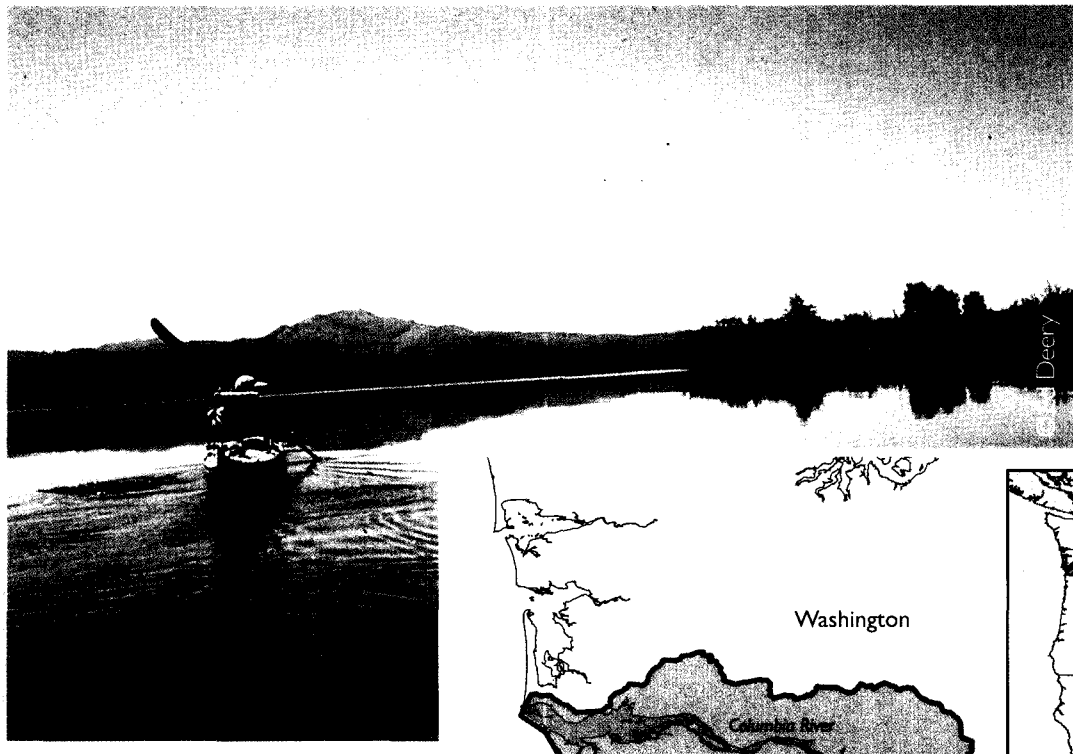
- Declines in marine species (e.g., salmon, groundfish, and orcas)
- Freshwater and marine habitat loss and alteration
- Water quality problems that continue to threaten the safe harvest of shellfish
- Stormwater runoff impacts on water quality, streams and wetlands, and biological resources
- Bacterial contamination from on-site sewage systems
- Non-native aquatic species that threaten the biodiversity, ecological stability, and commercial, agricultural, or recreational activities that depend on the Sound.

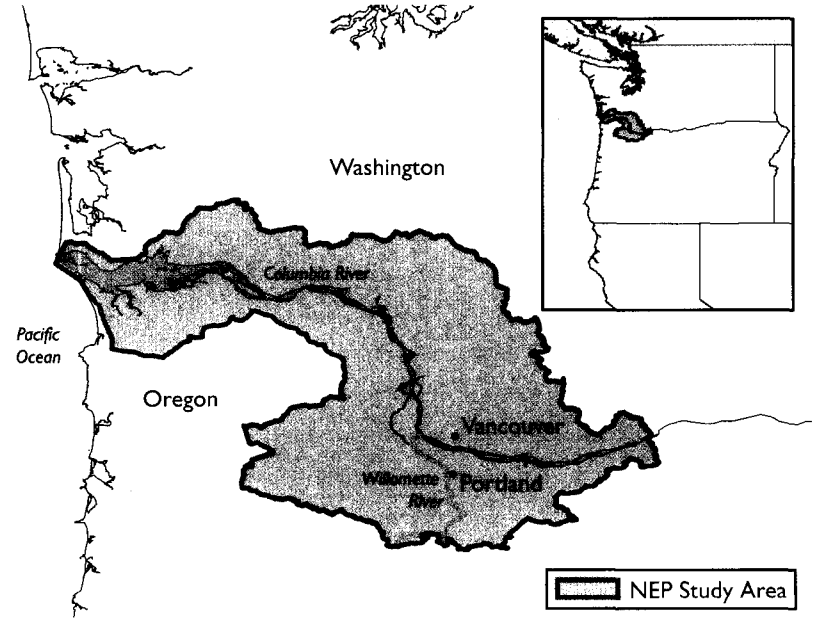
Conclusion

The overall view of the health of Puget Sound is clearly complex, with different indicators demonstrating different environmental quality results and trends over time. Encouraging signs have been noted for about half of the indicators measured by the NCA survey, as well as for the PSAT's shellfish harvesting, swimming, *Spartina* infestation, and salmon population indicators. Mixed or discouraging signals for the other NCA indicators and for a variety of fish, wildlife, and persistent toxic contamination indicators were observed by both EPA and the PSAT. PCB contamination remains a major concern, and several other chemicals are being closely watched to determine potential human health and ecological risks. Based on data from the NCA estuarine survey, the overall condition of Puget Sound is rated fair.

The Puget Sound provides invaluable habitat for orca whales (Captain Budd Christman, NOAA Corps).

Lower Columbia River Estuary Partnership





Lower Columbia River Estuary Partnership

www.lcrep.org

Background

The 4,300-mi^2 Lower Columbia River Estuary extends downstream from the Bonneville Dam at river mile 146 to the mouth of the Columbia River and into the Pacific Ocean to the 3-mile limit, which represents the point where coastal waters are no longer influenced by the plume of fresh water flowing into the ocean. This estuarine system contains a wide variety of habitats associated with marine, estuarine, and freshwater influences. These habitats range from open water to bottom sediments, tidal flats, and the riparian zone. The Lower Columbia River Basin drains approximately 18,000 mi^2, about 7% of the entire Columbia River Basin (LCREP, 1999).

The Lower Columbia River Estuary Partnership's (LCREP's) *Comprehensive Conservation and Management Plan, Volume 1* (LCREP, 1999) identifies many actions that can be conducted in the study area to improve water quality and habitat in the Lower Columbia River Estuary. The LCREP recognizes that many impacts in the study area are the result of problems or sources elsewhere in the Columbia River basin; therefore, efforts in the study area will be less effective if changes in the entire basin do not occur. For this

reason, it is important not to separate the Lower Columbia River Estuary from the larger watershed. Although the LCREP's CCMP includes many actions that specifically address the study area, it also considers the impacts from the larger watershed and incorporates actions to address these impacts, where needed.

Environmental Concerns

The LCREP completed its CCMP for the Lower Columbia River Estuary in June 1999. The CCMP contains 43 specific actions to address 7 priority issues: biological integrity, impacts of human activity and growth, habitat loss and modification, conventional pollutants, toxic contaminants, institutional constraints, and public awareness and stewardship. As part of the planning process, a comparative risk assessment process helped prioritize the LCREP's activities and identified loss of habitat as the greatest risk to the health of the Estuary. Based on this assessment, the LCREP has chosen to direct much of its energy toward the protection and restoration of habitat.

Population Pressures

The population of the 11 NOAA-designated coastal counties coincident with the LCREP study area increased by 78.4% during a 40-year period, from 0.9 million people in 1960 to 1.6 million people in 2000 (Figure 6-19) (U.S. Census Bureau, 1991; 2001). This rate of population growth was one of the lowest for the West Coast NEPs and was much lower than the population growth rate of 100.3% for the collective NEP-coincident counties of the West Coast region. In addition, the LCREP study area's population density of 138 persons/mi^2 was the third-lowest density of the West Coast NEPs (U.S. Census Bureau, 2001). This estuary is not surrounded by the large metropolitan areas that are characteristic of some other West Coast NEPs, such as Puget Sound or the San Francisco Estuary.

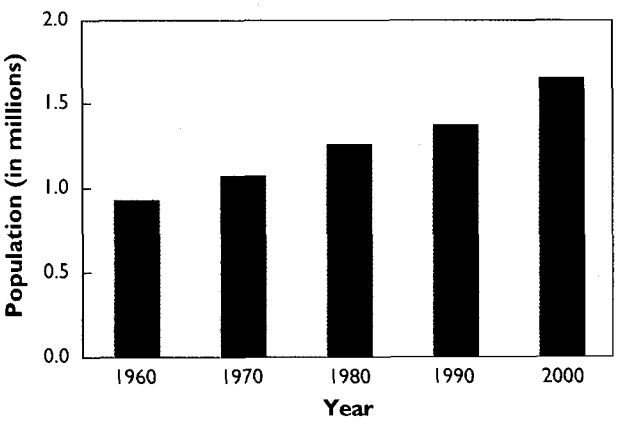


Figure 6-19. Population of NOAA-designated coastal counties of the LCREP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Lower Columbia River Estuary

The overall condition of the Lower Columbia River Estuary is rated fair based on three of the indices of estuarine condition used by the NCA (Figure 6-20). The water quality and sediment quality indices are rated fair, and the fish tissue contaminants index is rated poor. Although data on the condition of the benthic community were collected for this estuary, the Lower Columbia River Estuary could not be rated using an index based on deviations from the expected species richness. Figure 6-21 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 collected by ODEQ and the WSDE from 79 stations sampled in the LCREP estuarine area in 1999 and 2000. 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.

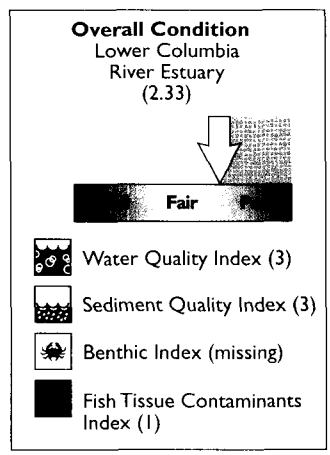


Figure 6-20. The overall condition of the LCREP estuarine area is fair (U.S. EPA/NCA).

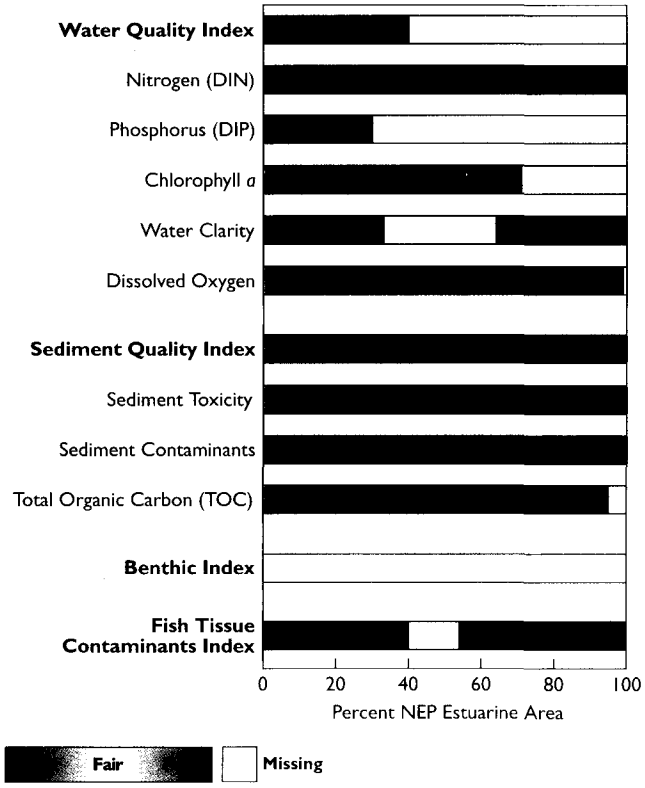


Figure 6-21. Percentage of NEP estuarine area achieving each ranking for all indices and component indicators — Lower Columbia River Estuary (U.S. EPA/NCA).

Coho salmon are found in the Lower Columbia River Estuary (Oregon Department of Fish and Wildlife).

Water Quality Index

Based on NCA survey results, the water quality index for the Lower Columbia River Estuary is rated fair (Figure 6-22). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Water quality was rated fair in 60% of the estuarine area due to limited water clarity and moderate DIP concentrations.

Dissolved Nitrogen and Phosphorus | The Lower Columbia River Estuary is rated good for DIN concentrations and fair for DIP concentrations. One-hundred percent of the estuarine area was rated good for DIN concentrations, and 70% of the estuarine area was rated fair for DIP concentrations.

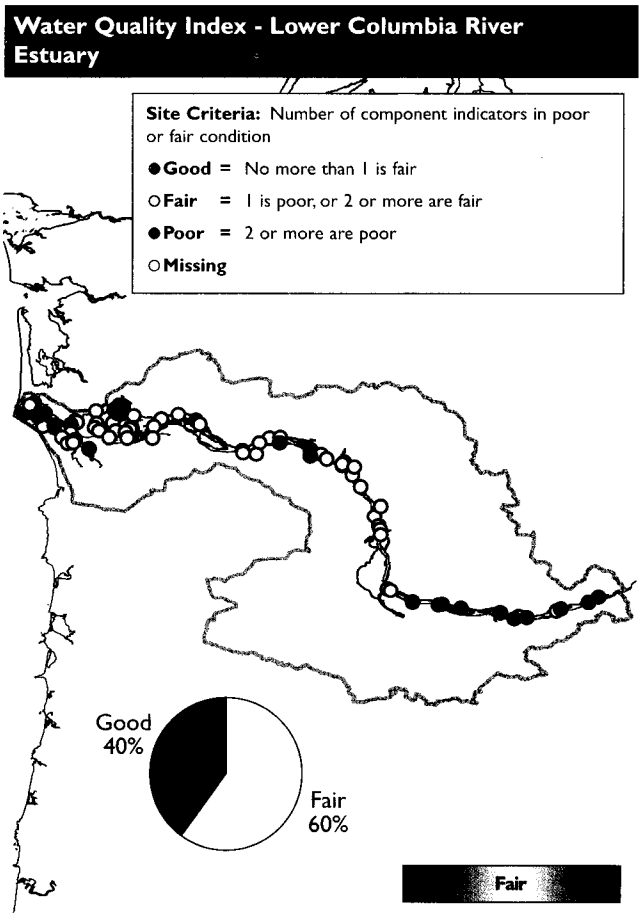


Figure 6-22. Water quality index data for the Lower Columbia River Estuary, 1999–2000 (U.S. EPA/NCA).

Chlorophyll a | Chlorophyll *a* concentrations in the Lower Columbia River Estuary are rated good. Approximately 29% of the estuarine area was rated fair for this component indicator, with the remaining 71% of the area rated good. None of the LCREP's estuarine area was rated poor for chlorophyll *a* concentrations.

Water Clarity | Water clarity in the Lower Columbia River Estuary is rated poor. Approximately 35% of the estuarine area was rated poor for water clarity, and an additional 31% of the area was rated fair.

Dissolved Oxygen | Dissolved oxygen conditions in the Lower Columbia River Estuary are rated good, with 99% of the estuarine area rated good for this component indicator. Although conditions in the Estuary appear to be good for dissolved oxygen, measured values reflect daytime conditions, and some areas of the Estuary may still experience hypoxic conditions at night.

Sediment Quality Index

The sediment quality index for the Lower Columbia River Estuary is rated fair, with 11% of the estuarine area exceeding thresholds for one or more of the three component indicators: sediment toxicity, sediment contaminants, or sediment TOC (Figure 6-23).

Sediment Toxicity | The Lower Columbia River Estuary is rated poor for sediment toxicity, with 10% of the estuarine area rated poor for this component indicator.

Sediment Contaminants | The Lower Columbia River Estuary is rated good for sediment contaminant concentrations, with only 1% of the estuarine area rated poor for this component indicator and none of the area rated fair.

Total Organic Carbon | The Lower Columbia River Estuary is rated good for sediment TOC. Ninety-five percent of the estuarine area was rated good for this component indicator, and 5% of the area was rated fair. None of the LCREP's estuarine area was rated poor for sediment TOC concentrations.

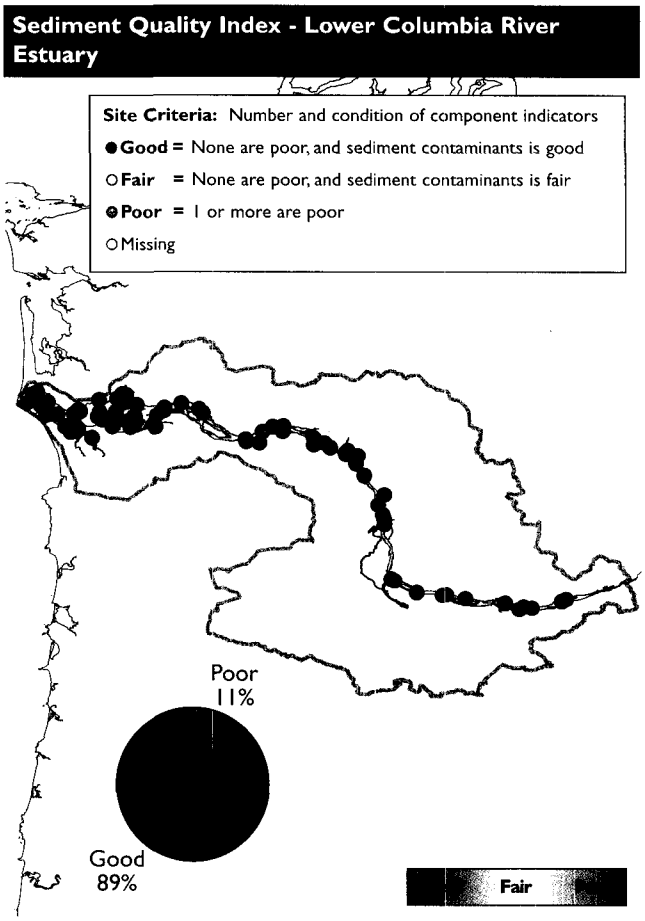


Figure 6-23. Sediment quality index data for the Lower Columbia River Estuary, 1999–2000 (U.S. EPA/NCA).

Benthic Index

The condition of the benthic invertebrate community in the Lower Columbia River Estuary currently cannot be rated using an index based on deviations from the expected species richness. This conclusion was based on 75 benthic samples taken in the LCREP estuarine area, of which 29 samples were collected in the side embayments in 1999 and 46 were taken in the main stem of the Columbia River in 2000. The NCA approach requires a significant regression between salinity and the log of species richness; however, this relationship was not significant in the Lower Columbia River Estuary ($r^2 = 0.03$, $p > 0.10$). The lack of a significant regression was not due to an inadequate range in salinity because salinity for the Estuary ranged from 0.04 to 31.3 ppt. Species richness was low in the Estuary, averaging only 6.0 species per sample over all

the samples and 4.4 species per sample in the samples collected along the main stem of the Columbia River. It is possible that stressors (e.g., dredging of the channel) or naturally low diversity in the Estuary obscured any simple relationship between salinity and species richness; however, when samples collected within 99 feet of the shipping channel were removed from the regression analysis, the regression relationship improved, but was still not significant due to the wide range of species richness values at freshwater sites. EPA was unable to provide a relative benthic index assessment for the Lower Columbia River Estuary using the NCA survey data, and additional data analysis will be required to find an alternate approach for the Estuary.

Fish Tissue Contaminants Index

The fish tissue contaminants index for the Lower Columbia River Estuary is rated poor. Forty-six percent of all stations sampled where fish were caught exceeded the EPA Advisory Guidance values using whole-fish contaminant concentrations and were rated poor (Figure 6-24). For populations that consume whole fish, these risk calculations are appropriate. The contaminants found in fish tissues at elevated concentrations in the Lower Columbia River Estuary most often included total PCBs, DDT, DDD, DDE, and mercury.

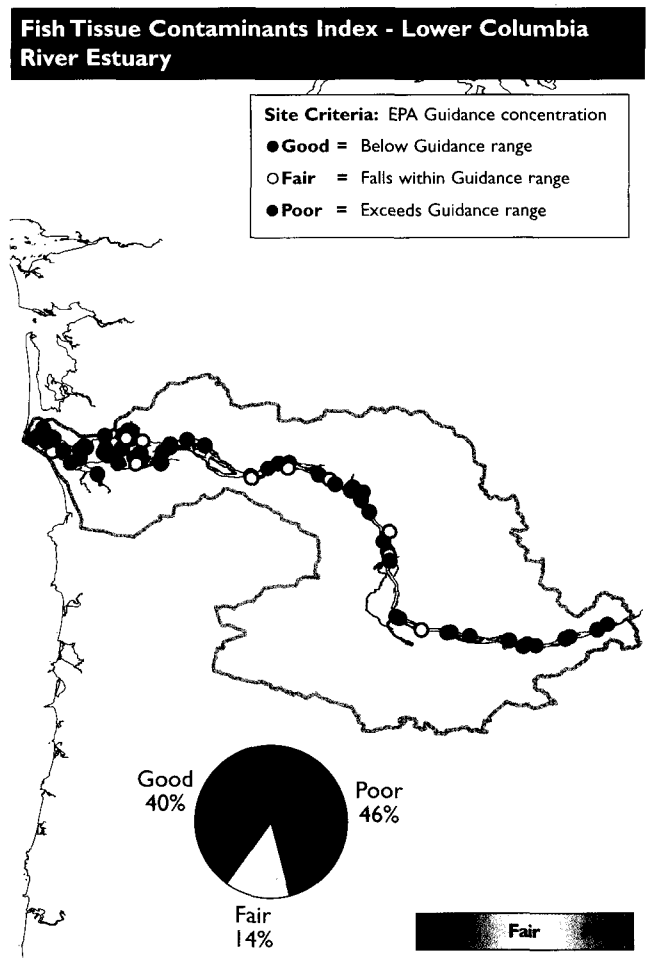
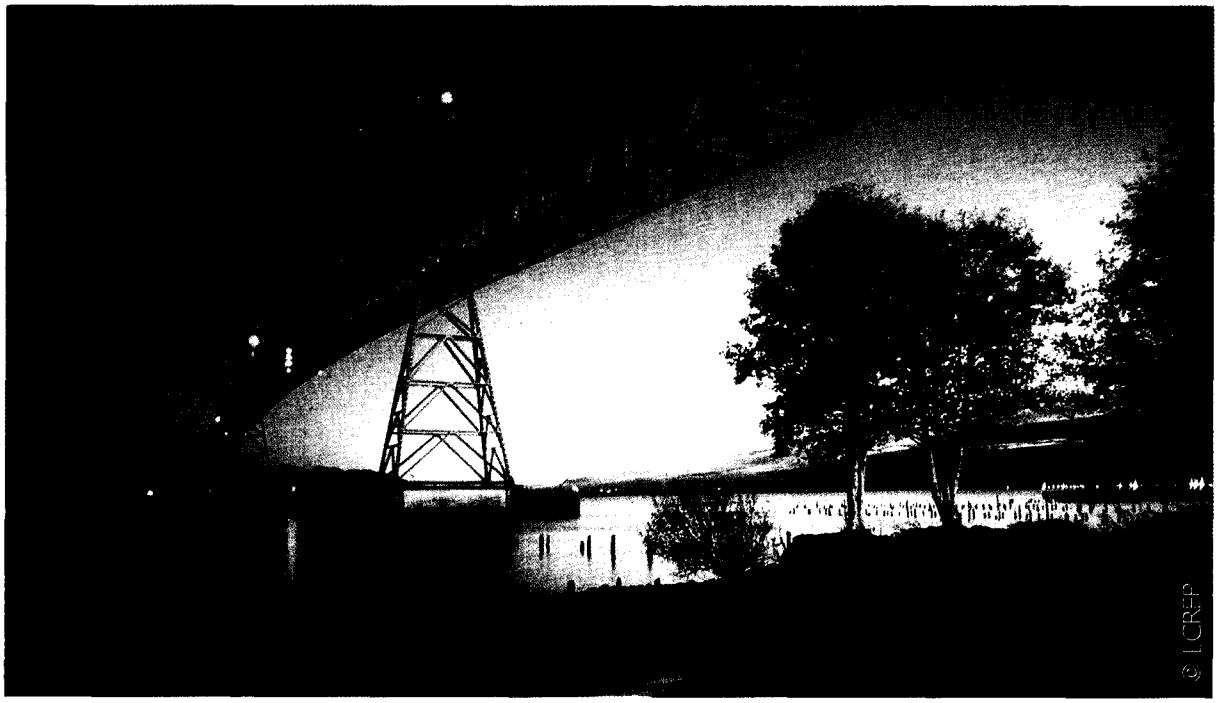


Figure 6-24. Fish tissue contaminants index data for the Lower Columbia River Estuary, 1999–2000 (U.S. EPA/NCA).



Astoria Bridge (LCREP).

Lower Columbia River Estuary Partnership

HIGHLIGHT

Habitat Protection and Restoration in the Lower Columbia

The floodplain of the Lower Columbia River Estuary historically contained extensive and diverse wetland and riparian habitats critical to fish and wildlife; however, the impacts of development over the past 150 years have significantly altered this complex system. Although the Estuary still provides essential habitat for a great number of freshwater and saltwater fish, numerous shellfish, a variety of marine and water-dependent land mammals, and over 175 species of birds, it is a very different area from the one explored by Lewis and Clark (ANEP, 2001a; LCREP, 2006). Loss of wetland habitat is one of the greatest problems being addressed by the LCREP. Evidence indicates that more than one-half of the wetland areas in the Estuary have been lost since 1870 as a result of diking, draining, filling, dredging, and flow regulation. Forested marshes in the lower 46 miles of the Lower Columbia River have decreased as much as 75%, whereas barren lands and open water areas have increased substantially (ODEQ, 2000).

The LCREP has made habitat restoration and protection a top priority. The Partnership's CCMP (LCREP, 1999) presents six actions specifically directed toward habitat protection and restoration, and several other actions involve a habitat element. The LCREP is working to establish a coordination structure to ensure that projects are developed using the best available scientific information and prioritized according to the life-cycle needs of endangered species, such as salmon and other native organisms.

Since 1999, the LCREP's habitat restoration program has funded 22 projects, resulting in the protection of more than 1,200 acres and the restoration of more than 850 acres. The program has also spent $2.7 million to leverage nearly $9 million in restoration funding with over 50 partners throughout Oregon and Washington, resulting in 4,600 total acres protected or restored in the Lower Columbia River Estuary (LCREP, 2005b). Some examples of these restoration projects are discussed in the following sections.

Reconnecting historic floodplains to regular tidal wetting, such as seen on this 80-acre parcel, is one of the habitat restoration techniques used by partners of the LCREP (Columbia Land Trust).

Scappoose Bay Conservation Plan and Restoration Projects

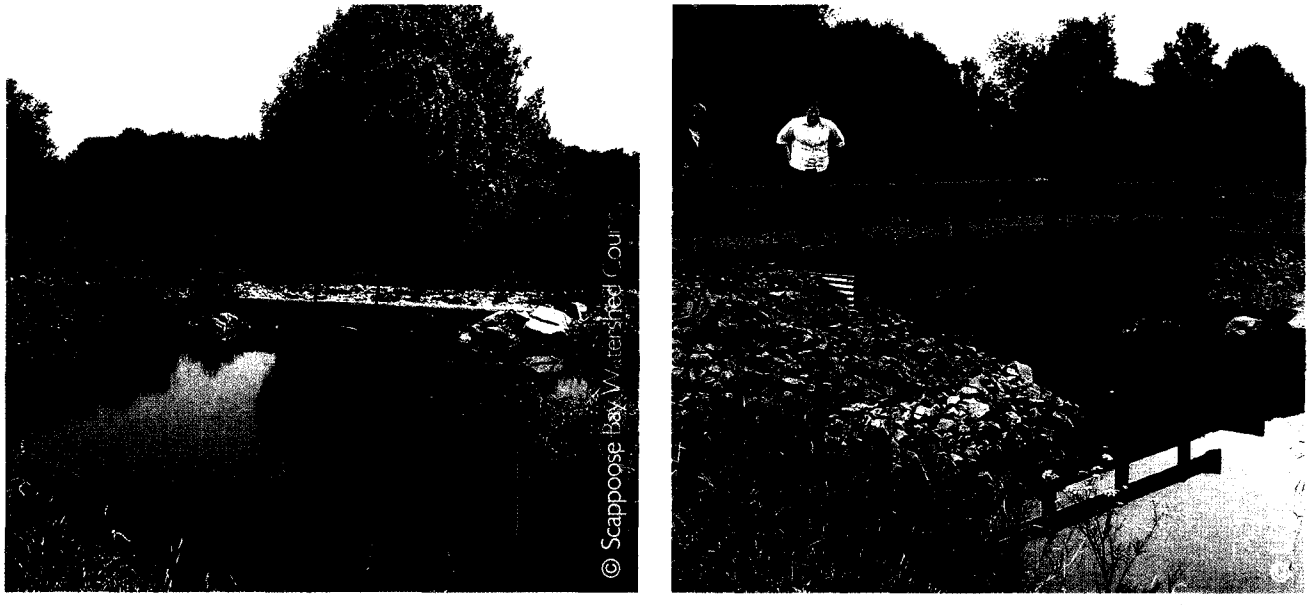
The LCREP worked with The Wetlands Conservancy to conduct an inventory of naturally valuable habitat within the 8,960 acres of the Scappoose Bay Bottomlands. Partnering with the Scappoose Bay Watershed Council, the LCREP allocated grant funding to remove multiple fish barriers, install fish-friendly bridges, and fence stream riparian areas. The planning area for these activities covers 200 acres of cattle farmland (The Wetlands Conservancy, 2004).

Grays Bay Area Conservation/Restoration Projects

Partnering with the Columbia Land Trust, the LCREP funded a multi-level restoration effort with grant funding from the EPA Watershed Initiative and the Bonneville Power Administration. At 5 different sites, the project resulted in the conservation of 880 acres of floodplain, the reconnection of 500 acres of historic floodplain, the restoration of 300 acres of salmon habitat, and the enhancement of 3 miles of riparian habitat (CREST, 2006).

Strategic Prioritization for Habitat Restoration

As a next step in the Partnership's habitat restoration program, the LCREP has initiated an effort with partners and interested parties to develop a focused Strategic Habitat Restoration Plan, which will detail the most ecologically beneficial locations for restoration and describe the most appropriate types of restoration strategies to undertake in those areas. Beginning in 2006, the LCREP will employ this tool in the restoration project selection process, which will identify project value based on its significance to the Columbia River ecosystem. Ultimately, projects selected through this framework will provide greater cumulative benefits to the entire system, while adaptive management and effectiveness monitoring of these projects will ensure continued progress and improvements to the system's health over the long term (Evans et al., 2006).



Replacing undersized, non-performing culverts, such as the one seen here on Honeyman Creek, allows for full fish passage and tidal influence in tributary streams. The photo on the left is a pre-restoration representation, whereas the photo on the right is after restoration (Scappoose Bay Watershed Council [left] and the LCREP [right]).

Lower Columbia River Estuary Partnership

Lower Columbia River Estuary Partnership Indicators of Estuarine Condition

The LCREP has developed a set of six environmental indicators that attempt to provide accessible information about the health of the Lower Columbia River Estuary. These indicators are considered key measures of the Estuary's ecological integrity and are meant to be a step in the process of relaying important information about the estuarine system to policy makers and the public. The LCREP's environmental indicators are the following:

- Habitat (loss, opportunity, protection and conservation, restoration, net change)
- Biotic integrity (native species assessment)
- Land use (land-use changes, riparian integrity)
- Water quality (concentrations of toxic contaminants and convention pollutants, temperature, and dissolved oxygen)
- Stewardship (children's educational and field programs, volunteer monitoring, and restoration)
- Appreciation (park visitors, recreational and shellfish permits, membership in environmental non-governmental organizations).

The LCREP's indicators were carefully chosen based on a number of factors. Each indicator had to be a measurable and quantifiable value, be understandable to the public, have sufficient historical records to show trends, relate to the overall condition of the Estuary, allow for an assessment of present conditions and a prediction of future trends, provide sufficient facts to support goal-setting and program management, and provide targets and endpoints for the restoration of the Estuary.

Water and Sediment Quality

In 2004 and 2005, the LCREP partnered with USGS and the ODEQ to monitor water quality at three fixed stations along the Lower Columbia River and the Willamette River. Selected water samples were analyzed for a variety of parameters, including nutrients, chlorophyll *a*, suspended sediment, total coliforms, trace elements, and a variety of chemical contaminants (LCREP, 2006). Water quality sampling using semipermeable membrane devices (SPMDs) was also conducted in the Lower Columbia River and its tributaries during 2003 and 2004. SPMDs are used to mimic the accumulation of contaminants in the fatty tissues of fish. During this study, concentrations of dieldrin and PCBs commonly exceeded human health criteria; DDT compound concentrations exceeded the criteria less frequently; and PAH concentrations were below the criteria (Johnson and Norton, 2005). Additional SPMD samples were collected in 2005. More information about the LCREP's water quality monitoring efforts is available at http://www.lcrep.org.

