CHARACTERIZATION OF THE JACQUES COUSTEAU NATIONAL ESTUARINE RESEARCH RESERVE

A Profile Report

Jacques Cousteau National Estuarine Research Reserve

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EXECUTIVE SUMMARY

The Jacques Cousteau National Estuarine Research Reserve (JCNERR) is one of the 27 national estuarine reserves created to promote the responsible use and management of the nation's estuaries through a program combining scientific research, education, and stewardship (Figure 1). The JCNERR, which lies on the gently sloping Atlantic Coastal Plain of New Jersey, is the 22nd program site of the National Estuarine Research Reserve System (NERRS), having been officially dedicated on October 20, 1997. It consists of more than 45,000 ha of aesthetic upland, wetland, and open water habitats. The Mullica River watershed is a concentrated patchwork of federal and state lands managed in partnership through a variety of agencies. These land areas are remarkably pristine largely because of the federally protected New Jersey Pinelands, state and federal managed lands surrounding the coastal bays, and only 553 ha of developed landscape (< 2% of the total area). Most of the land of the JCNERR is in public ownership.

Upland vegetation in the JCNERR consists of pine-oak forests which are replaced seaward by freshwater-, brackish-, and salt (*Spartina*) marshes. Marsh habitat covers more than 13,000 ha (> 28%) of the reserve. JCNERR habitats generally exhibit excellent environmental quality, although Little Egg Harbor and Barnegat Bay waters have been identified as highly eutrophic. The JCNERR's mission is consistent with that of the NERRS, that is, to preserve areas that retain a healthy ecosystem and provide the opportunity to serve the needs of long-term research and monitoring programs.

Rich and diverse plant and animal communities inhabit watershed areas of the JCNERR. For example, 275 species of macroinvertebrates, 91 species of fish, and 350 species of algae have been documented in inland habitats of the Mullica River and its tributaries. Watershed habitats support many species of shorebirds, wading birds, waterfowl, raptors, and songbirds. Amphibians, reptiles, and land mammals also utilize wetlands, riparian buffer, and upland habitats of the JCNERR and the contiguous pinelands.

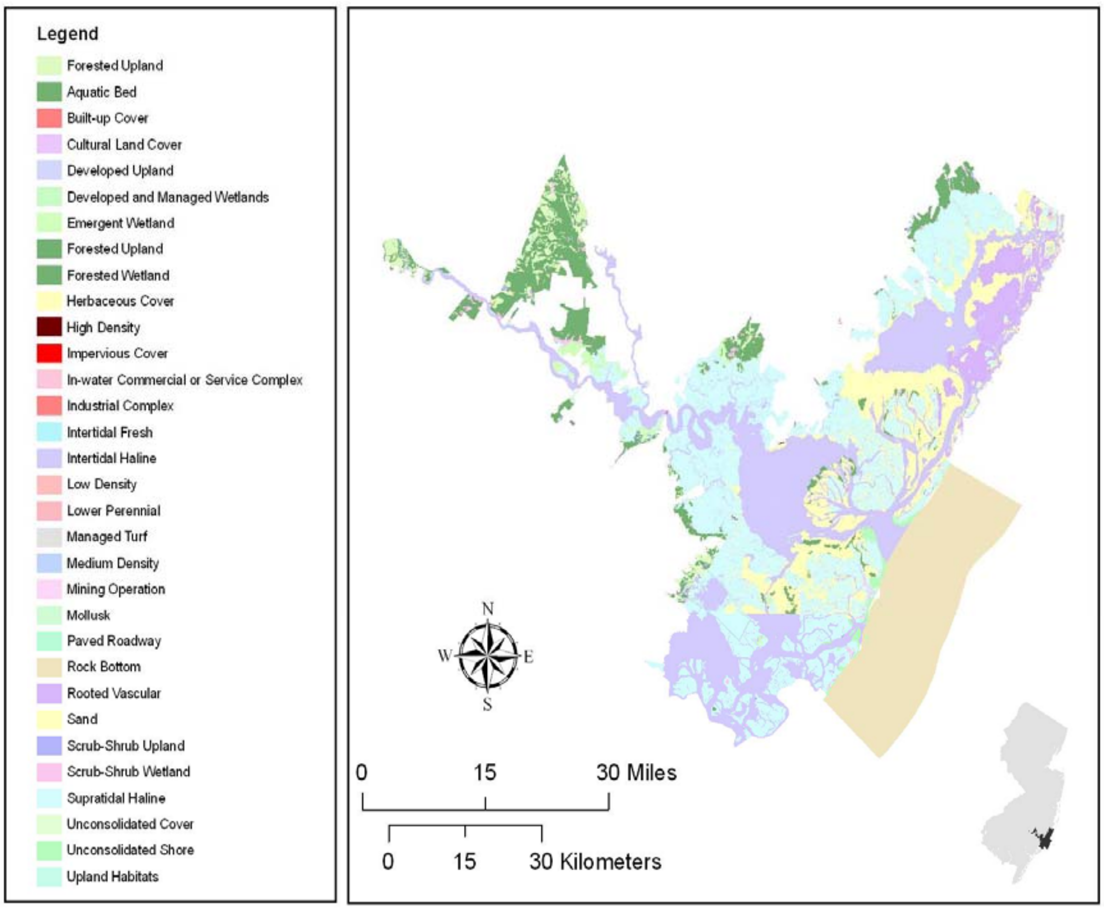


Figure 1. Map showing the location and habitats of the Jacques Cousteau National Estuarine Research Reserve (highlighted areas/Legend). Lower right: location of the JCNERR with respect to the state of New Jersey.

A wide range of aquatic habitats exists in the JCNERR, the most extensive of which consists of open waters covering more than 27,000 ha (Figure 1). Occurring within the unique New Jersey Pinelands forest ecosystem, the Mullica River-Great Bay Estuary is of special ecological value. Other open waters of the system include Little Egg Harbor, lower Barnegat Bay, Little Bay, Reeds Bay, and Absecon Bay to the south. These estuarine waters support numerous planktonic, nektonic, and benthic organisms. A number of finfish (e.g., bluefish, *Brevoortia tyrannus*; weakfish, *Cynoscion regalis*; summer flounder, *Paralichthys dentatus*; and winter flounder, *Pseudopleuronectes americanus*) and shellfish (e.g., blue crabs, *Callinectes sapidus* and hard clams, *Mercenaria mercenaria*) species are of recreational and commercial importance.

Submerged aquatic vegetation (SAV) forms critically important habitat in the coastal bays of the JCNERR. SAV, notably eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*), are found in lower Barnegat Bay and Little Egg Harbor. Seagrasses provide vital ecosystem services in the coastal bays, generating considerable primary production, supporting numerous benthic invertebrate populations, and comprising important spawning, nursery, and feeding grounds for an array of finfish species. Some fish (e.g., Acanthuridae and Scaridae), turtles, waterfowl (e.g., American brant, canvasbacks, and green-winged teal) and sea urchins consume SAV. In addition, these vascular plants baffle waves and currents and mitigate substrate erosion, thereby stabilizing bottom sediments. Eelgrass and widgeon grass are confined to the Barnegat Bay-Little Egg Harbor Estuary. In Great Bay and coastal bays to Absecon Bay, benthic macroalgae (e.g., *Ulva lactuca* and *Enteromorpha* spp.) proliferate, but seagrass is essentially absent due to elevated turbidity.

Eutrophication is an escalating problem in the coastal bays of New Jersey (Kennish and Townsend, 2007). The Barnegat Bay-Little Egg Harbor Estuary has been classified as a highly eutrophic system (Kennish et al, 2007a). Both phytoplankton and benthic algal blooms are becoming more frequent, as evidenced by repeated phytoplankton blooms in the summer months consisting of dinoflagellates, microflagellates, ultraplankton, and pelagophytes, as well as serious macroalgal blooms consisting of sea lettuce and other nuisance forms (Kennish et al., 2008). Picoplankton blooms commonly occur in the estuary, being dominated by *Nannochloris atomus* and *Aureococcus anophagefferens*. During bloom events, the phytoplankton cell counts often exceed 10^6 cells/ml. Brown tides composed of *A. anophagefferens* have been most intense and widespread in Little Egg Harbor, but they have also been documented in Barnegat Bay and Great Bay (Olsen and Mahoney, 2001). These phytoplankton blooms are problematic because they cause a brownish water discoloration and shading effects that can be detrimental to SAV.

Nutrient enrichment fuels rapid phytoplankton growth in the summer months. Phytoplankton productivity in JCNERR coastal bays rivals or exceeds that of many other coastal bays in the U.S. and abroad (Seitzinger et al., 2001; Kennish et al., 2007a). Phytoplankton directly supports zooplankton and benthic invertebrate populations in the bays. Calanoid and harpacticoid copepods are major components of the zooplankton community in JCNERR estuaries. Meroplankton and ichthyoplankton are also important constituents and provide forage for benthic invertebrate and finfish populations.

The benthic invertebrate community is well represented in estuarine waters of the JCNERR. More than 150 benthic invertebrate species have been recorded in Great Bay, and more than 200 benthic invertebrate species, in the Barnegat Bay-Little Egg Harbor Estuary. The composition of bottom sediments, particularly the grain size, strongly influences the distribution and abundance of the benthic organisms. The amount of silt and clay is significant in this regard.

Finfish assemblages are abundant in estuarine wates of the system, especially during the warmer seasons of the year. These assemblages can be divided into several major finfish groups, specifically resident species, warm-water migrants, cool-water migrants, and stray species. Forage species, such as the bay anchovy (*Anchoa mitchilli*) and Atlantic silverside (*Menidia menidia*), typically dominate in numerical abundance. The occurrence and abundance of finfish populations in the JCNERR estuaries are highly variable due to seasonal migrations and the reproductive flux by seasonal and year-round residents. Annual variations in abundance of finfish populations commonly range from 50-100%. Many species found in the estuaries exhibit a clear preference for specific habitats (e.g., tidal creeks, eelgrass beds, and deep channels). Surveys conducted in these systems by various investigators have revealed the significance of myriad habitats to the success of fishery resources in the JCNERR.

A comprehensive list of threatened and endangered species has been compiled for the Mullica River watershed and surrounding areas. This list includes a diversity of plants, amphibians, reptiles, mammals, birds, fish, and insects. These designations underscore the need to protect the environment of the JCNERR from habitat loss and alteration, over-exploitation, disturbance, contamination, and other anthropogenic impacts.

Waters of the Barnegat Bay-Little Egg Harbor Estuary are the most problematic within the JCNERR. This estuary is an impaired system both in respect to aquatic life support and human use. The principal cause of these problems is nitrogen over-enrichment mediated primarily by surface runoff from the Barnegat Bay watershed and atmospheric deposition from the overlying airshed.

Nutrient enrichment of the Barnegat Bay-Little Egg Harbor Estuary is closely linked to a series of cascading environmental problems, such as increased growth of phytoplankton and benthic macroalgae (including both harmful and nuisance forms), loss of SAV, and declining shellfish resources (Kennish et al., 2007a). These problems have also led to deterioration of sediment and water quality, loss of biodiversity, and disruption of ecosystem health and function. Human uses of estuarine resources have also been impaired.

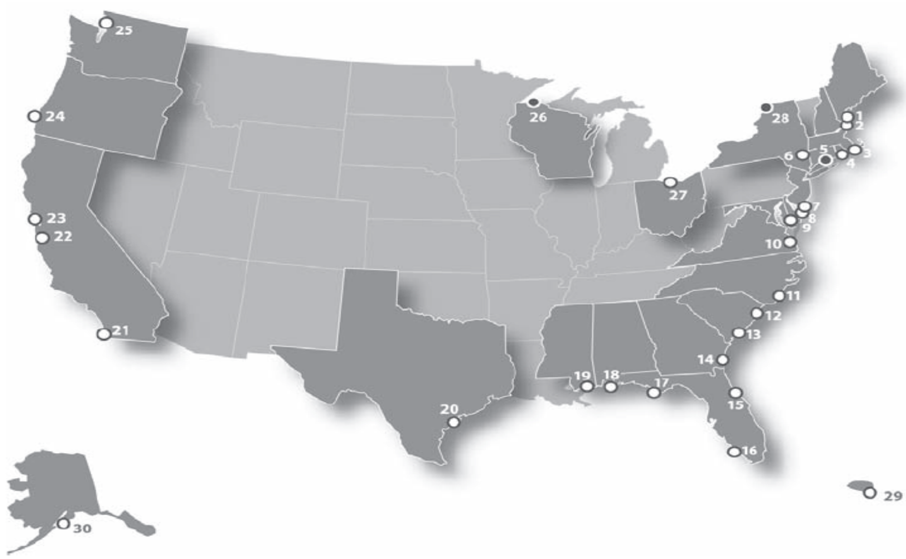
Because of serious eutrophication problems in this system, it is important to continue to investigate the dynamics of seagrasses, macroalgae, and phytoplankton in the estuary. In addition, a detailed study of the structure and function of the benthic faunal community is needed, as well as surveys of shellfish and finfish populations. This information is needed to determine if eutrophic conditions are impacting higher-trophic-level organisms in the estuary.

INTRODUCTION

The Coastal Zone Management Act of 1972 established the National Estuarine Research Reserve System (NERRS). The JCNERR and 26 other reserve sites now exist in the United States (Figure 2). Each site is a partnership between NOAA and a coastal state. These 27 reserves form a network of protected areas that have been established to augment the Coastal Zone Management program by providing data needed for effective resource management. Aside from addressing estuarine resource protection issues, the NERRS program generates and disseminates comprehensive environmental databases via system-wide water quality monitoring, instruction within the Coastal Training Program, and graduate research fellowships. Through these elements, the NERRS program serves as a vehicle to improve the health of the nation's estuaries and coastal habitats.

The 27 NERRS sites occur in 22 states and one territory (Puerto Rico). They span 19 biogeographical sub-regions along the coasts of the Atlantic Ocean, Gulf of Mexico, Caribbean Sea, Pacific Ocean, and Great Lakes, and they encompass more than 500,000 ha of coastal habitats. These sites are essentially demonstration sites where monitoring and research data are used to assess coastal issues of local, regional, and national interest for the purpose of sustaining estuarine systems (NERRS, 2006a, 2007). Considerable variation exists among the reserves, with site estuaries ranging from relatively pristine to highly impacted by anthropogenic activity. A major goal of the NERRS is to ensure a stable environment for research at the reserve sites through long-term protection of resources.