Water temperatures and dissolved oxygen concentrations are also monitored in the Lower Columbia River Estuary. Cool (68 degrees Fahrenheit or less) water temperatures in the Estuary are essential for native aquatic species, which experience stress as temperatures rise. Average and maximum summer water temperatures have increased by approximately 4 degrees since 1938. In 2002, measured dissolved oxygen concentrations in the Estuary were above Washington's and Oregon's state standard of 8 mg/L (LCREP, 2005a).

Habitat Quality

Habitats in the LCREP study area have been changing over time, and the acreage of developed land and open water in the Lower Columbia River Estuary has increased substantially since the 1880s. At the same time, the areal extents of the Estuary's tidal swamps and marsh habitat have decreased by 77% and 57%, respectively. Although the average tree cover in most of the study area (the region near Longview, WA, was excluded from this analysis) decreased from 46% to 24% between 1972 and 2000, the amount of area with thick, dense canopy tree cover has increased since 1986 (LCREP, 2005a).

The LCREP and its partners have undertaken several measures to monitor, assess, and map habitats in the Estuary. The Partnership's habitat status monitoring program was established to create a long-term data set used to assess the status and trends of the Estuary's aquatic habitats (LCREP, 2006). The Lower Columbia River and Estuary Ecosystem Classification System is under development by the LCREP, USGS, and the University of Washington to delineate the Estuary's

different landscape structures and guide habitat monitoring efforts (Simenstad et al., 2005). Field work has also been combined with satellite images, digital aerial photos, bathymetry, LIght Detection And Ranging (LIDAR), and high-resolution hyperspectral images to develop detailed and comprehensive habitat maps and habitat data layers (LCREP, 2006).

Living Resources

Approximately 24 threatened and endangered species of plants, fish, animals, and birds can be found in the Lower Columbia River Estuary. Although populations of some of these species (e.g., bald eagles) are slowly recovering, others (e.g., chinook salmon) are not. The number of occupied bald eagle nests along the Columbia River has been increasing slowly since 1978; however, the productivity of those nests located below river mile 60 remains low due to significant contaminant concentrations (e.g., DDE, PCBs, and dioxins) found in the egg shells collected from this portion of the Estuary. During the past 100 years, the number of chinook salmon returning to spawn in the Estuary has decreased from a range of 450,000–550,000 fish to an average of 100,000 salmon. Although a variety of factors (e.g., hydropower operations, harvest, ocean conditions) contributed to this population decline, habitat loss and degradation is cited as the leading cause. Since reaching a low of 25,000 returning fish in 1999, chinook salmon returns have improved slightly (LCREP, 2005a).

At least 81 invasive species (e.g., American shad, purple loosestrife, Chinese mystery snail, Eastern snapping turtle, nutria) have been introduced to the Lower Columbia River Estuary since the mid-1880s. The majority of these species originated in North America, and domestic shipping is most likely an important vector for the introduction of new species to the Estuary. The rate at which new species are discovered has increased from one every 5 years between the 1880s and the 1970s to one every five months since 1994. Although this rate of increase can be attributed to more new species being introduced to the Estuary, an increasing number of improved surveys to monitor invasive species has also contributed to the growing number of species detected. For example, an invasive species survey conducted at 134 stations in the LCREP study area during 2002 and 2003 identified 269 aquatic species. Twenty-one percent of these were invasive species, and the origins of another 45% of the identified species were unknown (Sytsma et al., 2004; LCREP, 2005a).

Lower Columbia River Estuary Partnership

Toxic contaminants have been detected in the fatty tissues of fish and wildlife living in the Lower Columbia River Estuary, and interim health advisories have been issued for dioxins, PCBs, and pesticides in the fatty tissue of all fish in the Estuary (LCREP, 2005a; U.S. EPA, 2005a). Starting in 2005, the LCREP and NOAA began testing juvenile salmon tissue and stomach contents for concentrations of chemical contaminants. The resulting data will be used to assess the effects of toxic contaminants on the survival and productivity of the Estuary's juvenile salmon and to assist with the development of three models designed to identify contaminant sources; describe potential modes and routes of transport, exposure, and uptake; and analyze the possible effects on survival and productivity of listed salmon species (LCREP, 2006).

Environmental Stressors

The LCREP uses the percentage of the study area's impervious surface and the number of innovative stormwater management projects implemented as indicators of estuarine condition. Between 2000 and 2005, the amount of impervious cover in the LCREP study area has increased significantly. Innovative stormwater management projects have been implemented in the study area, especially in the Portland and Vancouver areas (LCREP, 2005a). These projects are highlighted in the LCREP's *Lower Columbia River Field Guide to Water Quality Friendly Development*, which provides local examples of different stormwater management techniques and is available online at http://www.lcrep.org/fieldguide.

Current Projects, Accomplishments, and Future Goals

Monitoring the Estuary to track its condition over time and to develop a better understanding of the highly complex ecosystem is another critical element of the LCREP. During the development of its CCMP, the LCREP and a highly dedicated group of monitoring organizations spent almost 2 years developing the *Lower Columbia River Estuary Plan, Volume 2: Aquatic Ecosystem Monitoring Strategy for the Lower Columbia River-Information Management Strategy* (LCREP, 1998). The Monitoring Strategy of this report lays out a phased-in approach to implementing a comprehensive monitoring plan for the Lower Columbia River Estuary. Special projects have been initiated to enhance understanding of the Estuary, with attention paid to addressing the monitoring needs of salmon restoration.

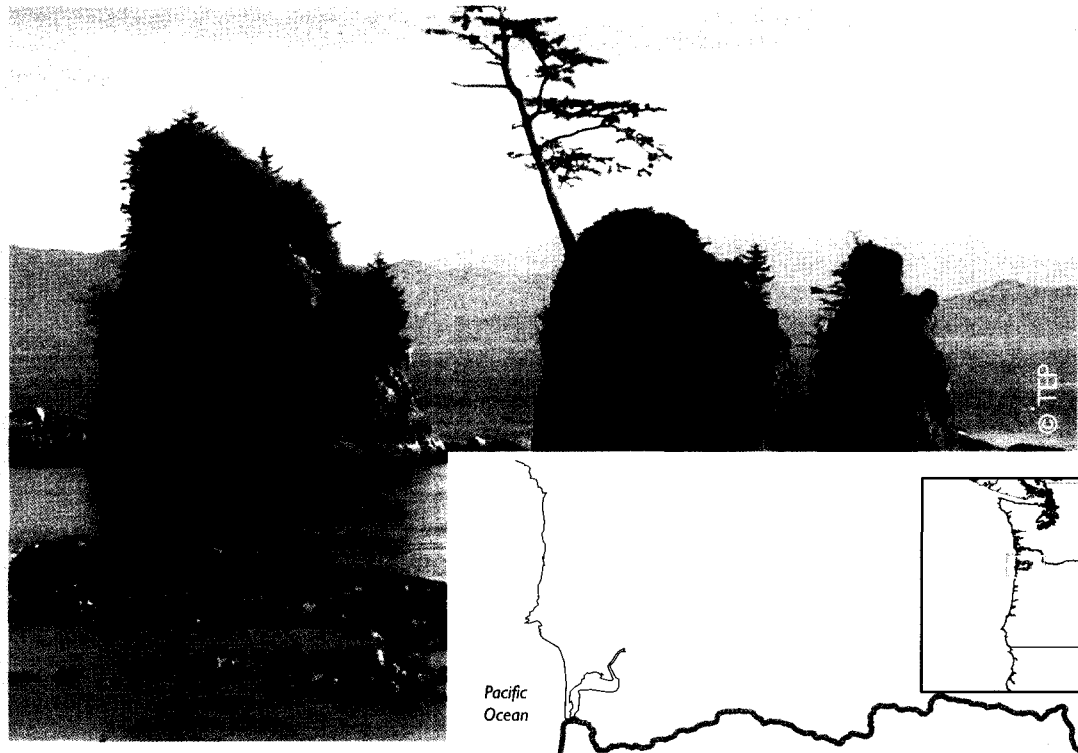
Data management is another focus of the LCREP's current efforts. Currently, there is no single place where one can go to find all the existing information about the Lower Columbia River Estuary. The Information Management Strategy of this report (LCREP, 1998) lays out a multi-phase approach for improving access to and management of data. An example of progress is the availability of technical data regarding the condition of the Estuary, including data from the Bi-State Water Quality Study, is available online at http://www.lcrep.org.

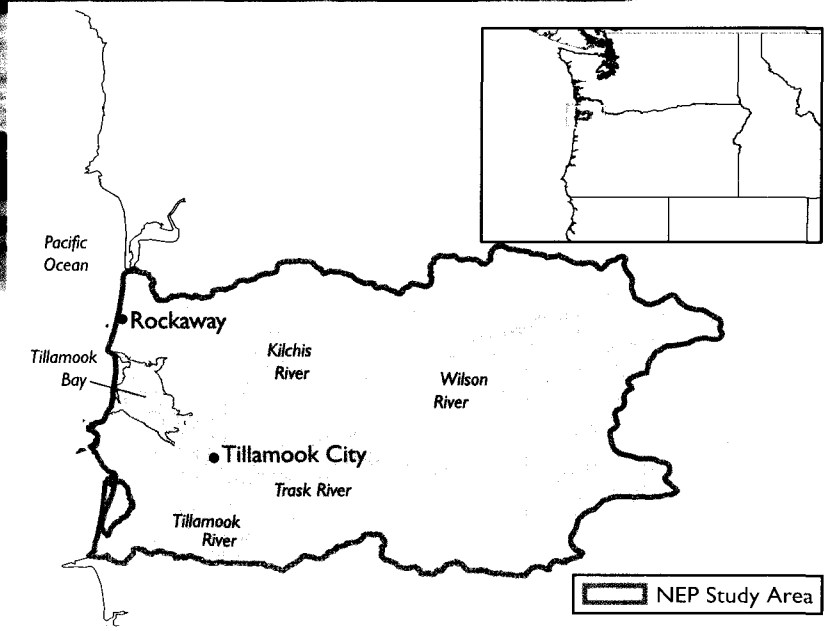
The LCREP has also focused its resources on developing educational programs for the area's students and volunteer opportunities for residents. Since 2000, the Partnership has developed more than 50 different field-based Columbia River education curricula for more than 32 school districts and assisted with classroom programs, field trips, and on-river trips for more than 45,000 students. The Partnership has also provided over 8,000 volunteers the opportunity to help plant more than 11,000 native trees and shrubs at 18 habitat restoration sites (LCREP, 2005a).

Conclusion

Based on data from the NCA estuarine survey, the overall condition of the Lower Columbia River Estuary is rated fair. The LCREP has been working collaboratively with many other organizations to monitor the ecosystem; educate the public; and assess, protect, and restore the extensive and diverse habitats that comprise the Lower Columbia River Estuary. These efforts have had positive effects in several areas of estuarine health (e.g., bald eagle population increases, acreage of restored habitat); however, other areas (e.g., water temperature increases, toxic contaminant concentrations in fish tissue) remain a concern.

Tillamook Estuaries Partnership





Tillamook Estuaries Partnership
A National Estuary Project

www.tbnep.org

Background

Although it is Oregon's second-largest estuary, Tillamook Bay is relatively small (approximately 13 mi^2) and shallow (average depth of 6 feet) compared to other NEP estuaries. Located on Oregon's northern coast, Tillamook Bay is part of a coastal, temperate rainforest ecosystem. Annual precipitation averages 90 inches in the lower basin and close to 200 inches in the uplands. This rainfall supplies fresh water to the basin's five major rivers (Tillamook, Trask, Wilson, Kilchis, and Miami), which drain a 597-mi^2 watershed that includes some of North America's richest timber and dairy lands (TBNEP, 1999). Known as the "land of cheese, trees, and ocean breeze," Tillamook County boasts a greater population of cows than people and is dominated by federal, state, and private forest land, which comprises almost 90% of the county (TBNEP, 1998). Tillamook Bay supports an oyster aquaculture industry, a commercial/recreational port, and a recreational salmon fishery (TBNEP, 1999).

Historically dependent on resource-extraction industries, the local economy of Tillamook County increasingly relies on tourism and transfer payments to provide for the county's 25,000 citizens (TBNEP, 1999). The

Tillamook Estuaries Partnership

county's median household income is well below the state average and was only 80% of the national average in 2002 (U.S. Census Bureau, 2006). Although the service sector is expanding because of tourism and a growing population of retirees, dairy farming, logging, and fishing still define the cultural landscape of the area (TBNEP, 1999).

By the early 1990s, local citizens began to voice concerns about the basin's declining natural resources. Loss of spawning and rearing habitat had reduced salmon runs, and decreasing water quality regularly violated federal water quality standards and led to closures of commercial shellfish beds. Erosion and sediment deposition, combined with development in the floodplain, exacerbated water quality issues and habitat degradation while increasing the magnitude and frequency of flood events. To reverse these trends, the Tillamook Estuaries Partnership (TEP) undertook 5 years of research, public outreach, and policy analysis, resulting in completion of the *"Restoring the Balance": Comprehensive Conservation and Management Plan for Tillamook Bay, Oregon* in 1999 (TBNEP, 1999). The TEP implements its CCMP under three program areas: habitat enhancement, education, and research and monitoring. The TEP also supports partner-led projects through its Local Grant Program.

Environmental Concerns

The most significant environmental problems in the Tillamook Bay watershed are habitat loss and simplification, water quality, erosion and sedimentation, and flooding, and the TEP researched and characterized these problems during its CCMP development. The Tillamook Bay basin has lost almost 85% of its historical intertidal wetlands to agricultural and urban development (TBNEP, 1999). In addition, populations of four of the five anadromous salmonid species (coho and chum salmon, steelhead and cutthroat trout) have dramatically decreased from historical levels. Loss of spawning and rearing habitats are the major contributors to the declining populations. None of Tillamook County's major watersheds meets the Clean Water Act standards established by EPA and ODEQ, and bacterial contamination and elevated water temperatures are the two parameters of highest priority. The flood of 1996, as well as the many floods that came before it, displaced residents and caused major environmental degradation and millions of dollars in property damage. Loss of floodplain function and stream complexity are the key contributors to increased flooding and are a focus of the TEP's enhancement efforts (TBNEP, 1999).

Population Pressures

The population of the NOAA-designated coastal county (Tillamook) coincident with the TEP study area increased by only 28% during a 40-year period, from 18,955 people in 1960 to 24,262 people in 2000 (Figure 6-25) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the TEP study area was one of the lowest rates of population growth for the West Coast NEPs, and only one-fourth the population growth rate of 100.3% for the collective NEP-coincident coastal counties of the West Coast region. Tillamook County also had the lowest population density (22 persons/mi^2) of any of the West Coast NEPs (U.S. Census Bureau, 2001). This estuary is not surrounded by the large metropolitan areas that are characteristic of some West Coast NEP estuaries, such as Puget Sound or the San Francisco Estuary.

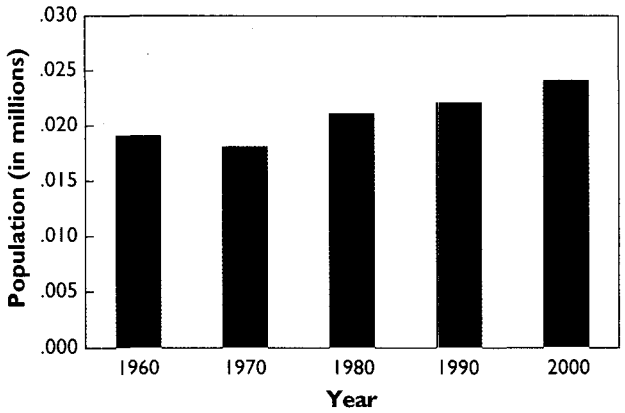


Figure 6-25. Population of NOAA-designated coastal county of the TEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Tillamook Bay

The overall condition of Tillamook Bay is rated good based on the four indices of estuarine condition used by the NCA (Figure 6-26). The water quality index is rated fair, and the sediment quality, benthic, and fish tissue contaminants indices are rated good. Figure 6-27 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 collected by ODEQ from 29 stations sampled in 1999. 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.

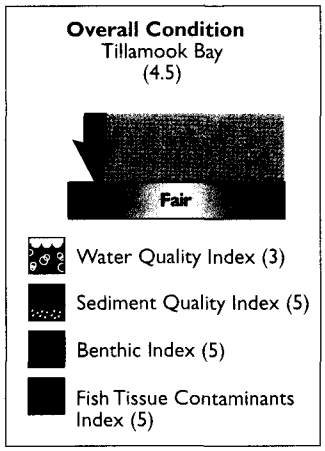


Figure 6-26. The overall condition of the TEP estuarine area is good (U.S. EPA/NCA).

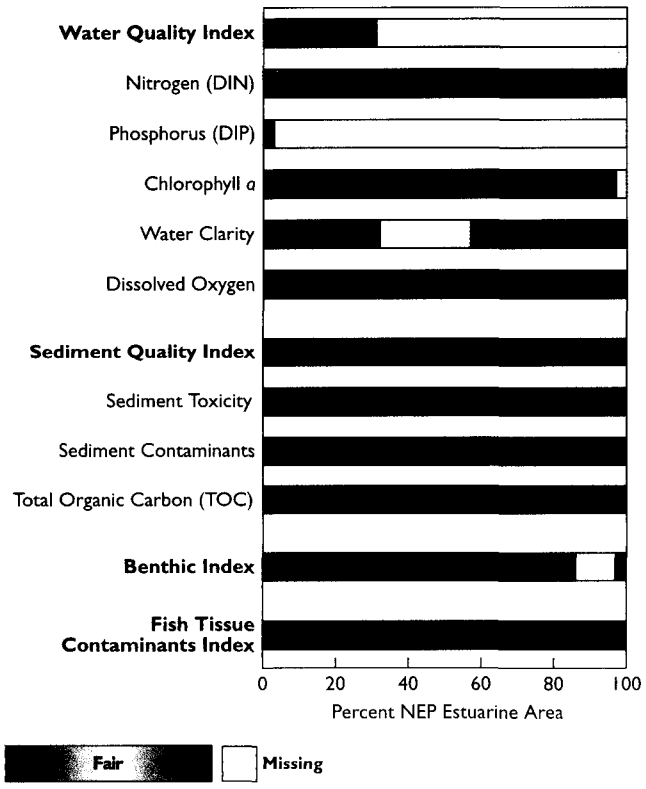


Figure 6-27. Percentage of NEP estuarine area achieving each ranking for all indices and component indicators — Tillamook Bay (U.S. EPA/NCA).

Water Quality Index

Based on NCA survey results, the water quality index for Tillamook Bay is rated fair. This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Most (69%) of the estuarine area was rated fair because of limited water clarity and moderate levels of DIP (Figure 6-28).

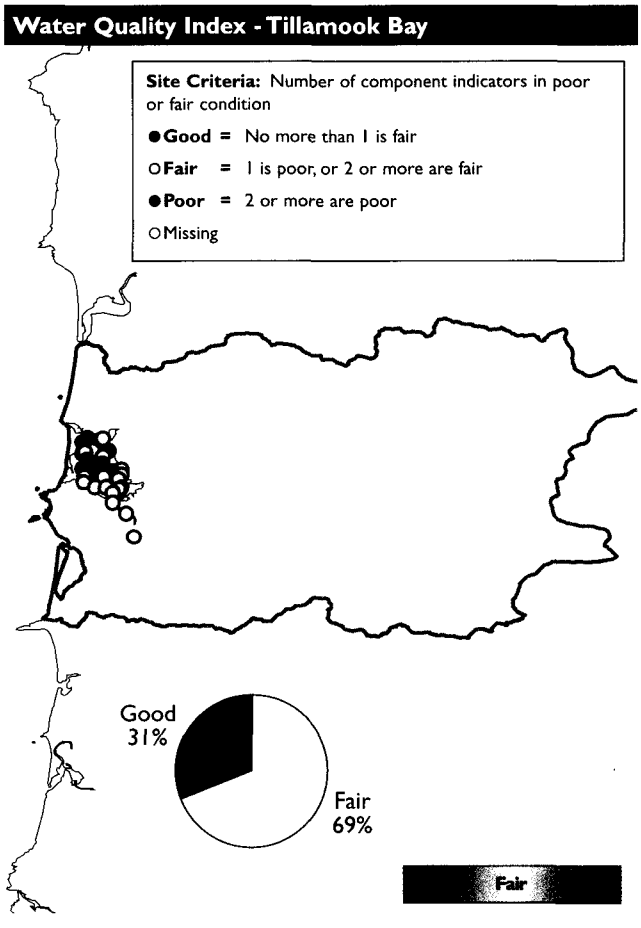


Figure 6-28. Water quality index data for Tillamook Bay, 1999 (U.S. EPA/NCA).

Tillamook Estuaries Partnership

Dissolved Nitrogen and Phosphorus

Tillamook Bay is rated good for DIN concentrations and fair for DIP concentrations. Concentrations of DIN were rated good in 100% of the estuarine area, and DIP concentrations were rated fair in 97% of the area.

Chlorophyll a

Chlorophyll *a* concentrations in Tillamook Bay are rated good. Three percent of the estuarine area was rated fair for this component indicator, with the remainder of the area (97%) rated good. None of the TEP estuarine area was rated poor for chlorophyll *a* concentrations.

Water Clarity

Water clarity in Tillamook Bay is rated poor. Approximately 43% of estuarine area was rated poor for this component indicator, and 25% of the area was rated fair.

Dissolved Oxygen

Dissolved oxygen conditions in Tillamook Bay are rated good, with 100% of the estuarine area rated good for this component indicator. Although conditions in Tillamook Bay appear to be generally good for dissolved oxygen, measured values reflect daytime conditions, and some areas of the Bay may still experience hypoxic conditions at night.

Fishing for Chinook salmon is popular in Tillamook Bay (TEP).

Sediment Quality Index

The sediment quality index for Tillamook Bay is rated good (Figure 6-29). This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC. No area of the Bay exceeded thresholds for any of these component indicators.

Sediment Toxicity

Sediment toxicity for Tillamook Bay is rated good, with none of the estuarine area rated poor for this component indicator.

Sediment Contaminants

Tillamook Bay is rated good for sediment contaminant concentrations, with 100% of the estuarine area rated good for this component indicator.

Total Organic Carbon

Tillamook Bay is rated good for TOC concentrations, with 100% of the estuarine area rated good for this component indicator.

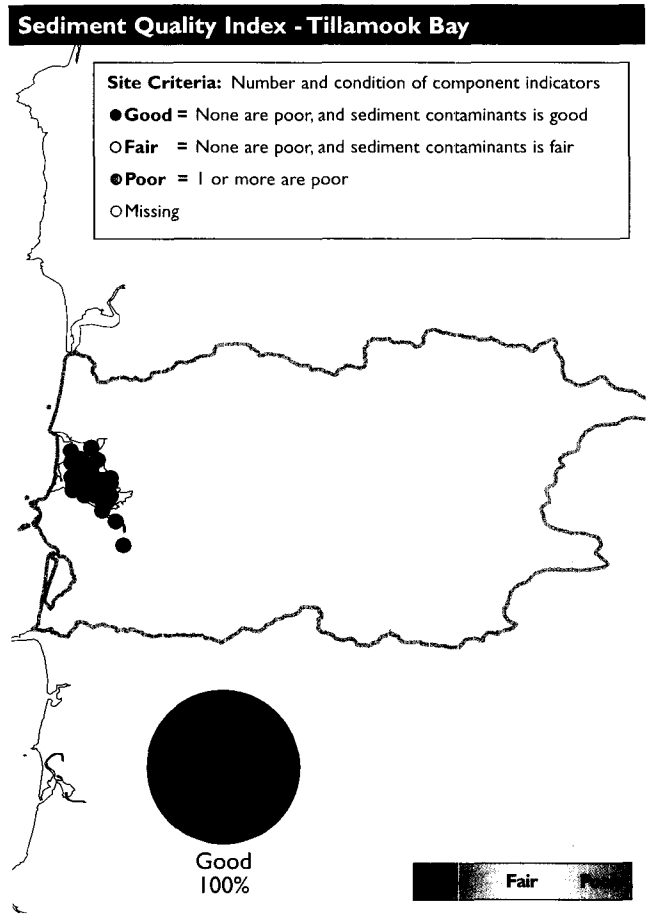


Figure 6-29. Sediment quality index data for Tillamook Bay, 1999 (U.S. EPA/NCA).

Benthic Index

The condition of the benthic invertebrate communities in Tillamook Bay is rated good based on deviations from the expected species richness (Figure 6-30). This analysis was based on 28 benthic samples collected during 1999. A significant linear regression between log species richness and salinity was found in Tillamook Bay, although it was not strong ($r^2 = 0.31$, $p < 0.01$). One site, representing about 3% of the estuarine area, was rated poor based on a lower-than-predicted species richness. The cause for the less-than-expected species richness at this site is not readily apparent because no sediment ERMs were exceeded, only three ERLs were exceeded, and TOC concentrations were within the range found in the Bay. Another three sites, representing 11% of the estuarine area, were rated fair, and 24 sites, representing 86% of the area, were rated good.

Fish Tissue Contaminants Index

This fish tissue contaminants index for Tillamook Bay is rated good (Figure 6-31), with only 8% of all stations sampled where fish were caught exceeding EPA Advisory Guidance values for whole-fish contaminant concentrations. These risk calculations are appropriate for populations that consume whole fish. The contaminant found most often in fish tissues from Tillamook Bay was total PCBs.

Sediment Contaminant Criteria (Long et al., 1995)

ERM (Effects Range Median)—Determined for each chemical as the 50th percentile (median) in a database of ascending concentrations associated with adverse biological effects.

ERL (Effects Range Low)—Determined for each chemical as the 10th percentile in a database of ascending concentrations associated with adverse biological effects.

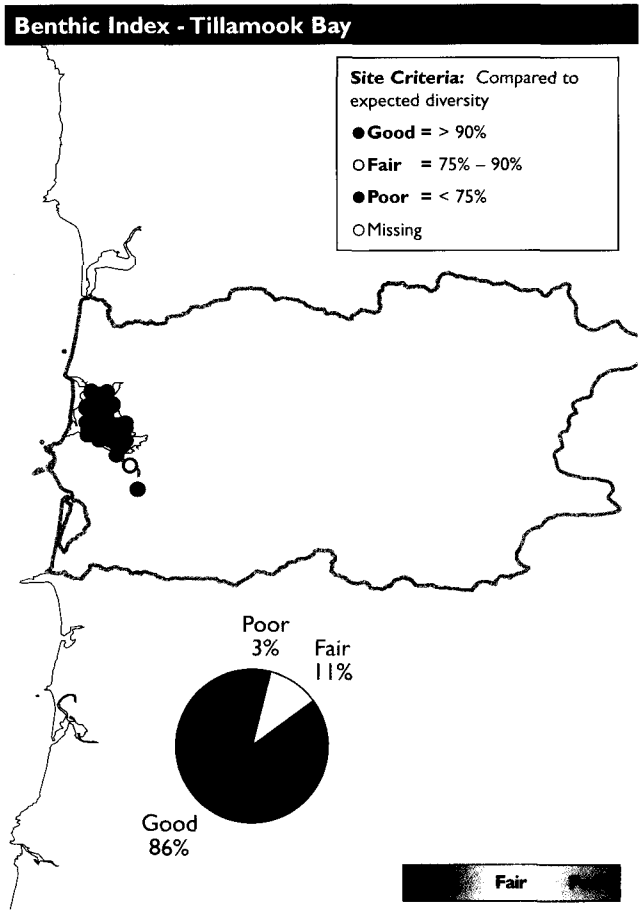


Figure 6-30. Benthic index data for Tillamook Bay, 1999 (U.S. EPA/NCA).

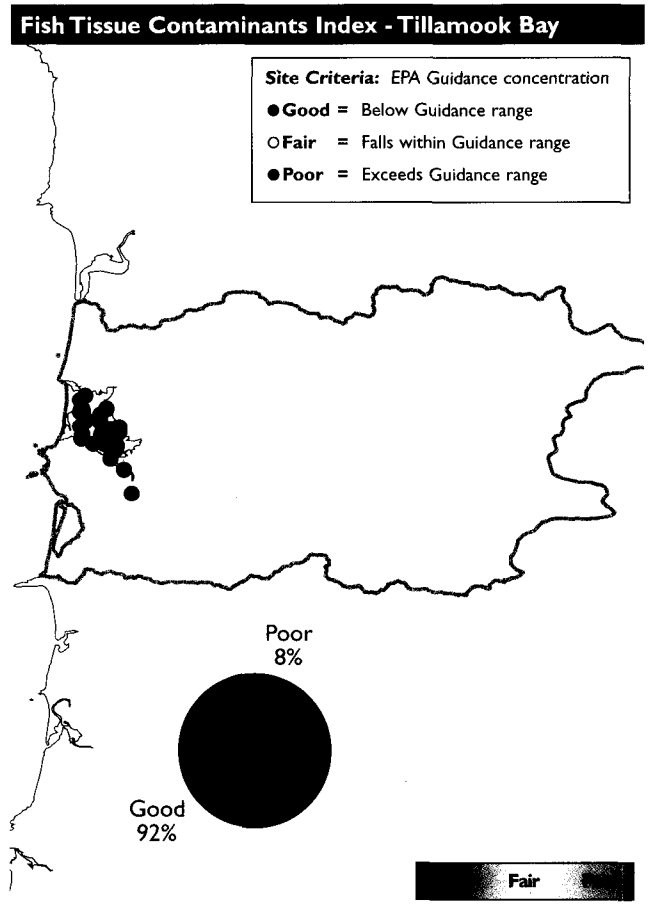


Figure 6-31. Fish tissue contaminants index data for Tillamook Bay, 1999 (U.S. EPA/NCA).

Tillamook Estuaries Partnership

HIGHLIGHT

Addressing Bacterial Contamination in Tillamook Bay

The driving force behind Tillamook Bay's nomination to the NEP was bacterial contamination. Inputs of fecal coliform bacteria have resulted in frequent water quality standard exceedences in the Bay's tributaries and periodic closures of the Bay's oyster shellfishing industry (Sullivan et al., 2005). To combat this problem, the TEP has initiated an innovative monitoring strategy to answer three key questions relating to bacteria in the Bay and its watershed:

1. Is bacteria loading to the lower reaches of the Bay's tributary rivers increasing or decreasing over timescales of years to decades?

2. Where, how often, and for what length of time does each of the Bay's five major tributary rivers violate state water quality standards for bacteria?

3. What are the sources of the contamination, and how much pollution do they contribute?

The TEP has instituted two complementary monitoring approaches to try and answer these questions: the Storm-Based Monitoring Program and the Volunteer Monitoring Program. In addition, the TEP has partnered with Oregon State University to embark on a complementary 3-year Genetic Marker Study.

The Storm-Based Monitoring Program measured fecal coliform bacteria concentrations and loads (as well as other water quality parameters) to the Bay during storm events. Between 1996 and 2002, the program monitored approximately 28 separate storms on the Bay's five tributary rivers. Results of this effort included the following insights: (1) fall storm events exhibited the highest levels of bacterial loading to the Bay; (2) bacteria concentrations increased dramatically during storm events, but varied greatly among the Bay's five rivers; (3) bacteria concentrations measured in the rivers appeared to be strongly influenced by precipitation patterns prior to a storm and by rainfall intensity during the storm; and (4) drier conditions prior to a storm and greater rainfall during a storm generally resulted in higher bacteria concentrations in the rivers (Sullivan et al., 2002).

In addition to the initial set of storm-sampling sites, the Storm-Based Monitoring Program also conducted an intensive storm-monitoring effort during a 2-year period on two river reaches identified as major bacteria-contributing areas. Potential bacteria sources were documented and mapped using photos, global positioning systems (GPSs), and field surveys to attempt to link bacteria concentration spikes to likely sources. Results of this effort are being used to identify those source areas that appear to be the largest bacteria contributors to the rivers and to prioritize the areas for corrective action (Sullivan et al., 2002).

Since 1995, participants in TEP's Volunteer Monitoring Program have braved wind, rain, sleet, and occasional sun to collect water samples from 37 sites across all 5 of the major tributaries entering Tillamook Bay. Monitoring results from this effort are entered into a long-term database that is shared with both local and state partners (TEP, 2006b). This information assisted in the development of a bacteria TMDL (ODEQ, 2001) for the watershed and has guided the TEP's process to prioritize sites for enhancement. Results of the Volunteer Monitoring Program revealed the following insights: all five of Tillamook Bay's main tributary rivers routinely violate Oregon's bacteria water quality standard for water contact recreation; bacteria concentrations peak during the summer low-water period and during some fall, winter, and spring storms; and the Tillamook River routinely has the highest bacteria concentrations of the five rivers (ODEQ, 2001).

Because bacterial contamination is largely a problem resulting from non-point source pollution, researchers are searching for new methods to differentiate among potential sources, such as manure from pastures, failing

septic systems, and STP overflows. A joint study by Oregon State University and the TEP seeks to identify bacteria sources by detecting genetic marker sequences that are specific to the host species that produced the feces. The intent of the study is to enable researchers to discriminate among human, cow, domestic pet, waterfowl, and other wildlife bacteria sources. Preliminary results indicate that ruminants (e.g., cows, elk) are a source of widespread bacterial contamination and that human contributions to the contamination in some river segments are also significant (TEP, 2006b).

The results of these efforts have led the TEP to undertake several priority projects to reduce bacterial contamination in the Bay. In collaboration with the Tillamook County On-Site Sanitation Division, private septic systems in the watershed will be inspected and repaired as needed. The City of Tillamook has recently completed a Stormwater Management Plan that will identify measures to reduce bacterial loading and other contaminants. In addition, a buffer-strip effectiveness study is testing an experimental demonstration buffer strip to determine its effectiveness in removing bacteria from pasture runoff and help select BMPs for manure management. Finally, a pilot project has begun to develop and implement performance-based policies for agriculture to meet or exceed water quality standards in the lower Tillamook Bay basin (TEP, 2006b).

A volunteer collects a plankton sample in Tillamock Bay (TEP).

Tillamook Estuaries Partnership Indices of Estuarine Condition

The TEP has developed a set of environmental indicators to assess water quality, habitat extent, and the status of living resources in Tillamook Bay. Each of the draft indicators is tied to objectives/goals from the TEP's CCMP and seek to answer one of the TEP's focus questions. For example, the number of stream miles opened through fish passage enhancement projects measures progress towards the CCMP goal of enhancing 100 miles of upland instream habitat by 2010 and determines whether more freshwater habitat is becoming available to native salmon and trout (TEP, 2004).

Water and Sediment Quality

Although not part of the NCA's water quality index, bacterial contamination is the priority water quality issue in Tillamook Bay and its tributaries (TBNEP, 1999). Sewer outfalls, leaking or malfunctioning septic tanks, and runoff from the watershed's dairy farms contribute fecal coliform bacteria to the Bay. Although bacterial loading has increased historically as farming and development in the area increased, recent monitoring has shown improving trends in some river reaches (TEP, 2006a). This is likely due to the implementation of the TEP's CCMP. The TEP indicators for water quality include ongoing monitoring in the Bay and tributaries to continue tracking changes in fecal coliform bacteria concentrations (TEP, 2004).

Dissolved oxygen concentrations and rises in stream temperatures are also major water quality concerns in the TEP study area (TEP, 2006a). Eutrophication and low dissolved oxygen concentrations have not been a problem in Tillamook Bay proper; however, low dissolved oxygen levels have been observed in some of the Bay's lowland sloughs and tributaries (TBNEP, 1999). Although the NCA data noted good dissolved oxygen concentrations throughout the Bay, the NCA sampling sites were primarily located in the main portion of the Bay. The TEP is working with ODEQ to further evaluate the extent and impact of low dissolved oxygen levels in Tillamook Bay sloughs. Low water temperatures in the Bay's streams are important for maintaining the area's salmon habitat; however, water temperatures in the Wilson, Trask, and Tillamook rivers

Dairy herds are a prominent agricultural use of land in Tillamook County (TEP).

have exceeded water quality standards for temperature (TBNEP, 1999). The TEP's indicators include monitoring water temperature in streams and dissolved oxygen levels in sloughs (TEP, 2004).

Habitat Quality

Maintaining and improving the habitats necessary to support this estuary's declining salmonid populations is an important priority for the TEP. Healthy freshwater and riparian habitats are important for maintaining low water temperatures and for providing spawning grounds for salmonids, whose young need salt marshes, tidal channels, and eelgrass beds for food and protection (TEP, 2006a). The TEP has developed several draft indicators for assessing habitat quality and quantity in Tillamook Bay, including changes in the distribution and type of riparian vegetation along the Bay's tributary rivers, the number of stream miles affected by fish passage enhancement projects, the areal extent of wetlands and open water restored through the removal of tidal restrictions, and changes in the extent of seagrass beds (TEP, 2004).

The amount of historical information available for the TEP indicators varies. For example, historic and recent data indicate that Tillamook Bay has lost roughly 85% of its intertidal wetlands to agricultural and residential development. To address these losses, the CCMP establishes a goal of restoring 750 acres of these habitats (TBNEP 1999), and the Partnership will have restored approximately 400 acres by the summer of 2007. In cases where the TEP knows little about historic habitats, indicators characterize the status of the resource and track change from the present. For example, the TEP monitors the change in eelgrass distribution from its current coverage of 897 acres (TEP, 2005).

Living Resources

The TEP has been implementing projects aimed at evaluating the status and trends of the abundance and distribution of aquatic species. Examples of these projects include an exotic species detection effort, a rapid bioassessment, and a study on fish use of the estuary. In addition, the TEP's living resource indicators of estuarine condition include the annual number of coho salmon adults returning to the study area for spawning, as well as the annual number of coho, chum, Chinook, steelhead, and cutthroat smolts migrating downstream from the Little North Fork Wilson River and Little South Fork Kilchis River (TEP, 2004).

The Exotic Species Project, which is being pursued for the LCREP, TEP, and PSAT, is seeking to develop a consistent approach for monitoring aquatic nuisance species. Together, these three NEPs and other partners in these basins will develop a regionally coordinated approach for monitoring aquatic nuisance species in the Pacific Northwest using models developed and tested in the San Francisco Estuary watershed (TEP, 2006b). As an initial step for this project, the TEP has developed *An Exotic Species Detection Plan for Tillamook Bay* (Cohen, 2004).

The TEP's Tillamook Bay Rapid Bio-Assessment is designed to quantify the abundance and distribution of four species of juvenile salmonids throughout the Bay's watershed. The full basin view of each species' distribution and their spatial shifts in abundance will provide valuable information for the development of a restoration strategy based on passage barriers, peak spawning and rearing reaches, temperature-limiting habitats, and upstream-migration behaviors. The 3-year inventory began in 2005 and is encompassing approximately 350 stream miles. In 2005, the inventory found that the number of coho salmon returning to the Bay's streams for spawning was insufficient to adequately seed the watershed's available habitat (Bio-Surveys, L.L.C., 2005; TEP, 2006b).

The primary objectives of the Fish Use of the Estuary study were to develop baseline information on fish use of the Tillamook Bay estuary and to test and evaluate a sampling approach for long-term monitoring of fish abundance and distribution across major habitat types within the estuary. The sampling design for the long-term monitoring program was structured to allow the testing of hypotheses regarding the use of three regions of the estuary (lower, middle, and upper), two major substrate types (fine-grained and coarse-grained), and the effect-sampling time (months, within months, and years) for relatively abundant anadromous salmonid and non-salmonid species. Monitoring data from 1999 through 2001 indicated that fish species composition in the estuary has been relatively stable since the mid-1970s (Ellis, 2002; TEP, 2006b).

Tillamook Estuaries Partnership

Current Projects, Accomplishments, and Future Goals

The TEP's primary goals are to enhance water quality to meet state and federal standards, restore native salmonid populations, reduce the frequency and impacts of catastrophic flooding, and encourage stewardship among residents and visitors. To attain these goals, the TEP and its many partners are implementing targeted resource-enhancement projects, characterizing the estuary and its watersheds, and educating citizens and visitors about the Bay's natural resources and the importance of stewardship. The TEP plans to continue pursuing these activities through three programs: the Habitat Enhancement Program (developing and implementing on-the-ground projects aimed at improving the production and function of natural systems); the Research and Monitoring Program (characterizing the interactions of human and natural systems, tracking system-wide trends, and evaluating the effectiveness of CCMP implementation); and the Education Program (working to facilitate a stewardship ethic among visitors and residents of Tillamook County through hands-on learning and outreach activities).

The TEP's annual workplan details the projects that the Partnership undertakes within each of these programs. One of the tools the TEP is using to track CCMP implementation is an innovative Web site known as the Performance Indicators Visualization and Outreach Tool (PIVOT), which is available at http://gisweb.co.tillamook.or.us/mapping/pivot/tillamook.htm. The TEP is also currently developing a comprehensive monitoring program to more fully characterize long-term, system-wide trends and the impact of CCMP implementation (TEP, 2005).

To implement the CCMP's actions aimed at reconnecting intertidal wetlands and enhancing tidal marshes, the TEP raised more than $1.3 million to acquire three properties that form a 375-acre peninsula at the confluence of the Wilson and Trask rivers. Currently underway, this project is expected to result in the protection and restoration of a natural, functioning ecosystem on approximately 200 acres within the formerly-diked tidelands and forested wetlands at the Bay's southern end. The remaining 175 acres will be restored under a "muted tidal connection" to ensure flood mitigation. Primarily, the fully reconnected areas will be restored to intertidal habitats consisting of high salt marsh, brackish marsh, and forested wetlands. Existing remnant floodplain forests will be permanently protected and managed to maintain their natural values (USACE, 2004a).

In 2003, the TEP initiated its Backyard Planting Program (BYPP) to help landowners on high-priority streams restore degraded riparian zones. The BYPP coordinator collaborates with interested landowners to develop an enhancement plan for their property. The BYPP provides free removal of invasive vegetation, plants native trees and shrubs, and maintains the site for 3 years. By the end of its third year, the BYPP will have enrolled more than 80 landowners and restored 15 miles and 75 acres of high-priority riparian habitat (TEP, 2006b).

Conclusion

Tillamook Bay is representative of many small Pacific Northwest estuaries. Dominated by rugged mountains with narrow coastal plains, it presents a challenging combination of environmental concerns. Elevated bacteria levels have closed oyster beds to shellfishing, and loss of habitat and increasing stream temperatures have impacted local salmonid populations. Based on the results of the NCA survey, the overall condition of Tillamook Bay is rated good. Although fair and poor conditions were noted for several indicators, this was the highest rating received by any of the six West Coast NEP estuaries monitored. The TEP is finding ways to protect both the area's natural resources and its natural resource-dependent economy. The TEP has focused on reducing bacteria contamination in the Bay and its tributaries and improving the area's habitat quality for salmonid populations.

San Francisco Estuary Project

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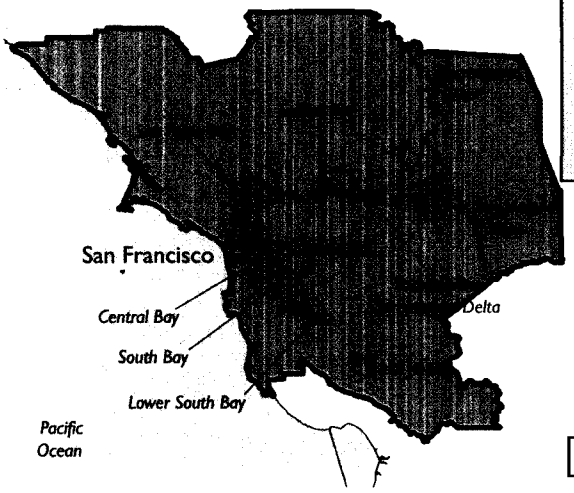


Background

The San Francisco Estuary is one of the largest estuaries on the West Coast, encompassing about 460 mi^2 of open water. The Estuary is shallow, and approximately one-third of the total water area has a depth of less than six feet. The Sacramento and San Joaquin rivers supply approximately 90% of the Estuary's freshwater input and drain about 40% of California's land area. These rivers enter the Estuary through the Sacramento-San Joaquin River Delta, a large area of diked and drained swampland in the northern portion of the Estuary (SFEP, 1999). Major embayments within the San Francisco Estuary include the Suisun, San Pablo, Central, South, and Lower South bays.

The San Francisco Estuary and its associated tributaries encompass roughly 1,600 mi^2, provide drinking water to 23 million Californians (two-thirds of the state's population), and irrigate 4.5 million acres of farmland. The Estuary also enables the residents of the nation's fifth-largest metropolitan region to pursue diverse activities, including shipping, fishing, recreation, and commerce. Finally, the Estuary hosts a rich diversity of flora and fauna, with nearly half of the birds that migrate along the Pacific Flyway and about two-thirds of the state's salmon passing through the Estuary (SFEP, 2004).

Environmental Concerns

Freshwater management is an environmental concern in the San Francisco Estuary region. Each day, millions of people, industries, and municipalities around the Estuary use river water for an array of activities, then collect, recycle, treat, and discharge their wastewater into the Estuary. In rural areas, farmers irrigate crops and water their livestock. Maintaining river flows under the pressure of exporting water to southern California is a major environmental concern in the Estuary, and during droughts and heavy rain years, this pressure makes managing the system even trickier. Add to these needs other issues, such as pesticides and other pollutants that get washed into the creeks, rivers, and bays, and water quality management for the Estuary becomes even more challenging.

Population Pressures

The population of the 12 NOAA-designated coastal counties coincident with the San Francisco Estuary Project (SFEP) study area increased by 96.1% during a 40-year period, from 4.5 million people in 1960 to 8.7 million people in 2000 (Figure 6-32) (U.S. Census Bureau 1991; 2001). This rate of population growth for the SFEP study area was slightly lower than the population growth rate of 100.3% for the collective NEP-coincident coastal counties of the West Coast region. However, the coastal counties surrounding the SFEP had the highest population density (844 persons/mi^2) of any of the West Coast NEP study areas (U.S. Census Bureau, 2001). The San Francisco Estuary is surrounded by major metropolitan areas that serve as large centers for international commerce and industrial and recreational activities.

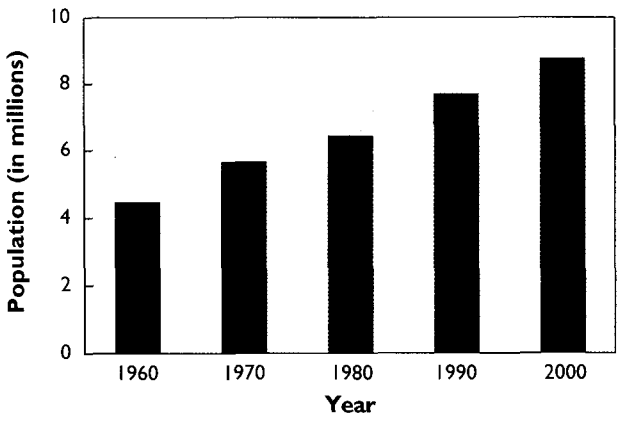


Figure 6-32. Population of NOAA-designated coastal counties of the SFEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—San Francisco Estuary

The overall condition of the San Francisco Estuary is rated fair based on the four indices of estuarine condition used by the NCA (Figure 6-33). The water quality index is rated fair to poor, the sediment quality index is rated fair, the benthic index is rated good, and the fish tissue contaminants index is rated poor. Figure 6-34 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 collected by the NS&T Program and Moss Landing Marine Laboratories, under contract to the Southern California Water Resources Research Project (SCWRRP), from 50 stations sampled in the San Francisco Estuary in 2000. 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.

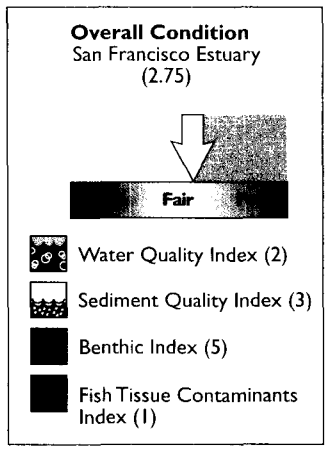


Figure 6-33. The overall condition of the SFEP estuarine area is fair (U.S. EPA/NCA).

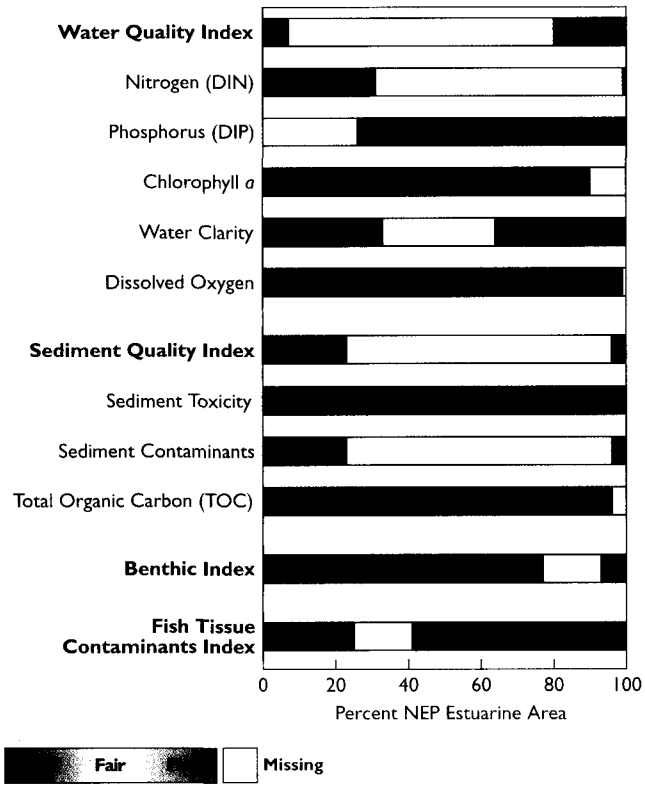
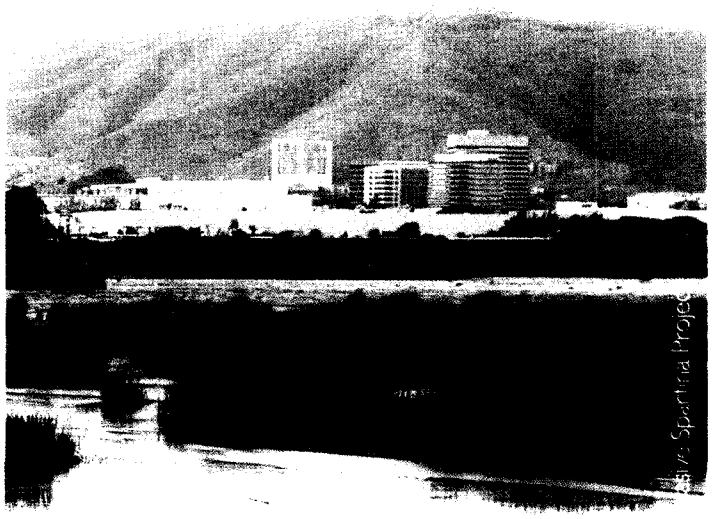


Figure 6-34. Percentage of NEP estuarine area achieving each ranking for all indices and component indicators – San Francisco Estuary (U.S. EPA/NCA).



The dominant marsh vegetation in this area of the San Bruno Marsh is an invasive, non-native *Spartina*, which is a hybrid of an introduced and a native species (San Francisco Estuary Invasive Spartina Project).

Water Quality Index

Based on NCA survey results, the water quality index for the San Francisco Estuary is rated fair to poor (Figure 6-35). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Some 20% of the estuarine area was rated poor for water quality, and 73% of the area was rated fair. Diminished water quality in the Estuary was primarily due to limited water clarity and to elevated levels of DIN and DIP.

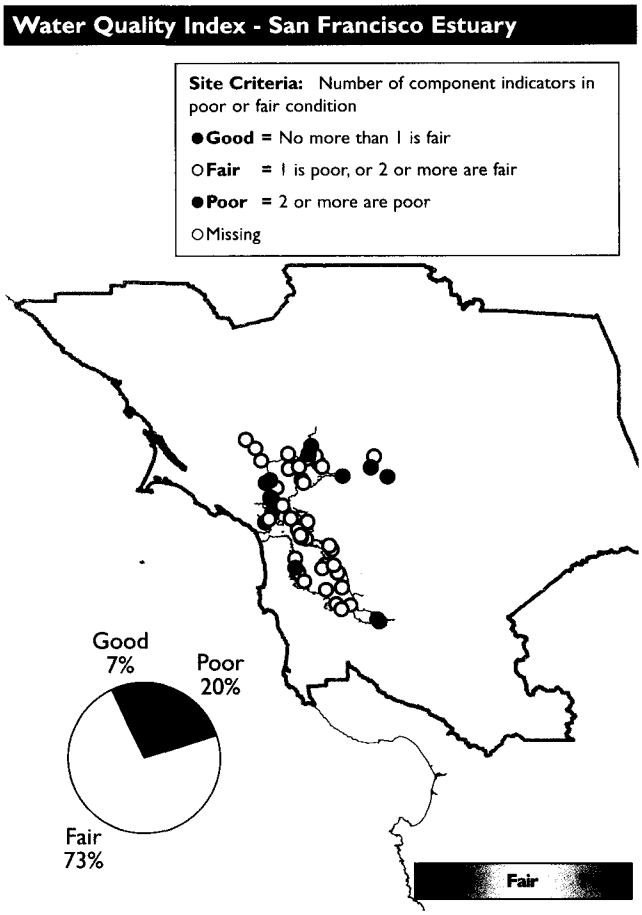


Figure 6-35. Water quality index data for the San Francisco Estuary, 2000 (U.S. EPA/NCA).

Dissolved Nitrogen and Phosphorus | The San Francisco Estuary is rated fair for DIN concentrations and poor for DIP concentrations. Concentrations of DIN were rated fair in 68% of the estuarine area, and DIP concentrations were rated poor in 74% of the area. In addition to natural inputs of nutrients from offshore coastal upwelling, high levels of urban and agricultural runoff into the Sacramento River may also be major contributors to the elevated nutrient levels found in the San Francisco Estuary.

Chlorophyll a | Chlorophyll *a* concentrations in the San Francisco Estuary are rated good. Ten percent of the estuarine area was rated fair for this component indicator, and the remaining 90% was rated good.

Water Clarity | Water clarity in the San Francisco Estuary is rated poor. Approximately 36% of the estuarine area was rated poor for this component indicator, and 31% of the area was rated fair.

Dissolved Oxygen | Dissolved oxygen conditions in the San Francisco Estuary are rated good, with 99% of the estuarine area rated good for this component indicator. Although conditions in the San Francisco Estuary appear to be generally good for dissolved oxygen, measured values reflect daytime conditions, and some areas of the Estuary may still experience hypoxic conditions at night.

Sediment Quality Index

The sediment quality index for the San Francisco Estuary is rated fair (Figure 6-36). This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC. Four percent of the estuarine area was rated poor for sediment quality, exceeding thresholds for at least one of these component indicators, and 73% of the area was rated fair, primarily as a result of sediment contaminant levels.

Sediment Toxicity | Sediment toxicity in the San Francisco Estuary is rated good, with 100% of the estuarine area rated good for this component indicator.

Sediment Contaminants | The San Francisco Estuary is rated good for sediment contaminant concentrations, with 4% of the estuarine area rated poor for this component indicator and 73% of the area rated fair.

Total Organic Carbon | The San Francisco Estuary is rated good for sediment TOC. TOC concentrations were rated good in 96% of the estuarine area and fair for the remaining 4% of the area.

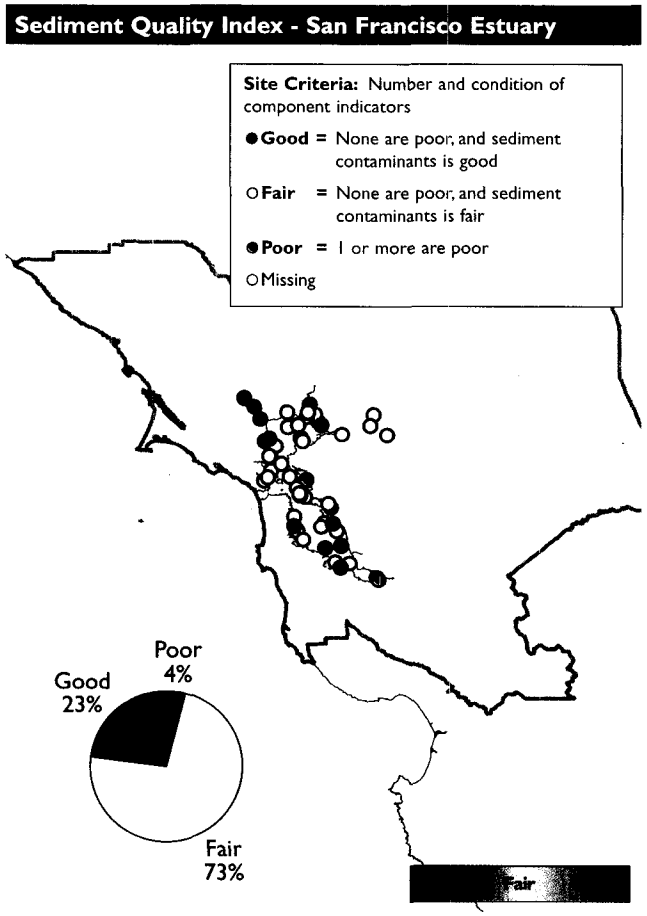


Figure 6-36. Sediment quality index data for the San Francisco Estuary, 2000 (U.S. EPA/NCA).

Benthic Index

The condition of the benthic invertebrate communities in the San Francisco Estuary is considered good based on deviations from the expected species richness (Figure 6-37). A significant linear regression between log species richness and salinity that was moderately strong ($r^2 = 0.54$, $p < 0.01$) was found in the Estuary. Six percent of the estuarine area was rated poor based on a lower-than-predicted species richness, and 16% of the area was rated fair. The remaining 78% of the estuarine area was rated good for benthic condition. It is possible that sediment contamination contributed to the lower species richness in several of the areas rated poor and fair because 6 ERLs were exceeded at 6 of the 11 sampling sites in these areas. However, the reduced species richness is not simply related to sediment contamination because 21 of the 39 sites rated good for the benthic index had an equivalent or greater number of contaminants exceeding their ERLs.

Fish Tissue Contaminants Index

The fish tissue contaminants index for the San Francisco Estuary is rated poor. Fifty-eight percent of all stations sampled where fish were caught exceeded EPA Advisory Guidance values using whole-fish contaminant concentrations (Figure 6-38). These risk calculations are appropriate for populations that consume whole fish. The contaminants found in the fish tissues sampled included total PCBs and, occasionally, mercury.

Sediment Contaminant Criteria (Long et al., 1995)

ERM (Effects Range Median)—Determined for each chemical as the 50th percentile (median) in a database of ascending concentrations associated with adverse biological effects.

ERL (Effects Range Low)—Determined for each chemical as the 10th percentile in a database of ascending concentrations associated with adverse biological effects.

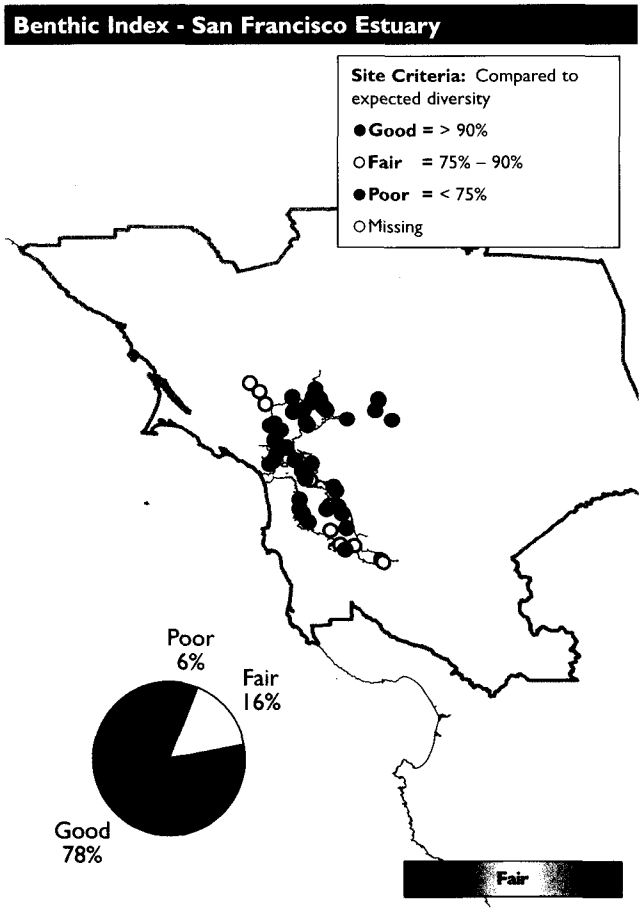


Figure 6-37. Benthic index data for the San Francisco Estuary, 2000 (U.S. EPA/NCA).

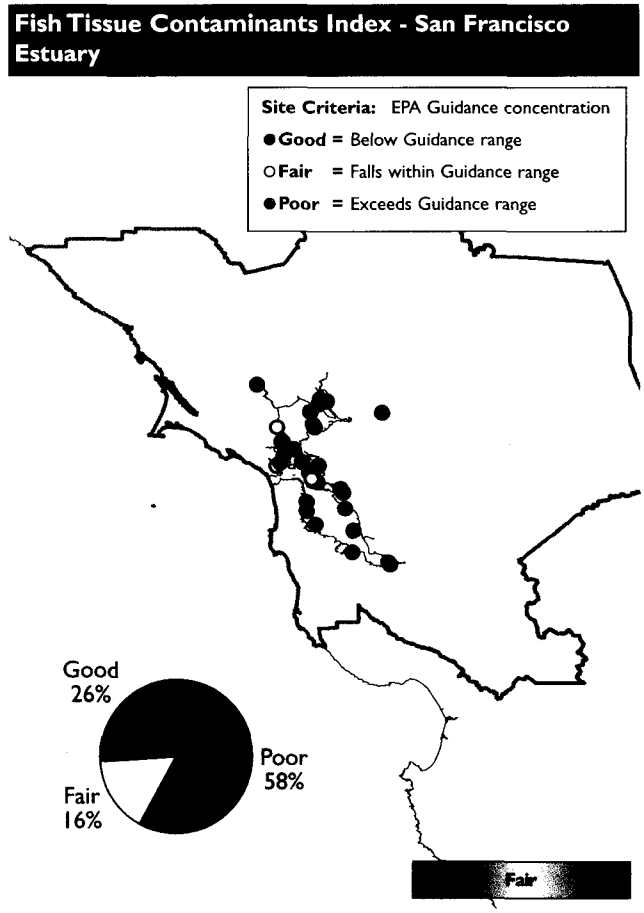


Figure 6-38. Fish tissue contaminants index data for the San Francisco Estuary, 2000 (U.S. EPA/NCA).

San Francisco Estuary Project

HIGHLIGHT

Ecosystem Indicators for the San Francisco Estuary

The San Francisco Estuary is considered one of the best-studied ecosystems in the world; however, the myriad of disparate data-collection efforts for the Estuary has not resulted in a coherent performance-measurement system. Currently, no single, objective, and comprehensive assessment of the health of the San Francisco Estuary and its watersheds is widely recognized as valid by ecosystem managers and policy makers. Such an assessment would identify problems early, direct agency efforts towards real priorities, and measure the impacts that collective actions are having on the system's health so that the SFEP can continue to adapt and improve its management strategies. The assessment would be conducted using a variety of environmental indicators, which are the vital signs derived from the chemical, biological, and physical measurements that mark the improvement or deterioration of the ecosystem. A recently released U.S. Government Accountability Office (GAO) report (U.S. GAO, 2004) recommends that leadership at the highest levels of government mesh the disparate efforts of multiple agencies and organizations into a coherent, science-based environmental management system for the Estuary.

Although no program in the San Francisco Estuary area is currently charged with integrating measurements and indicators into an assessment of ecosystem condition, identifying attributes that define ecosystem condition, or pinpointing gaps in that knowledge, progress is being made towards these goals. In 2004, The Bay Institute (TBI) and its partners made the first attempt to assess the ecological condition of the Estuary and reported the results using language accessible to the general public in its Ecological Scorecard (TBI, 2003). Additional partnerships between organizations studying the Estuary have been created to develop a consensus set of indicators for use by all stakeholders. These partnerships recently completed a report (Thompson and Gunther, 2004) documenting 47 separate recommended environmental indicators and have organized indicator workshops. These efforts build on previous indicator identification efforts and existing Bay-region monitoring programs, including the Interagency Monitoring Program and the USGS Regional Monitoring Program.

The Ecological Scorecard was a collaborative project between the San Francisco Estuary Institute (SFEI), the Center for Ecosystem Management, and TBI. Assisted by a grant from the SFEP, this project evolved over a 3-year period, with input from a wide-range of local scientists and a panel of nationally recognized experts. The Scorecard's Bay Index uses science-based indicators to grade the condition of the San Francisco Bay region, the first of a series of four major ecological regions of the Estuary (i.e., San Francisco Bay, San Francisco Delta, San Joaquin River, and Sacramento River) to be assessed. The Scorecard's indicators are combined into eight indices that track the Estuary's environment (e.g., habitat, freshwater inflow, water quality); its fish and wildlife (e.g., food web, shellfish, fish); and the management of its resources (e.g., fishable, swimmable, drinkable). The grading system compares current conditions in the Bay and its watershed to historical conditions, environmental and public health standards, and restoration goals. Grades in the 2005 Scorecard (see figure) range from B to F, reflecting the long-term decline in the Bay's ecological health; however, there are some small but noticeable short-term improvements in the area's habitat and shellfish populations (TBI, 2003; 2005).

Another effort to develop environmental indicators is being led by the SFEP and its partner, SFEI. These agencies have formed a Bay Area Indicator Consortium to provide direction in strategizing the development of ecosystem indicators for the San Francisco Estuary. The Consortium recommends that the same indicators developed for the Ecological Scorecard be expanded and used as the starting point for the ecosystem indicators. In May 2004, the SFEP partnered with the SFEI and

the Consortium to produce the report *Development of Environmental Indicators of the Condition of San Francisco Estuary: A Report to the San Francisco Estuary Project*, which was submitted to EPA Headquarters in September 2004 (Thompson and Gunther, 2004).