National Estuarine Research Reserves — *A network of 27 protected areas*



1. Wells, Maine
2. Great Bay, New Hampshire
3. Waquoit Bay, Massachusetts
4. Narragansett Bay, Rhode Island
5. Connecticut *
6. Hudson River, New York
7. Jacques Cousteau, New Jersey
8. Delaware
9. Chesapeake Bay, Maryland
10. Chesapeake Bay, Virginia
11. North Carolina
12. North Inlet-Winyah Bay, South Carolina
13. ACE Basin, South Carolina
14. Sapelo Island, Georgia
15. Guana Tolomato Matanzas, Florida
16. Rookery Bay, Florida
17. Apalachicola, Florida
18. Weeks Bay, Alabama
19. Grand Bay, Mississippi
20. Mission-Aransas, Texas
21. Tijuana River, California
22. Elkhorn Slough, California
23. San Francisco Bay, California
24. South Slough, Oregon
25. Padilla Bay, Washington
26. Wisconsin *
27. Old Woman Creek, Ohio
28. St. Lawrence River, New York *
29. Jobos Bay, Puerto Rico
30. Kachemak Bay, Alaska

** Proposed Reserve*

Figure 2. Location of designated and proposed reserve sites within the National Estuarine Research Reserve System. From the Estuarine Reserves Division, National Oceanic and Atmospheric Administration, Silver Spring, Maryland.

The NERRS also promotes increased public awareness of the importance of estuarine systems. To this end, the program focuses on four priority coastal management issues: (1) land use and population growth; (2) habitat loss and alteration; (3) water quality degradation; and (4) changes in biological communities (NERRS, 2006b). The NERRS 2005-2010 Strategic Plan outlines the strengths of the reserve system, and how it addresses the major challenges of coastal management on local, regional, and national scales. The following goals of the NERRS are outlined in the plan.

1. Strengthen the protection and management of representative estuarine ecosystems to advance estuarine conservation, research, and education.
2. Increase the use of reserve science and sites to address priority coastal management issues.
3. Enhance peoples' ability and willingness to make informed decisions and take responsible actions that affect coastal communities and ecosystems.

SYSTEM-WIDE MONITORING PROGRAM

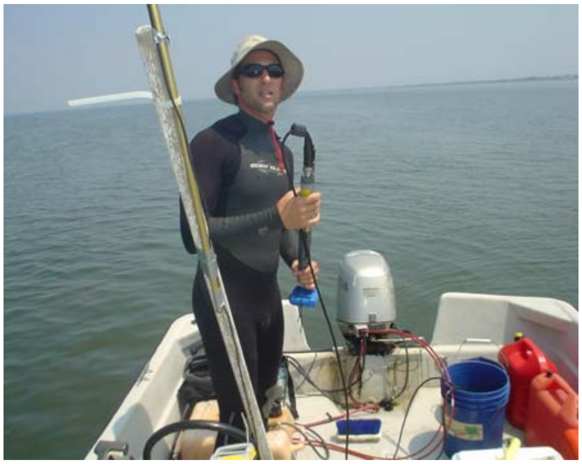
The NERRS established the System-wide Monitoring Program (SWMP) in 1994 to track physical, chemical, and biological conditions and ecological processes of estuarine ecosystems using system-wide, quality assurance protocols (Wenner et al., 2001; Sanger et al., 2002). Since their inception, the long-term monitoring and iterative habitat assessments conducted within the NERRS program have resulted in comprehensive databases for multiple purposes. Monitoring data serve as a basis for research to enhance fundamental understandings of the temporal and spatial dynamics of estuarine processes. In addition, the data provide management-relevant information to evaluate changes in the ecosystem in response to natural perturbations and anthropogenic disturbance. Moreover, continued operation of the long-term monitoring effort will yield valuable data to inform user groups of assessments and models of the cumulative effects of environmental stressors in estuarine ecosystems (NERRS, 2007).

As noted above, a major focus of the SWMP is to improve the understanding of estuarine variability associated with both natural processes and anthropogenic activities through measurements of short-term variability and long-term changes in water quality, biotic community structure, aquatic habitat characteristics, and watershed land use and land cover (NERRS, 2007). In this regard, the SWMP initiatives have included efforts to obtain extensive and useful environmental databases. According to the NERRS (2002), some problems that could be targeted by the collection of these comprehensive databases include:

1. Changes in water quality associated with land use change, nutrient loading, or altered freshwater flow;
2. Comparison of natural, altered, and restored habitats; and
3. Correlation of water quality over broad spatial scales with occurrence, density, and distribution of biological resources.

Research and monitoring at the NERRS sites have yielded data on the processes that govern stability and change in estuarine ecosystems. The SWMP anchors research and monitoring efforts at the NERRS sites and ensures the standardization of sampling protocols, which allows reliable comparisons to be made of data collected at the reserve sites. The SWMP consists of three major elements: (1) abiotic monitoring; (2) biotic monitoring; and (3) land use and habitat change characterizations (NERRS, 2007). Each of these elements contributes long-term data that are valuable for tracking changes in ecosystem features and for assessing relationships between these features to better understand the drivers of the observed changes.

Abiotic Monitoring



Abiotic monitoring focuses on data acquisition of three major SWMP components: (1) water quality; (2) physical conditions; and (3) weather. Baseline data acquisition for these three components provides important contextual information on the physico-chemical dynamics of an estuary. They also help track changes over time and across space that may be induced by human activities. For example, nutrient enrichment has increased dramatically in estuaries around the country and has become recognized as a significant stressor in many estuarine systems (Kennish and Townsend, 2007). The abiotic monitoring conducted through the SWMP provides important data on nutrient concentrations, on how nutrient concentrations are influenced by physical processes (e.g., precipitation, freshwater inflow, and tidal cycles), and on how they may affect other ecosystem conditions (e.g., chlorophyll *a* and dissolved oxygen). As this example shows, the tracking of abiotic features in the NERRS facilitates greater understanding of estuarine processes and the factors that influence these processes. It also provides baseline data that guides improved management of estuarine ecosystems.

The SWMP fills an important void for an integrated national program that evaluates the status of marine environmental resources and the trends in estuarine water quality over protracted periods. Therefore, it differs from most existing nationwide monitoring programs which generally monitor estuarine conditions over shorter periods each year. Water quality parameters—temperature, conductivity, pH, dissolved oxygen, turbidity, and water depth—have been monitored within all NERR sites since 1995. Data are gathered using 6-series data sondes from Yellow Springs Instrument Company (YSI™), Yellow Springs, Ohio (YSI 6600 or YSI 6600 EDS models); they are deployed at four primary, long-term stations in each reserve. Each water quality parameter is measured at 15 minute intervals, and data from at least one data sonde per reserve (e.g., Buoy 126 in the JCNERR) are telemetered hourly via satellite to a central receiving station for near real-time use (NERRS, 2007). All data and metadata are archived and made web-available via the Centralized Data Management Office (CDMO) currently located at the North Inlet-Winyah Bay NERR in South Carolina (http://cdmo.baruch.sc.edu). The measured parameters track changes in key physico-chemical conditions and are indicative of habitat quality for numerous species. They also document environmental criteria that relate to human health and influence human use of estuarine areas.

Nutrients have been monitored at the data-sonde sites since January 2002. Replicate grab samples are collected monthly; in addition, monthly diel samples are taken at 2.5 h or shorter intervals over a lunar day (24 h: 48 min) at one site using an ISCO sampler (Teledyne Isco, Inc., Lincoln, Nebraska, USA). All of the NERRS reserve sites gather data on ammonium, nitrate, nitrite, orthophosphate, and chlorophyll *a*. Additional nutrient parameters are measured by some of the reserves (e.g., silica, particulate nitrogen and phosphorus, dissolved total nitrogen and phosphorus, particulate and dissolved carbon, and total suspended solids) (NERRS, 2007). As coastal development and associated eutrophication problems have increased, nutrient monitoring is important for investigating patterns and drivers of change in nutrient concentrations and for devising effective mitigation and remediation strategies (Kennish, 2003; Kennish and Townsend, 2007).

Meteorological Monitoring

Meteorological data are collected year-round through the NERRS SWMP. Monitoring stations are sited at locations typical of natural conditions of each reserve and are installed according to National Weather Service guidelines. The JCNERR collects meteorological data at the Richard Stockton College Marine Field Station at Nacote Creek. The parameters (i.e., air temperature, wind speed and direction, barometric pressure, relative humidity, precipitation, and phytosynthetically-available radiation) are measured every five seconds, with an average or total value output every 15 minutes. Data are telemetered hourly via satellite to a central receiving station for near real-time use (NERRS, 2007). The meteorological monitoring provides valuable contextual data for interpreting water quality implications of short-term weather events and for investigating estuarine responses to longer-term climatic variability. In addition,

understanding links between atmospheric deposition and nutrient loading to estuaries requires accurate meteorological records (Paerl, 1997; Paerl et al., 2002; Gao et al., 2007).

Biotic Monitoring

The SWMP biomonitoring initiatives have yielded data on the species abundance, distribution, and diversity of biotic communities in the NERRS estuarine systems. These initiatives have also been used to track temporal changes in characteristics of the biotic communities. Biomonitoring projects also address specific research questions or management issues, such as the effect of water quality on species distributions or the influence of habitat degradation on the communities. More information on key biomonitoring components of the SWMP can be found in the focus areas of the NERRS Research and Monitoring Plan.

The implementation of the SWMP biomonitoring efforts commenced in 2004, with initial efforts focused on the monitoring of submerged aquatic vegetation (SAV) and emergent vegetation (Moore and Bultuis, 2003). Since that time, baseline data have been collected at most reserve sites to document the occurrence, growth, and spatial distribution of emergent and submerged vegetation. The monitoring of SAV and emergent vegetation is conducted using two approaches. One approach (referred to as Tier I) documents the areal extent and spatial distribution of SAV and emergent vegetation within reserve boundaries at annual or multi-annual time scales. Mapping is conducted using remote sensing, in-situ field surveys, or a combination of these methods as defined in NOAA's Coastal Change Analysis Program and the Chesapeake Bay Program (Dobson et al., 1995; NERRS, 2001). The second approach (referred to as Tier

II) examines the community and vegetative characteristics at permanent sampling stations located along transects within selected stands of SAV and emergent vegetation. It employs the protocols used in other successful monitoring programs (Neckles and Dionne, 2001; Roman et al., 2001; Neckles et al., 2002; Short et al., 2002) and targeted studies (e.g., Haag et al., 2008; Kennish et al., 2008; Moore and Jarvis, 2008). Tier II characterization of local plant communities can yield critically important data on vegetative growth and compositional changes over short- or long-term temporal scales.

As the biomonitoring program is expanded, it will track a suite of ecosystem components to elucidate basic ecological processes in estuaries and to better understand the implications of abiotic and biotic changes at the ecosystem level. Other components to be incorporated into the biomonitoring program include plankton, nekton, benthos, invasive species, and marsh birds (Kennish, 2003; NERRS, 2007). These biotic groups serve ecological roles ranging from primary producers to top-level consumers in the food web. They may also be indicators of disturbance (e.g., nutrient enrichment, habitat alteration, and climate change) and thus are of great interest and concern to coastal managers. As part of the SWMP, consistent protocols will be developed and tested for monitoring these biotic groups across the NERRS. Some of the NERRS sites already conduct site-specific monitoring and research of key indicator organisms.

Land Use and Habitat Change Characterizations

Human settlement and population growth in the coastal zone have significantly altered the landscape of estuarine watersheds via habitat destruction and fragmentation. Secondary effects of landscape change have degraded water quality due to increased surface water runoff, accelerated loading of nutrients and sediments, and freshwater diversions (Kennish, 2002). The land use and habitat characterization component of the SWMP tracks the magnitude and extent of habitat change and how these changes are linked to watershed land use practices.

To track land use and habitat change, a set of two standard monitoring procedures are applied at relevant scales in each reserve and its surrounding watershed. Through a partnership with NOAA's Coastal Services Center, the NERRS characterizes land cover in each reserve's watershed at moderate resolution (30-m) using data and protocols associated with the Coastal Change Analysis Program (C-CAP) (NERRS, 2001). These products are developed using remotely sensed imagery from which coastal intertidal areas, wetlands, and adjacent uplands are inventoried. Current inventories are maintained, and change analyses are conducted by updating the land cover maps at five-year intervals.

Fine-scale, high resolution habitat mapping and change analyses are conducted within each reserve's boundaries using a standardized classification scheme that incorporates habitat types as well as land use types (Kutcher et al., 2005). This classification structure organizes habitats by their salinity zone, flooding regime, substrate type, and vegetation cover to provide very detailed inventories of resources within each reserve. In most reserves, data for this characterization are derived from aerial photographs or other high-resolution, remotely-sensed images. Extensive ground-truthing ensures high levels of classification accuracy to support sensitive change analyses and trend assessments over time. A habitat classification map for the JCNERR is shown in Figure 1 above.

This component of the SWMP enables investigators to compare the local, regional, and national differences in watershed land use patterns, to understand how these differences influence estuarine habitat quality, and to assess the sensitivity of specific habitat types given land use change patterns. At local levels, these products provide important information needed for effective coastal land use planning and decision-making. They also provide critical data needed to assess specific issues, such as the risk posed to coastal habitats by sea level rise.

JACQUES COUSTEAU NATIONAL ESTUARINE RESEARCH RESERVE

The National Oceanic and Atmospheric Administration (NOAA) designated the Mullica River-Great Bay Estuary as the 22nd National Estuarine Research Reserve System (NERRS) program site on November 17, 1995. NOAA officially renamed this site the Jacques Cousteau National Estuarine Research Reserve (JCNERR) on October 20, 1997, in honor of the famous ocean explorer, Jacques-Yes Cousteau. The principal mission of the JCNERR program is to conduct long-term scientific research and monitoring to characterize the natural and anthropogenic processes governing change and stability in the reserve, and to provide the data necessary to effectively address coastal management problems. The reserve program also focuses on improving the protection of estuarine resources for designated uses such as public health, recreation, fish and shellfish populations, and support of the estuarine ecosystem. It attempts to enhance public awareness and understanding of estuarine and watershed areas through public education and interpretation.

The Institute of Marine and Coastal Sciences at Rutgers University oversees day-to-day operations of the JCNERR program. Rutgers University has been conducting research within the Mullica River-Great Bay estuarine system since the 1950s. With the acquisition of its marine field station on Great Bay in 1972, the University began collecting extensive data sets on the system. Other agencies and partners of the reserve have also conducted studies on the Mullica River-Great Bay Estuary and surrounding watershed areas. These include the Richard Stockton College of New Jersey, New Jersey Department of Environmental Protection (Division of Fish, Game and Wildlife at Nacote Creek), U.S. Fish and Wildlife Service, the Pinelands Commission, and Tuckerton Seaport.