With support from EPA, the Consortium organized an Indicators Workshop in January 2005. Workshop participants explored new state and federal initiatives highlighting the need for "performance-based environmental management," as well as recent successes by the SFEP to develop a meaningful environmental indicator system. The workshop's purpose was to build consensus on the importance of and the need for scientifically valid, leading environmental indicators; to develop a framework for interagency cooperation and collaboration on the development, refinement, and use of environmental indicators; and to attract commitments of ongoing financial and programmatic support. Workshop attendees included approximately 40 participants representing the agencies developing and entities using the data (SFEP, 2006).

AREA	GRADE	SUMMARY	LONG-TERM	SHORT-TERM
	D+ Score = 31	**Habitat** Bay habitat loss is slowly being reversed, but pace of restoration unchanged since 2003 – at current rate, more than 150 years to reach tidal marsh restoration goal.	▼	▲
	C+ Score = 58	**Freshwater Inflow** Reduced inflows still degrade the Bay ecosystem – inflow improved in 2004, but overall conditions since 2000 are worse than two previous decades.	▼	◀▶
	B- Score = 65	**Water Quality** Open waters are cleaner than in 2003, but not all standards are met in parts of the Bay. Toxic sediments, stormwater runoff are major problems. South and San Pablo Bays are most polluted.	▲	▲
	F Score = 10	**Food Web** Plankton levels in Suisun Bay are still critically low, reducing food resources for fish and birds. Phytoplankton levels in all other parts of the Bay are improving.	▼	◀▶
	B Score = 73	**Shellfish** Crab and shrimp numbers rise in Central and South Bays, but not in the upper Bay. Estuarine species lose ground to marine shellfish.	▼	▲
	C- Score = 45	**Fish** Recent upward trend reverses, fish populations return to critically low levels. Estuarine species of the upper Bay are hardest hit.	▼	◀▶
	C- Score = 38	**Fishable-Swimmable-Drinkable** More fish were caught but most are still unsafe to eat. Beach closures continue to rise, drinking water violations hold steady.	▼	◀▶
	C- Score = 46	**Stewardship** Little progress towards conserving more water, reducing pesticide use, and restoring freshwater inflows, but some efforts to issue pollution limits move forward.	▼	◀▶

Grades are for the 2002-2005 period

A = Excellent
B = Good
C = Fair
D = Poor
F = Critical

Short-term = trend over last 5 years

Long-term = trend over last 25 years or more

▲ = improving
▼ = declining
◀▶ = stable

San Francisco Bay Index 2005 Scorecard (TBI, 2005).

San Francisco Estuary Project Indicators of Estuarine Condition

The San Francisco Estuary has had the benefit of several long-term monitoring programs, including the Regional Monitoring Program for Trace Substances (RMP), sampling and analysis by USGS, and the Interagency Ecological Project (IEP). The RMP has investigated chemical contamination in the water, sediments, and biota of the Estuary since 1993 and provides data on spatial patterns and long-term trends for use in management of the Estuary (SFEI, 2003). The USGS has more than 35 years of water quality data on various parameters, such as chlorophyll, nutrients (phosphorus and nitrogen), suspended sediments, salinity, and dissolved oxygen. The USGS data provide a record of biological and chemical changes in the Estuary. These data have been used to show improvements in dissolved oxygen concentrations in the South Bay and changes in phytoplankton production in Suisun Bay (USGS, 2006b). The IEP has monitored fisheries and the effects of freshwater diversions on the biota of the San Francisco Bay proper and the Sacramento-San Joaquin Delta since 1971 (IEP, 2006). Recent IEP data have shown drastic declines in important delta fish species, such as striped bass, delta smelt, and longfin smelt (Hieb et al., 2005). Other local, state, and national programs, such as the Bay Protection and Toxic Cleanup Program, Coastal Intensive Sites Network (CISNet), EMAP, and NOAA's NS&T Program, have also provided data on the water, sediments, and biota of the San Francisco Estuary. It is beyond the scope of this writeup to comprehensively discuss all of these indicators; however, several indicators of particular interest are discussed in the following sections. Additional information about the San Francisco Estuary is available from http://sfep.abag.ca.gov or http://www.sfei.org.

Water and Sediment Quality

Current and historical activities in California have contributed PCBs, pesticides, and mercury and other heavy metals (e.g., silver and copper) to the sediments of the San Francisco Estuary. Urban runoff in area watersheds is a significant, contemporary source of various contaminants, including mercury and PCBs, which are currently the topic of TMDLs proposing large reductions in urban runoff (CRWQCB, 2004). Although many of these contaminants have been banned, they are persistent in the environment, biomagnify through the food web, and bioaccumulate in fish and wildlife. The issue of sediment contamination in the Estuary is exacerbated by the waterbody's current levels of turbidity. Hydraulic gold mining in the Sierra Nevada foothills during the Gold Rush washed hundreds of millions of metric tons of sediment into the Estuary (Wright and Schoellhamer, 2004), which was enough sediment to decrease water depths by as much as five to ten feet (CRWQCB, 2004). Sediments within the shallow Estuary continue to be resuspended by daily tidal actions and winds. Resuspension of contaminated sediments introduces biologically available contaminants into the water column. The turbidity that is caused by this resuspension also controls the depth to which natural light can penetrate in the water column, limiting photosynthesis and affecting the food web.

The highest concentrations of contaminants in the sediments are most often found at the urbanized edges of the Estuary, and the distribution of these contaminants is primarily driven by two factors: inputs from industrial and military sources near San Jose, southern San Francisco, and Oakland, as well as the East Bay shoreline; and the distribution of the fine particles to which these contaminants are sorbed. Many of the areas with high concentrations of PCBs, DDT, and/or chlordane in sediment correspond to the areas of the Estuary (e.g., South San Francisco Bay, San Pablo Bay, and along the East Bay shoreline) with high percentages of fine sediments (Connor et al., 2004).

PCB contamination remains one of the greatest water quality concerns in the Estuary, and PCB cleanup is a primary focus of the San Francisco Regional Water Quality Control Board (SFRWQCB). PCB contamination is greatest in the South Bay; all samples from the South Bay exceeded the PCB water quality objective, with maximum concentrations measured at the southern end of the South Bay. The few samples that did not exceed the objective were from the northern portion of the San Francisco Estuary (CRWQCB, 2004). In another study, the California Toxic Rule (CTR) water quality criteria for PCBs were exceeded in 90% of RMP water samples collected from the Estuary from 1993 to 2003, and regression analyses have shown

exponential declines in PCB concentrations in mussels at most transplant locations from 1980 to 2003 (Davis et al., in prep).

Although concentrations of legacy pesticides (i.e., pesticides that have been banned, including DDTs, chlordane, and dieldrin) in the Estuary continue to be an issue, there are some indications that water quality has improved over time. Legacy pesticide concentrations exceeded CTR water quality criteria in 5% to 20% of water samples collected during 1993–2001 (Connor et al., 2004); however, declining concentrations of legacy pesticides have been observed in transplanted mussels from the Estuary (Davis et al., in prep).

Mercury contamination in the Estuary dates back to 19th-century mining practices, and sediment cores from the South Bay reflect the historic changes in concentrations over time (SFEI, 2004). Pre-mining concentrations were about four to five times lower than today's concentrations (Conaway et al., 2003). The legacy of mercury mining in the South Bay has created a reservoir of high mercury concentrations within the Bay's water and sediments (Figure 6-39). Old mines are also a continuing source of mercury, which can be mobilized from land and transported to the Estuary during rainfall events. In 2002, the concentration of total mercury exceeded the water quality objective in 32% of samples and was above the sediment target concentration in 84% of the samples (SEFI, 2004).

Other contaminants, such as copper, have demonstrated declines in the San Francisco Estuary. Copper concentrations in water, clams, and sediments collected from the South Bay declined from 1979 to 2003. RMP water data show statistically significant declines in copper concentrations at all historical South Bay stations, and USGS data show corresponding declines in copper concentrations measured in the clam *Macoma balthica* and in sediments from the South Bay. Declines of copper in *Macoma* have been correlated with declines in copper in effluents from the Palo Alto WWTP, located in the South Bay (SFEI, 2004).

Primary production of phytoplankton in the San Francisco Estuary has historically been light-limited because of the waterbody's turbidity (SFEI, 2004). In recent years, chlorophyll levels in the Estuary have

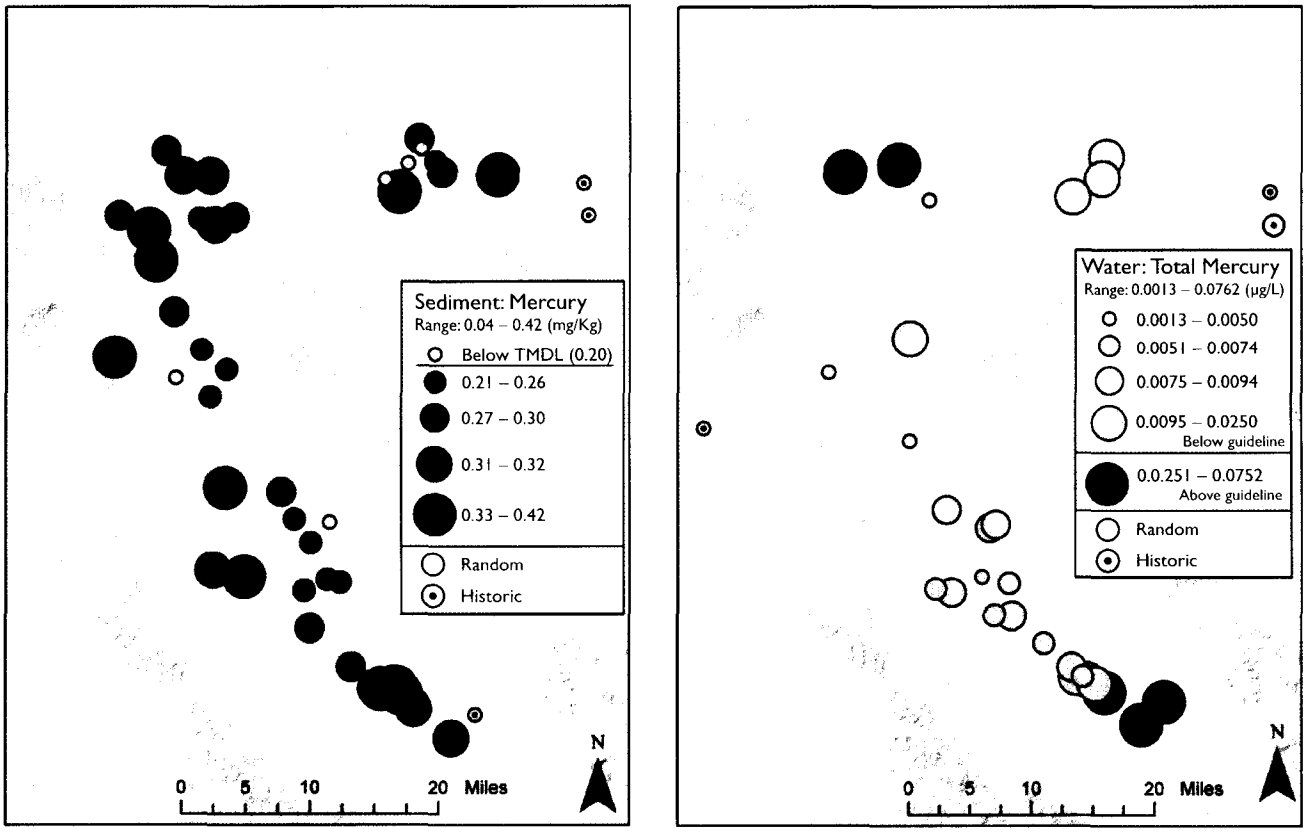


Figure 6-39. Maps of mercury concentrations in water and sediment of the San Francisco Estuary (SEFI, 2004).

increased, while turbidity in the Bay has declined (SFEI, 2006). A South Bay suspended-sediment model, developed by USGS, predicts that increases in wetland area (as proposed under the South Bay Salt Pond Project) could result in increased sediment deposition onto wetlands and a subsequent decrease in suspended sediments in the water column (Shellenbarger et al., 2004). The resulting increase in light penetration could cause higher phytoplankton productivity. In the northern reaches of the Estuary, chlorophyll concentrations have dramatically decreased in Suisun Bay sites since the invasion of the freshwater clam *Potamocorbula* in 1986. The high abundance of this filter-feeding clam has resulted in declines in chlorophyll in this Bay, from an average of 9.8 mg/L (pre-invasion) to 2.1 mg/L (post-invasion) (SFEI, 2003).

Habitat Quality

Wetlands serve several important functions in the San Francisco Estuary, including acting as natural filters, trapping sediment, and providing habitat for a variety of fish, shellfish, waterfowl, and other wildlife. It is estimated that the Estuary has lost more than 500,000 acres of tidal wetlands since 1850 (SFEP, 1999). The acquisition and restoration of the region's wetlands is a top implementation priority of the SFEP's *Comprehensive Conservation and Management Plan* (SFEP, 1993), and the SFEP has focused on tracking this issue as an indicator of the health of the Estuary. Since 2001, 15,000 acres of Cargill salt ponds and related lands have been acquired in the South Bay, and 1,400 acres have been acquired in the North Bay (SFEP, 2004).

Habitat in the Estuary has been affected by the introduction of invasive species. For example, giant reed (*Arundo donax*) was originally introduced into California by the Spanish in the late 1800s for erosion control along drainage canals. Since then, this species has become a significant problem along riparian areas around the Estuary because it spreads easily, requires large amounts of water, can smother native riparian vegetation, and is highly flammable. The reed has been found from Sacramento River tributaries to small urban streams throughout the Estuary. Eradication and education programs for this invasive species are currently underway in areas of the Estuary (SFEP, 2000).

Living Resources

Public attention has focused on invasive species in the Estuary since the 1990s, when the first comprehensive study was pursued (Cohen and Carlton, 1998). Some of the many invasive species present in the San Francisco Estuary include the green crab, shimofuri goby, *Spartina alterniflora* and its hybrids, Asiatic clams, and Asiatic zooplankton. For example, the green crab (*Carcinus maenas*), native to the Atlantic coast of Europe, was first found in the southern portion of the San Francisco Estuary in the early 1990s and has spread north at least as far as the Carquinez Strait. Researchers have found that, in contrast to their slow growth rates in Europe, green crabs grow rapidly and reach sexual maturity during their first year in the Estuary. During the course of a 9-year study, the green crab significantly reduced the abundance of 20 invertebrate species, and within just 3 years of being introduced, reduced densities of native clams and native shore crabs by 5% to 10% (SFEP, 2000). Studies are still underway to determine the full impacts of these recent invaders on the estuarine ecosystem.

Chemical contaminant levels in fish and wildlife are a concern in the San Francisco Estuary. For example, 25 years after the ban on the use of PCBs in California, concentrations in some Estuary sport fish remain 10 times higher than human health consumption guidelines (Davis et al., in prep). An interim human health consumption advisory issued by the California Office of Environmental Health Hazard Assessment (OEHHA), in response to elevated levels of mercury, PCBs, and other contaminants, has been in place since 1994 (SFEI, 2005). Between 1994 and 2003, 93% of all fish sampled by the RMP exceeded the California OEHHA screening value for PCBs; roughly 50% exceeded the screening value for mercury; and 3.5% exceeded the screening value for DDT. In addition, all leopard shark samples and almost all striped bass samples exceeded the mercury screening value (Greenfield et al., 2005). The SFRWQCB has calculated that a 40% reduction in mercury levels in striped bass would be necessary to meet the TMDL target of 0.2 ppm (Looker and Johnson, 2004). Over the long term, concentrations of lipid-normalized DDTs in leopard shark, shiner, and white croaker suggest statistically significant declines in

concentrations from 1994 to 2003. Decreases in chlordane concentrations in leopard sharks, striped bass, and white croaker were also observed (Connor et al., 2004). No long-term trends have been detected in lipid-normalized PCB data. PCB levels in leopard shark, white croaker, and striped bass were higher in 1994 compared to other years, but the interannual variation since 1994 has fluctuated without a clear decline. Mercury concentrations in striped bass have shown no decline during the period from 1970 to 2003 (Greenfield et al., 2005).

Similarly, mercury levels in bird eggs remain a concern for Estuary managers. Concentrations of mercury in eggs from area terns and endangered California clapper rails have been close to the wet-weight threshold-effects level target of 0.5 ppm proposed in the draft TMDL for mercury (Schwarzbach and Adelsbach, 2003). Recent RMP data show median wet-weight concentrations of mercury in least tern eggs to be 0.6 ppm (SFEI, 2006). A more conservative threshold may be established to protect more sensitive species, such as the endangered least tern.

Scientists from the RMP and the Southern California Coastal Water Research Project (SCCWRP) have developed a multi-metric approach for measuring the effects of contaminants on benthic communities. Benthic communities were assessed based on taxa diversity, abundance of organisms per sample, number of contaminant-tolerant organisms, and the proportion of contaminant-sensitive benthic amphipods to sensitive mollusks. Highly impacted sites were concentrated in the lower-central and southern portions of the Estuary, and the most severely impacted benthic sites were located in sub-embayments, coves, and channels along the margins of the Estuary (Figure 6-40). In particular, all samples from San Leandro Bay were classified as severely impacted, and samples from the deeper areas of the Estuary indicated minimal impact. Combining this method with other measures of contamination, such as sediment toxicity and sediment chemistry, can help support the link between contamination and benthic impact (SWRCB, 2004).

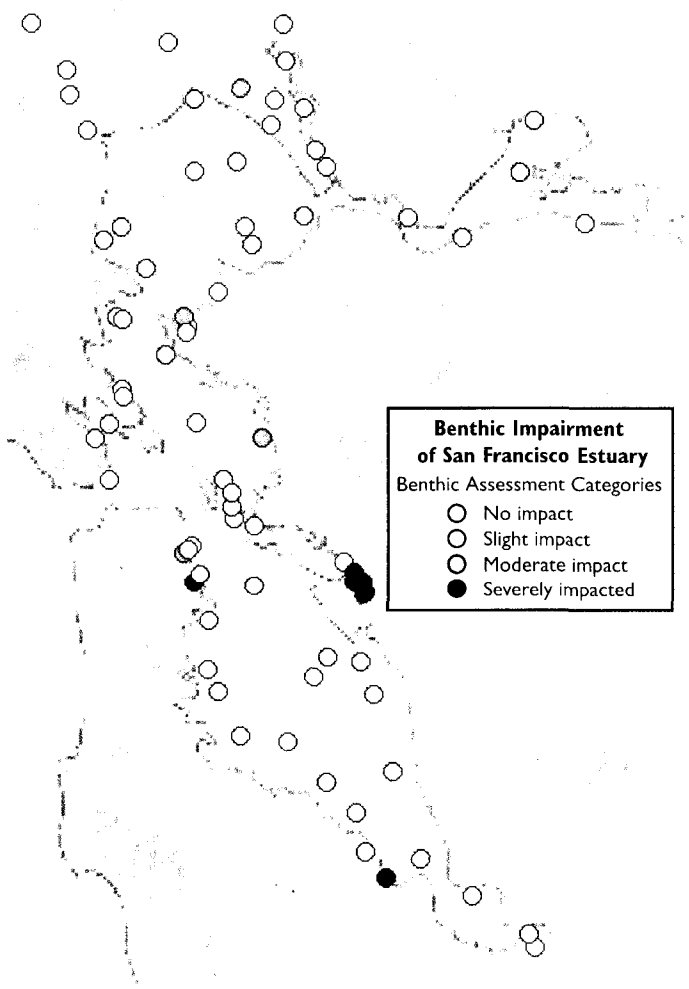
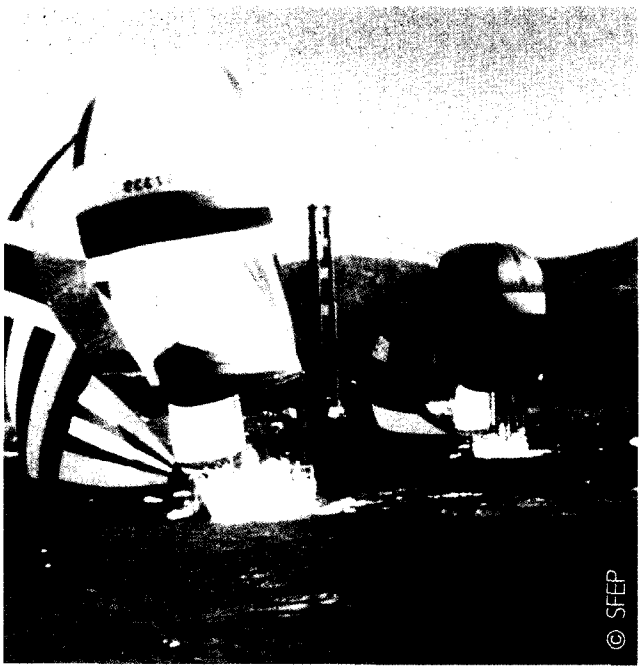


Figure 6-40. Map of benthic impact based on assessment of benthic assemblage. Data from from NOAA-EMAP, RMP, Bay Protection and Toxic Cleanup Program, and CISNet (SFEI).



Racing on the San Francisco Estuary (SFEP).

Current Projects, Accomplishments, and Future Goals

Probably the biggest, most visible accomplishment of the SFEP is the large number of environmental education and outreach efforts taking place around the San Francisco Estuary, as well as an incredible number of watershed management planning activities. Almost every city or town now has a "friends of" creek or river group that has adopted the waterway running through its midst, and parks, ponds, and marshes have likewise been taken under someone's wing. Interest and a sense of ownership in the Estuary—in part encouraged by the improved public access offered by the San Francisco Bay Trail—is on the rise. As the state's population increases and open space and wildlife habitat continue to be lost to housing and development, the Estuary becomes yet an even more important resource to Bay-area residents. This grassroots energy in turn feeds regulatory efforts to protect and enhance the Estuary.

Water supply reliability and adequate inflows to protect aquatic resources are priorities of the SFEP's CCMP (SFEP, 1993). Cutoff of California's surplus water supplies from the Colorado River by the U.S. Department of Interior (DOI) provided the impetus for a historic shift from an era of centralized state and federal water planning to a more regionally and market-driven approach. Working together several years ago, water and environmental interests helped pass Proposition 50, the largest water bond in California history.

Data from the RMP and other programs have been integral in the development of TMDL reports by the SFRWQCB. TMDLs are action plans that set targets for acceptable levels of the contaminants that threaten the beneficial uses of the Estuary, such as sport fishing, wildlife habitat, and the preservation of rare and endangered species. The SFRWQCB plans to issue TMDLs for mercury and PCBs within the next year; these contaminants have exceeded thresholds of concern by factors of almost 4 to 10 (SFEI, 2005). TMDLs for other contaminants are also planned. Except for diazinon, which is driven by the impacts of the contaminants on human and wildlife consumers of contaminated fish (Figure 6-41) (SFEI, 2005). Since many contaminants partition to the sediments, the SFRWQCB is proposing sediment targets as a means of reducing contaminant levels in fish and wildlife to safe levels. Fish targets are also likely to be included.

Stronger planning, improved regulations, and increased acquisition and restoration are the main thrust of 12 wetland management actions called for in the SFEP's CCMP. One element, the setting of goals for the types, locations, and quantities of wetlands desired to maintain the ecosystem's health, will provide the biological foundation for the regional wetlands management plan.

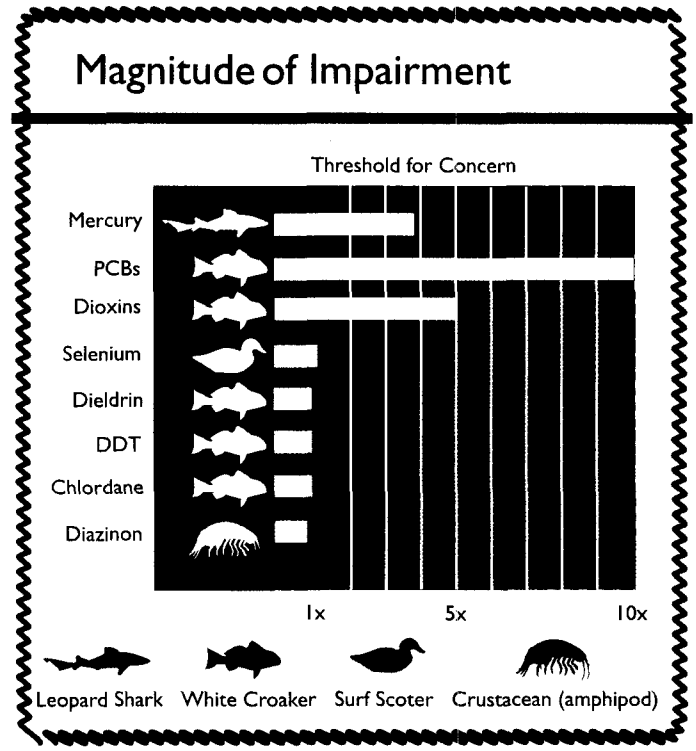


Figure 6-41. Summary of degree of Estuary impairment by high-priority pollutants in various species (SFEI, 2005).

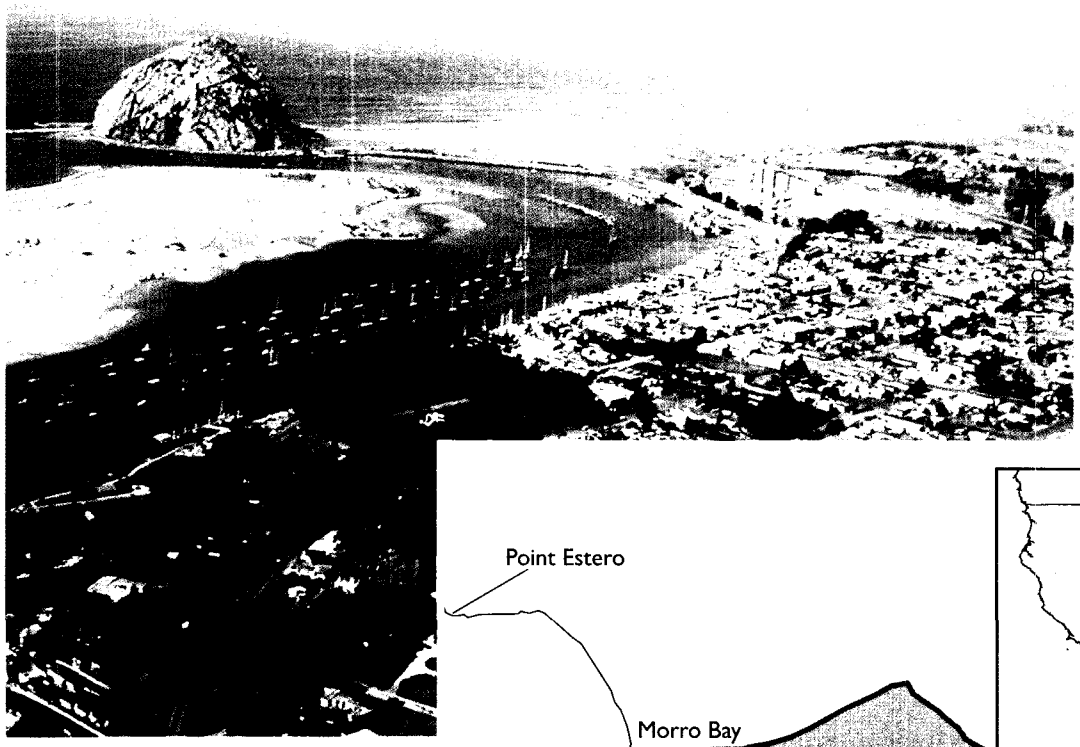
Public support for wetlands and creek restoration has been tremendous, as indicated by the large numbers of volunteers who have adopted creeks and participated in restoration activities. One SFEP Implementation Committee member reported that, in his organization alone, more than 12,000 people logged 36,000 volunteer hours. Planned restoration projects include about 19,000 acres in the North Bay (13,000 acres of tidal marsh and 6,000 acres of non-tidal or mixed hydrology) and 18,000 acres in the South Bay (SFEP, 2004).

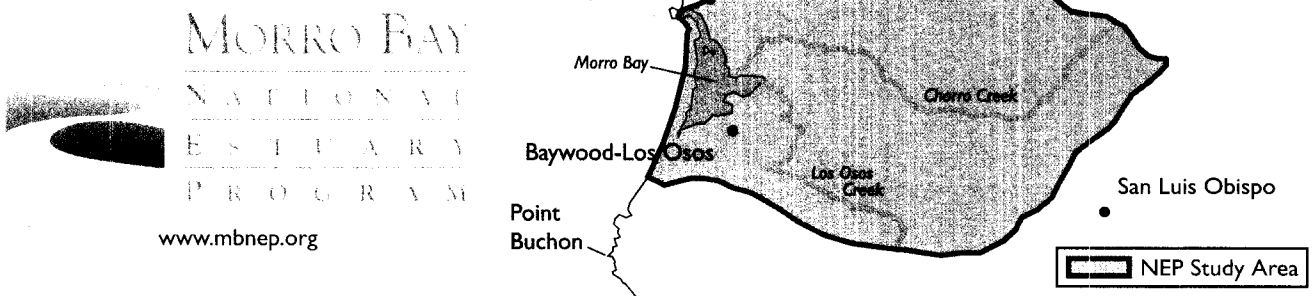
Conclusion

The task confronting those working on assessing and managing the San Francisco Estuary and its watershed is complex because of the diversity and scale of the human demands on the Estuary. Many potentially competing needs must be carefully balanced by many different agencies and stakeholder groups. Within this context, there are a variety of monitoring and assessment initiatives and concerns. Based on data from the NCA, the overall condition of the San Francisco Estuary is rated fair; however, data from the SFEP and other sources indicate that chemical contaminants are affecting the beneficial uses of the Estuary. Water quality guidelines continue to be exceeded for PCBs and legacy pesticides; chemical contaminant levels in many popular sport fish continue to exceed human health screening values; and evidence exists that benthic communities are affected by high levels of contamination. The aquatic food web of the San Francisco Estuary is continually exposed to multiple contaminants, and these contaminant levels pose a threat to the fish and wildlife in the Estuary, as well as to sport fish consumers. Estuary managers, through the TMDL process, are establishing target values for protection of the Estuary's beneficial uses. Long-term monitoring is crucial in illuminating changes in contaminant levels in the waters, sediments, and wildlife of the Estuary. Integrating this information into policy allows for a scientifically sound basis for the management of the San Francisco Estuary.

Alcatraz Island is located in the San Francisco Estuary (Jennifer Lloyd Blough).

Morro Bay National Estuary Program





Background

Morro Bay is a 3.6-mi^2, semi-enclosed body of water located along the central California coast. This shallow estuarine system includes a diverse array of wetland habitats, including subtidal and intertidal eelgrass beds, mudflats, salt marsh, and brackish and freshwater wetlands on the Bay fringe. The Morro Bay watershed covers approximately 75 mi^2 of San Luis Obispo County. The predominant land use in the watershed is rangeland for beef cattle, and other uses include irrigated agriculture, open space, and developed lands. The area is seismically active, and several earthquake faults are located within or near the watershed. Morro Rock, a local landmark, is the most westerly visible in a chain of extinct volcanic plugs that divide the two coastal valleys that drain into the Bay (Morro Bay NEP, 2000).

Morro Bay is a major tourist attraction, with more than 25,000 people living within the Bay's watershed and an average of 1.5 million visitors per year. The area's economy is dominated by tourism and visitor-serving businesses, which generate 37% of all jobs and one-third of the general fund revenues for the City of Morro Bay. The Bay provides critical resources to fishing and recreational boating industries, with more than

100 commercial vessels providing a value of roughly $7 million to the local economy. Recreational fishing takes place from shore, docks, piers, and a variety of boats, and catches include a diversity of species, such as Pacific halibut, shark, jacksmelt, black surfperch, and starry flounder. More than 270 acres of the estuary are leased for commercial shellfish operations focused on the Pacific oyster. The estuary and surrounding habitats are an important stop-over area on the Pacific Flyway for migratory birds and are home to 16 federally threatened or endangered species, some of which are found nowhere else in the world (Morro Bay NEP, 2000).

In 1995, the Morro Bay National Estuary Program (Morro Bay NEP) was established to address the environmental concerns facing this nationally significant estuary, and the program's *Morro Bay Comprehensive Conservation & Management Plan* was finalized in 2000 (Morro Bay NEP, 2000). The Morro Bay NEP study area includes Morro Bay, its watershed, and to some extent, Estero Bay from Point Buchon in the south to Point Estero in the north.

Environmental Concerns

Erosion in the watershed and the resulting sedimentation of the estuary is one of the most severe threats facing Morro Bay. Sediment delivery has increased over time due to changes in land use, as well as to the alteration and loss of streams and flood plains. The Bay has lost more than a quarter of its tidal volume in the past century, and left unchecked, sedimentation will continue to degrade and destroy subtidal and intertidal habitats. In addition to sedimentation, development, and other land-use changes, changes in drainage patterns, erosion, and growth of invasive species such as *Arundo donax* (giant reed) in riparian corridors and veldt grass in the coastal dunes have contributed to the loss of natural habitat in the study area. Some obvious effects of habitat loss in Morro Bay include the likely extinction of the Morro Bay kangaroo rat and decreases in populations of steelhead trout, a federal endangered species (Morro Bay NEP, 2000).