The JCNERR is unique for several reasons. The Mullica River-Great Bay Estuary exhibits exceptional environmental quality and is generally considered one of the most pristine and least (anthropogenically) impacted systems in the densely populated urban corridor of the northeastern United States. This is largely attributed to the extensive undeveloped lands of the Pinelands National Reserve, state wildlife management areas, and federal reserves surrounding these waters (Figure 1). The Pinelands National Reserve, totaling nearly 450,000 ha, encompasses much of the forested land in the area that is not state-owned land. It restricts future

development (Psuty et al., 1993). Domestic and industrial development in the watershed, therefore, is limited. Encompassing more than 45,000 ha, the JCNERR consists of a wide array of terrestrial, wetland, and aquatic habitats ranging from upland pine-oak forests and hardwood swamps in the alluviated stream valleys of the Pinelands to tidal marshes, barrier islands, and open estuarine and coastal ocean waters. The land habitats are entirely in public ownership, which affords a significant level of resource protection.

Water is the predominant habitat in the JCNERR, covering 27,599 ha (~60% of the area). Marsh blankets an additional 13,034 ha (>28% of the area). Forest cover is the next largest category; it amounts to 4,616 ha (~10% of the area). Developed landscape, which is relatively sparse, provides the least cover (553 ha or slightly over 1% of the area). Domestic development is concentrated in two small communities, Mystic Island and Tuckerton, whose boundaries extend to within 3 km of Great Bay (Psuty et al., 1993).

Fringing wetlands (e.g., freshwater wetlands along the Mullica River, small palustrine (nontidal) wetlands, and *Spartina* salt marshes) and submerged aquatic vegetation (e.g., *Zostera marina* and *Ruppia maritima*) support numerous organisms, including a number of endangered and threatened species. The marshes also serve as nursery and reproductive habitats, filters of nutrients and contaminants, and agents of flood and erosion control. The most extensive salt marshes

(~33.8 km^2) occur along the perimeter of Great Bay. The marginal areas of the lower Mullica River are dominated by the smooth cordgrass (*Spartina alterniflora*) in the lower marsh and salt-meadow cordgrass (*S. patens*) in the upper marsh. Freshwater tidal marshes predominate along the tributary streams and headwaters of the Mullica River. A Holocene barrier island complex, which trends northeast-southwest, forms the seaward boundary of much of the reserve. This complex consists of one totally undeveloped barrier island fronting Great Bay, and the undeveloped parts of two other barrier islands (Psuty et al., 1993). Coastal habitats in the system serve as major migratory stopovers and wintering areas for many species of waterfowl, shorebirds, wading birds, raptors, and songbirds.

The boundaries for the JCNERR are designed to constitute a natural ecological unit. They encompass a core area of contiguous wetlands, riparian habitats, open waters in Great Bay, and nearshore ocean areas off Little Egg Inlet. The buffer zone includes upland forested areas adjacent to the core wetland habitats. These boundaries form a highly productive system that supports a rich diversity and high abundance of finfish, shellfish, and wildlife.

Great Bay harbors large concentrations of planktonic, benthic, and nektonic organisms. Biotic resources in the bay are similar to those of the Barnegat Bay-Little Egg Harbor Estuary to the north and the Brigantine Bay and marsh complex to the south. In addition, the Mullica River and its tributaries, notably the Batsto and Wading Rivers, support hundreds of plant and animal species (e.g., 350 species of algae, 62 species of aquatic macrophytes, 275 species of macroinvertebrates, and 91 species of fish) (U.S. Fish and Wildlife Service, 1996).

Scientific investigations in the JCNERR have concentrated on coastal upwelling effects, life history and habitat ecology of fishes, habitat characterization and mapping, shellfish resources, submerged aquatic vegetation, and potential impacts of human disturbance. Water quality monitoring is another important component of the program. The JCNERR is a vital area of estuarine research, as well as a natural field laboratory, that provides valuable educational opportunities for teachers, students, and other individuals interested in this unique and relatively undisturbed coastal ecosystem. It is ideally suited as a reference site for assessing the modification and recovery of other estuarine systems.

Field and Laboratory Facilities

The Rutgers University Marine Field Station (RUMFS) in Little Egg Harbor Township provides field and laboratory facilities for the JCNERR and visiting scientists who conduct research and monitoring within reserve waters. It is situated at the end of a peninsula adjacent to Little Egg Inlet and is the site of a former

U.S. Coast Guard Lifesaving Station. RUMFS provides access to the New Jersey continental shelf and the Mullica River-Great Bay Estuary. RUMFS resources include the R/V CALETA, a 28 ft. aluminum hull research vessel, equipped with an A-frame and winches and a 48 ft. research vessel, the R/V ARABELLA, equipped with an A-frame, GPS navigation system, lab facilities, and mast-mounted wind sensors. JCNERR's boat, a 23' Carolina Skiff (R/V THE MULLICA EXPLORER) is docked at RUMFS. Several other small boats, docking facilities for larger vessels, analytical laboratories, a running seawater lab, dark room, dive locker, and a 20-bed dormitory and a classroom are also available. This field station serves as the shore base for the Rutgers' Long-term Ecosystem Observatory at 15 meters on the continental shelf (LEO-15), a component of the JCNERR. Research activities focus on fishery-related investigations including recruitment of marine organisms, early life history studies, and studies of sediment transport on the continental shelf. From 1957 to 1986, measurements of nutrient concentrations, productivity and basic physical parameters were made in the watershed and continue in partnership with the JCNERR.

A rail system connecting the dock to a service bay exists at RUMFS for servicing research vessels and oceanographic equipment. There is also additional dormitory/office/storage complex a short distance from the main laboratory. Recently, funds were awarded from NOAA/NERRS to renovate and expand laboratory space at RUMFS for use by JCNERR investigators. This renovation added much needed capacity to handle and analyze field samples, and improve space required to support the SWMP. The JCNERR Education Center also has dormitory facilities for visiting scientists and students who conduct research within the reserve boundaries.

JCNERR Outreach and Education Programs

Coastal Training Program

The JCNERR Coastal Training Program (CTP) offers a variety of training programs, resources and outreach materials for New Jersey's coastal management community. The JCNERR has enhanced informed decision-making on coastal issues by transferring technical information to audiences that influence management of coastal resources. In 2006, the JCNERR CTP updated its strategic planning. Prior to 2003, the JCNERR hosted a variety of coastal decision maker workshops as noted below.

Small Motorized Watercraft Workshop 2000

The JCNERR hosted science and management workshops to provide scientific research on the impacts of small motorized watercraft to habitats, living resources, chemistry, and water quality. On November 7 and 8, 2000, at the Impacts of Motorized Boats on Shallow Water Systems workshop, speakers throughout the country presented research results and management strategies on small motorized watercraft. A second workshop convened on December 12 and 13, 2000 delivered successful management approaches from state, county, and local governments.

Stormwater Management Roundtables

Chaired by the JCNERR CTP, the Barnegat Bay Phase II Steering Committee has been conducting Phase II Stormwater outreach and offering technical assistance for the past five years. These efforts have been concentrated in the Barnegat Bay watershed which consists of 34 municipalities in Ocean County and 4 municipalities in Monmouth County. During this time, 10 workshops/technical assistance opportunities have been offered to municipal staff, and elected and appointed officials within the watershed.

Evaluation results showed an increased understanding of stormwater management topics that have enabled municipalities within the Barnegat Bay watershed to take the necessary steps to ensure compliance with their permits. A full evaluation of the stormwater outreach was conducted in spring 2007. These results can be found online at: www.JCNERR.org/coastal_training.

Coastal Hazards Mitigation Outreach

The JCNERR, in partnership with the New Jersey State Police, Office of Emergency Management Services, Federal Emergency Management Agency (FEMA), and the New Jersey Department of Environmental Protection, offered a CTP workshop on developing hazard mitigation plans for coastal municipalities. In light of hurricane Katrina and other recent coastal disasters, this workshop was created to meet the growing concerns of coastal municipalities regarding impacts of coastal storms.

As a follow-on program, the CTP offered a technical assistance seminar in the computer classroom at the JCNERR Coastal Center. A FEMA official demonstrated the use of an electronic hazard mitigation toolkit. Participants working in county-specific groups from Ocean, Monmouth and Essex counties gained hands-on experience with the toolkit and discussed preparation of mitigation plans. An outcome resulting from these outreach sessions included an agreement between all 34 municipalities in Ocean County to work cooperatively on a multi-jurisdictional hazard mitigation plan.

Project Power

The JCNERR offered a workshop on "Protecting Our Wetlands through Education and Regulations" (PROJECT POWER) in partnership with the staff of the New York Aquarium and the NJDEP Division of Land Use Regulations and the Coastal and Estuarine Land Use Compliance. A grant from the EPA enabled the New York Aquarium to partner with various educational associations throughout the coastal zone to deliver these workshops. A local workshop was delivered to local realtors and past wetland regulation violators. Presentations focused on the ecological and functional importance of wetlands, the NJDEP freshwater and coastal wetland regulations, and compliance and enforcement issues.

Adopt-A-Storm Drain Municipal Assistance

The JCNERR CTP, in partnership with the Barnegat Bay National Estuary Program, implemented an Adopt-a-Storm-Drain program in three towns within the watershed in 2007. A flyer was developed to promote the program to all residents.

Towns adopting the program received GPS units and training on how to mark and map their storm drain inlets, individualized database programs for maintenance of storm drain adoption records, and personalized storm drain labels.

Online Outreach Training Courses

In order to maintain their licenses, local construction code officials are required to continue education through the New Jersey Department of Community Affairs (DCA). In August 2006, needs assessment construction code officials identified land use regulations as a highly desired topic for additional technical training. The online course was offered through the JCNERR CTP website (www.JCNERR.org/coastal_training). The five-week course was divided into five modules which included information pertaining to waterfront development, CAFRA, coastal and freshwater wetlands, stream encroachment and tidelands, and map and data miner webquest. As a result of the success of this course, four additional sessions have been offered.

Based on the success of the Land Use Regulations Online Course and the results of the 2006 needs assessment, a second online course was developed and offered in March 2007. This course covered the floodplain regulations and construction standards. In addition to construction code officials, this course was offered to state floodplain managers. The modules included an overview, and information pertaining to forces of floods on buildings, floodplain mapping, design and construction standards, and administration of a local floodplain program.

The JCNERR, in partnership with the NJDEP, also developed a day-long workshop to provide the most current and relevant scientific data regarding submerged aquatic vegetation (SAV) to staff of the NJDEP's Land Use Regulations and Enforcement Department. Hosted at Island Beach State Park, the workshop highlighted the importance of SAV as a habitat, its biology and the major impacts affecting SAV. An update was given on the current state of knowledge on the restoration of SAV. Overviews of GIS products available for mapping SAV were provided by the Center for Remote Sensing Spatial Analysis (CRSSA) of Rutgers University. An explanation of a scientific model to predict SAV habitat and the techniques on evaluating SAV habitat in the winter were also presented. Participants went on a field trip to SAV habitats in Island Beach State Park.

K-12 Education

The education program of the JCNERR uses state-of-the-art science and technological assets to develop innovative education programs and products that meet the educational needs of K-12 educators and their students. Elements of these programs are extended to the general public or watershed community, most notably individuals likely to visit partner institutions such as the Cape May Nature Center, Tuckerton Seaport, and Forsythe Refuge. Education programs offered as part of outreach initiatives at the Tuckerton Seaport and other partner institutions provide vital information on water quality conditions, habitats, and biotic resources in the JCNERR.

Marine Activities, Resources and Education (MARE)

In 1994, Rutgers' Institute of Marine and Coastals Sciences adopted an interdisciplinary K-8 marine science curriculum called the Marine Activities Resources and Education (MARE) program which now serves as a valuable source of information and inspiration for creative, hands-on teaching. This interdisciplinary, whole-school program engages teachers, students, parents, administrators and the community in the transformation of elementary and middle schools into dynamic laboratories for the study of the ocean. The program, created in 1991 by the Lawrence Hall of Science at the University of California at Berkeley, has been successfully implemented in hundreds of inland and coastal schools nationally. MARE is especially designed to improve science instruction for all students while promoting equity, language acquisition, environmental awareness, and academic excellence.

The MARE program has achieved the following results since its inception in New Jersey in 1994: (1) approximately 3,650 educators have been directly trained as Leadership Teams through the annual six-day MARE Summer Institute; (2) approximately 12,000 K-6 educators have received training or have become involved in the program through turn-key training opportunities conducted by Summer Institute participants or MARE Master Trainers; (3) approximately 150 Ocean Week Celebrations have been conducted in elementary schools throughout the state; (4) dozens of student field trips associated with the MARE program have been supported; and (5) more than 20 pedagogical workshops and collaborative projects, including “Bay Grasses for Classes” and the Tidal Marsh Assessment Protocol (TMAP) project have been conducted.

COOL Classroom

The JCNERR education staff, with support from the National Ocean Partnership Program (NOPP) and the help of a group of scientists, technicians, school administrators, and educators, developed a series of instructional modules for use on the Internet known as the Coastal Ocean Observation Laboratory (COOL) Classroom (www.coolclassroom.org). These modules are designed to capitalize on the technology and data associated with the New Jersey Shelf Observing System to develop critical thinking and analytical skills among middle and high school students. Using the modules, students participate in the same predictive process used by scientists through the comprehension of basic scientific principles as applied to marine science, accessing real-time oceanographic data, analyzing data patterns and trends, and predicting ocean conditions.

The COOL Classroom site began as a series of professional development workshops in 1998 and 1999, where educators learned about the data and technologies associated with the research of the NJSOS. Participants helped to develop several online lesson plans over the two-year period, and a basic web site was developed to host the lessons. Evaluation results from the workshops in 1998-99 indicated that participants were more comfortable with integrating technology into their lesson plans following the training, but were less comfortable with using real-time scientific data with their students.

In 1999, additional support was secured from NOPP and an advanced web site was developed through a collaboration of educators, scientists and the JCNERR education staff. The COOL Classroom site was formally launched in an advanced draft state in the spring of 2002, and has since been piloted twice with classroom educators. The latest pilot, involving 20 educators from around the country, was completed during April – June 2003. The COOL Classroom site continues to be improved and updated. The launch of a newly improved COOL Classroom website is scheduled for summer 2008.

Shore Bowl

Since 2000, the JCNERR has engaged high school students in the study of coastal and ocean sciences through the Shore Bowl, a high school academic competition focused on ocean-related topics. These topics include the biology, chemistry, physics, and geology of the oceans, as well as navigation, geography, and related history and literature. The Shore Bowl is one of 23 regional competitions that comprise the National Ocean Sciences Bowl, sponsored by the Consortium for Oceanographic Research and Education (CORE). Each year, the Shore Bowl provides the opportunity for up to 16 teams to compete for a variety of prizes and awards, including the right to compete in the national competition.