Population Pressures

The population of the NOAA-designated coastal county (San Luis Obispo) coincident with the Morro Bay NEP estuarine study area increased by 204.4% during a 40-year period, from 0.08 million people in 1960 to 0.25 million people in 2000 (Figure 6-42) (U.S. Census Bureau, 1991; 2001). This rate of population growth for the Morro Bay NEP was the highest rate observed for any of the six West Coast NEPs and was more than double the average growth rate of 100.3% for the collective NEP-coincident coastal counties of the West Coast region. In contrast, San Luis Obispo County had the second-lowest population density (75 persons/mi^2) of any of the West Coast NEPs (U.S. Census Bureau, 2001). This estuary is not surrounded by a large metropolitan area, but is a major recreational area and agricultural center for the local coastal community.

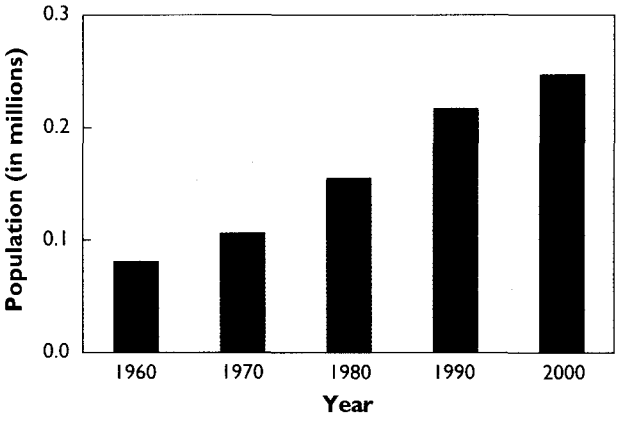


Figure 6-42. Population of the NOAA-designated coastal county of the Morro Bay NEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001)

NCA Indices of Estuarine Condition—Morro Bay

The overall condition of Morro Bay is rated good based on three of the indices of estuarine condition used by the NCA (Figure 6-43). The water quality and fish tissue contaminants indices are rated good, and the sediment quality index is rated fair. Although data on the condition of the benthic community were collected for this estuary, Morro Bay could not be rated using an index based on deviations from the expected species richness. Figure 6-44 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 collected by the Moss Landing Marine Laboratories, under contract to the SCWRRP, from 30 sites sampled in the Morro Bay NEP estuarine area in 2003. 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.

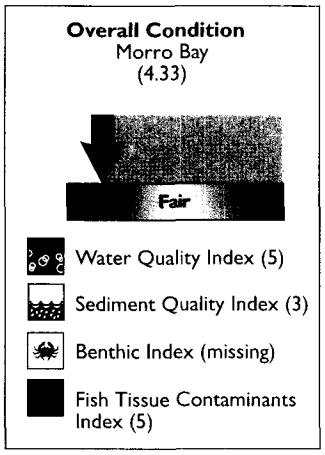


Figure 6-43. The overall condition of the Morro Bay NEP estuarine area is good (U.S. EPA/NCA).

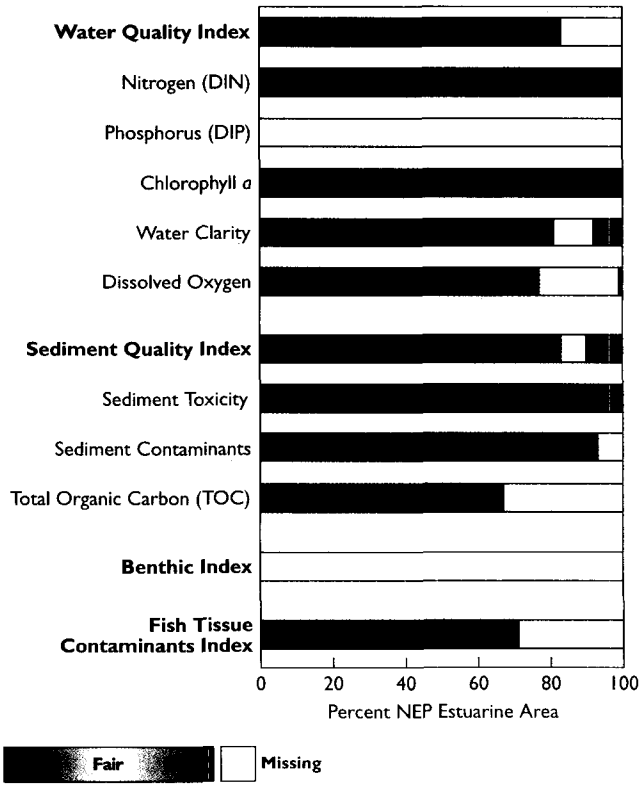


Figure 6-44. Percentage of NEP estuarine area achieving each ranking for all indices and component indicators — Morro Bay (U.S. EPA/NCA).

Water Quality Index

Based on NCA survey results, the water quality index for Morro Bay is rated good (Figure 6-45). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Seventeen percent of the estuarine area was rated fair for water quality, and 83% of the area was rated good. Diminished water quality was primarily due to limited water clarity and elevated levels of DIP.

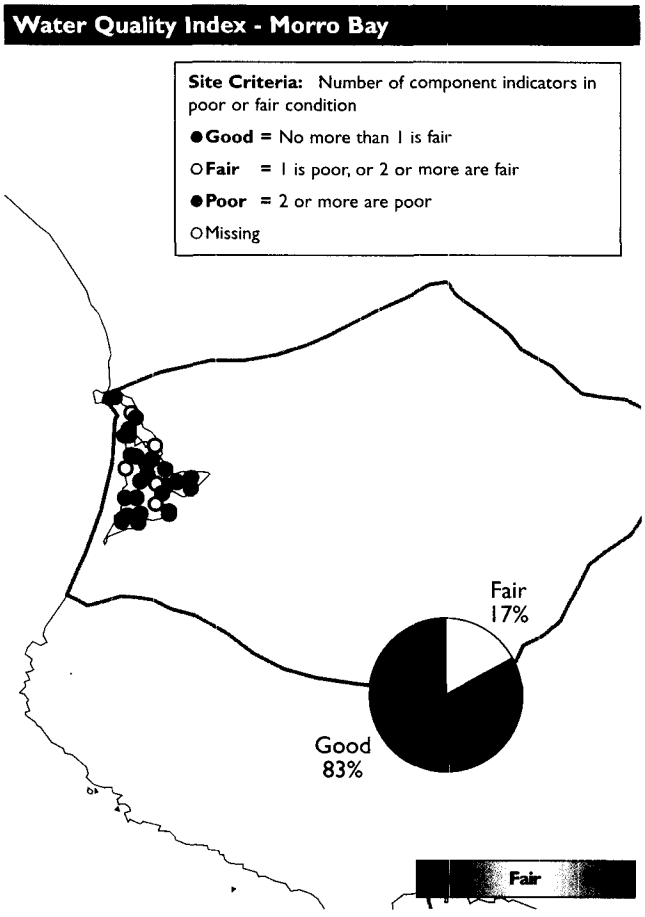


Figure 6-45. Water quality index data for Morro Bay, 2003 (U.S. EPA/NCA).

Dissolved Nitrogen and Phosphorus | DIN concentrations in Morro Bay are rated good, but DIP concentrations are rated fair. Concentrations of DIN were rated good in 100% of the estuarine area, whereas fair DIP concentrations occurred in 100% of the area. In addition to natural inputs of nutrients from offshore coastal upwelling, high levels of urban and agricultural runoff may also be major contributors to the elevated nutrient levels found in Morro Bay.

Chlorophyll a | Chlorophyll *a* concentrations in Morro Bay are rated good, with 100% of the estuarine area rated good for this component indicator.

Water Clarity | Water clarity in Morro Bay is rated good. Approximately 8% of the estuarine area was rated poor for this component indicator, and 11% was rated fair.

Dissolved Oxygen | Dissolved oxygen conditions in Morro Bay are rated good, with 77% of the estuarine area rated good and 22% of the area rated fair. Only 1% of the estuarine area was rated poor for this component indicator; however, these measured values reflect daytime conditions, and some areas of the Bay may still experience hypoxic conditions at night.

Sediment Quality Index

The sediment quality index for Morro Bay is rated fair (Figure 6-46). This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC. Ten percent of the estuarine area was rated poor for sediment quality, and 7% of the area was rated fair, primarily as a result of sediment toxicity.

Sediment Toxicity | Sediment toxicity for Morro Bay is rated poor, with 10% of the estuarine area rated poor for this component indicator.

Sediment Contaminants | Morro Bay is rated good for sediment contaminant concentrations because none of the estuarine area was rated poor for this component indicator and 7% of the area was rated fair.

Total Organic Carbon | Morro Bay is rated good for sediment TOC because 67% of the estuarine area was rated good for TOC concentrations and the remaining 33% of the area was rated fair.

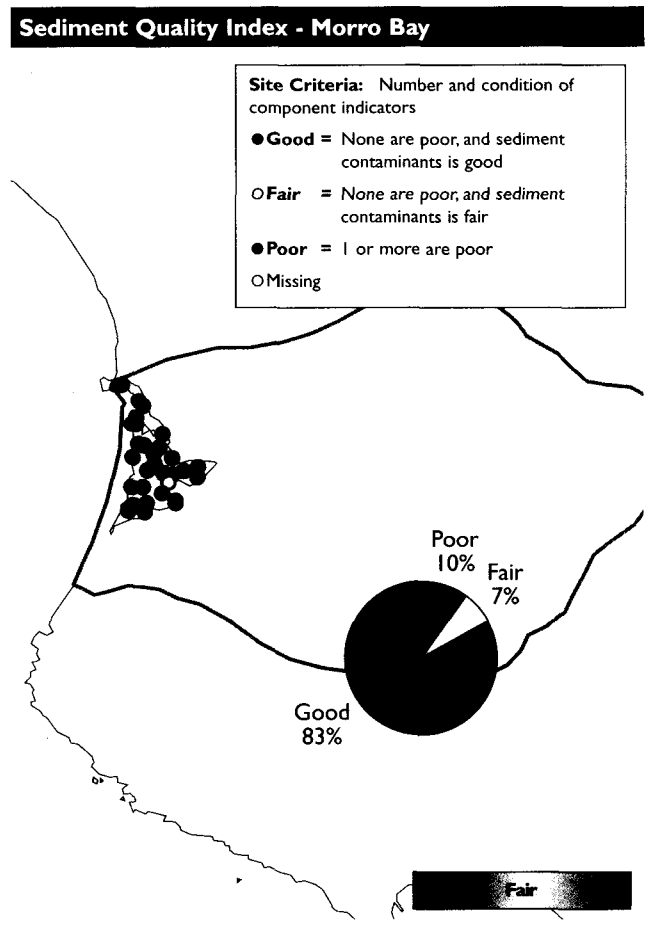


Figure 6-46. Sediment quality index data for Morro Bay, 2003 (U.S. EPA/NCA).

Benthic Index

Currently, the condition of the benthic invertebrate communities in Morro Bay cannot be rated using an index based on deviations from the expected species richness because this approach requires a significant regression between salinity and the log of species richness. This relationship was not significant in the Morro Bay data collected during the 2003 NCA survey. The lack of a significant regression was probably due to an inadequate range in salinity because the Bay's salinity ranged only from 33.9 to 35.1 psu (or salinity values indicative of ocean water). Species richness in the Bay ranged between 2 and 19 species per sample.

Fish Tissue Contaminants Index

The fish tissue contaminants index is rated good for Morro Bay, although this rating should be interpreted cautiously because of the small number of sample stations where fish tissues were obtained (7 of 30 stations). Figure 6-47 shows that fish tissue at 71% of stations (5 of 7) where fish were caught had tissue contaminant levels below EPA Advisory Guidance values using whole-fish contaminant concentrations. These risk calculations are appropriate for populations that consume whole fish. Samples from two Morro Bay stations were rated fair based on concentrations of mercury and DDT.

Fish Tissue Contaminants Index - Morro Bay

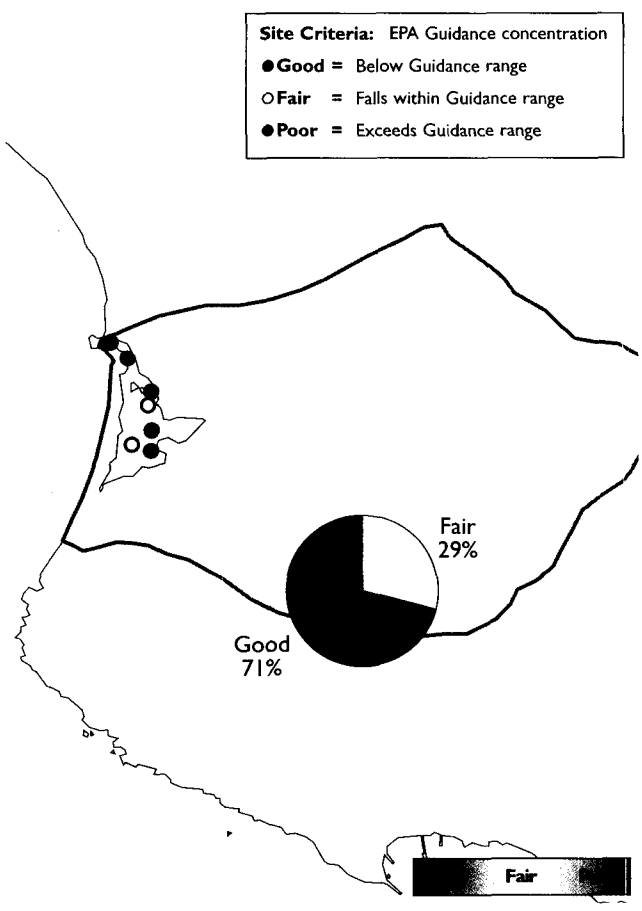


Figure 6-47. Fish tissue contaminants index data for Morro Bay, 2003 (U.S. EPA/NCA).

© Morro Bay NEP

A great egret lazily takes flight across Morro Bay (Morro Bay NEP).

Morro Bay National Estuary Program

HIGHLIGHT

Kids' Beach Cleanup Event and Aerial Art a Success

Two hundred second-grade students traveled from the Central Valley to Cayucos State Beach, CA, on May 13, 2005, for the Kids' Beach Clean-up Event. In an effort to protect marine resources, the students volunteered to collect trash and other debris from the beach to keep these materials from entering the ocean. The participating students were from Strathmore and Seville, CA, two small towns in the Central Valley county of Tulare. This was the first visit to the seashore for many of the students. A week before the field trip, Morro Bay NEP staff member Cheryl Lesinski gave a classroom presentation to students that focused on the impacts that marine debris and pollution can have on beach resources. This project was funded by the California Coastal Commission's Whaletail License Plate program.

As part of the beach cleanup event, the entire group took part in an aerial art formation (see photo). Standing together in lines, the children spelled out the word "PROTECT" as a reminder to all Californians that the ocean is a valuable resource that needs our help (Morro Bay NEP, 2005).

California students involved in beach cleanup event (Morro Bay NEP).

Morro Bay National Estuary Program Indicators of Estuarine Condition

The Morro Bay NEP and its partners employ a variety of monitoring methods and use a suite of indicators to track changes in water quality, suitable habitat areas, and the health of living resources in the Morro Bay estuary. The following section discusses selected key indicators that are used by the Morro Bay NEP to evaluate the health of the estuary and its watershed. Additional information is available at http://www.mbnep.org.

Water and Sediment Quality

The Morro Bay NEP's Volunteer Monitoring Program (VMP) is the main program conducting water quality monitoring in the study area. The Morro Bay VMP monitors monthly for total coliform and *E. coli*, nutrients, dissolved oxygen levels, pH, salinity, flow, temperature, and HABs (Kitajima, 2003). In accordance with EPA's recommendations, the Morro Bay VMP has begun using *Enterococci* as the main pathogen indicator for marine waters (Morro Bay NEP, 2006b).

Ongoing monitoring indicates that bacterial contamination and nutrient over-enrichment are key water quality concerns in the estuary and watershed. From 2002 to 2004, bacteria sampling results indicated that the majority of the creek sites sampled were unsafe for human contact in at least 30% of the samples collected and that three of the seven sites in the estuary were unsafe in 10% to 20% of the samples collected (Morro Bay NEP, 2006a). High fecal bacteria levels are of concern for shellfish beds, as well as for human health impacts from recreational contact with creek and Bay waters. Two of the three commercial shellfish lease areas in Morro Bay are partially closed because of elevated bacteria levels, and all harvesting areas are closed following storm events (Morro Bay NEP, 2000; 2006a). High levels of nitrates and phosphates are present in portions of the Chorro and Los Osos drainages. These increased levels of nutrients are mostly attributed to agricultural runoff, WWTP effluent, grazing lands, and poorly functioning septic systems (Morro Bay NEP, 2000).

Habitat Quality

One of the key indicator measures used to evaluate habitat changes in Morro Bay is the acres and/or linear miles of habitat protected and restored. Since 2001, more than 3,000 acres of valuable wildlife habitat have been permanently protected in the Morro Bay watershed, and 4.5 miles of stream habitat have been restored (Morro Bay NEP, 2006a).

The monitoring of changes in the areal extent of different estuarine habitat areas (e.g., eelgrass, mudflats, salt marsh) is also useful. In particular, the Morro Bay NEP has found that the number of acres of eelgrass in Morro Bay is a good indicator of the health of living resources in the watershed. In 2003, the estuary contained approximately 330 acres of subtidal and intertidal eelgrass, 380 acres of salt marsh, 1,200 acres of intertidal mud flats, and 175 acres of subtidal habitat (USACE, 2003). The Morro Bay eelgrass beds are some of the largest and healthiest in central and southern California and support the highest diversity of invertebrates of any habitat in the estuary (Morro Bay NEP, 2000).

Sediment deposition is being tracked carefully to observe its impact on habitat conditions in the Morro Bay estuary because modeling of future sedimentation has suggested that the area suitable for eelgrass could be reduced by 48% during the next 50 years if sedimentation rates are not slowed (USACE, 2003). One specific goal of the Morro Bay NEP is a 15% reduction in average annual sediment loads in stream and estuary waters by 2010 (Morro Bay NEP, 2000). The recently adopted sediment TMDL calls for a 50% reduction in average annual sediment load during the next 50 years (CCRWQCB, 2002a). Monitoring stations to track deposition rates in the estuary were recently established, and detailed bathymetric surveys of the Bay will provide ongoing information about overall sedimentation rates (Morro Bay NEP, 2006a).

The number of invasive species in Morro Bay is another potentially useful indicator that is still under development by the Morro Bay NEP, but which may become a useful measure for habitat quality and the health of living resources over time. Portions of the estuary's various habitat have been impacted by invasive plant species. During a habitat survey conducted in

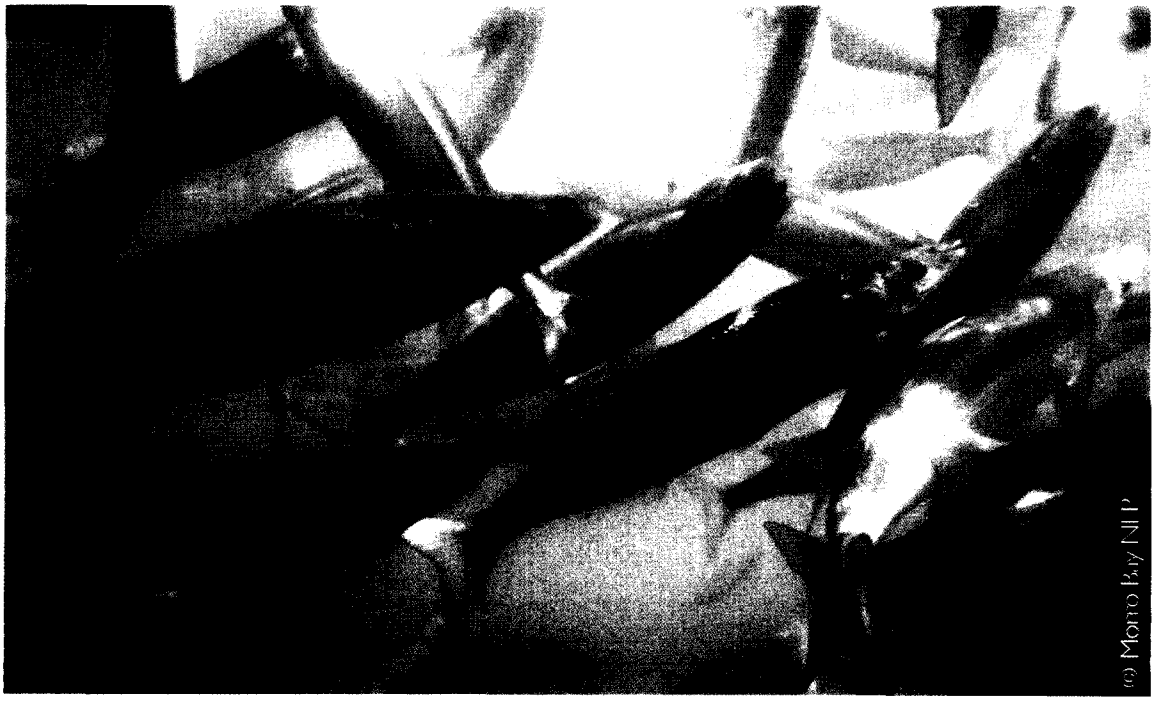
1998, the invasive species cape ivy was a dominant plant in the herb layer of Chorro Creek and was also present along the lower reaches of Los Osos Creek (Morro Bay NEP, 2000).

Living Resources

Measurements of macroinvertebrate populations and diversities are also used to indicate the health of living resources in Morro Bay. Benthic infauna have been monitored annually at a number of creek sites in the Morro Bay watershed. Water quality monitoring provides a snapshot of conditions at that time, whereas macroinvertebrate analysis reflects stream health over a longer time period because long-term water quality affects which species ultimately establish themselves or thrive in the estuary watershed (Kitajima, 2003). The abundance of macroinvertebrates and the ease of sampling also make benthic infauna good environmental indicators.

Central Coast steelhead trout have been listed as a federal threatened species by the NMFS because of declining habitat quality throughout the species range. By 2000, the steelhead population in Morro Bay had decreased to less than 1% of the 1950 population size. Anadromous (migratory) fish are good indicators of resource health because they depend on the entire ecosystem, from the upper watershed to the coastal ocean, for their life cycle (Morro Bay NEP, 2000). Local population size and availability of habitat for this species are two of the indicators used to evaluate living resources in Morro Bay.

Morro Bay is also increasingly being recognized as an area that is critical in supporting resident and migratory bird species. Black brant and other migratory waterfowl utilize the Bay as an overwintering site and as a feeding and resting site during their migration along the Pacific Flyway. Surveys of the black brant population are used to study the density, age composition, and habitat delineation of this species. Average mid-winter, single-day counts of the brant have declined from about 7,000 in the 1930s to roughly 3,000 in 2000 (Roser, 2003). The Morro Bay NEP coordinates biannual surveys of shorebird abundance and diversity, which have shown relatively stable trends since the mid-1990s (Morro Bay NEP, 2006a). The Audubon Society consistently rates Morro Bay as among the top 5 areas (out of 963 sites nationwide) for diversity of winter bird species, with around 200 species and more than 50,000 individual birds counted in a single day in December (Morro Bay NEP, 2000).



Schools of top smelt are common in Morro Bay (Morro Bay NEP).

Current Projects, Accomplishments, and Future Goals

Some of the recent environmental success stories and restoration efforts in Morro Bay include the following:

- Project Clearwater (formerly the Morro Bay Watershed Enhancement Project) has helped farmers and ranchers improve land management practices. These efforts have resulted in the implementation of more than 235 BMPs and helped prevent more than 172,000 tons of soil erosion (CSLRCD, 2006).
- The 1,860-acre Maino Ranch Conservation Easement has been purchased to protect the natural resources, rural character, and working landscape of the Maino Ranch in the Morro Bay watershed. The easement greatly restricts the subdivision and development potential of the ranch (Morro Bay NEP, 2000).
- A 580-acre property spreading below Hollister Peak and across Chorro Creek has become one of California's newest ecological reserves. The Chorro Creek Ecological Reserve, once slated for a golf course and resort, includes approximately two miles of Chorro and San Luisito creeks, as well as large swaths of restorable flood plain near scenic Highway 1. The Morro Bay NEP is working with the California Department of Fish and Game to restore the natural floodplain and freshwater wetlands on this property (Morro Bay NEP, 2006a).
- The Morro Bay NEP's efforts to reduce bacterial pollution include working with the boating community, limiting cattle access to watershed creeks, and encouraging the implementation of a centralized WWTP for the bayside community of Los Osos, which is currently on individual septic systems (Morro Bay NEP, 2000).
- The Central Coast Regional Water Quality Control Board (CCRWQCB) has declared Morro Bay and its creeks as impaired waters for a number of pollutants and has adopted TMDLs covering the estuary and creeks for pathogens, sedimentation, nutrients, and dissolved oxygen (CCRWQCB, 2002a; 2002b; 2004a; 2004b; 2004c; 2005). The Morro Bay NEP is a key component of the implementation and monitoring for these efforts to improve water quality. Specific actions taken to control nutrient inputs to the Bay include implementing nitrogen-control measures for wastewater effluent, improving wastewater treatment in Los Osos, and assisting farmers and ranchers with BMPs (Morro Bay NEP, 2000; 2004).

Conclusion

Based on data from the NCA survey, the overall condition of Morro Bay is rated good. The Morro Bay NEP considers the primary threats facing the estuary and its watershed to be erosion and sedimentation, bacterial contamination, low freshwater flows to the Bay, elevated levels of heavy metals and other toxics in Bay sediments, nutrient over-enrichment, loss of wildlife habitat, and the decline of the local steelhead trout population. The Morro Bay NEP is a collaborative effort that brings local citizens, local government, non-profit agencies, and landowners together to protect and restore the physical, biological, economic, and recreational values of the Morro Bay estuary. The primary goals of the NEP are to slow the process of Bay sedimentation; protect and enhance steelhead trout populations and habitat; protect and restore the integrity of the diverse habitats in the watershed and the wildlife that depend on them; promote public awareness and involvement in estuarine management through outreach, education, and volunteering; and ensure that estuary and creek waters are clean and fully support healthy eelgrass beds, safe recreational uses, and thriving fish and shellfish populations.

Santa Monica Bay Restoration Commission

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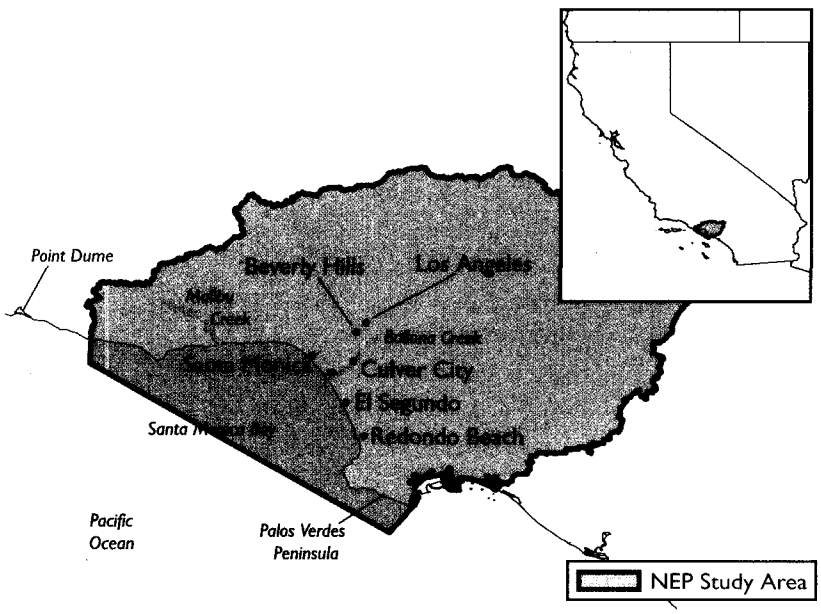


Santa Monica BAY Restoration Commission

www.santamonicabay.org

Background

Santa Monica Bay is a 306-mi^2 estuary located west of Los Angeles on the Pacific Coast of California and bordered on the north by the Santa Monica mountains. The Bay reaches depths of up to 1,640 feet and has a total volume of about 6.8 trillion gallons. The Santa Monica Bay watershed encompasses more than 400 mi^2 and includes a large number of highly populated communities, including Beverly Hills, Calabasas, Culver City, El Segundo, Malibu, Redondo Beach, Santa Monica, West Hollywood, and part of Los Angeles. More than 3 million people live within the watershed, and between 50 to 60 million visits are made to Santa Monica Bay each year. The Bay receives freshwater inputs from 28 stream drainage basins, with the largest flows coming from Malibu Creek and Ballona Creek (Martin et al., 1996).

The Santa Monica region features a range of habitat types, including coastal scrub, wetland and rocky intertidal zones, kelp beds, open water, and both hard- and soft-bottom areas (Martin et al., 1996). The Bay serves as home to more than 5,000 species of birds, fish, mammals, plants, and other wildlife. The Bay's 50 miles of coastline provide recreational opportunities for an

Santa Monica Bay Restoration Commission

estimated 500,000 visitors a day at the height of the summer season (ANEP, 2001d). Sport fisheries are a booming industry, and the Bay is home to chub mackerel, barred sand bass, kelp bass, and California spiny lobster, among other species (Martin et al., 1996). Human development has replaced more than 95% of the Bay's historic coastal wetlands and degraded the remaining 5%, putting some species in danger of local extinction (ANEP, 2001d). Only a few thousand acres of wetlands (e.g., riparian zones, lakes, ponds, coastal marshes, and lagoons) remain in the watershed (Martin et al., 1996).

The State of California and EPA established the Santa Monica Bay Restoration Project (SMBRP) as an NEP in December 1988. The project was formed to develop a plan that would ensure the long-term health of the Bay and its watershed. In January 2003, the SMBRP formally became an independent state organization and is now known as the Santa Monica Bay Restoration Commission (SMBRC) (SMBRC, 2006).

Environmental Concerns

Research suggests that there are 19 pollutants of immediate concern in Santa Monica Bay (SMBRC, 2006). Sources and pathways of contaminants include industrial discharges, urban runoff into creeks and storm drains, municipal WWTPs, boating and shipping activities, dredging, and advection of pollutants from other areas (Martin et al., 1996). About 645 million gallons of treated wastewater are discharged to Santa Monica Bay each day via 7 major point-source facilities and more than 160 permitted smaller commercial and industrial facilities (Martin et al., 1996; SMBRC, 2006). Urban and stormwater runoff carried through the region's massive storm drain systems and few remaining streams is a serious year-round concern. Each year, an average of 30 billion gallons of storm water and urban runoff are discharged through more than 200 outlets into Santa Monica Bay (Martin et al., 1996).

Population Pressures

The population of the 4 NOAA-designated coastal counties (Los Angeles, Orange, San Bernardino, and Ventura) coincident with the SMBRC study area increased by 99.2% during a 40-year period, from 7.4 million people in 1960 to 14.8 million people in 2000 (Figure 6-48) (U.S. Census Bureau 1991; 2000). This rate of population growth for the SMBRC study area was slightly less than the average growth rate of 100.3% observed for the collective NEP-coincident coastal counties of the West Coast region; however, the SMBRC-coincident coastal counties had the second-highest population density in 2000 with 553 persons/mi^2 (U.S. Census Bureau, 2001). This estuary is surrounded by a large, sprawling metropolitan area and is a major recreational area for the local coastal community.

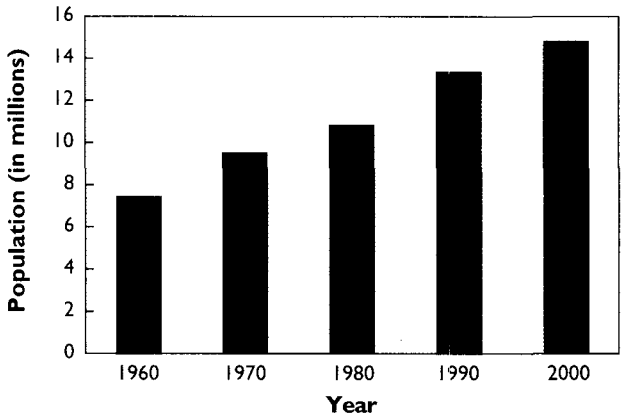


Figure 6-48. Population of NOAA-designated coastal counties of the SMBRC study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

NCA Indices of Estuarine Condition—Santa Monica Bay

The overall condition of Santa Monica Bay is rated fair based on three of the indices of estuarine condition used by the NCA (Figure 6-49). The water quality index is rated good, and the sediment quality and fish tissue contaminants indices are rated poor. Although data on the condition of the benthic community were collected for this estuary, Santa Monica Bay could not be rated using an index based on deviations from the expected species richness. Figure 6-50 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 collected by the Moss Landing Marine Laboratories, under contract to the SCWRRP, from 47 sites sampled the SMBRC estuarine area in 2003. 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.

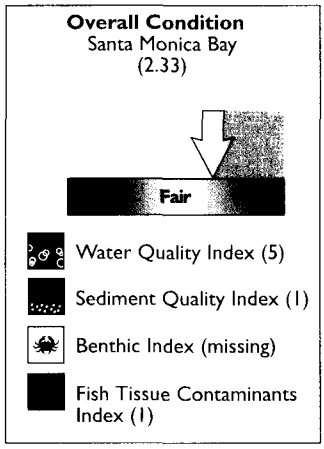


Figure 6-49. The overall condition of the SMBRC estuarine area is fair (U.S. EPA/NCA).