National Estuaries Day

On behalf of National Estuaries Day, the JCNERR has conducted programs to engage the local citizenry in a better understanding of their estuarine resources, as well as the mission and programs of the reserve. National Estuaries Day is an interagency campaign to celebrate the importance of estuaries and the need to protect them. Local communities across the country celebrate their estuaries with a variety of special events, many of which are hosted by reserves within the NERRS.

The JCNERR has gone beyond a local celebration of National Estuaries Day by participating in EstuaryLive, a series of live Internet video broadcasts from several reserves and National Estuary Program sites around the country. The live field trips are available to educators, students, and the public via any computer with an Internet connection, and participants can interact with on-camera personalities in real time via e-mail. The JCNERR participated in the live broadcasts of the event each fall from 2001 to 2005 involving scientists, educators, and students.

Graduate Research Fellowship Program

The JCNERR Graduate Research Fellowship (GRF) program provides graduate students with an opportunity to conduct research of local and national significance that focuses on enhancing coastal zone management. Fellows conduct their research at a NERRS site and gain hands-on experience by participating in their host reserve's research and monitoring programs. GRF projects are based on a reserve’s local needs, the NERRS national priorities, and the student’s interest.

Since 1999, the JCNERR has supported the research and education activities of 11 GRFs (Appendix 1). The research projects of the GRFs have involved studies in the coastal watersheds of the reserve (Mullica River and Barnegat Bay watersheds) as well as the estuarine waterbodies themselves (notably the Mullica River-Great Bay Estuary and Barnegat Bay-Little Egg Harbor Estuary). The projects have included the application of land use change models, nutrient biogeochemistry, the investigation of fish species dynamics and habitat use, fish larval occurrence and abundance, decapod crustacean abundance and diversity, and seagrass epiphytic biomass.

JCNERR CHARACTERISTICS

The JCNERR is located in southeastern New Jersey (~39°N, 74°W) approximately 15 km north of Atlantic City. It lies astride the Pinelands forest ecosystem on the Atlantic Coastal Plain and the Pleistocene and Holocene barrier island complexes of the coastal margin. The geographic scope includes a part of the Mullica River drainage basin (Figure 3). It also encompasses lower Barnegat Bay, Little Egg Harbor, Great Bay, and inland back-bays (e.g., Little Bay, Reeds Bay, and Absecon Bay) as far south as Absecon. The downstream boundary extends about 9 km onto the adjacent inner continental shelf to the area of the Long-Term Ecosystem Observatory (LEO-15), a 2.8

km^2 offshore research site of Rutgers University. LEO-15 is located at a shallow (~15 m deep) sand ridge (Beach Haven Ridge at 39°8'18"N, 74°15'10"W) measuring about 4.5 km long and 1 km wide on the inner continental shelf off Little Egg Inlet.

Physical-Chemical Characteristics

Estuary/Watershed

The Great Bay-Little Egg Harbor estuarine complex, which occurs in the central portion of the Mid-Atlantic Bight, consists of shallow, polyhaline embayments bordered by more than 280 km of shoreline, as well as extensive salt marshes. Great Bay covers an area of 41.6 km^2, and Little Egg Harbor, an area of ~125 km^2. These coastal bays are shallow microtidal systems (tidal range < 0.5-1 m in Little Egg Harbor and > 1 m near the mouth of Great Bay) with an average depth of < 2 m at mean low water

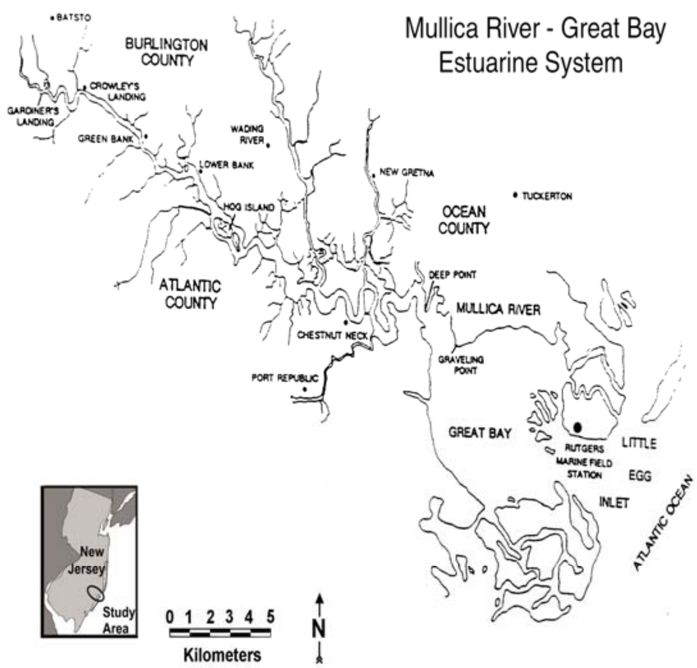


Figure 3. Map of the Mullica River-Great Bay Estuary. The inset shows the location of the estuary with respect to the state of New Jersey.

(Chizmadia et al., 1984; Durand, 1984). Because of their shallow depths, both systems respond relatively rapidly to air temperature changes; thus, they are characterized by a broad annual temperature range (~2 to 30°C). Salinity in the embayments ranges from ~10->32‰ (Szedlmayer and Able, 1996).

Most land areas surrounding the Mullica River, Great Bay, Little Egg Harbor, and lower Barnegat Bay systems are managed by state and federal government agencies which minimizes adverse anthropogenic impacts. Among the state-owned lands are the following: Absecon Wildlife Management Area, Great Bay Boulevard Wildlife Management Area, Port Republic Wildlife Management Area, Swan Bay Wildlife Management Area, Clarks Landing State Natural Lands Trust, Kinslow Preserve, Mystic Island State Natural Lands Trust, Bass River State Forest, Wharton State Forest, North Brigantine State Natural Area, Absegami State Natural Area, and Great Bay State Natural Area. Federal-owned and managed lands include the Brigantine National Wildlife Refuge and the Barnegat National Wildlife Refuge. The upper part of the Mullica River-Great Bay drainage basin also lies in the pristine Pinelands National Reserve which affords a considerable degree of protection from anthropogenic environmental alteration (Good and Good, 1984; Able et al., 1996). The Pinelands Management Area encompasses ~75% of the Mullica River watershed, and most of the watershed remains in public ownership. Underwater lands of the Mullica River-Great Bay Estuary are all state owned.

Climate

A number of weather stations collect meteorological data in the region. The National Weather Service at Pomona (~16 km west of Atlantic City; elevation 19.5 m) monitors weather conditions 24 hours a day and has a comprehensive meteorological database dating back to 1943. Other official National Weather Service observation sites maintained in the Pine Barrens include Belleplain State Forest (9.1 m elevation), Chatsworth (30.5 m), Hammonton (25.9 m), Indian Mills (30.5 m), Lakehurst Naval Air Station (39.0 m), Mays Landing (6.1 m), McGuire Air Force Base (43.6 m), Pemberton (24.4 m), and Toms River (3.0 m) (Havens, 1998). More locally, the Oyster Creek Nuclear Generation Station, located in the Barnegat Bay watershed at Forked River, has collected meteorological data since 1966. The U.S. Coast Guard Station on Long Beach Island at Barnegat Light also collects meteorological data, as does the Rutgers University Marine Field Station at the terminus of the Great Bay Boulevard Wildlife Management Area. Finally, a Campbell Scientific Weather Station operated by the Richard Stockton College in partnership with the JCNERR records meteorological data near Nacote Creek as part of the NERRS System-wide Monitoring Program.

Havens (1998) has reviewed the climate in the region. The JCNERR is characterized by temperate conditions typical of the Mid-Atlantic region. The seasons are well defined; however, seasonal air temperatures vary considerably from year to year as in other temperate systems. The coldest temperatures occur during January, and the warmest temperatures, during July. While the average winter temperature ranges from 0-2.2°C, the average summer temperature ranges from 22-24°C. The Atlantic Ocean moderates seasonal air temperature extremes in the lower drainage basin and open estuarine areas. Farther inland away from the influence of the ocean, temperature extremes can be great. For example, winter temperatures less than -20°C have been recorded in the Pine Barrens region, with summer temperatures occasionally exceeding 38°C.

Winds predominate from the northwest and southwest during the year (Figure 4). The prevailing winds from the December through March period are from the northwest. Southerly onshore winds dominate in the late spring and summer. Wind velocities are generally less than 15 km/hr. Warm tropical air masses from the south and southwest bring hot, humid weather conditions during summer. Afternoon sea breezes reduce summer temperatures within 10-15 km of the shoreline.

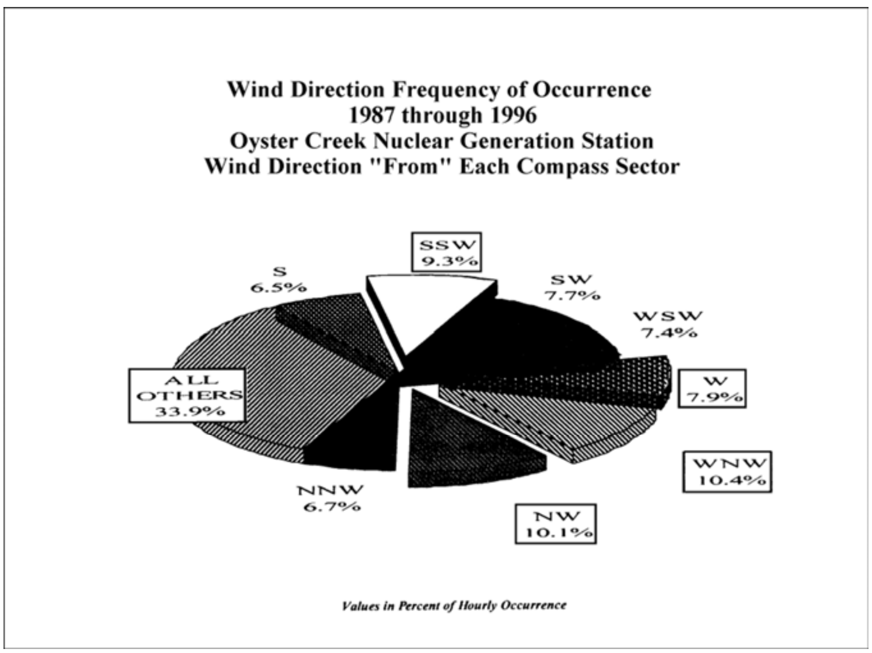


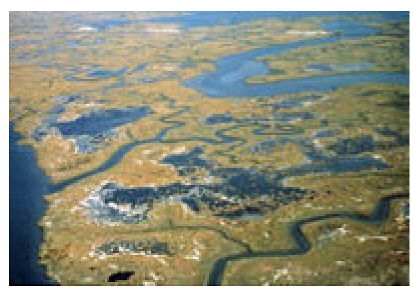
Figure 4. Wind direction frequency of occurrence recorded at the Oyster Creek Nuclear Generating Station during the 1987 to 1996 period. From Kennish, M. J. (ed.). 2001a. Characterization Report of the Barnegat Bay-Little Egg Harbor Estuary and Watershed. Technical Report Submitted to the Barnegat Bay Estuary Program, Toms River, New Jersey. 1,100 p.

Northwesterly winds in winter develop from high pressure areas with very cold air masses over central Canada and the northern Great Plains of the United States. Periodic surges of cold air masses flow southeastward across the eastern United States, and they affect the study area. The frequency of these cold air surges diminishes through the spring, as the jet stream retreats northward, ultimately being replaced in summer by warm and humid southerly breezes originating from a large, subtropical high pressure area (a semi-permanent feature) centered near Bermuda in the Atlantic Ocean (i.e., Bermuda high). More quiescent weather conditions typically arise in the fall in association with stationary or slow-moving, high pressure areas which originate as cold, shallow highs over Canada and stagnate over the eastern United States as warm highs (Havens, 1998).

Precipitation, mainly in the form of rain, averages between 100-122 cm/yr in the region. It is relatively evenly distributed year-round. Northeasters commonly deliver large amounts of precipitation in the winter, with thunderstorms caused by localized convection frequently observed during the summer and early fall. The thunderstorms are generally of high intensity and short duration. Northeasters typically develop in waters off the southeast coast of the United States and move north and northeast producing strong winds, heavy surf, and occasional tidal flooding. Extratropical storms and hurricanes arise during late summer and early fall, although they often pass east of the reserve. These storms can also generate destructive winds and considerable precipitation (e.g., 10 cm or more) that occasionally cause serious flooding problems, soil erosion, and structural damage.

The Gulf Stream plays a vital role in the development of northeasters. This northward flowing, warm-water current parallels the eastern seaboard, heating the overlying air and creating a front along the coast. Subsequently, surface low pressure systems can form as jet stream disturbances move over this newly formed temperature gradient. Heavy rains and strong winds often ensue because of the large amount of moisture from the ocean and the aforementioned temperature gradient of the coastal front. Strong winds from the east and northeast associated with these storms may cause barrier beach erosion, overwashes, and back-bay flooding. In severe storms, wind gusts have exceeded 90 km/hr, and sustained winds, 80 km/hr. During any given calendar year, three-to-five coastal storms typically occur in the region, with the most severe storms observed in the fall.

Geology



The Mullica River watershed lies within the Atlantic Coastal Plain, which formed during the last 170-200 million years by depositional and erosional processes (Figure 5). In New Jersey, the coastal plain covers ~10,500 km^2 and is underlain by a thick wedge (400-1,830 m) of unconsolidated clays, silts, sands, green sands, and marls deposited during the past 135 million years in response to multiple sea level changes and associated transgressive and regressive sequences. These sediments comprise at least 15 geologic formations predominantly of Cretaceous and Tertiary Age. The Raritan Formation (lower Cretaceous Age) lies at the bottom of the wedge, and the Kirkwood and Cohansey Formations of Tertiary (Miocene)

Age (overlain by a thin veneer of Quaternary deposits) occur at the top (Table 1). The wedge of sediments thickens eastward (seaward), exceeding 1,900 m in southern Cape May County (Zapecza, 1989). The alternating layers of clay, silt, sand, and gravel characterizing coastal plain sediments trend northeast-southwest and dip gently eastward at ~2 m/km (New Jersey Geological Survey, 1996). Most sedimentary strata underlying the Atlantic Coastal Plain have formed by deposition in deltaic and shallow marine environments.

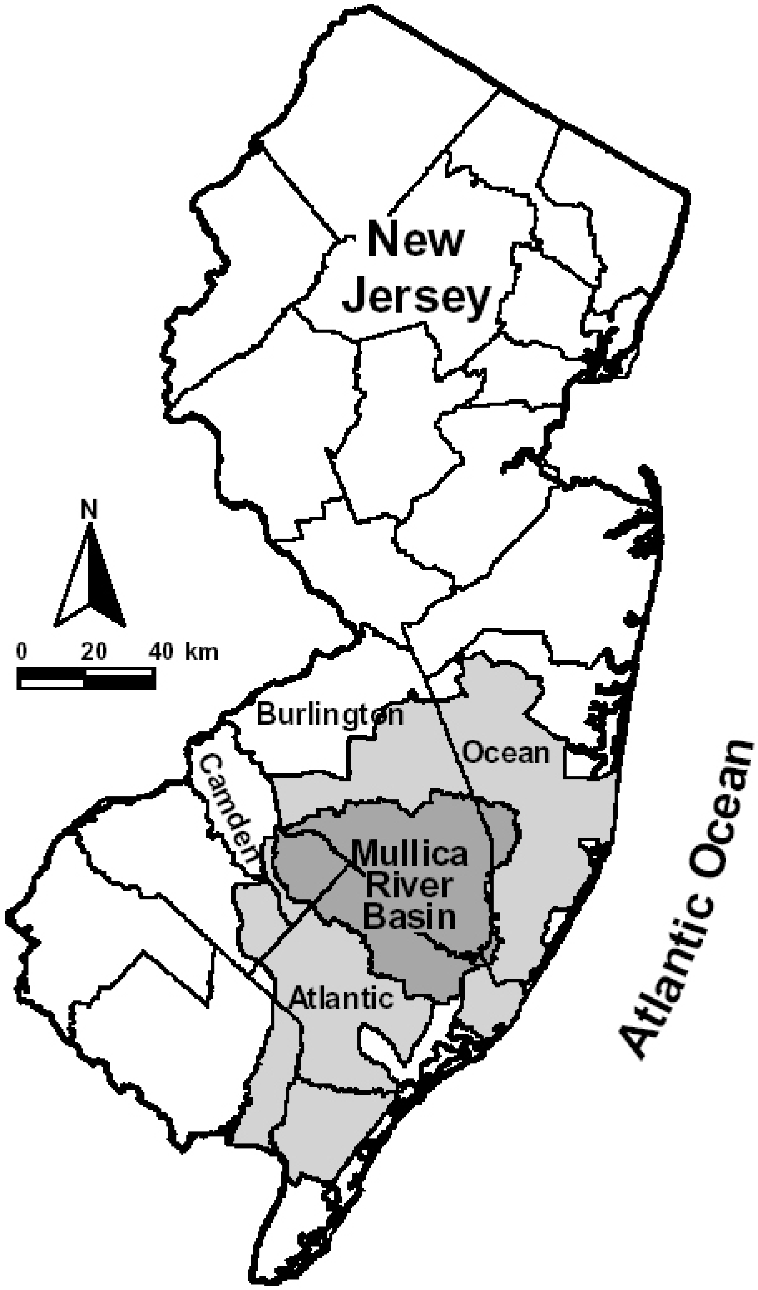


Figure 5. Map illustrating the regional location of the Mullica River Basin. From Zampella, R. A., J. F. Bunnell, K. J. Laidig, and C. L. Dow. 2001. The Mullica River Basin. Technical Report, New Jersey Pinelands Commission, New Lisbon, New Jersey.

Table 1. Upper strata of the New Jersey coastal plain.

Time and age	Lithology	Thickness (m)
Quaternary Holocene (0.01)	Clay, silt, sand, bog iron, and peat	0-3
Pleistocene (1.8)	Clay, silt, sand, and gravel	0-37
Tertiary Pliocene (?) (5)	Gravel, sand, and silt; some sand beds	0-6
and	are hardened with iron oxide	0-21
Miocene (?)	Sand and Gravel	0-6, usually <3
	Sand with gravel, silt, and clay	8-61
Miocene (22.5)	Clay, silt, sand and gravel	15-137

From Rhodehamel, E. C. 1998a. Geology of the Pine Barrens in New Jersey. In: R. T. T. Forman (ed.), *Pine Barrens: Ecosystems and Landscape*. Rutgers University Press, New Brunswick, New Jersey, pp. 39-60.

Geological characteristics of the Pinelands, specifically low relief, sandy, droughty soils underlain by water-bearing sandy layers and confining clay layers, provide a unique surface and ground water system (Markley, 1998; Zampella and Bunnell, 2000; Zampella et al., 2001). The Kirkwood and Cohansey Formations are the principal aquifers in the region, with ground water seepage from the Cohansey aquifer providing inflow (base flow) to the regional stream system. They contain an estimated 65 trillion liters of freshwater. Overlying Quaternary deposits, such as the Cape May Formation, serve an important hydrologic function by transmitting water to these underlying aquifers. The underlying Potomac-Raritan-Magothy aquifer system is the most productive and heavily used confined aquifer in the coastal plain, with withdrawal rates from individual wells ranging up to 7,700 l/min.

Four other aquifers occur in the watershed area. These include (from shallowest to deepest): (1) the Atlantic City 800-Foot Sand; (2) the Wenonah-Mount Laural aquifer; (3) the Englishtown aquifer system; and (4) the Potomac-Raritan-Magothy aquifer system. These productive formations consist principally of sand and gravel, with confining units in the sedimentary wedge comprised of silts and clays. The only unconfined aquifer in the region is the Kirkwood-Cohansey system.

Soils

In general, the surface of the coastal plain is a gently rolling terrain, with sandy, droughty soils and few outcrops. The lower component of the region's Kirkwood outcrop consists of very fine, dark, micaceous sand with a pebbly glauconitic basal layer. The upper component is made up of silt and clay. The 8,930 km^2 Cohansey formation ranges from the surface to depths of 6 m to more than 60 m. The Cohansey consists of fine to coarse grained quartzose sand with foot-thick lenses of gravel. Generally, clay content is less than 20%. The Cohansey and the Kirkwood are the principal aquifers in the region and may contain as much as 65 trillion liters of water. The tremendous water reserves are a result of the sandy soil, flat terrain, and evenly distributed precipitation.

The Mullica River watershed contains sandy, siliceous, droughty soils with low nutrient concentrations. They derive largely from the Cohansey Sand, which in the Wharton Tract consists of 93% sand beds, 3.5% silt beds, and 3.5% clay beds. The lithology of the Cohansey Sand varies within the Pine Barrens region, being composed principally of yellow limnetic quartz sand with minor amounts of pebbly sand, fine to coarse sand, silty and clayey sand, and interbedded clay (Rhodehamel, 1998a). The quartz dominated Cohansey Sand yields soils with little or no clay and minimal textural change upon weathering. In addition, the soils are highly acidic with small amounts of organic matter, low cation exchange capacity, and poor capacity to attenuate nutrients.

Markley (1998) identified 16 soil series in the Pine Barrens ranging from excessively drained to very poorly drained types. These include the following series: (1) Lakewood; (2) Evesboro; (3) Woodmansie; (4) Downer; (5) Sassafras; (6) Aura; (7) Lakehurst; (8) Klej; (9) Hammonton; (10) Atsion; (11) Berryland; (12) Pocomoke; (13) Muck; (14) Woodstown; (15) Fallsington; and (16) Fort Mott. The distribution of these soils forms a conspicuous mosaic pattern in the Pine Barrens region (Table 2).

Several soil types predominate in the Mullica River watershed, notably the Lakewood, Evesboro, Woodmansie, Downer, Lakehurst, Klej, Atsion, and Muck series. Lakewood soil, a podsol, consists of highly leached sands with a thickly bleached surface horizon (≥ 18 cm). The Evesboro is comprised of loose, excessively drained soils devoid of a thickly bleached surface horizon. Both the Woodmansie and Downer series are well-drained soils with a sandy loam subsoil. Lakehurst soils have relatively poorly drained sands with a bleached gray sandy surface 18 cm or more thick. Rather poorly drained sands or loamy sands characterize the Klej series. Atsion soils also exhibit poorly drained sands, and in addition, have a gray or thin black surface soil and a dark brown subsoil. In contrast to the aforementioned sandy series, Muck soils consist of poorly drained, organic-rich soils overlying a sandy substratum. They form in narrow submerged valleys (Markley, 1998).

Table 2. General distribution and extent of soils in the New Jersey Pine Barrens.

Soil Series	Former Classification	General Distribution in Pine Barrens	Area in Pine Barrens and Percent of Pine Barrens (Hectares)	Position in Landscape	Most Common Trees (In Order of Abundance)
Lakewood	Lakewood	Rare in southern part	56,000 (12%)	High	Pitch and shortleaf pines, and few chestnut oaks; dwarf form where fires have been severe
Evesboro	Sassafras	Entire region	40,000 (9%)	High	Pitch and shortleaf pines and few chestnut oaks
Woodmansie	Lakewood	Burlington and Ocean counties	20,000 (4%)	High	Dwarf pitch pine
Fort Mott	Sassafras	Mostly in southern part	45,000 (<1%)	High	Black, white, and chestnut oaks, hickories, and few pitch and short leaf pines
Downer	Sassafras	Entire region	80,000 (17%)	High	Black, white, scarlet, red, and chestnut oaks, hickories, and few pitch and shortleaf pines
Sassafras	Sassafras	Mostly in southern part	12,000 (3%)	High	Black, red, white, and scarlet oaks, hickories, and few beeches
Aura	Sassafras	Mostly in southern part	24,000 (5%)	High	Black, white, red, and scarlet oaks, hickories, and few pitch and shortleaf pines
Lakehurst	Lakewood	Mostly in northern part	52,000 (11%)	Intermediate	Pitch pine and few black, white and chestnut oaks

Klej	Sassafras	Entire region	16,000 (3%)	Intermediate	Black and white oaks, blackgum; and few red maples, sweetgums, pitch and shortleaf pines
Hammonton	Woodstown	Entire region	20,000 (4%)	Intermediate	Black, white, red, southern red, and scarlet oaks and few pitch and shortleaf pines
Woodstown	Woodstown	Mostly in southern part	2,000 (<0.5%)	Intermediate	Red, white, black, southern red oaks, hickories, and few beeches
Atsion	Leon[b]	Entire area except Cape May County	58,000 (12%)	Low	Pitch pine, red maple, and blackgum
Fallsington	Portsmouth	Southern part	2,000 (<0.5%)	Low	Swamp white oak, red maple, blackgum, sweetgum, sweet birch, beech, and few pitch pines
Berryland	St Johns[b]	Entire area	20,000 (4%)	Low	Pitch pine, red maple, blackgum, and few Atlantic white cedars
Pocomoke	Portsmouth	Entire area	8,000 (2%)	Low	Swamp white oak, red maple; blackgum, sweetgum, willow oak, and few pitch pines
Muck	Swamp	Entire area	48,000 (10%)	Low	Atlantic white cedar and bay magnolia

From Rhodehamel, E. C. 1998a. Geology of the Pine Barrens in New Jersey. In: R. T. T. Forman (ed.), *Pine Barrens: Ecosystems and Landscape*. Rutgers University Press, New Brunswick, New Jersey, pp. 39-60.

Most soils in the New Jersey Coastal Plain range from sandy clay loam to sand. Organic-rich soils exist along estuarine shorelines and in surrounding wetlands habitat. They also occur near the mouth of coastal plain streams and in broad flooded reaches of the streams. These soils have greater nutrient holding capacity.

Overall, most soils of the Mullica River watershed consist of fine to coarse sands that form a dry, infertile, acid-rich environment. They typically are well leached with low nutrient holding capacity. As a result, the soils are depleted in nutrients, which tend to be concentrated within the vegetative media of the coastal plain.

Topography

The coastal plain at the site of the Mullica River watershed is characterized by low and relatively flat terrain. To the west in the Pine Barrens, the coastal plain undulates gently eastward, but relief is low throughout this region (Tedrow, 1998). Although the coastal plain in New Jersey consists of a series of marine terraces, there are no steep slopes or mountain peaks in the watershed area. Small hills (maximum height = 62 m) sporadically interrupt the low topographic relief of the Pinelands landscape, which mainly lies between 15-46 m above sea level.

Historical and Cultural History

People have been living in the Mullica River-Great Bay region for more than 8000 years. Evidence of these pre-historic cultures has been found in over 1000 sites in the Pine Barrens, including over 100 sites along the Mullica River and its tributaries. The people living in the Mullica River-Great Bay area at the time of contact with early settlers were part of a large group known as the Lenni Lenape. These Native Americans became known as the Delawares to the settlers. The Delawares occupied the areas which are now the state of Delaware, southeastern Pennsylvania, and all of southern New Jersey. In 1758, the remnant of the Delaware Indians living in New Jersey was placed on a reservation of over 1200 ha (3000 ac), known as Edgepillock or "Brotherton." The reservation was located at the headwaters of the Mullica River at what is now known as Indian Mills, Burlington County. The Delawares were relocated to New York State in 1801 and again later to Oklahoma. The Native Americans which originally resided in the Mullica River-Great Bay region were known to be skilled gamehunters and fishers of finfish and shellfish.

The first settlement of the Mullica River-Great Bay region occurred in 1697, when the Finnish settler Eric Palsson Mullica obtained a piece of land from other settlers in the nearby Swedish settlements along the Delaware River. Most of the early settlers in the region were from Sweden. In the late 1690's, several parcels of land were sold within the area that is now Tuckerton. Mullica obtained one of these pieces of land in what is now Lower Bank on the Mullica River. Before the outbreak of the Revolutionary War, there were more than 30 homesteads reaching from Tuckerton up the Mullica and Wading Rivers. By 1735, the area consisted of 35 to 40 dwellings. By the mid-18th century, there were sawmills on each of the

Mullica River's four stream branches. A dam was built on the Basto River in 1765 and a grist mill, and several more sawmills were built in the early 1700's. The first ship to be built in the area was constructed in 1724, marking the beginning of a long shipbuilding history.

Pirating and privateering trade also began, with ships built in the area being used to raid British ships and for contraband activities. On September 30, 1778, British forces, 400 strong in nine ships, destroyed the fort at Chestnut Neck, but their flagship Zebra with Captain Henry Collins in command, ran aground and had to be abandoned by the British troops. Their plan to continue up the Mullica River and destroy Batsto was abandoned. However, the British Captain and his crew did destroy the small village of Chestnut Neck, killing several men and destroying their storehouse, as well as taking prisoners. The Chestnut Neck Battle Site is on the National Registry of Historic Places.

The industrial and commercial ventures along the Mullica River and Great Bay region drew on the natural resources of both the land and water. The river was used to transport goods to the bay where they were then shipped to New York, Philadelphia, and even the West Indies. In addition, iron furnaces were crafted in Batsto and Atsion, which provided the bulk of musket and cannon balls for American troops in the American Revolution and the War of 1812. Beginning in 1814, a glass industry was established in the Pine Barrens. Bottle glass and window glass were both produced in these factories. Two cotton mills were established on the upper reaches of the river system located in Pleasant Mills in Atsion. One was later converted into a paper mill. Paper mills in the area used native salt hay. Sawmills produced lumber for both housing and shipbuilding throughout the industrial period.