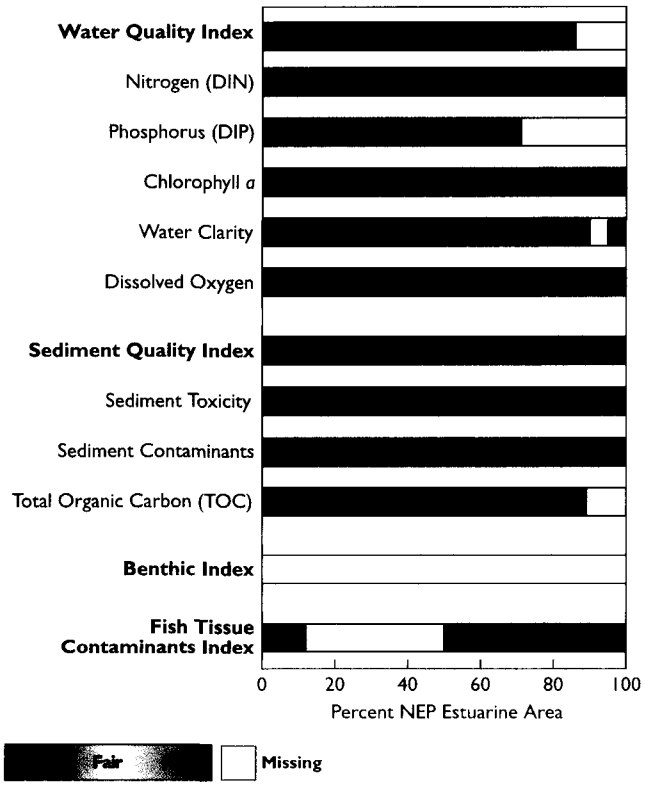


Figure 6-50. Percentage of NEP estuarine area achieving each ranking for all indices and component indicators — Santa Monica Bay (U.S. EPA/NCA).

Water Quality Index

Based on NCA survey results, the water quality index for Santa Monica Bay is rated good. This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Fourteen percent of the estuarine area was rated fair for water quality, and 86% of the area was rated good (Figure 6-51).

Dissolved Nitrogen and Phosphorus | DIN

and DIP concentrations in Santa Monica Bay are rated good. All of the estuarine area was rated good for DIN concentrations, whereas 29% of the area was rated fair for DIP concentrations. In addition to natural inputs of nutrients from offshore coastal upwelling, high levels of urban and agricultural runoff may also be major contributors to the nutrient levels found in Santa Monica Bay.

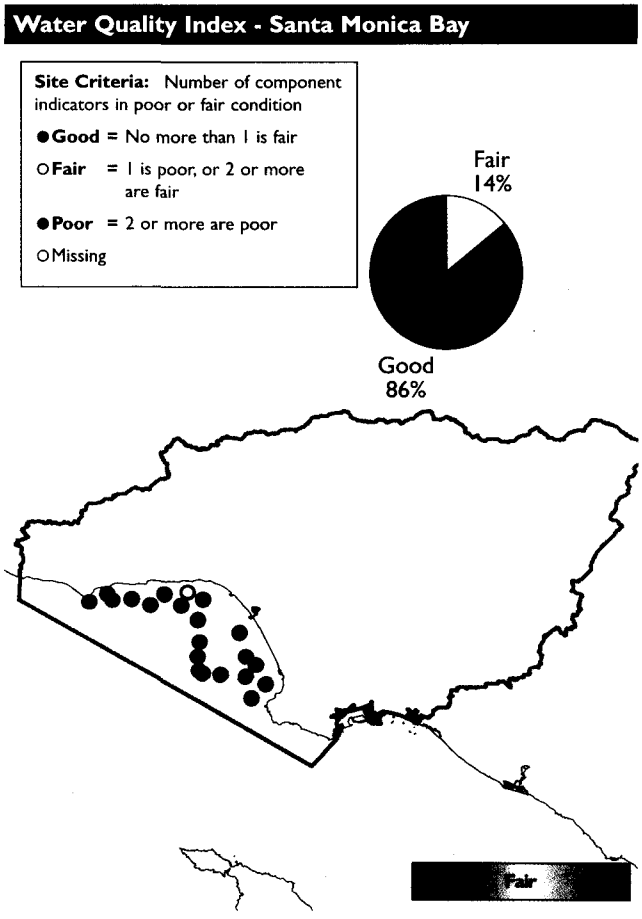


Figure 6-51. Water quality index data for Santa Monica Bay, 2003 (U.S. EPA/NCA).

Chlorophyll a | Chlorophyll *a* concentrations in Santa Monica Bay are rated good, with 100% of the estuarine area rated good for this component indicator.

Water Clarity | Water clarity in Santa Monica Bay is rated good. Approximately 5% of the estuarine area was rated poor for this component indicator, and 5% of the area was rated fair.

Dissolved Oxygen | Dissolved oxygen conditions in Santa Monica Bay are rated good, with 100% of the estuarine area rated good for this component indicator. It should be noted that these measured values reflect daytime dissolved oxygen conditions, and some areas of the Bay may still experience hypoxic conditions at night.

Sediment Quality Index

The sediment quality index for Santa Monica Bay is rated poor. This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC. Fifty-nine percent of the estuarine area exceeded thresholds for at least one of these component indicators and was rated poor, and 41% of the estuarine area was rated good (Figure 6-52).

Plover (Brad Ashbaugh).

Sediment Toxicity | Sediment toxicity for Santa Monica Bay is rated poor, with 21% of the estuarine area rated poor for this component indicator.

Sediment Contaminants | Santa Monica Bay is rated poor for sediment contaminant concentrations, with 59% of the estuarine area rated poor for this component indicator.

Total Organic Carbon | Sediment TOC for Santa Monica Bay is rated good, with 89% of the estuarine area rated good for this component indicator.

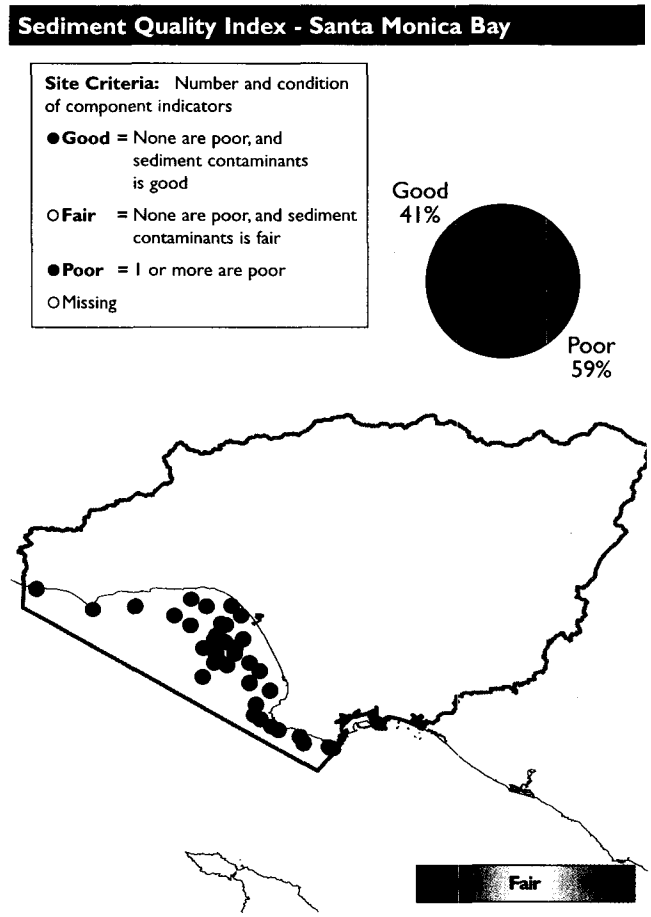


Figure 6-52. Sediment quality index data for Santa Monica Bay, 2003 (U.S. EPA/NCA).

Benthic Index

Presently, the condition of the benthic invertebrate communities in Santa Monica Bay can not be rated using an index based on deviations from the expected species richness because this approach requires a significant regression between salinity and the log of species richness. This relationship was not significant in the Santa Monica Bay data collected during the 2003 NCA survey.

Fish Tissue Contaminants Index

The fish tissue contaminants index for Santa Monica Bay is rated poor because 50% of the stations where fish were caught were rated poor (Figure 6-53). However, this rating should be interpreted cautiously because of the small number of Bay stations (8) where fish tissues were collected.

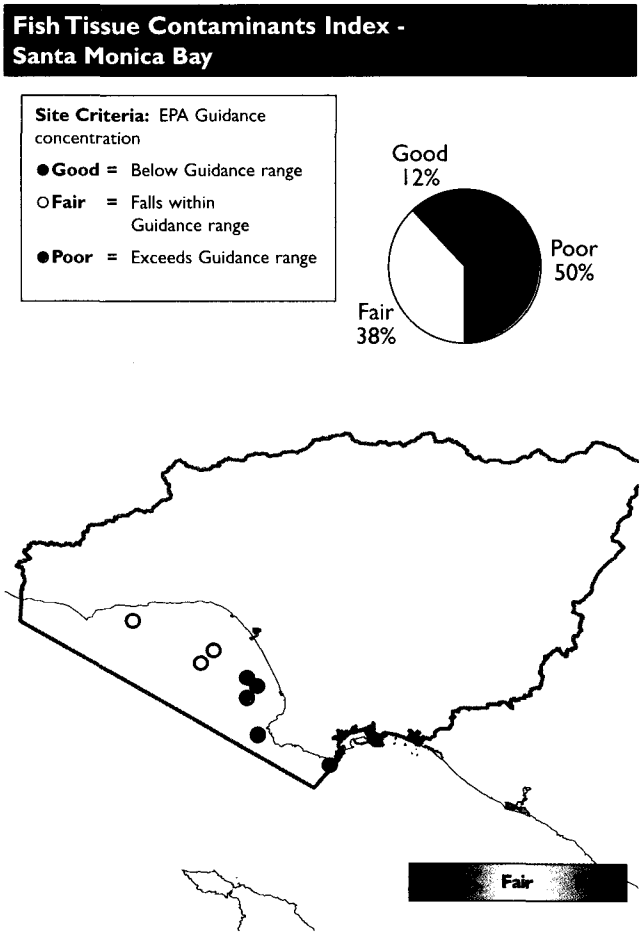


Figure 6-53. Fish tissue contaminants index data for Santa Monica Bay, 2003 (U.S. EPA/NCA).

Santa Monica Bay Restoration Commission Indicators of Estuarine Condition

The SMBRC is using or developing several indicators to evaluate water and sediment quality, habitat conditions, and stressors for the SMBRC estuarine area. Indicators are typically ranked with regard to availability of data for reporting on the state of the Bay; some of the indicators of higher quality are described below.

Water and Sediment Quality

Indicators used by the SMBRC for water and sediment quality include the following:

- Concentrations of five heavy metals: cadmium, copper, lead, silver, and zinc
- Concentrations of fecal and total coliform bacteria and *Enterococci* (pathogen indicators)
- Beach Report Card grades (summer and winter) based on measurement of bacterial indicators
- Number and effectiveness of pathogen-reduction projects along the Bay's beaches (SMBRC, 2004).

Since the early 1970s, the loading of seven heavy metals from the two largest WWTPs has decreased by 67% to 99%, and the loading of total suspended solids has decreased by more than 80%. As a result, impaired estuary bottom habitats near discharge outfalls have shown signs of recovery (SMBRC, 2006).

Monitoring of bacterial indicators on beaches is usually conducted on a daily basis (Heal the Bay, 2004). In general, the number of days per year during which at least one beach is closed due to sewage spills has greatly decreased (ANEP, 2001d). The environmental group Heal the Bay compiles grades for a Beach Report Card system based on bacterial indicator measurements. The 2003–2004 Annual Beach Report Card (Heal the Bay, 2004) shows that most beaches had very good water quality, with 268 of 373 (72%) locations receiving A grades for the year during dry weather. In addition, other grade ratings included 44 B grades (12%), 27 C grades (7%), 15 D grades (4%), and 19 F grades (5%). The monitored beach with the poorest dry weather water quality during 2003 and 2004 was Surfrider Beach (Heal the Bay, 2004).

Santa Monica Bay Restoration Commission

HIGHLIGHT

Santa Monica Bay Stormwater Projects

The SMBRC is taking many different approaches to address the issue of pollutants found in stormwater runoff (see table). Since 1992, the SMBRC has secured more than $30 million in state and local bond funding for more than 30 pollution-control projects, including dry-weather runoff diversions from storm drain outlets along Santa Monica Bay beaches, a state-of-the-art urban runoff treatment and reclamation facility in Santa Monica, and many devices to capture trash, oil, grease, and sediments in storm drains throughout the watershed (SMBRC, 2006).

Many of the SMBRC projects funded to date have been in the Ballona Creek watershed. Before its extensive settlement and urbanization, Ballona Creek was a meandering perennial stream that was lined with dense vegetation and met the Pacific Ocean in a broad expanse of tidal lagoons, salt marshes, and wetlands. Today, Ballona Creek is a nine-mile long flood-protection channel that drains the Los Angeles basin, including all or parts Beverly Hills, Culver City, Inglewood, Los Angeles, Santa Monica, West Hollywood, and unincorporated Los Angeles County. To address impairments to waterbodies in the Ballona Creek watershed, the SMBRC, in partnership with the Los Angeles County Department of Public Works, the City of Los Angeles, and the Ballona Creek Renaissance, led the efforts of the Ballona Creek Task Force and developed a comprehensive watershed management plan for Ballona Creek. This work is essential towards efforts to restore the water quality and ecology of Santa Monica Bay and its watershed (SMBRC, 2006).

Examples of Approaches to Managing Stormwater Runoff

- Structural BMPs, such as dry-weather runoff diversion, installation of in-stream trash capture devices and catchbasin retrofits, and installation of filtration devices along roadways or in parking lots
- Public education and outreach
- Elimination of illicit connections and illegal discharges to the storm drains via enhanced storm drain inspections and improved ordinances
- Non-structural BMPs, such as catchbasin stenciling, enhanced catchbasin/trash can cleanings, and street sweeping
- New land-use practices to increase on-site stormwater infiltration and reduce erosion
- Promotion and enforced implementation of BMPs at industrial facilities and construction sites (SMBRC, 2006).

Recent Stormwater Pollution-Prevention Projects (SMBRC, 2006)

Project	Jurisdiction	Cost	Treatment Device(s)	Purpose
Ballona Creek Litter Collection Project	County of Los Angeles	$600,000	200 catchbasin debris-excluder devices and several vortex separation systems	Capture, analyze, and characterize trash from eight different land-use types
Ballona Creek Water Quality Improvement Project	City of Culver City	$168,500	Continuous deflective separation (CDS) device	Reduce total suspended solids, hydrocarbons, oil, grease, and trash
Pollutant Removal Devices in Storm Drain System	City of Los Angeles	$1,336,000	Urban stormwater devices in Ballona Creek watershed. Trash collection devices will be installed at four locations in south central Los Angeles and a gravity system will be installed in an industrial land-use area of Manchester	Remove sediment, metals, oil, and grease
Pollutant Removal Devices in Storm Drain System	City of Santa Monica	$500,000	Two-stage filter system to remove pollutants from a catchment discharging to Ballona Creek	Remove gross solids and floatables (Stage 1) and additional trash, sediment, and soluble compounds (Stage 2)
Pollutant Removal Devices in Storm Drain System	City of Manhattan Beach	$215,000	CDS devices	Reduce total suspended solids, hydrocarbons, oil, grease, and trash
Catchbasin Debris Excluder Devices	City of West Hollywood	$30,000	20 catchbasin debris-excluder devices	Reduce the amount of litter and debris

Santa Monica Bay Restoration Commission

Habitat Quality

A variety of indicator measures are being evaluated by the SMBRC to help monitor the range and condition of habitats that exist in this estuary system. Examples of the indicator measures being considered for habitat loss or change over time are the following:

- Acres of wetlands gained or lost and the number of acres of riparian habitat (e.g., wetlands and open habitat areas)
- Size of kelp canopy and abundance of kelp beds along the Palos Verdes Shelf and Malibu coast
- Concentration of metals in Bay sediments and condition of benthic community (benthic habitat) (SMBRC, 2004).

Measurements of the size and abundance of kelp beds in this estuary system are considered to be good indicators for evaluating this important habitat and resource. From the mid-1970s to 1997, improved wastewater treatment processes resulted in an 80% reduction in discharge of total suspended solids from the White Point outfall. This reduction, along with kelp replanting efforts in the 1970s, resulted in a remarkable increase in kelp canopy, from a low of 5 acres in 1974 to a peak of more than 1,100 acres in 1989 (SMBRC, 2006).

Concentrations of heavy metals (e.g., lead, copper, zinc, mercury) in Bay sediments are considered an important indicator for evaluating the condition of benthic habitats. The City of Los Angeles' Environmental Monitoring Division has data from 1974–2003 and has indicated that soft-bottom habitats have been one of the most highly impacted habitats in this estuary, primarily due to discharges from STPs. The Marina Del Rey Harbor, the Palos Verdes Shelf, and the Ballona Creek Entrance Channel have typically been some of the hot spots for concentrations of DDT, PCBs, copper, zinc, or other contaminants in sediment (SMBRC, 2006).

Living Resources

One of the key indicators used by the SMBRC for evaluating living resources is the CPUE of select resident species in Santa Monica Bay. Species that can serve as indicators include rockfish, surf perches, kelp bass, sand bass, sheepshead, and halibut. Species that could be potential indicators, but for which no current data exist, include red sea urchins and spiny lobsters (SMBRC, 2006).

Changes in the abundance of target species (e.g., rockfish, sea stars, mussels) and in species diversity within intertidal zones are considered two good quality indicators, but adequate data are not yet available. The

The SMBRC evaluates the size and abundance of kelp beds in Santa Monica Bay (NOAA).

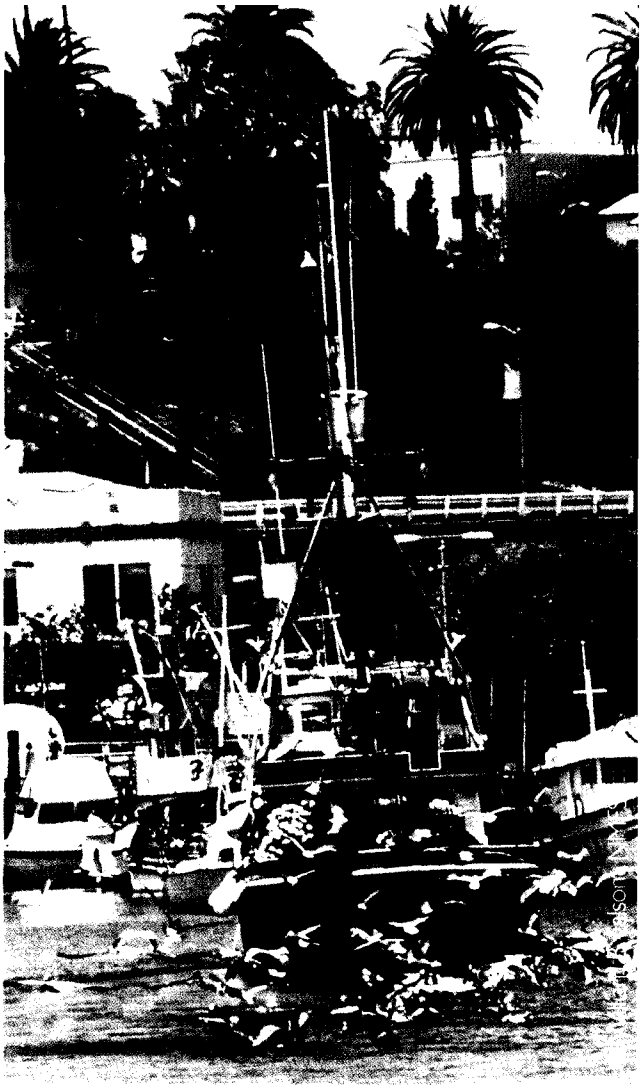
condition of runs for the amazing grunion fish population is also an indicator being considered (SMBRC, 2004). Evidence suggests that many rockfish species have been experiencing significant population declines due to overfishing along the West Coast, including species in Santa Monica Bay. According to federal assessments, bocaccio (one type of rockfish) has declined to about 5% of its historic abundance (SMBRC, 2006). Another source of concern is the rapid decline of black abalone, a rocky intertidal species. Although the cause of the decline of this species is not completely understood, researchers have speculated that a combination of over-harvesting, predation, competition, environmental changes, and disease may be responsible (SMBRC, 2006).

One of the major environmental concerns facing the SMBRC is improving the status of threatened and endangered species in Santa Monica Bay, while minimizing and/or eliminating the varied effects of invasive species. The measurement of the number of acres of invasive plant species and the number of invasive predators are indicators under development to assess the threats to the ecosystems and living resources in Santa Monica Bay. Invasive plants and animals (e.g., the giant reed, castor bean, wild tree tobacco, crayfish, bullfrog, mosquito fish, and largemouth bass) have decreased the biological diversity of native ecosystems by outcompeting or displacing native species. They also reduce habitat availability and water quality for native species in Santa Monica Bay (SMBRC, 2006).

Data on levels of DDT and PCBs in white croaker and kelp bass tissue are reported by the Los Angeles County Sanitation Districts, EPA, and the Montrose Settlements Restoration Program. These indicators are considered to be the most useful for evaluating health risks associated with seafood consumption (SMBRC, 2004). Average concentrations of DDT and PCBs in most seafood species have fallen to near or below levels of concern for human consumption, but remain high in white croaker collected on the Palos Verdes shelf (ANEP, 2001d; U.S. EPA, 2006e). Fish consumption advisories have been posted in the Bay area since 1985 (U.S. EPA, 2005a).

Environmental Stressors

Information collected on the amount of trash in Bay waterways shows that more than 4,000 tons of trash are collected from Santa Monica Bay beaches each year (Martin et al., 1996). Additionally, a 1994 survey found that 25% of bottom sediments sampled in Santa Monica Bay contained man-made materials of some kind (SMBRC, 2006).



Pelicans following a fishing boat into the harbor (William B. Folsom, NMFS).

Santa Monica Bay Restoration Commission

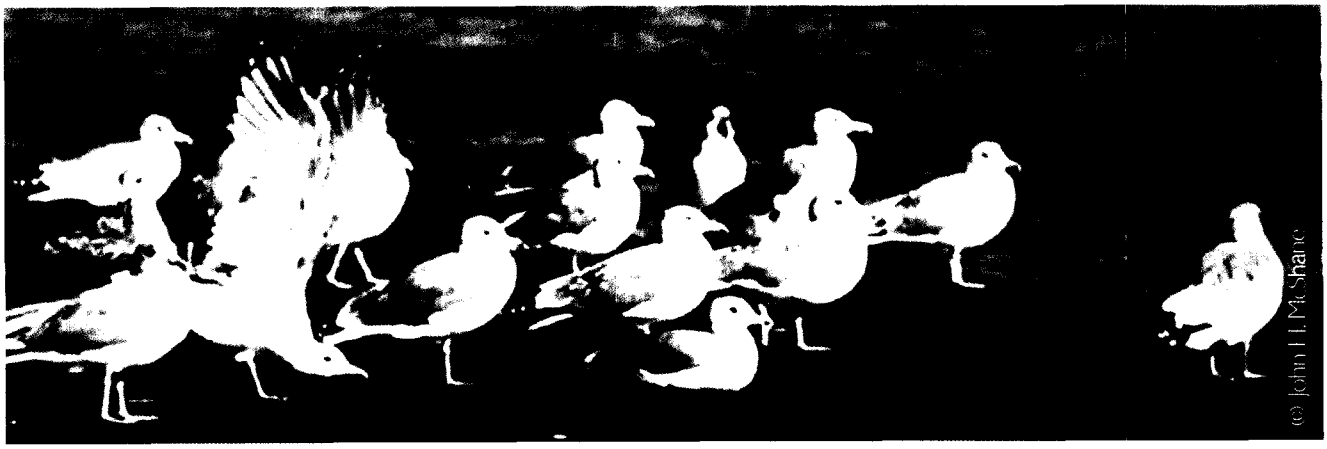
Current Projects, Accomplishments, and Future Goals

Some of the environmental accomplishments and restoration efforts in the Santa Monica Bay area include the following:

- Development of a comprehensive Bay-wide monitoring program and funding for an in-depth study to assess the loading of toxic air pollutants to the watershed (ANEP, 2001d).
- Completion of upgrades to full secondary treatment by the Los Angeles Hyperion Wastewater Treatment Plant and Wastewater Pollution Control Plant operated by the Los Angeles County Sanitation District, which greatly reduces the amount of direct waste discharge to the Bay.
- Approval of a Santa Monica ordinance to reduce the amount of urban runoff pollution that reaches Santa Monica Bay, requiring a 0.75" reduction in rainfall leaving impermeable surfaces of newly developed parcels in the city (City of Santa Monica, 2006).
- An EPA-conducted pilot program to cap contaminated sediments with clean sediment in DDT/PCB-contaminated areas of the Palos Verdes shelf.
- Provision of more than $450,000 by the SMBRC to community groups, local governments, and schools to educate and inspire people of all ages to take care of Santa Monica Bay (ANEP, 2001d).
- Acquisition by the State of California of 483 acres of the Ballona wetlands, the largest remaining coastal wetland in the Santa Monica Bay ecosystem (The Trust for Public Land, 2003).
- Restoration of the Zuma Lagoon and wetland, the first coastal freshwater wetland project in the area (ANEP, 2001).

Conclusion

Santa Monica Bay faces a series of environmental challenges. Sediment quality in the Bay is still threatened by levels of DDT, PCBs, copper, and zinc. Most recreational beaches in the estuary have very good water quality, as evidenced by the local Beach Report Card system, but the amount of trash and debris entering the Bay is still a significant concern. The monitoring of certain target species of fish and wildlife (e.g., rockfish, black abalone) and other threatened resources in this estuary is important to control population declines. In addition, invasive species still have an impact on the natural plant and animal populations in the watershed because they crowd out native biota and damage functioning ecosystems. Habitat conditions in the Santa Monica Bay estuary are being continually monitored by the SMBRC and its partners to prevent declines in the size and quality of wetlands, riparian habitat, kelp beds, and intertidal habitats. In addition, the SMBRC is faced with educating Los Angeles' diverse audiences about the importance of pollution prevention and environmental restoration, as well as implementing a comprehensive monitoring program to more effectively assess the condition across the Bay. Based on data from the NCA estuarine survey, the overall condition of Santa Monica Bay is rated fair.



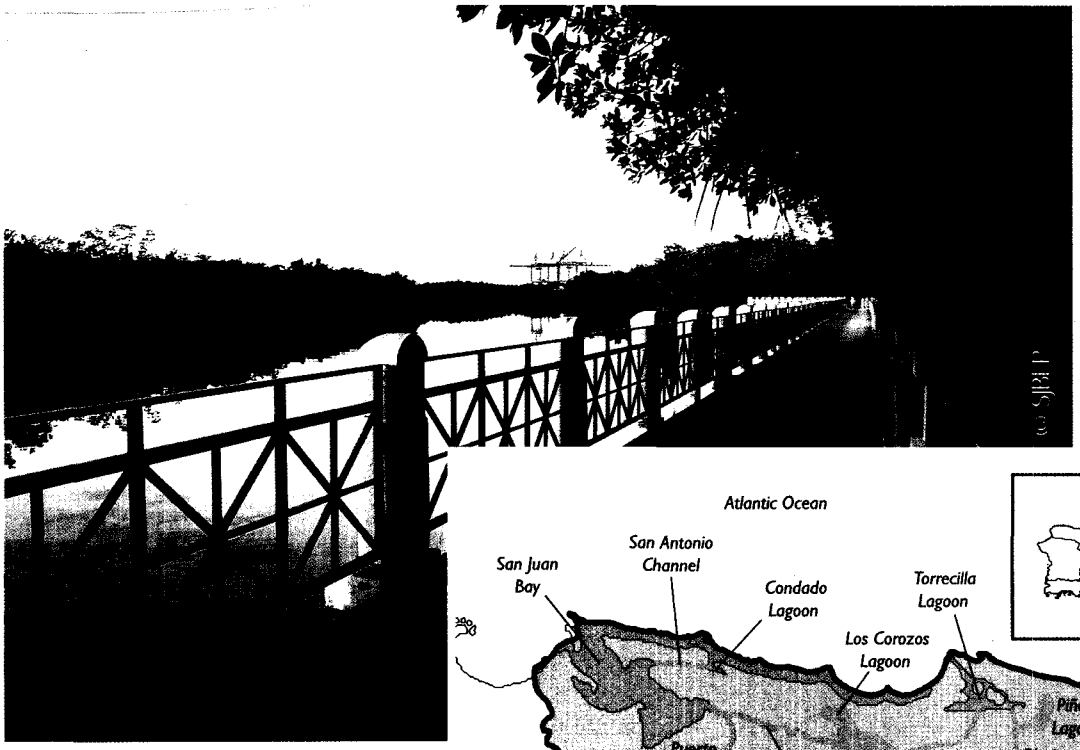
Seagulls rest on a sand bar (John H. McShane).

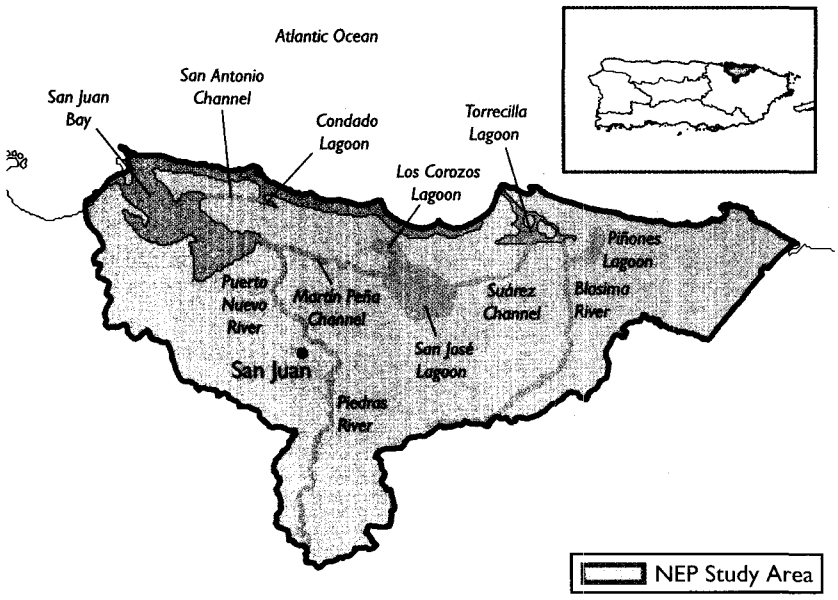
CHAPTER 7

PUERTO RICO NATIONAL ESTUARY PROGRAM COASTAL CONDITION

San Juan Bay Estuary Partnership

San Juan Bay Estuary Partnership





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Background

Located on the northern coast of the island territory of Puerto Rico, the San Juan Bay Estuary (Estuario de la Bahía de San Juan) is semi-enclosed by the surrounding mainland, mangroves, and wetlands and is linked to the Atlantic Ocean via a series of interconnected bays, channels, and lagoons. This estuarine system includes San Juan Bay; the Martín Peña, San Antonio, and Suárez channels; and the Condado, Los Corozos, San José, Torrecilla, and Piñones lagoons. Multiple tributaries flow into the San Juan Bay Estuary, the largest being the Puerto Nuevo River. Salt water enters the Estuary from the Atlantic Ocean through the Boca del Morro to San Juan Bay, through El Boquerón to Condado Lagoon, and through Boca de Cangrejos to Torrecilla Lagoon. The limited flushing capacity and low tidal range of this estuarine system make the San Juan Bay Estuary susceptible to the retention of toxic pollutants (Martin et al., 1996).

For centuries, the San Juan Bay Estuary has provided a number of invaluable resources for the residents of Puerto Rico, including commercial port facilities, beaches, recreational parks, and natural and historic areas; however, the societal needs associated with the

growth of the surrounding population have resulted in the degradation of the natural resources of this system. Recognizing the constant threats to the Estuary, the Governor of Puerto Rico nominated San Juan Bay Estuary for inclusion into EPA's NEP in 1992, leading to the official creation of the San Juan Bay Estuary Partnership (SJBEP).

Environmental Concerns

One of the SJBEP's first tasks was to identify the priority problems of the San Juan Bay Estuary. To carry out this task, the SJBEP considered information from different scientific studies, expert scientific opinion, and public meetings and workshops. Based on these combined inputs, the SJBEP is addressing the following problems (listed in order of importance):

- Poor water circulation
- Illegal sanitary discharges
- Contamination by toxic substances and nutrients
- Lack of an ecosystem management plan
- Lack of community participation.

Population Pressures

The SJBEP study area is coincident with eight urban municipalities on the northeast coast of Puerto Rico. The population of these coastal municipalities (Bayamón, Carolina, Cantaño, Guaynabo, Loiza, San Juan, Toa Baja, and Trujillo Alto) was almost 1.18 million people in 2000 (Figure 7-1), and the population density was 5,055 persons/mi^2 (U.S. Census Bureau, 2001). This represents the highest population density observed for any of the 28 NEPs—more than 60% higher than the population density of the counties coincident with the HEP study area. Development and population pressures are especially strong surrounding the San Juan Bay Estuary, which has long served as a center of commerce and shipping in the Caribbean and is currently a center for commercial and recreational fisheries and recreational activities for the area's highly urbanized island community.