Early horticulture was practiced by the Native Americans when the early settlers arrived. Most of the houses built during the 18th and 19th century were farmsteads. Work was seasonal, with most farming done at the subsistence level. The cranberry industry started in 1835 and is still flourishing today. Cranberry bogs were dug out along the freshwater reaches of the streams that flow into the Mullica River. Blueberries were first cultivated in the Pine Barrens early this century. Fruit and vegetables grown in the area were sent to markets by truck beginning in the mid 1800's.

Mullica River Watershed

The Mullica River Basin is the largest watershed in the Pinelands, covering an area of 1,474 km^2 and draining parts of 23 municipalities (Figures 6 and 7). The Mullica River drainage basin delivers most of the freshwater that enters Great Bay, with an annual mean discharge of 29 m^3/s (MacDonald, 1983). The Mullica River watershed is divided into the Upper Mullica-, Lower Mullica-, Batsto River-, Bass River-, Oswego River-, Mullica Wading-, and Great Bay subwatersheds (Figure 7). Undeveloped forested habitat predominates, with only about 15% of the basin being developed or farmed (Figures 8-10). The Upper and Lower Mullica River subwatersheds have the greatest potential for increase in development, whereas the Great Bay and Bass River subwatersheds have the least available land for development. Eighty-two percent of the watershed lies within Pinelands Management Areas.

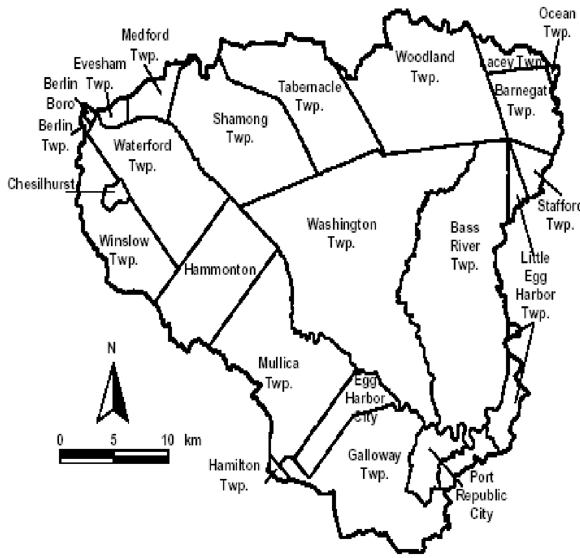


Figure 6. Location of 23 municipalities in the Mullica River Basin (Atlantic, Burlington, Camden, and Ocean Counties). From Zampella, R. A., J. F. Bunnell, K. J. Laidig, and C. L. Dow. 2001. The Mullica River Basin. Technical Report, New Jersey Pinelands Commission, New Lisbon, New Jersey.

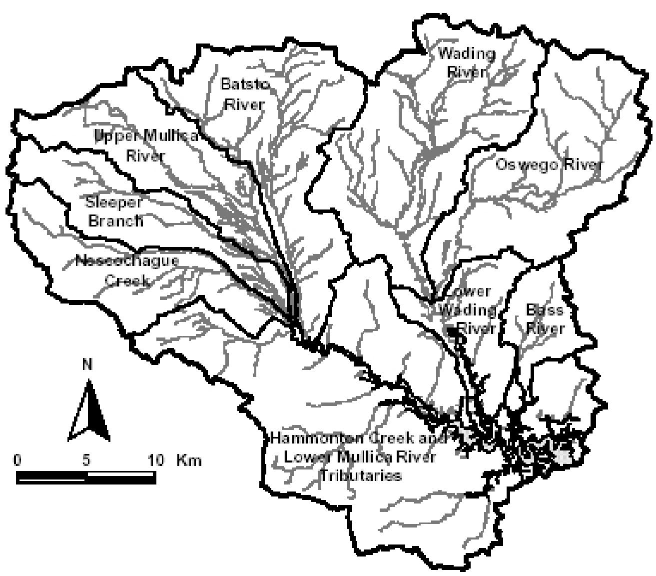


Figure 7. Major tributaries draining into the Mullica River-Great Bay Estuary. From Zampella, R. A., J. F. Bunnell, K. J. Laidig, and C. L. Dow. 2001. The Mullica River Basin. Technical Report, New Jersey Pinelands Commission, New Lisbon, New Jersey.

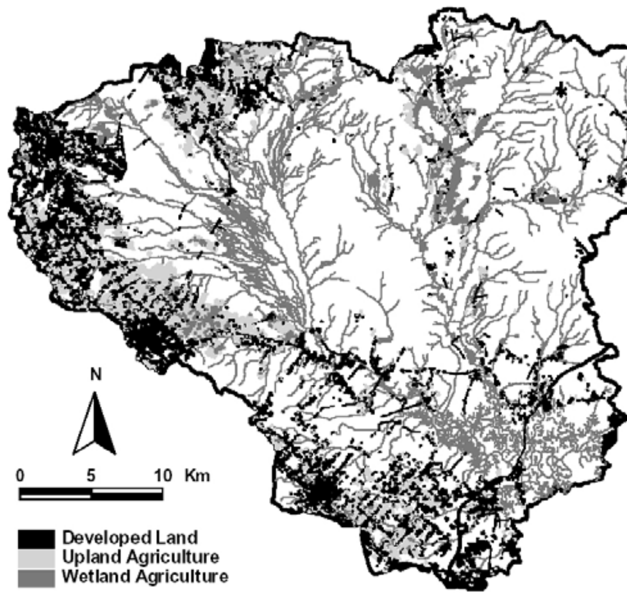


Figure 8. Distribution of developed land, upland agriculture, and wetland agriculture in the Mullica River Basin. From Zampella, R. A., J. F. Bunnell, K. J. Laidig, and C. L. Dow. 2001. The Mullica River Basin. Technical Report, New Jersey Pinelands Commission, New Lisbon, New Jersey.

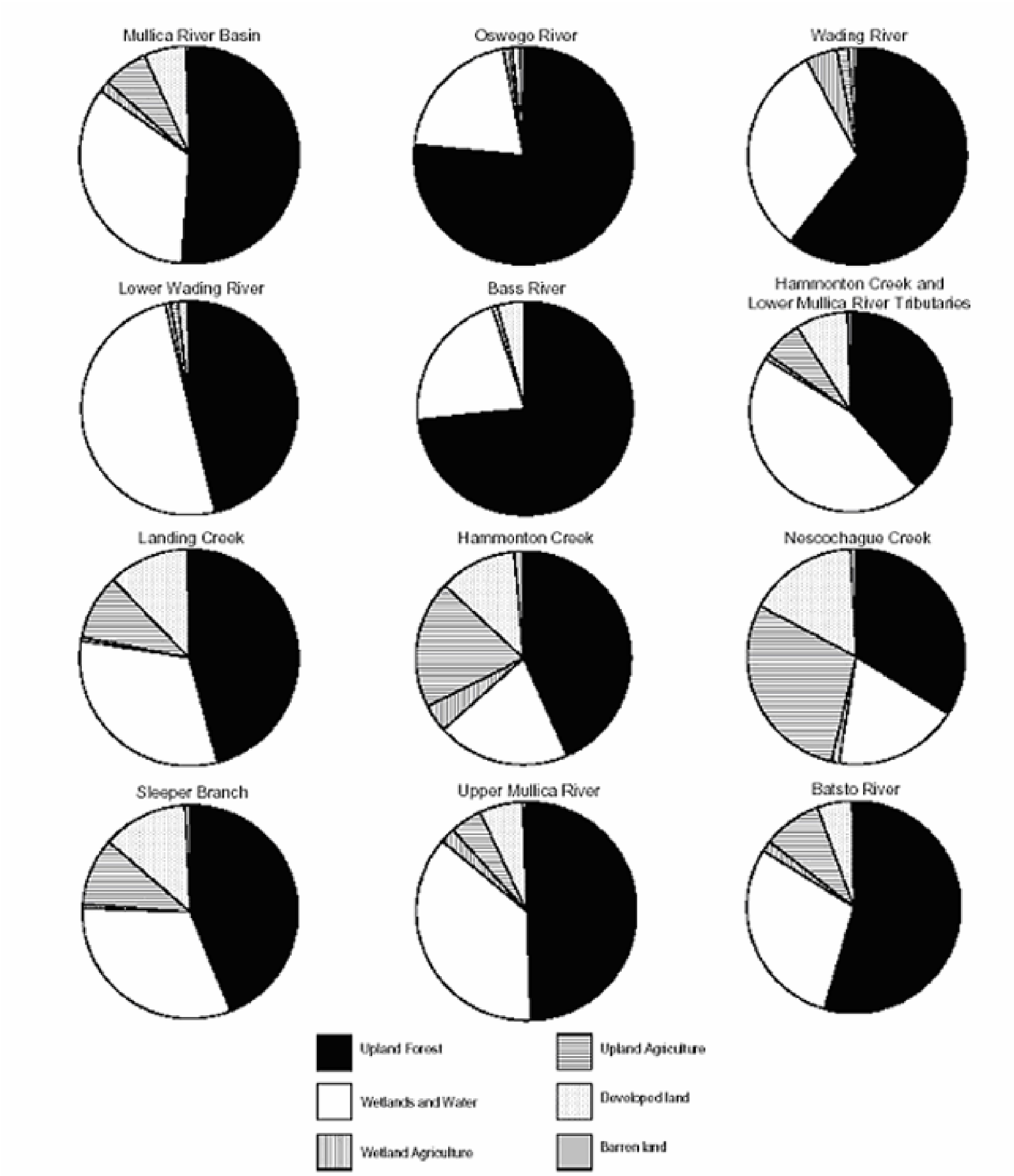


Figure 9. Land use profiles within the Mullica River Basin. From Zampella, R. A., J. F. Bunnell, K. J. Laidig, and C. L. Dow. 2001. The Mullica River Basin. Technical Report, New Jersey Pinelands Commission, New Lisbon, New Jersey.

Zampella et al. (2001) investigated landscape changes in the Mullica River Basin during the 1979 and 1991 periods. Land cover types identified in the basin by Zampella et al. (2001) included salt marsh, herbaceous vegetation, scrub/shrub, forest, cranberry bogs, blueberry fields, orchards, crop land, barren land, managed grassland, developed land, and water (Table 3). Changes in land cover and land use through time are important in the basin because investigators have shown that the unique acid-water plant and animal communities inhabiting the Pinelands are vulnerable to water quality degradation, fires, and other human activities (Forman and Boerner, 1981). Most important are the changes in water quality coupled to developed and agricultural landscapes (Zampella and Laidig, 1997; Zampella and Bunnell, 1998, 2000; Bunnell and Zampella, 1999; Zampella et al., 2001). Forests covered ~75% of the basin in 1991, with all other land cover types totaling less than 5% each at this time. Zampella et al. (2001) estimated that 5.3% of the total basin area had a change in land cover type between the 1979 and 1991 periods, including several major basinwide transitions. According to Zampella et al. (2001, p. 19), these changes were as follows:

- Orchard land was converted to crop land and blueberry fields.
- Barren land cover was also converted to blueberry fields.
- Crop land was converted to orchards and managed grassland, and some crop land succeeded to scrub/shrub cover.
- Herbaceous cover succeeded to scrub/shrub cover and forest cover.
- Scrub/shrub cover was converted to forest cover.

Table 3. Commission land-cover types and related Landsat and NJDEP classes found within 72 photoplots in the Mullica River Basin. Commission and Landsat classifications were modified from the NOAA Coastal Change Analysis Program. For Commission forest, scrub/shrub, herbaceous, barren-land, and water cover types, disturbances included development, agricultural activities, resource extraction, timber harvests, and fire. NJDEP land-use classes are referred to using the revised Pinelands terminology.

1979 and 1991 Commission Land-cover Types	1991 Landsat Thermatic Mapper Land-cover Types	1995 NJDEP Land-use Classes
• Developed Land • Residential development, including houses/driveways, outbuildings, and swimming pools • Nonresidential development, including buildings/asphalt, paved roads, railroads, campgrounds vehicles, and junkyard/storage areas	• Developed land (% impervious and barren land) •Light: wooded (25-50%) •Light: unwooded (25-50%) •Moderate (50-75%) •High (>75%)	• Developed land, excluding recreational lands and athletic fields • Rural density residential development • Low density residential development • Medium density residential development • High density residential development • Nonresidential development, including commercial/services, industrial, transportation/communications/utilities, and other urban uses
• Crop land, including crop land, turf fields, and gardens • Orchards •Tree farms • Blueberry fields • Cranberry bogs, including bogs and reservoirs	• Agricultural land • Vines/Bushes	• Upland agriculture, excluding orchards/vineyards/nurseries/horticultural areas • Orchards/vineyards/nurseries/horticultural areas • Wetland agriculture
• Managed grassland •Residential grass (lawns) •Nonresidential grass, including pastures/corrals, recreation land, athletic fields, commercial lawns, and roadside vegetation • Herbaceous, including several unmanaged disturbance-related herbaceous covers	• Grassland, including managed and unmanaged herbaceous areas	• Recreation lands, athletic fields, and managed wetlands • Herbaceous wetlands • Old fields (<25% brush covered)
• Forest, including undeveloped vegetated land and several disturbance-related tree covers • Scrub/shrub, including	• Forest, including seven forest types • Scrub/shrub, including two scrub/shrub types	• Upland forest and wetlands, excluding scrub/shrub subclasses and tidal, herbaceous, disturbed, and managed wetlands • Upland forest and wetlands composed of scrub/shrub subclasses

several disturbance-related scrub/shrub covers		and excluding tidal, herbaceous, disturbed, and managed wetlands
• Barren land •Residential barren land •Nonresidential barren land, including several disturbance-related barren-land covers •Sand roads •Fire breaks	• Barren land, including barren land and areas with <25% vegetated cover	• Barren land, including extractive mining, altered lands, transitional areas, undifferentiated barren lands, and disturbed wetlands
• Salt marsh	• Salt marsh, including unconsolidated shore and emergent wetlands	• Tidal wetlands, including saline marshes
• Water, including tidal water, retention basins, impoundments, irrigation ponds, ditches/canals, and other disturbance-related water cover	• Water, including unconsolidated shore and emergent wetlands	• Water and tidal waters

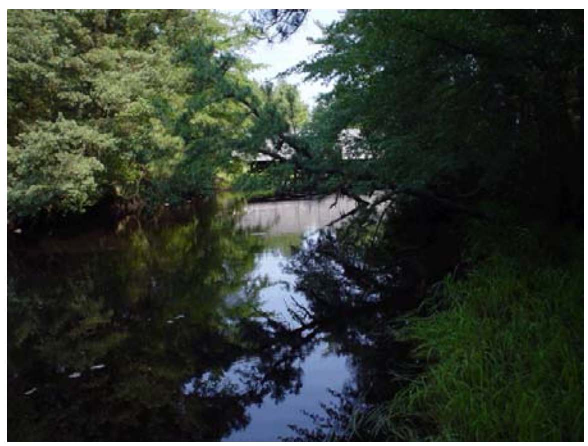
From Zampella, R. A., J. F. Bunnell, K. J. Laidig, and C. L. Dow. 2001. The Mullica River Basin. Technical Report, New Jersey Pinelands Commission, New Lisbon, New Jersey.

A net decrease in forested land cover occurred between 1979 and 1991 largely due to its conversion to barren land, managed grassland, and developed land. The conversion of one agricultural type to another was also evident during this time period.

Watershed Build-Out

A build-out analysis has been completed for both the Mullica River watershed (Appendix 2) and Barnegat Bay watershed (Appendix 3). The objective of this work is to map the expected location of future development in the watershed and to provide estimates of the number of new dwelling units when all land available in the watershed for development has been developed to the highest intensities possible. Although the build-out analysis of the watersheds does not project when build-out will actually occur, it yields valuable information for long-term planning efforts as a way to understand potential future growth. This is accomplished by assessing three indicators - the number of dwelling units, population, and percent impervious cover - as ways to quantify the amount of development possible at build-out.

There is currently little development in the Mullica River watershed, whereas considerable development exists in the Barnegat Bay watershed, particularly in the northern portion. As a result, land areas in the Mullica River watershed, as well as in the southern part of the Barnegat Bay watershed may be the target of future development. To determine the amount of developable land in these watersheds, it is necessary to exclude land already developed, wetlands, preserved open space, parcels with severed developmental rights, and buffer zones around water bodies and wetlands. A Geographic Information System (GIS) has been applied to map land use and future developmental pressures in the watersheds.



The Mullica River watershed remains one of the most pristine watersheds in New Jersey. A total of 88% of the watershed was in a natural or unaltered state in 1986. Between 1986 and 2000, little degradation occurred here, with only 0.7% of the forest and wetlands cover lost. Urban land cover in the watershed increased from 5.8% in 1986 to 6.6% in 1995 and 6.9% in 2000; most development occurred in areas designated for growth along the southwest perimeter. There was a real loss of only ~1% of the watershed to development between 1986 and 2000. Impervious surfaces (e.g., roads, driveways, sidewalks, roofs, and other impenetrable surfaces) covered an estimated 1.34% of the Mullica River watershed in 1986 and 1.53% in 1995. The build-out analysis predicts a range of impervious surface in the watershed between 2.50% and 2.83%. By comparison, the impervious surface is projected to increase to 12% in the Barnegat Bay watershed. The low percentage of impervious surface projected for the Mullica River watershed reflects a non-impacted condition, well below the 10% threshold level for impacted areas defined by Arnold and Gibbons (1996). The amount of impervious surface in a watershed is an indicator of the intensity of human land use and also correlates with water quality degradation and altered runoff patterns (Arnold and Gibbons, 1996; Charbeneau and Barrett, 1998).

The population in the Mullica River watershed increased by 9% from 1990 (n = 76,383) to 2000 (n = 83,501). The build-out population is projected to range from 110,363, to 124,334 people (Appendix 2). This population is far less than the 812,556 to 842,777 people projected at build-out for the Barnegat Bay watershed (Appendix 3).

Hydrography

Rivers and Streams

The Mullica River flows eastward across southern New Jersey and the Pine Barrens covering a distance of ~65 km, and it discharges into Great Bay (Figure 10). The river terminates at a line drawn between Graveling Point and Oysterbed Point on the northwestern side of Great Bay. The Batsto River, a major tributary, enters the Mullica River ~40 km upstream from its mouth. The Wading River, in turn, discharges into the Mullica River ~13 km from its mouth (Durand, 1988, 1998).

Most of the freshwater flowing into estuaries of the reserve enters as discharge from streams draining the Pine Barrens, a 550,000-ha area of pristine habitat covering a large portion of the New Jersey Coastal Plain (Figure 10). These low-gradient, southeasterly flowing streams originate as ground water inflow from the Kirkwood-Cohansey aquifer. According to Nicholson and Watt (1997), the aquifer system is generally in good hydraulic connection with surface water bodies, and streams typically gain flow from the aquifer year-round. The unique surface and ground water system in the Mullica River watershed derives from the sandy, droughty soils of the Pine Barrens which are underlain by water-bearing sand layers and confining clay layers as noted above. The low relief of the region also influences surface runoff.

The depth to the water table in upland forests of the watershed ranges from ~1 to 25 m. However, water occurs near the land surface in lowland forests at least part of the year. Water table levels vary by as much as 3 m from spring to fall in a given year (Rhodehamel, 1998b).

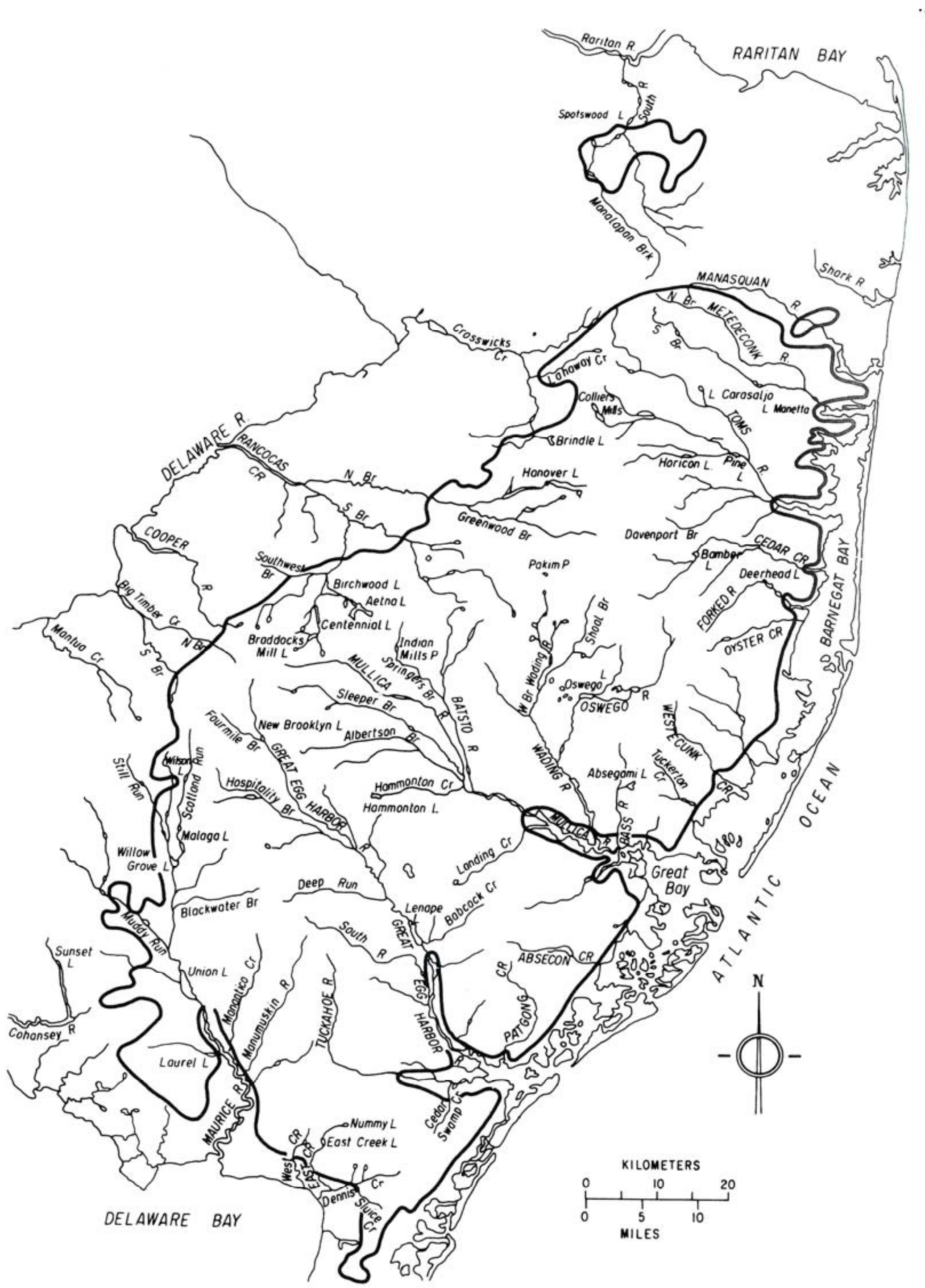


Figure 10. Location of the New Jersey Pine Barrens (within bold boundary line) showing the Mullica River and other major rivers and streams in the region. From Patrick, R., B. Matson, and L. Anderson. 1998. Streams and lakes in the Pine Barrens. In: R. T. T. Forman (ed.), *Pine Barrens: Ecosystems and Landscape*. Rutgers University Press, New Brunswick, New Jersey, pp. 169-193.

As precipitation falls on the Mullica River drainage basin and the Barnegat Bay watershed, it rapidly percolates through porous and droughty, sandy soils to the shallow water table, which then feeds the area streams as ground water seepage. Surface water discharge, therefore, is limited (U.S. Fish and Wildlife Service, 1996). For example, because of the large infiltration of precipitation into the porous soils and surface strata, only ~5% of the total precipitation falling on the Mullica River basin discharges as surface flow into the head of Great Bay (Psuty et al., 1993). In general, ground water seepage accounts for ~80% of the total discharge of South Jersey streams. Streams in the watershed gradually receive ground water as they flow seaward. Much of the precipitation in the watershed, therefore, discharges through shallow aquifers to the surface water system, supporting the base flow of streams.

Only a small amount of the total precipitation in the area falls directly on the stream surfaces. Approximately 45% of the total precipitation entering the drainage basin infiltrates into the ground water system with a considerable amount lost via evapotranspiration. Most of the ground water in the unconfined aquifer system follows short flow paths and discharges locally to surface water bodies or follows longer, deeper flow paths and discharges to distant streams at lower elevations, or directly to the estuaries. A minor fraction leaks into deeper aquifers. Ground water relative to surface water in the Pine Barrens has: (1) higher concentrations of carbon dioxide, iron, and aluminum; (2) lower concentrations of sulfate and phosphate; and (3) less variable pH, sodium chloride, silica, temperature, and color (Rhodehamel, 1998b).

The Bass, Wading, Oswego, and Batsto rivers, as well as several smaller tributaries (e.g., Bull Creek, Landing Creek, Nacote Creek, Nescochague Creek, and Hammonton Creek) occur in the Mullica River drainage basin (Figure 7). The Pinelands streams have a high concentration of humic acids from decaying vegetation, as well as a high iron content, which causes brown coloration of the water. Several major subwatersheds join at the head of tide near the town of Batsto to form the mainstem of the Mullica River; they include the Batsto River, Atsion (upper Mullica) River, Sleeper Branch (Mechesactauxin), Nescochague Creek, and Hammonton Creek. The headwater areas of the Mullica River, Sleeper Branch, Nescochague Creek, Hammonton Creek, and Landing Creek drainage basins contain the most developed land and upland agriculture in the Mullica River Basin.

Upper headwaters of the Mullica River are bordered by an array of unique habitats, such as cranberry bogs, *Sphagnum* bogs, and white cedar swamps. The tidally-influenced mainstem from Batsto to the mouth at Great Bay (Deep Point) is ~34 km long. Tributaries that enter the Mullica River from the south include the Landing Creek and Nacote Creek. Those entering the Mullica River from the north are the Bull Creek, Wading River, and Bass River. Tidal marsh communities fringe all of these tributaties.

The Mullica River, with a surface drainage area of 119.4 km^2, has a mean annual runoff of 83.8 cm. By comparision, the Batsto River has a surface drainage area of 182 km^2 and a mean annual runoff of 61.2 cm, and the Oswego River, a drainage area of 102 km^2 and a mean annual runoff of 46.4 cm (Rhodehamel, 1998b). Seasonal stream flow fluctuates considerably in response to variations in meteorologic and hydrologic conditions. However, cyclic seasonal stream flow patterns are evident in the drainage basin, with highest stream discharges recorded during winter and early spring when evapotranspiration is slight, and lowest stream discharges registered during late summer and fall after a protracted period of elevated evapotranspiration. Rhodehamel (1998b) noted that the Pine Barrens receives more than 40 cm of precipitation during the December through April period, when direct runoff from riparian areas peaks at ~175.4 m^3/day/km^2 or 1.02 x 10^6 m^3/day for the 5,828 km^2 contiguous Pine Barrens region. The annual ground water contribution to runoff equals more than 50 cm or ~89% of the total annual discharge. Thus, ground water flow for the 5,828 km^2 contiguous Pine Barrens region amounts to ~1,388 m^3/day/km^2 or 8.1 x 10^6 m^3/day.

Several small streams in the Pine Barrens also discharge limited volumes of freshwater from the Barnegat Bay watershed into Little Egg Harbor. Included here are Cedar Run, Westecunk Creek, and Tuckerton Creek. In addition, a number of other creeks (i.e., Thompson Creek, Ezras Creek, Dinner Point Creek, and Parker Run) terminate near the upland-salt marsh boundary in the area. Absecon Creek drains into the shallow backbay region ~15 km south of Great Bay. Relative to the Mullica River, all of these small influent systems discharge substantially smaller volumes of freshwater to the coastal bays of the reserve.

Table 4 provides an annual hydrological budget for the New Jersey Pine Barrens region based on the work of Rhodehamel (1998b). This budget relates water input (precipitation) to water yield (stream runoff) plus water loss (evapotranspiration) for the system. It is defined by the following equation: precipitation (114.3 cm) = interception (15 cm) + evapotranspiration from undrained depressions (2.3 cm) + evapotranspiration from soil and ground water (39.9 cm) + direct runoff (6.3 cm) + ground water contribution to runoff (50.8 cm). Nearly 40% of the total precipitation, therefore, is lost via evapotranspiration, with the remainder entering the ground water reservoir. The annual runoff of Pine Barrens streams equals 57.1 cm and ranges from 36 cm to 84 cm of water. This runoff is important when considering salinity levels in the lower reaches of Pine Barrens streams and contiguous estuarine waters.