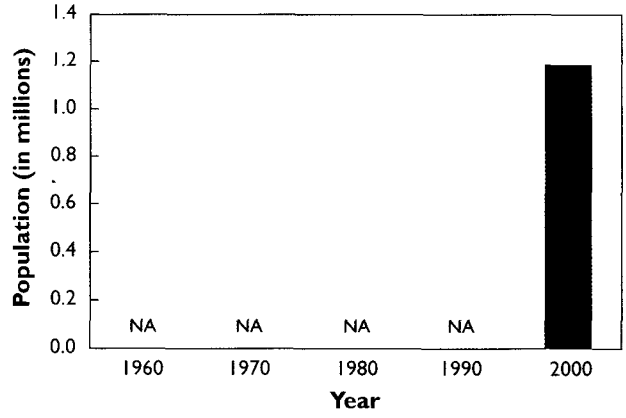


Figure 7-1. Population of the coastal municipalities coincident with the SJBEP study area, 1960–2000 (U.S. Census Bureau, 1991; 2001).

San Juan Bay Estuary Partnership

The following sections of this report discuss 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 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 assessments 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.

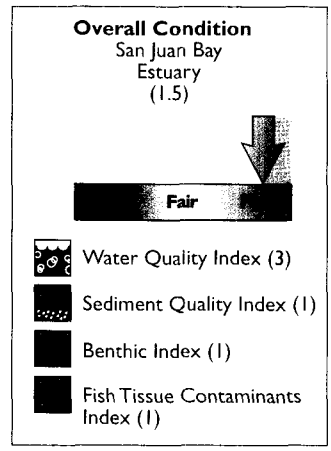


Figure 7-2. The overall condition of the SJBEP estuarine area is poor (U.S. EPA/NCA).

NCA Indices of Estuarine Condition—San Juan Bay Estuary

In the winter of 2002, EPA's Region 2 conducted a survey in the San Juan Bay Estuary that focused on generating a comprehensive biological and chemical assessment of sediment throughout the Estuary (U.S. EPA, 2002b). In partnership with the NCA, a survey design and data-collection strategy that was compatible with EPA's NEP assessment effort was employed. Thirty-four sites were visited during this survey for the SJBEP assessment. Additionally, Region 2 conducted an independent fish tissue contaminants survey in San José Lagoon—a coastal lagoon within the San Juan Bay Estuary system—and the data from this survey contributed to the fish tissue contaminants evaluation for this Estuary.

Based on the data collected during the Region 2 survey efforts, the overall condition of the San Juan Bay Estuary is rated poor (Figure 7-2). The water quality index for the Estuary is rated fair, and the sediment quality, benthic, and fish tissue contaminants indices are rated poor. Figure 7-3 shows the percent of estuarine area rated good, fair, poor, and missing for each parameter considered. 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.

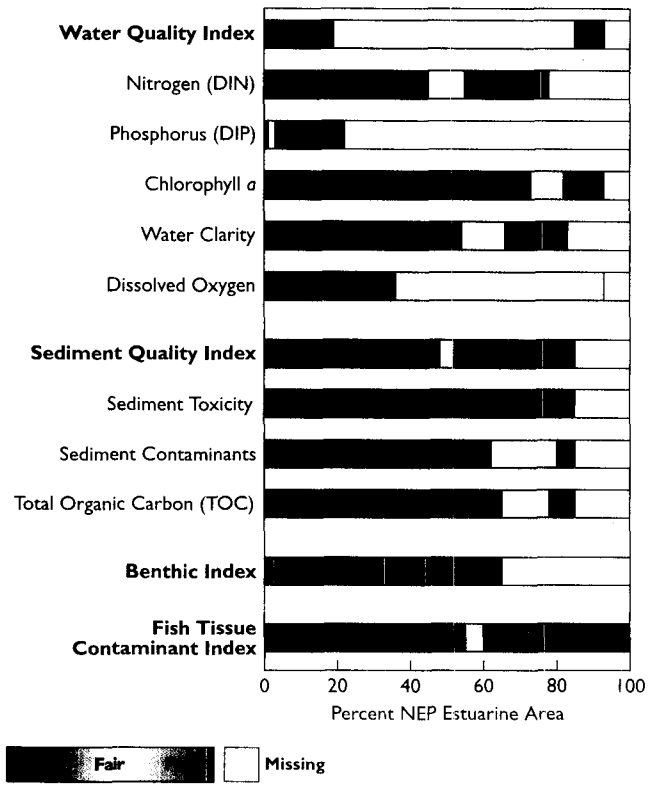


Figure 7-3. Percentage of NEP estuarine area achieving each ranking for all indices and component indicators — San Juan Bay Estuary.

Water Quality Index

The water quality index for San Juan Bay Estuary is rated fair because 74% of the estuarine area was rated fair or poor for water quality (Figure 7-4). This index was developed using NCA data on five component indicators: DIN, DIP, chlorophyll *a*, water clarity, and dissolved oxygen. Threshold values used to determine the condition of individual water quality parameters were based on those used by the NCA for assessing tropical waters (see Chapter 1 for additional details), and all water quality component indicators were rated fair.

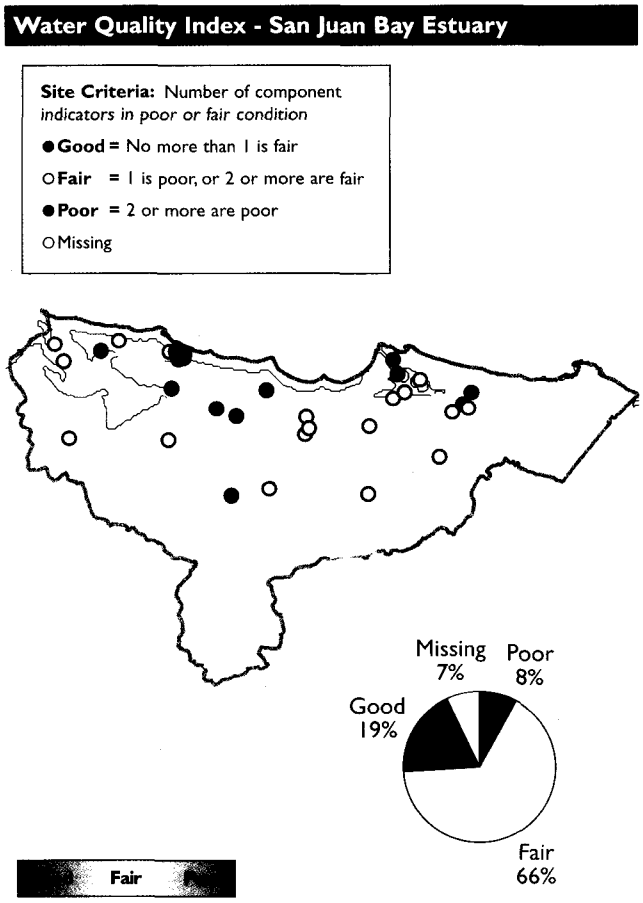


Figure 7-4. Water quality index data for San Juan Bay Estuary, 2002 (U.S. EPA/NCA).

Dissolved Nitrogen and Phosphorus | The San Juan Bay Estuary is rated fair for both DIN and DIP concentrations. With respect to DIN concentrations, 45% of the estuarine area was rated good, 10% was rated fair, and 23% was rated poor. Poor DIP levels occurred in 19% of the estuarine area, with 2% of the area rated fair and only 1% of the area rated good; however, NCA data on DIP concentrations were unavailable for 78% of the SJBEP estuarine area.

Chlorophyll a | Chlorophyll *a* concentrations in the San Juan Bay Estuary are rated fair. The NCA survey results showed good chlorophyll *a* conditions for 73% of the estuarine area, with 9% of the area rated fair and 11% of the area rated poor. NCA data on chlorophyll *a* concentrations were unavailable for 7% of the SJBEP estuarine area.

Water Clarity | Water clarity for the San Juan Bay Estuary is rated fair. For tropical waters, a range of 20% to 40% expected light penetration at 1 meter is considered fair. Measurements above this range are considered good, and those below are considered poor. In the San Juan Bay Estuary, only Secchi depth measurements were available to assess water clarity. A light extinction coefficient was calculated for each Secchi depth reading and compared to the light extinction coefficient of the expected or reference value (at 1 meter) appropriate for the region (Smith et al., 2006). These evaluations show that 54% of the estuarine area was rated good for water clarity, 12% was rated fair, and 17% was rated poor. Water clarity data were unavailable for 17% of the SJBEP estuarine area.

Dissolved Oxygen | The San Juan Bay Estuary is rated fair for dissolved oxygen concentrations. Estimates show that 57% of the estuarine area was rated fair, 36% of the area was rated good, and none of the area was rated poor. NCA data on dissolved oxygen concentrations were unavailable for 7% of the SJBEP estuarine area.

San Juan Bay Estuary Partnership

Sediment Quality Index

The sediment quality index for San Juan Bay Estuary is rated poor (Figure 7-5). This index was developed using NCA data on three component indicators: sediment toxicity, sediment contaminants, and sediment TOC. About one-third (33%) of the estuarine area was rated poor for sediment quality, and another 4% was rated fair. NCA data on sediment quality were unavailable for 15% of the SJBEP estuarine area.

Sediment Toxicity | The San Juan Bay Estuary is rated poor for sediment toxicity. Twenty-nine percent of the estuarine area was rated poor for this component indicator, and 56% of the area was rated good. NCA data on sediment toxicity were unavailable for 15% of the SJBEP estuarine area.

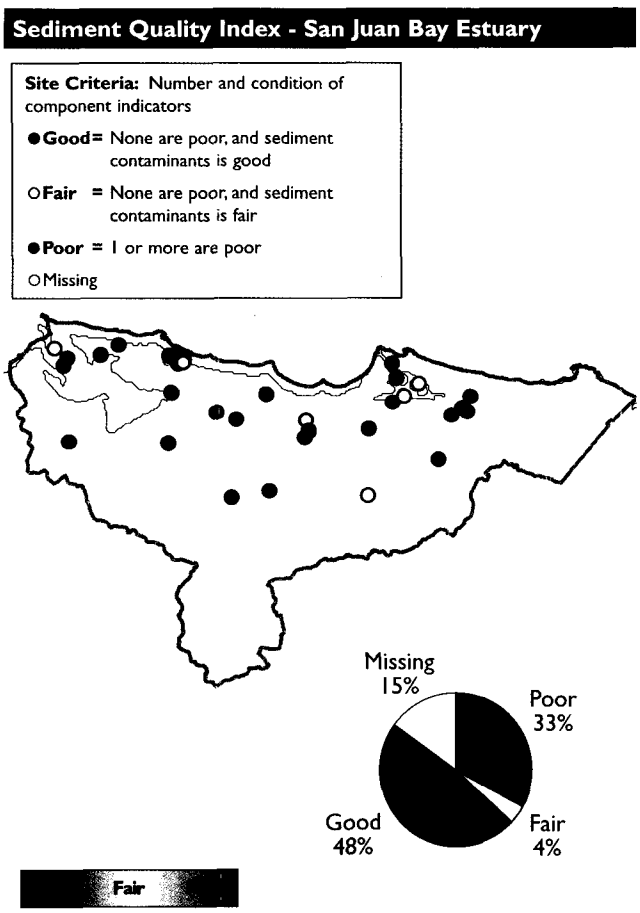


Figure 7-5. Sediment quality index data for San Juan Bay Estuary, 2002 (U.S. EPA/NCA).

Sediment Contaminants | The San Juan Bay Estuary is rated fair for sediment contaminant concentrations. Five percent of the estuarine area was rated poor for sediment contaminants, and 18% of the area was rated fair. NCA data on sediment contaminant concentrations were unavailable for 15% of the SJBEP estuarine area.

Total Organic Carbon | TOC concentrations in the sediments of the San Juan Bay Estuary are rated good, with 65% of the estuarine area rated good for this component indicator. TOC concentrations were rated fair and poor in 13% and 7% of the estuarine area, respectively, and NCA data on this component indicator were unavailable for 15% of the SJBEP estuarine area.

Benthic Index

A benthic index has not been developed for Puerto Rico. As a surrogate for benthic condition, benthic samples from the San Juan Bay Estuary were examined using ecological community indicators that contribute to all of the benthic indices developed by the NCA for the Northeast Coast, Southeast Coast, and Gulf Coast regions, and benthic diversity was used directly to evaluate benthic condition. If benthic diversity was less than 75% of the observed mean diversity for all locations sampled in Puerto Rico during the NCA surveys, the site was rated poor.

The benthic index for the San Juan Bay Estuary is rated poor because 65% of estuarine area had low benthic diversity and was rated poor (Figure 7-6). Benthic diversity data were unavailable for the remaining 35% of the estuarine area. When the areas that were rated poor for benthic condition were compared with the areas rated poor for water and sediment quality, it was determined that all of the SJBEP areas with low benthic diversity were also rated poor for at least one other index. Eighty-three percent of the area with low benthic diversity co-occurred with both poor sediment and water quality condition; 10% co-occurred with only poor sediment quality conditions; and 7% occurred with only poor water quality conditions.

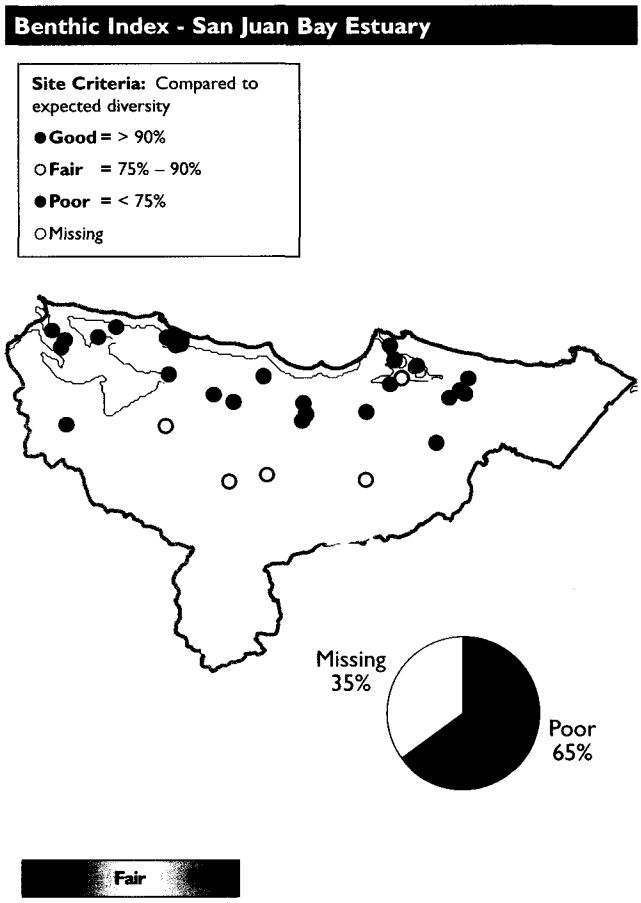


Figure 7-6. Benthic index data for San Juan Bay Estuary, 2002 (U.S. EPA/NCA).

Fish Tissue Contaminants Index

The results from a separate survey conducted in the San José Lagoon, one of the larger coastal lagoons within the San Juan Bay Estuary, were used as a surrogate for the NCA's fish tissue contaminants evaluation. The goals of the San José Lagoon survey were to evaluate whether toxic compounds were present in edible fish and shellfish tissues and to develop risk-based human health consumption advisories for the Lagoon. The survey design partitioned the Lagoon into four quadrants that were as equal in size as geographically possible. Trawls were conducted in each of these quadrants to collect tissue samples from four target species: blue crab (*Callinectes sapidus*), yellowfin mojarra (*Eugerres cinereus*), striped mojarra (*Eugerres brasilianus*), and snook (*Centropomus sp.*). Five individuals of each species were culled for contaminant analysis. Finfish fillets (with skin) and separate crab tissue and hepatopancreas samples were used for analysis (U.S. EPA, 2000d).

Based on the concentrations of contaminants found in fish and crustacean tissues during the San José Lagoon survey, the fish tissue contaminants index for the San Juan Bay Estuary is rated poor because 40% of all samples analyzed for contaminants exceeded EPA Advisory Guidance values (Figure 7-7).

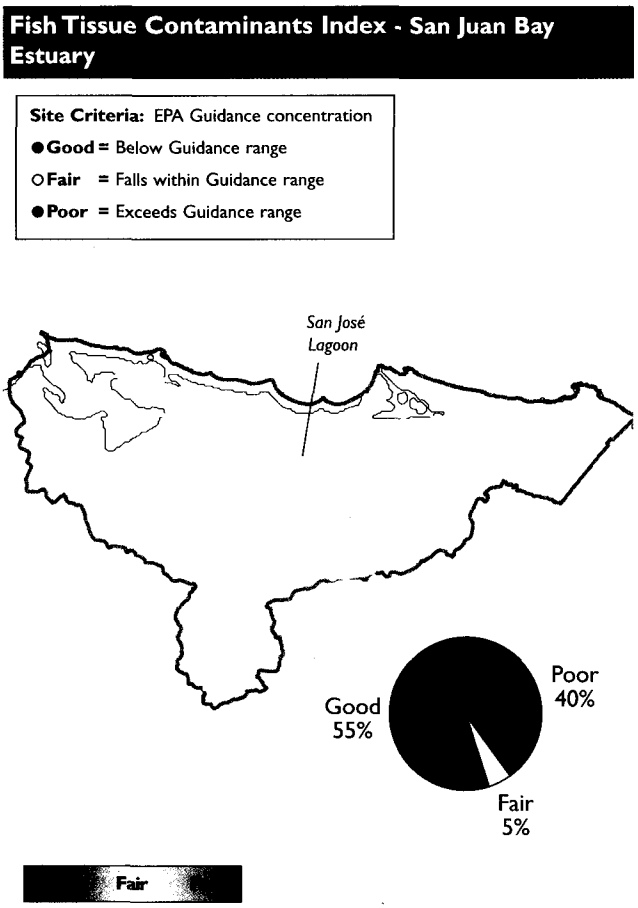


Figure 7-7. Fish tissue contaminants index data for San Juan Bay Estuary, 2002 (U.S. EPA/NCA).

San Juan Bay Estuary Partnership

HIGHLIGHT

Getting the Message to the People—The San Juan Bay Estuary Partnership Educational Outreach Efforts

The SJBEP has been working very hard in the area of educational outreach. Several projects have been implemented to increase public awareness of the Estuary and its ecological importance.

Bay Day Festival of the Estuary

The SJBEP held its first Bay Day Festival of the Estuary: Two Windows, Land and Sea (Festival del Estuario: Dos Ventanas, Tierra y Mar) in May 2003. A large number of people participated in the festival, which included more than 30 environmental art exhibitions and presentations; diving and kayaking lessons; and environmental arts and crafts workshops, as well as a number of activities specifically designed for children. Numerous local artists participated in the festival, which received significant coverage from various media, including television, radio, and newspaper. The event also provided the setting for the expansion and continuation of cooperative efforts and collaborations between federal and local government agencies, community groups, and the SJBEP.

Teacher Training Workshops

Workshops developed and presented on environmental topics train local teachers about the effective use of San Juan Bay Estuary environmental education curriculum and related educational materials. In October 2004, one workshop for private school science teachers drew more than 100 participants. These one-day workshops take place periodically and have the support of the Department of Education, which sent out an official announcement to the schools located around San Juan Bay Estuary. The workshops provide a session on the use and application of the curriculum and feature information on the ecological values of the San Juan Bay Estuary system, environmental threats to the Estuary, and proposed solutions. Workshops also include environmental games and presentations by representatives from the Puerto Rico Department of Natural and Environmental Resources, Environmental Quality Board, Solid Waste Management Authority Agency, Highway and Transportation Agency, and the group working on restoration of the Cucharillas marsh.

This fish and wildlife exhibit shows species that are in danger of extinction (Susan Rivera, SJBEP).

School Day for the San Juan Bay Estuary

The School Day for the San Juan Bay Estuary encourages students to complete a project related to the Estuary. Students from the municipalities coincident with the SJBEP study area are invited to participate and submit abstracts of possible projects. The participating schools then plan an environmental activity that focuses on conservation efforts for the Estuary, and these activities are normally completed in April as part of the Earth Day celebration. Past student projects have involved a variety of activities, including beach cleanups, recycling, theater plays, monologues, and poster- and wall-painting contests. These activities create awareness about the importance of protecting, restoring, and conserving the San Juan Bay Estuary.

Volunteer Program

Long-term public support and participation in Estuary protection and restoration activities is necessary and critical for the successful implementation of the SJBEP's *Comprehensive Conservation and Management Plan for the San Juan Bay Estuary* (SJBEP, 2001). A volunteer program was created to encourage and facilitate active involvement by citizens in the Estuary's restoration process. University students participating in this program are encouraged to work with the SJBEP, using the SBJEP's objectives as potential subjects for developing their own research. These environmental volunteers will provide the resources needed to complete many of the SJBEP's proposed projects.

Outdoor activities accomplished during the 2005 Teacher Training Workshop included teachers kayaking or paddling to several areas of the Estuary, providing a first-hand, unforgettable experience for most of the participants (SJBEP).

San Juan Bay Estuary Partnership

San Juan Bay Estuary Partnership Indicators of Estuarine Condition

A Long-Term Environmental Indicator Program (LTEIP) has been proposed for the San Juan Bay Estuary to help assess the effectiveness of the area's conservation and restoration efforts. The indicators monitored by the LTEIP will be divided into four groups: Water-Sediment Quality, Biological Productivity and Respiration, Biota Distribution, and Biota-Pollutant Interactions. An important component of the LTEIP will be the preparation and dissemination of educational material as part of the SJBEP's outreach component. Other monitoring efforts have been proposed in the SJBEP's CCMP (SJBEP, 2001) to focus on the consequences of such events as petroleum spills, discharges from boats and ships, and high-temperature cooling water releases from thermoelectric plants. These events reduce the capacity of the Estuary's waters to retain oxygen.

Water and Sediment Quality

The SJBEP uses both chemical and bacteriological indicators to evaluate point and non-point sources of contamination. The most common indicators reported in the SJBEP CCMP are concentrations of nitrogen and phosphorus, dissolved oxygen, fecal coliform bacteria, and toxic substances (e.g., mercury, lead, arsenic, PCBs). Although the SJBEP does not monitor for these indicators directly, the indicators have been monitored for previous studies conducted by independent consultants, EPA, and the Puerto Rico Environmental Quality Board (EQB), as well as for previous studies supported by the SJBEP. Some of these indicators are currently evaluated for the Puerto Rican Water Quality Standards to define designated uses for different waterbodies.

The most common and widespread impairments to the Estuary's waters are nutrient enrichment/eutrophication and fecal contamination caused primarily by sewage discharges through non-point sources. Malfunctioning on-site septic systems, illegal connections to storm sewers, and direct discharges from unsewered areas are some of the current non-point sources of nutrients and fecal contamination related to sewage discharges into the San Juan Bay Estuary and its tributaries.

Nutrient and dissolved oxygen concentrations have been used to assess water quality in the San Juan Bay Estuary. No evidence of use impairments due to nitrogen and phosphorus loads have been reported in most of the San Juan Bay Estuary since point-source discharges from the Puerto Nuevo STP outfall into the Estuary were eliminated in 1985 (Tetra Tech, Inc., 1992). Dissolved oxygen levels in the Estuary's eutrophic waters vary widely depending on the time of day. This variation in dissolved oxygen concentrations is typically found in the San José and Los Corozos lagoons; however, the control of oxygen-consuming substances from industrial point-source discharges has gradually improved the dissolved oxygen levels in some areas of the Estuary (Webb and Gómez-Gómez, 1998).

Fecal coliform concentrations in most areas of the Estuary remain above the levels required to meet water quality standards (SJBEP, 2001), and as a result, the SJBEP sponsored a study to determine the public health risks from direct and indirect contact activities (e.g., bathing, fishing) in areas where fecal coliform concentrations were measured. These concentrations were measured in single samples collected at 16 sites in the Estuary. Although the fecal coliform concentrations measured in samples from six of the sites exceeded water quality standards, the study concluded that risk levels associated with water contact activities were within acceptable levels. The study also interviewed area residents about their fish-consumption habits and found that, although more than 40% of the people interviewed consumed food from Estuary waters, none reported any illnesses as a result of this consumption (Seguinot-Barbosa & Vázquez, 1999).

The San Juan Bay Estuary is also affected by other types of pollutants (e.g., metals, oils, and other substances) that gain access to the Estuary through storm sewers or runoff. The total volume of runoff can be much greater than the volume from other sources, causing significant contribution of contaminants (Horsley & Witten, Inc., 1995). Furthermore, the urbanization of drainage basins, removal of in-stream and bank vegetation, and alteration of streams and rivers due to channelization contribute to erosion and sedimentation rates in the area, as well as to the degradation of water quality in the Estuary and its tributaries. In the upper part of the watershed, erosion

accounts for an average loss of 4 inches of soil per year, much of which enters the Estuary (Webb and Gómez-Gómez, 1998).

PCBs, the pesticide DDT (and its metabolites DDD and DDE), the common elasticizing agent bis(2-ethylhexl)phthalate, lead, and mercury are the most abundant contaminants in the sediments of the SJBEP system. Figures 7-8 and 7-9 show the trends in the sediment contaminant concentrations from 1925 through 1995 (SJBEP, 2001). Although the occurrence of these contaminants in San Juan Bay Estuary sediments is expected to decrease with time, toxic pollutants in the surface bottom sediments of some areas may persist at relatively high concentrations for some time. The average sediment deposition rate for the San Juan Bay Estuary (excluding Martín Peña Channel) is about two

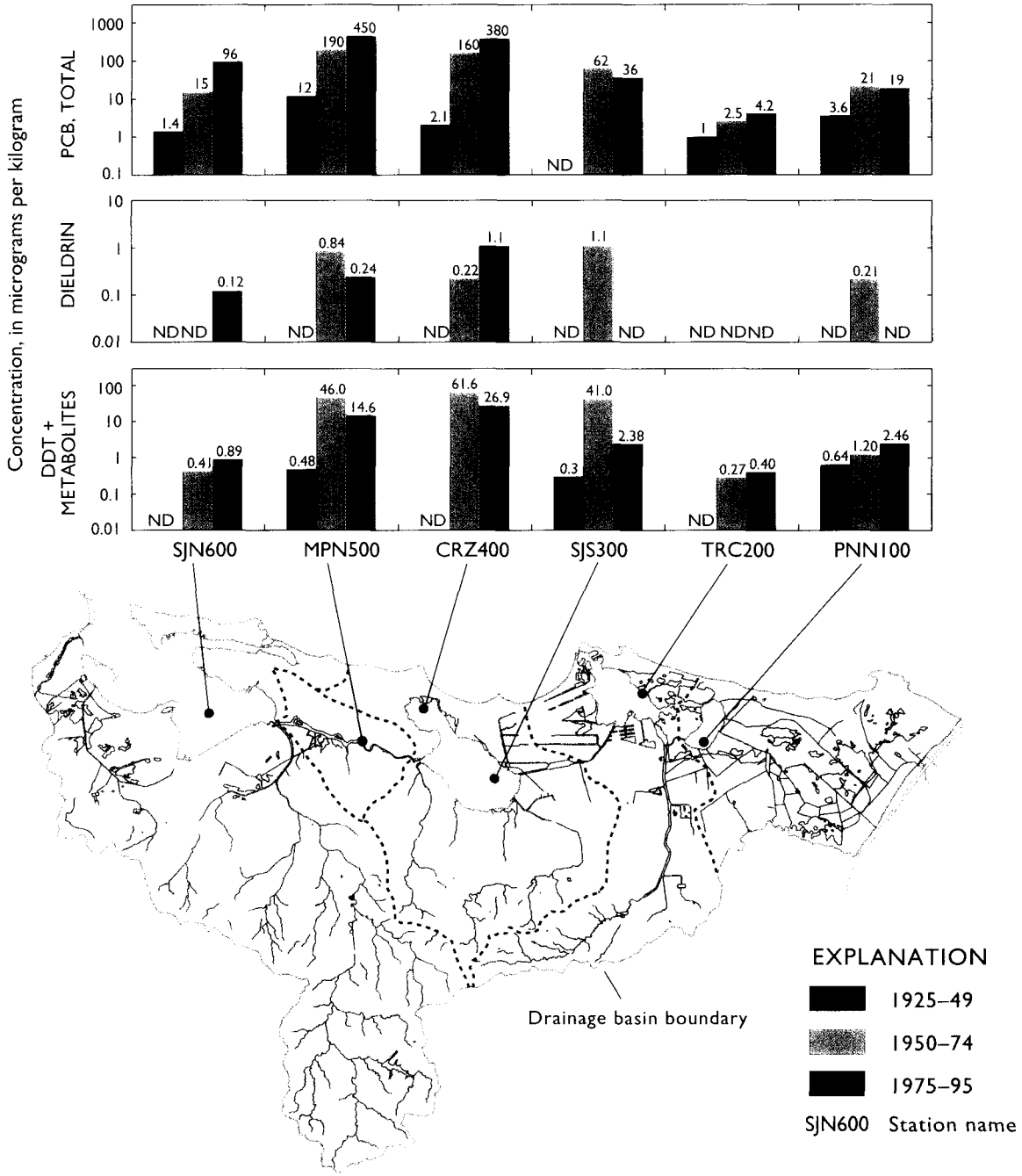


Figure 7-8. Sediment concentrations (µg/kg) of PCB, dieldrin, and DDT and its metabolites at different locations in the San Juan Bay Estuary and during different time periods (SJBEP, 2001).

San Juan Bay Estuary Partnership

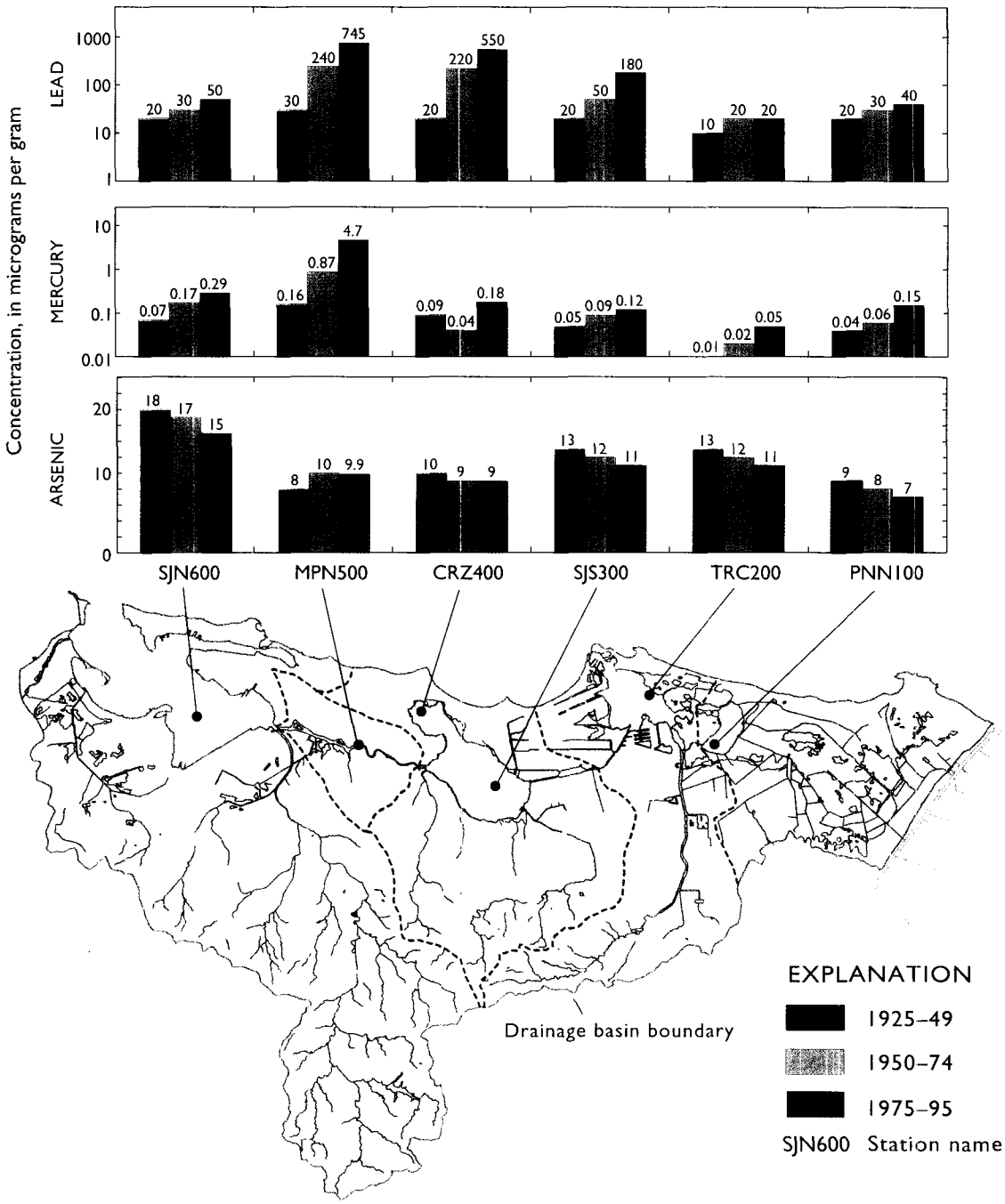


Figure 7-9. Sediment concentrations (µg/kg) of mercury, lead, and arsenic at different locations in the San Juan Bay Estuary and during different time periods (SJBEP, 2001).

inches per decade; therefore, contaminated sediments will need significant time to be buried by incoming, less-contaminated sediments (Webb & Gómez-Gómez, 1998). For these reasons, Webb & Gómez-Gómez (1998) concluded that contaminated sediments in such areas of the estuary as the Martín Peña Channel and the San José and Los Corozos lagoons present a potential threat to human health; however, EPA reviewed this assessment and concluded that, based on the confined nature of the contaminated sediments, there was no threat to human health by direct contact (U.S. EPA, 1996). This determination certified that a CERCLA removal action, consisting of identifying and remediating hazardous waste sites, was not warranted.

Habitat Quality

Swamps, marshes, mangroves, aquatic vegetation, coral reefs, and sandy beaches are some of the habitats that are found in the San Juan Bay Estuary, which harbors very rich and diverse aquatic communities. Marshes and mangroves support a great variety of juvenile fish and invertebrates and provide food and nesting habitat for many different bird species. Marshes also play an important role in the cycle of nutrients and filter contaminants that have been washed into the Estuary from the upper parts of the basin by runoff. The preservation of marsh and mangrove habitats is clearly included as an objective in the SJBEP CCMP (SJBEP, 2001).

Table 7-1 shows the area of marsh and mangrove habitats, as well as the change in area between 1936 and 1995, in different locations within the Estuary. The area between the Torrecilla and Piñones lagoons showed a significant net increase based on an increase in the mangrove area; however, this increase could be due to the succession of one kind of mangrove habitat by another, and not necessarily due to an improvement in the original habitat. This was the only area around San Juan Bay Estuary that exhibited a positive gain in total marsh and mangrove acreage between 1936 and 1995 (SJBEP, 2001).

Puerto Rico has one of the most diverse ecosystems of seagrass and SAV in the North Atlantic Ocean. Table 7-2 shows the areal coverage of these habitats, which are very important in supporting biodiversity and a variety of other ecological resources. For example, these habitats provide nutrients and primary energy for different fish species. The SJBEP places high emphasis on improving the overall condition of these habitats by improving the San Juan Bay Estuary's water quality (SJBEP, 2001).

Table 7-1. Trends in the Acreage of San Juan Bay Estuary Marsh and Mangrove Habitats Over Time (SJBEP, 2001)

Location	Time Period	Mangrove Area (Acres)	Marsh Area (Acres)	Total Change (Acres)
San Juan Bay and Condado Lagoon	1936	458	1,327	1,785
	1995	329	566	895
	% change	-28%	-57%	-50%
Martín Peña Channel	1936	1,029	578	1,607
	1995	327	197	524
	% change	-67%	-84%	-73%
San José Lagoon to Suárez Channel	1936	704	68	772
	1995	327	197	524
	% change	-54%	+190%	-32%
Torrecilla and Piñones areas	1936	2,790	1,904	4,694
	1995	4,561	1,101	5,662
	% change	+63%	-42%	+21%

Table 7-2. Areal Extent of Seagrass (acres) and Surface Water (mi^2) in the San Juan Bay Estuary (SJBEP, 2001)

Habitat	San Juan Bay	Condado Lagoon	San José Lagoon	Torrecilla Lagoon
Surface water area (mi^2)	4.56	0.15	2.11	0.95
Seagrass area (acres)	31	35	0	0.1

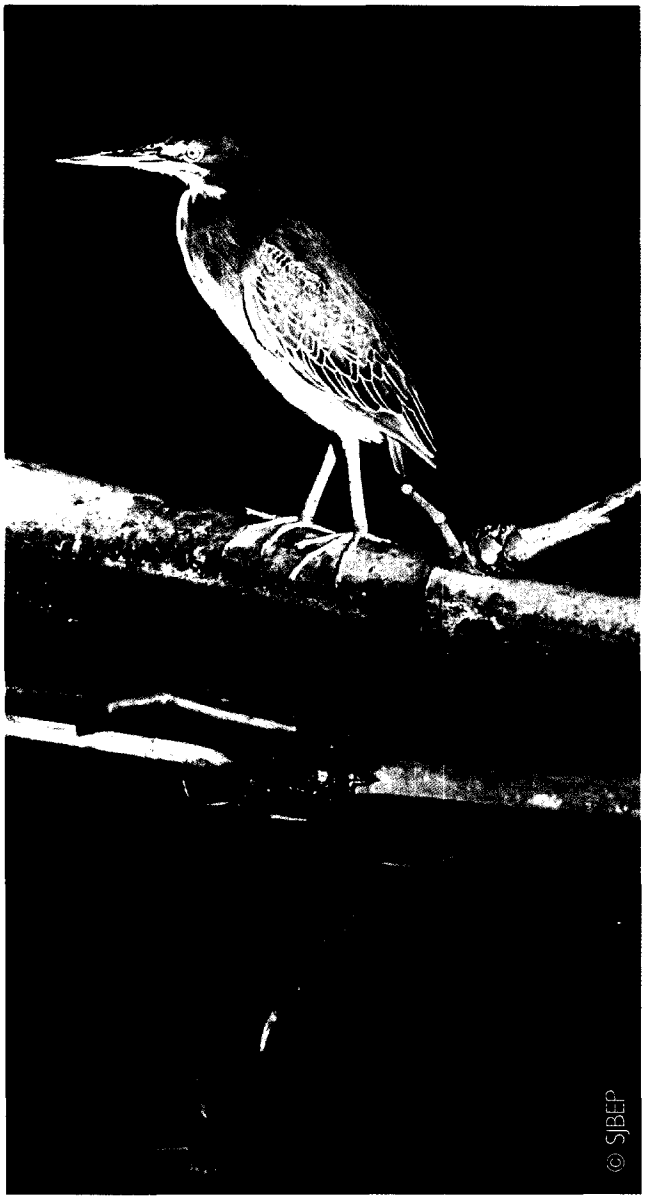
San Juan Bay Estuary Partnership

Living Resources

In 1998, the SJBEP supported a study to investigate the levels of seven heavy metals in the tissue of mojarra, blue crabs, and false mussels taken from the San José and Corozos lagoons. This study found that the concentrations of mercury and lead in some samples were above the standards recommended by the FDA. Although the average mercury concentration in mojarra was below the FDA standard, two samples had concentrations that exceeded the FDA standard. In addition, the average lead concentration in mojarra exceeded the lead standard. None of the blue crab samples exceeded the standard for mercury or lead; nevertheless, the regular consumption of blue crabs, particularly the hepatopancreas tissue, from these lagoons poses a potential public health problem resulting from elevated PCB levels in the tissue. Concentrations in some samples of false mussels exceeded the standard for lead, but not the standard for mercury; however, false mussels are typically not consumed by humans (Delgado-Morales et al., 1999).

Environmental Stressors

The discharge of nutrients and bacteria from septic systems and illegal sewer connections impacts water quality in the San Juan Bay Estuary; therefore, monitoring septic system performance and/or the number of illegal sewer connections may provide insight into ways of resolving the problem. At the present time, information about the number of septic systems functioning properly or malfunctioning, as well as how frequently these on-site systems are maintained, is not available. Illegal connections of sanitary sewers to storm sewers, as well as direct discharges of sewage, have been reported throughout the Estuary and its watershed; however, this condition is most common in the communities closest to the Estuary (Puerto Rico EQB, 1989; 1994; 1996). In a study performed by the Puerto Rico EQB from 1986 to 1989, almost 40% of the structures surveyed in the communities adjacent to the Martín Peña Channel were found to discharge raw sewage into storm sewers or directly into the Estuary or its tributaries (Puerto Rico EQB, 1989). The SJBEP CCMP recommends the construction of a sanitary sewer system that would connect to the existing regional STPs for those communities bordering the Estuary (SJBEP, 2001). As shown by a similar effort undertaken in the Condado Lagoon during the 1960s and 1970s (Rivera-Cabrera, 1990), a sanitary sewer system is expected to be the most effective and efficient way of eliminating illegal storm sewer connections and direct sewage discharges to the Estuary.



The green heron (*Butorides virescens*) is a common resident of the San Juan Bay Estuary. This small, gray-green waterbird forages mostly in shallow waters, such as mangrove swamps, searching for small fish and invertebrates (SJBEP).

Current Projects, Accomplishments, and Future Goals

The SJBEP has implemented 41 projects—10 new projects financed by grants from past years, 14 new projects financed in this fiscal year, and 17 projects that were in progress and scheduled to be completed during the 2004–2005 fiscal year. Simultaneously, the SJBEP has been able to finalize 15 projects from past years, complying with 11 actions proposed in the Partnership's CCMP (SJBEP, 2005). The SJBEP will base its future goals on goals already established in the CCMP, which are divided into three areas of concern:

- **Improve the water and sediment quality of San Juan Bay Estuary to ensure suitability for fishing and swimming and to promote other compatible recreational and commercial activities** – The SJBEP will accomplish part of this goal through the LTEIP, which will provide the NEP with data to inform the public about the health of the Estuary and to take corresponding actions. The SJBEP is also actively working as a new member of the Ecological Corridor Commission of San Juan, which was created as part of the Law of the San Juan Ecological Corridor in 2003 (Law 206) to oversee the acquisition of parcels of land and transform them into an ecological corridor of approximately 1,000 acres.
- **Enhance and maintain an ecosystem that supports an optimum diversity of living resources on a sustained basis** – The SJBEP will continue to implement 18 actions conceptualized to fulfill this important goal through its Volunteer Program. In 2006, the SJBEP will implement 6 of the 18 actions and will build partnerships to reinforce future conservation projects.
- **Maximize public involvement in the implementation of the CCMP** – Nine projects have been approved by the SJBEP Board of Directors to support 100% of the actions under this area of concern, and the SJBEP Volunteer Program will help to achieve this goal.

The following new activities were implemented during 2005 to enrich the SJBEP and its CCMP:

- **Integrated Media and Communications Program** – In 2002, 84% of the Estuary's local residents interviewed did not recognize the word or concept of an "estuary" (Personal communication, Bauza-Ortega, 2006). In order to resolve this challenge, the Partnership conducted a focus group study in which a comprehensive media plan was developed. The integrated media approach outlined in the plan conveyed a message of restoration and conservation for the Estuary using multiple resources, including electronic media (e.g., interactive Web page), traditional media (e.g., newsletter, radio programs), and monthly seminars.
- **Christmas Card Competition** – During this project, Puerto Rico elementary school students learned about San Juan Bay Estuary and helped promote the SJBEP's mission through the development of a Christmas card exhibit. One card design, selected by a jury, was printed and delivered to all members of the SJBEP mailing list and contacts.
- **Collaboration with the Enlace del Caño Martín Peña Project** – This project is responsible for dredging the Martín Peña Channel, relocating people affected by dredging activities, constructing new homes, and developing and implementing the complex educational strategy that requires relocating people who have lived in a particular community for decades. The SJBEP collaborates with the Enlace Project in the educational phase and has completed several important activities through the years, such as theater workshops, community concerts, contests, publications, and technical support and environmental consulting through the staff scientist.
- **Annual Audubon Society Bird Census** – For the past 9 years, the annual Audubon Society Bird Census has helped identify bird species density in the SJBEP study area. Local species data are updated through this annual census.

San Juan Bay Estuary Partnership

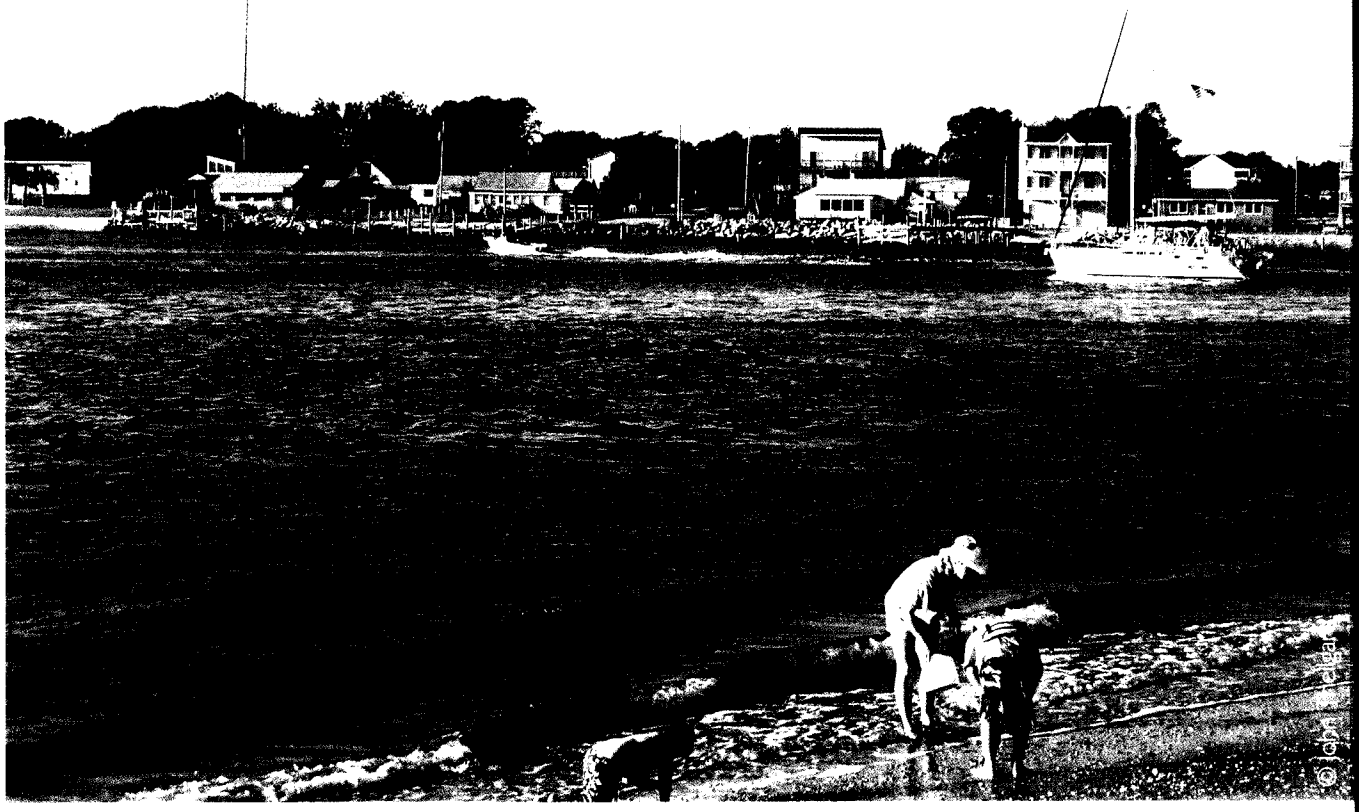
Conclusion

Based on data from the NCA estuarine survey, the overall condition of the San Juan Bay Estuary is rated poor. Although the Estuary's water quality index is rated fair, the sediment quality, benthic, and fish tissue contaminant indices are rated poor. The data used by the SJBEP to assess water quality in the Estuary indicate that bacterial contamination caused by the discharge of sewage from non-point sources is a concern in the area and has negatively affected water quality. A variety of toxic chemicals have been detected in Estuary sediments and may persist at relatively high concentrations for some time. The development of a maritime and air transportation infrastructure, as well as of residential and industrial areas, have caused significant modification and loss of important habitats in the Estuary. Most of these modifications have occurred in the western half of the Estuary basin, where the pressures of urban growth and development on the San Juan Bay Estuary are greatest. The SJBEP is focusing its attention on developing a strong outreach program to inform the local population about conditions in the Estuary.

The green iguana (*Iguana iguana*), locally known as "gallina de palo", is an invasive species that was introduced into Puerto Rico from Central and South America by the pet trade in the 1970s. The SJBEP plans to study the ecology of the green iguana and evaluate its potential for negative impact to the local biodiversity (SJBEP).

APPENDIX A

PROCEDURES FOR CALCULATING TOTAL POPULATION, POPULATION GROWTH RATE, AND POPULATION DENSITY FOR VARIOUS GEOGRAPHIC AREAS



APPENDIX A

PROCEDURES FOR CALCULATING TOTAL POPULATION, POPULATION GROWTH RATE, AND POPULATION DENSITY FOR VARIOUS GEOGRAPHIC AREAS

Introduction

Human population pressures can be evaluated using several measures. For the U.S. Environmental Protection Agency's (EPA's) National Estuary Program Coastal Condition Report (NEP CCR), three measures were used to evaluate the impact of human population pressures on the 28 NEP estuaries of the United States: total population, population growth rate over a specified time interval, and population density (persons/mi^2 of land area). These population pressures were measured for each individual NEP estuary and compared to those calculated for other NEP estuaries, all coastal areas, all non-coastal areas, and the conterminous United States to assess the relative impacts of human populations on estuarine condition.

The National Oceanic & Atmospheric Administration (NOAA) recently published the report *Population Trends along the Coastal United States: 1980–2008* (Crossett et al., 2004), which presents an overview of coastal population trends from 1980 through 2003, projected changes in coastal populations through 2008, and the definition of a NOAA-designated coastal county. The NOAA Special Projects office designates a county as a coastal county if one of the following criteria is met:

- At a minimum, 15% of the county's total land area is located within a coastal watershed
- A portion of a county or an entire county accounts for at least 15% of a cataloging unit.

It should be noted that this NOAA report and the other NOAA report (Culliton et al.,1990) referenced in this Appendix differ from the NEP CCR in that the NOAA reports include the Great Lakes region as a coastal area. In addition, the NEP CCR only covers marine coastal areas in the conterminous 48 states because none of the NEP estuaries are located in Alaska or Hawaii. Population pressures for the one NEP estuary located in Puerto Rico (San Juan Bay Estuary) were evaluated separately for this NEP CCR due to a lack of comparable population data for this region. An overview of this evaluation is provided later in this Appendix.

In order to determine the human population pressures exerted on counties coincident with individual NEP study areas, population data were obtained from the U.S. Census Bureau (1991; 2001). These data were used to calculate total population for 1960, 1970, 1980, 1990, and 2000; population density in 2000; and the population growth rate between 1960 and 2000 for the following:

- Each NEP study area (using all NOAA-designated coastal counties or municipalities coincident with an individual NEP study area)
- All NEP coastal counties collectively (using the NOAA-designated coastal counties coincident with all 27 NEPs located in the conterminous 48 states)
- All NOAA-designated coastal counties (using both NEP and non-NEP coastal counties in the 48 conterminous U.S. states and excluding coastal counties in Puerto Rico and those adjacent to the Great Lakes)

- All non-coastal counties (using all counties in the 48 conterminous U.S. states that are not considered NOAA-designated coastal counties, as well as the NOAA-designated coastal counties that are adjacent to the Great Lakes)
- All counties in the 48 conterminous U.S. states, as a whole.

Population statistics for the study area for Puerto Rico's NEP, the San Juan Bay Estuary Partnership (SJBEP), were calculated differently because of variances in available data for the region. Population data for the SJBEP study area were only available for the year 2000. In addition, Puerto Rico was not included in the available list of NOAA-designated coastal counties, and a separate section in this text has been devoted to describing the processes employed for deriving population density estimates for the SJBEP study area. Due to the differences in methodology and available source data for the SJBEP study area, the results for this NEP estuary are not included in the values cited in Chapter 1 that provide national population data for Figure 1-2.

Selection of Coastal Counties in the NEP Study Areas

Geographic information systems (GIS) technology was used to identify which NOAA-designated coastal counties are spatially coincident with NEP study area boundaries. These counties were identified using the following steps:

- A GIS shapefile was developed delineating the NOAA-designated coastal counties
- A separate GIS shapefile delineating the 2003 boundaries of each NEP study area was obtained from EPA
- GIS was used to compare the two shapefiles electronically and identify which NOAA-designated coastal counties overlap the boundaries of a specific NEP study area
- A visual inspection was conducted to refine the selection of NOAA-designated coastal counties in the NEP study area.

For comparison purposes in the NEP CCR, only the NOAA-designated coastal counties in the U.S. regions that contain NEP estuaries were processed as coastal counties. The NOAA-designated coastal counties bordering the Great Lakes were processed as non-coastal counties because there are no NEP estuaries in this region. In addition, this analysis was limited to coastal and non-coastal counties in the conterminous United States because no NEP-designated estuaries are located in Alaska or Hawaii and because insufficient data were available for the island territory of Puerto Rico.

Methodology for the 27 NEPs in the Conterminous United States

To identify the NEP-coincident coastal counties for the 27 NEPs in the conterminous United States, a shapefile of NOAA-designated coastal counties was created by electronically linking coastal county data from NOAA (Culliton et al.,1990) to a GIS shapefile of all U.S. counties (National Atlas of the United States, 2005). The coastal county data were obtained from the NOAA report *50 Years of Population Change Along the Nation's Coasts 1960–2010, A Special Earth Week Report* (Culliton et. al., 1990), which contains a table entitled "Population and Development in Coastal Areas Coastal Counties List," hereafter referred to as the NOAA Coastal Counties Table. This table presents the land area (in mi^2), population, and unique Federal Information Processing Standards (FIPS) code for each coastal county in the conterminous United States.

The NOAA Coastal Counties Table was divided into sections based on the waterbody associated with each coastal county. The sections of the table associated with Great Lakes, Hawaiian, and Alaskan waters were excluded so that only the sections that provided data for the Atlantic, Gulf, and Pacific coasts of the conterminous United Sates were used. The FIPS codes in these sections of the NOAA Coastal Counties Table were linked electronically with the matching FIPS codes in the U.S. counties shapefile to create a subset of NOAA-designated coastal counties. This subset was saved as a separate shapefile and used in the population calculations described below.

Once the NOAA-designated coastal counties shapefile was created, GIS technology was used to determine which NOAA-designated coastal counties were coincident with NEP study areas. A spatial comparison of the NOAA-designated coastal county boundaries and the NEP study area boundaries was performed. GIS technology automatically selected those counties from the NOAA-designated coastal counties shapefile that spatially intersected NEP study area polygons in the NEP boundary shapefile obtained from EPA.

This automatic selection of spatially coincident counties was further refined using a visual inspection in GIS. When GIS shapefiles are obtained from different sources, slight discrepancies in the scale or accuracy of the polygons in the file are common. For example, when an NEP study area boundary coincided with a county border, the automatic selection process often included the neighboring county due to discrepancies between the two shapefiles. The objective of this visual inspection was to identify any counties that were included in the automatic selection as a result of discrepancies between the polygonal boundaries of the NOAA-designated coastal counties shapefile and the NEP boundary shapefile. These counties were then removed from the NEP-coincident coastal counties shapefile.

Figure A-1 provides an example of how GIS analysis was used to generate the final shapefile of NEP-coincident coastal counties. The NOAA Coastal Counties Table was used to select all of the NOAA-designated coastal counties (shown in yellow and purple). Note that Highlands County (shown in orange) does not meet the NOAA Special Projects office's definition of a coastal county and was not included in the spatial selection. The Indian River Lagoon NEP (IRLNEP) study area boundary polygon from EPA's NEP boundary shapefile is outlined in green. The automatic GIS selection of coincident coastal counties generated an initial data set that included Volusia, Brevard, Indian River, Okeechobee, St. Lucie, Martin, and Palm Beach counties. Visual inspection of the GIS selections revealed that the NEP boundary polygon intersected significant portions of Volusia, Brevard, Indian River, Okeechobee, St. Lucie, and Martin counties, and these counties were included in the final shapefile (shown in purple). However, the NEP boundary polygon did not intersect a significant portion of Palm Beach County, and the inclusion of this county was likely due to a discrepancy. As a result, Palm Beach County was deselected and excluded from the final NEP-coincident coastal county shapefile for the IRLNEP.

Methodology for the San Juan Bay Estuary Partnership (SJBEP)

Puerto Rico is divided into municipalities rather than counties, and these municipalities were not included in the NOAA Coastal Counties Table or the NOAA-designated coastal counties shapefile. As a result, the methodology for determining the NEP-coincident municipalities for the SJBEP study area differed from the methodology used to identify the NEP-coincident coastal counties for the other 27 NEPs. For Puerto Rico, each NEP-coincident municipality was selected by hand using a visual inspection. The inspection selected all of the municipalities that significantly intersected the boundary of the SJBEP study area polygon. The selected municipalities were then used to create a shapefile for the SJBEP study area.

Calculation of Population Statistics for all U.S. NEPs

When data were available, the total population in 1960, 1970, 1980, 1990, and 2000; population growth rate (1960–2000); and population density in 2000 were calculated for several geographic areas of interest. These geographic areas are the conterminous United States, all NOAA-designated coastal counties (collectively), all NEP-coincident coastal counties (collectively), the coastal counties coincident to each individual NEP study area, and all non-coastal counties (collectively). A unique data set of population and land area data was created for each area of interest, and the same general formulas were used to calculate total population, population growth rate, and population density for each data set. It should be noted that Puerto Rico's population growth rate and total population figures for 1960, 1970, 1980, and 1990 were not calculated because population data for Puerto Rico prior to 2000 were unavailable from the U.S. Census Bureau (1991).

In order to develop a data set for the conterminous United States, land area values and 1960, 1970, 1980, 1990, and 2000 population data for all of the states

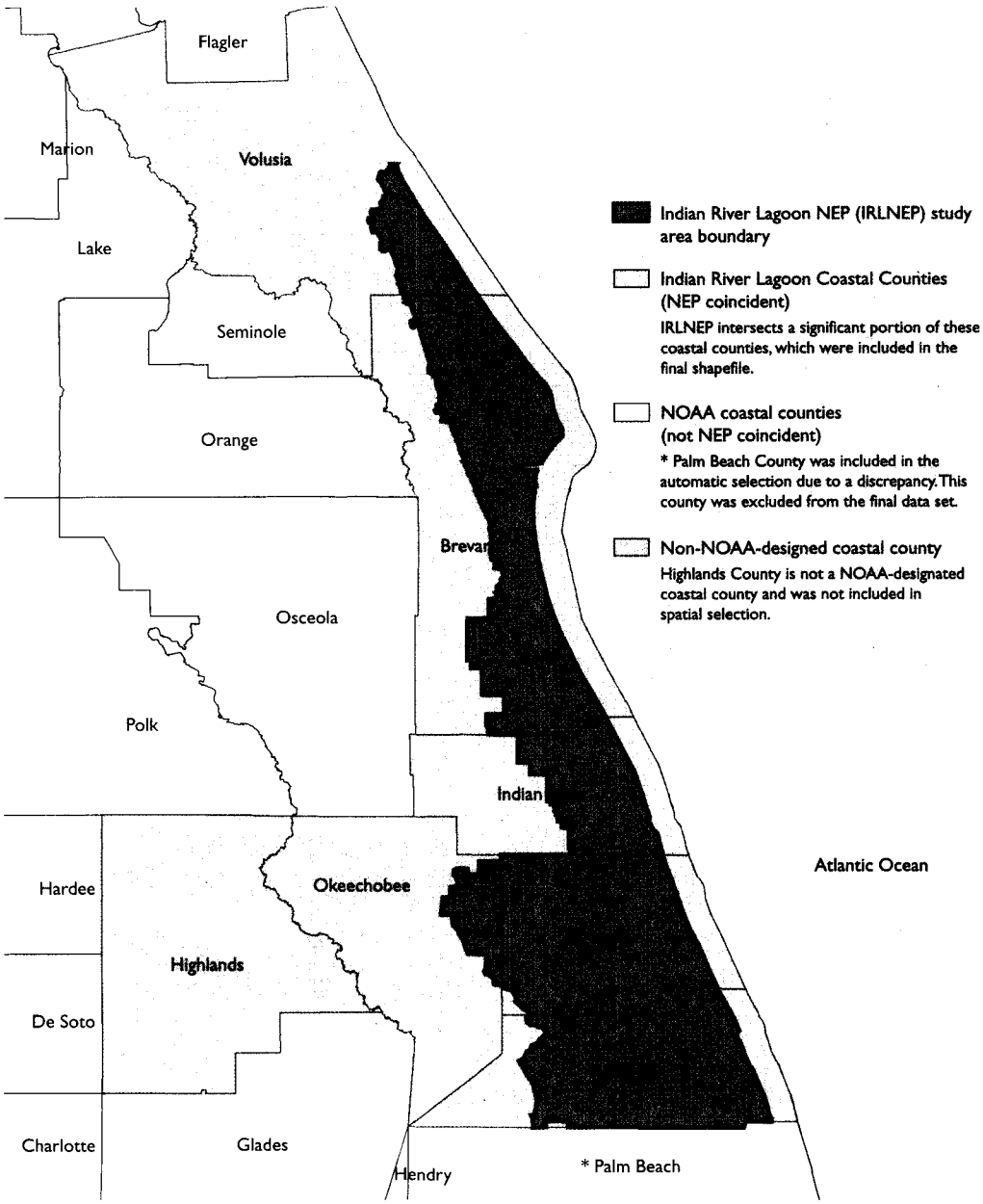


Figure A-1. An example of the spatial selection process used to identify NEP-coincident coastal counties for the Indian River Lagoon NEP.

(excluding Puerto Rico and other commonwealths, territories, and protectorates) were obtained from the U.S. Census Bureau (1991; 2001). The data set was refined to include only the 48 conterminous states by subtracting population data and land area values for Alaska and Hawaii.

The raw data necessary to calculate total population, population growth rate, and population density for all the NOAA-designated coastal counties were obtained from several sources. The land area of each county in 2000 and the population data for each county in 1960, 1970, 1980, and 1990 were obtained from the portions of the NOAA Coastal Counties Table providing data for the Atlantic, Gulf, and Pacific coasts. The population data for each county in 2000 was obtained from the U.S. Census Bureau (2001) and are hereafter referred to as the 2000 Census Counties Table. Both tables were linked by the county FIPS codes to create a population data set that ranged from 1960 to 2000 for all NOAA-designated coastal counties.

The NOAA-designated coastal counties data set was refined to create the NEP-coincident coastal county data set. During this process, FIPS codes were used to link the NOAA-designated coastal counties data set with the NEP-coincident coastal counties shapefile to isolate the population and land area data for the NEP-coincident coastal counties.

The NEP-coincident coastal counties shapefile contains a field that associates each NEP-coincident coastal county with an individual NEP. This field was retained in the NEP-coincident coastal counties data set and used to create the data sets for each of the 27 individual NEPs in the conterminous United States. For the San Juan Bay Estuary, land area and population data for the SJBEP study area in 2000 were obtained from the U.S. Census Bureau (2001). The SJBEP data set was created by linking the FIPS codes in the SJBEP shapefile to those in the data from the U.S. Census Bureau.

The non-coastal counties data set was generated using the NOAA-designated coastal counties data set and the data set for the conterminous United States. The population and land area data for all of the non-coastal counties in the 48 conterminous U.S. states were calculated by subtracting the data for the NOAA-designated coastal counties from the data for all of the 48 conterminous U.S. states. This process is demonstrated in the text box below.

The data in each data set were then used to calculate the total population, population growth rate, and population density for each geographic area of interest. The general formulas used to calculate these statistics are presented in the text box below. The results of these calculations and the corresponding variables for the conterminous United States, all NOAA-designated coastal counties (collectively), all NEP-coincident coastal counties (collectively), the coastal counties coincident to each individual NEP study area, and all non-coastal counties (collectively) are summarized in Table A-1. The results for the data sets of coastal counties coincident with each individual NEP study area are presented in the individual NEP discussions within the main body of the NEP CCR.

Formulas:

$$2000Population_{48States} - 2000Population_{CoastalCounties} = 2000Population_{NonCoastalCounties}$$

$$TotalPopulation_{GivenArea} = \Sigma\ Population_{EachCounty}$$

$$Population\ Growth\ Rate = \frac{2000Population_{Total} - 1960Population_{Total}}{1960Population_{Total}}$$

$$2000\ Population\ Density = \frac{2000Population_{Total}}{TotalLandArea}$$

Table A-1. Comparison of U.S. Trends in Total Population, Population Growth Rate, and Population Density for the Nation, NOAA-designated Coastal Counties, NEP-coincident Coastal Counties, and Non-coastal Counties*

Year	Total population (millions)	Growth rate since 1960 (%)	Population density (persons/mi^2)	Land area (mi^2)
National (Conterminous U.S.)				
1960	178.46		60	
1970	202.23		68	
1980	225.18		76	
1990	247.34		84	
2000	279.58	56.66	94	2,959,065
NOAA-designated coastal counties				
1960	70.05		181	
1970	82.99		214	
1980	92.50		239	
1990	105.89		273	
2000	119.25	70.24	308	387,473
NEP-coincident coastal counties				
1960	51.42		313	
1970	60.55		368	
1980	65.48		398	
1990	73.68		448	
2000	81.91	59.28	498	164,382
Non-coastal counties				
1960	108.42		42	
1970	119.24		46	
1980	132.68		52	
1990	141.45		55	
2000	160.33	47.88	62	2,571,592

* Excludes population data and land area from Alaska, Hawaii, and Puerto Rico and other commonwealths, territories, and protectorates.

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