Seawater enters Great Bay and Little Egg Harbor through Little Egg Inlet. Great Bay and the backbays to the south (e.g., Little Bay, Reeds Bay, and Absecon Bay) experience semidiurnal tides, and tidal influence extends a considerable distance up Pine Barrens streams. For example, tidal effects are observed over the lower ~40 km of the Mullica River, although the upper limit of saltwater penetration is ~20 km (Durand and Nadeau, 1972). Lower Bank, located ~25 km upstream from the head of Great Bay, marks the upper end of the estuary (Durand, 1988). Above this location, salinities are generally <1‰. The saltwater-freshwater interface in Pine Barrens streams usually lies 8-16 km upstream from the head of the bay, but reduced stream flow can cause upstream extension of the saline water and upstream displacement of salinity gradients. Salinity in these low gradient streams varies from upriver to downriver and seasonally in response to semidiurnal tides, frequency and intensity of precipitation, and evapotranspiration (Durand, 1988). Seasonal variations can be significant; for example, in the lower 8 km of the Mullica River, seasonal salinity levels vary by as much as 10-20‰ (Durand, 1988). Great Bay, Little Egg Harbor, and backbay waters to the south are generally well mixed, with mean salinity values typically ranging from ~25-30‰. From the head of the Mullica River to the nearshore ocean at LEO-15, salinity ranges from ~0->34‰.

Table 4. Annual hydrological budget for the New Jersey Pine Barrens region, 1931-1964. [1,2]

		Centimeters of Water	**Water (m3/day/km2)**	**Water (m3/day/km2)**
Water input	Precipitation	114.3	3127	18,224,000
Water loss	Interception	15.0	409	2,384,000
	Evapotranspiration from undrained depressions	2.3	58.5	341,000
	Evapotranspiration	39.9	1096	6,387,000

	from soil and ground water			
		———	———	————
Water yield	Total water loss	57.2	1563.5	9,112,000
	Direct runoff	6.4	175.5	1.023,000
	Ground water contribution to runoff	50.8	1388	8,089,000
			———	————
	Total water yield	57.2	1563.5	9,112,000

[a]Water input – water loss = water yield, or Precipitation = evapotranspiration + runoff.
[b]Pine Barrens region is approximately 5,828 km^2.
From Rhodehamel, E. C. 1998b. Hydrology of the New Jersey Pine Barrens. In: R. T. T. Forman (ed.), *Pine Barrens: Ecosystems and Landscape*. Rutgers University Press, New Brunswick, New Jersey, pp. 147-167.

Estuarine Circulation

The extreme enclosure and shallowness of estuaries in the reserve strongly influence circulation patterns. Winds, tides, and salinity gradients are also of paramount importance. Northeasters, hurricanes, storm surges and other meteorological events can significantly alter the circulation patterns in these systems, although their effects are ephemeral. The strongest currents occur in the vicinity of Little Egg Inlet, where they are dominated by semidurnal tidal motion. However, the shallow depths and complex morphologies of these backbays result in the distortion of the semidiurnal tidal motion via overtides and strong residual motion. Relatively rapid tidal currents (> 2 m/s) are observed at Little Egg Inlet, and they flow westward into Great Bay and northward into Little Egg Harbor. The tidal range at the inlet exceeds 1 m (Chant et al., 2000).

Great Bay

Great Bay is a roughly circular embayment ~7 km in diameter, with an average depth of ~3 m at mean high water. Shallow sand bars occur near Little Egg Inlet at the mouth of the bay. Sandy sediments, which derive from marine sources, predominate in the eastern bay. Silt and clay increase in the western bay and likely originate from riverine inputs and fringing salt marshes (Figure 11) (Durand and Nadeau, 1972). The predominant circulation pattern in the bay is counterclockwise, with currents entering at Little Egg Inlet flowing mainly along the northern perimeter. Sediments entering the bay through Little Egg Inlet and the Mullica River have built extensive intertidal sandflats and mudflats covering 1,358 ha, which constitute ~22% of the total area of the estuary (U.S. Fish and Wildlife Service, 1996). Salt marsh islands (e.g., Seven Islands) exist along the northeastern margin near the Great Bay Boulevard Wildlife Management Area. The principal outflow is along the southeastern perimeter, which incorporates discharge from the Mullica River and Motts Creek. This circulation pattern creates a counterclockwise gyre in the central portion of the bay (Durand, 1988) (Figure 12), which helps to retain biotic and abiotic components in the estuary . For instance, nutrient inputs from the Mullica River may concentrate for longer periods of time in the bay, thereby stimulating primary production when light conditions are favorable. Eggs and larvae of organisms also tend to be retained in the bay by this type of circulation. Because Great Bay is a spawning and nursery area for many organisms, the cyclonic circulation pattern appears to play a significant role in the overall production of the system.

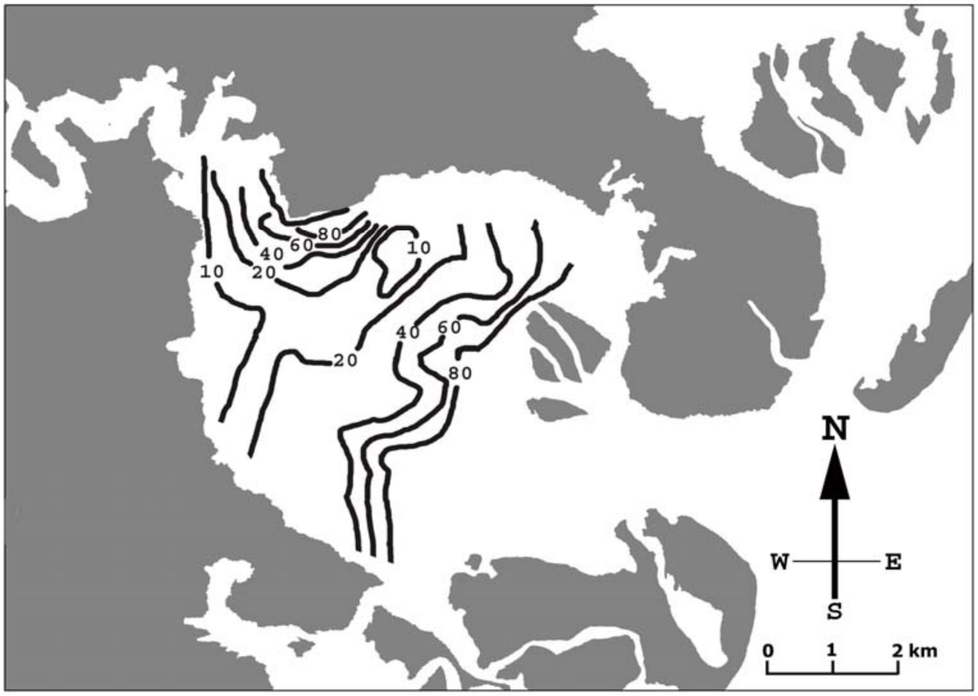


Figure 11. Map of Great Bay displaying the percent sand in bottom sediment contours. Modified from Durand, J. B. and R. J. Nadeau. 1972. Water Resources Development in the Mullica River Basin. Part I. Biological Evaluation of the Mullica River-Great Bay Estuary. Technical Report, New Jersey Water Resources Research Institute, Rutgers University, New Brunswick, New Jersey. 138 p.

Turbidity values are higher along the southern part of the bay because more turbid water flows from the Mullica River along this perimeter. Incoming seawater has less turbidity, and hence water clarity along the northern part of the bay is greater (Durand, 1988). Although the principal circulation in the bay follows a cyclonic pattern, much of the water exits the bay during periods of high flow from the Mullica River (Durand and Nadeau, 1972). In addition, a component of seaward-flowing water along the southeastern part of the bay flows southward into Little Bay.

Great Bay is affected by periodic upwelling of cold, higher density seawater from deeper waters on the continental shelf. For example, during 2000, 12 episodes of coastal upwelling were recorded at the LEO-15 site. The effects of upwelling on circulation, nutrient inputs, productivity, and other factors in the estuary have not been extensively investigated.

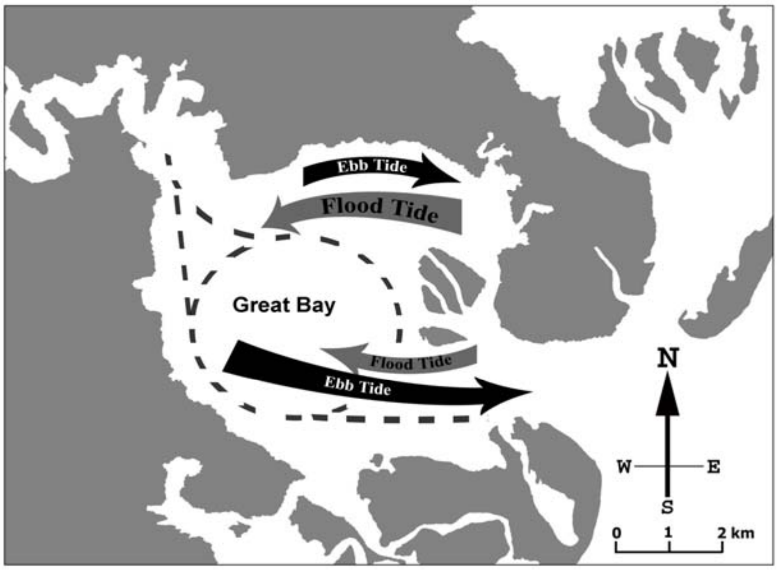


Figure 12. Major water circulation patterns in Great Bay. Modified from Durand, J. B. and R. J. Nadeau. 1972. Water Resources Development in the Mullica River Basin. Part I. Biological Evaluation of the Mullica River-Great Bay Estuary. Technical Report, New Jersey Water Resources Research Institute, Rutgers University, New Brunswick, New Jersey. 138 p.

Little Egg Harbor

Little Egg Harbor is a shallow (1-7 m), irregular tidal basin located immediately north of Great Bay. It is enclosed by Long Beach Island (a barrier island) on the east and the New Jersey mainland on the west. Seawater enters the estuary via Little Egg Inlet, a relatively wide (~2.5 km) breach in the barrier island complex. Coastal pumping driven by sea level motion, together with the inlet-bay configuration, strongly influences water exchange within the backbay system (Chant, 2001). Water circulation in lower Little Egg Harbor is greatly affected by tidal currents through Little Egg Inlet, deep channels (> 10 m) landward of the inlet, and a cluster of sand bars and marsh islands (i.e., Story Island, Hither Island, Middle Island, Drag Sedge, Good Luck Sedge, and Johnny Sedge) in the southern perimeter. Tidal currents, which flow northward during flood tide, diverge into northwestward and northeastward components (Carriker, 1961; Figure 13a). Strongest flood currents are observed on the western side of the lower embayment, where they pass through narrow channels between marsh islands on their northward path. Complex circulation patterns develop in the central basin of lower Little Egg Harbor in response to the diverging northward-flowing tidal currents. As the currents flow northward, they dissipate from maximum velocities of ~0.5 m/s in the southern reach to <0.05 m/s in upper Little Egg Harbor. During flood tide, lateral variability in currents and salinities is enhanced. Currents are reversed during ebb tide, being stronger on the eastern side of the embayment (Figure 13b). Hydrodynamic surveys conducted by Chant et al. (2000) in the spring of 1996 and 1997 show the magnitude of tidal currents in lower Little Egg Harbor (Figure 14).

Little Egg Harbor exhibits weak vertical salinity and thermal stratification. In summer, wind action (including strong sea breezes), high evaporation rates, small inputs of freshwater runoff, and the aforementioned advective processes create more homogeneous conditions in the water column and relatively uniform (high) salinities. These conditions are indicative of extensive mixing of the water column. However, as stated by Chant et al. (2000, p. 539), "Maximum salinity occurs at the end of flood, which corresponds to the mid-tidal stage on the falling tide, while minimum salinity occurs at mid-stage during the rising tide." Figure 15 shows salinity differ ences at flood and ebb in Little Egg Harbor.

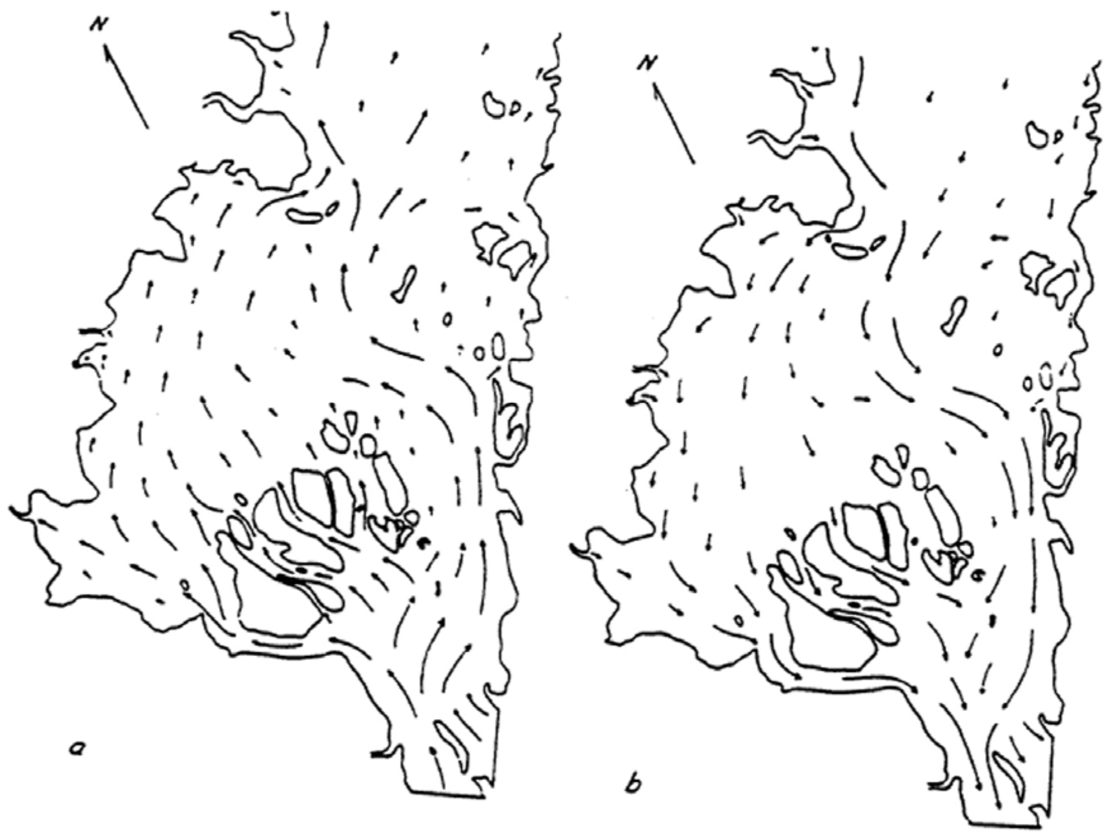


Figure 13. Direction and magnitude of tidal currents in lower Little Egg Harbor during the mid to late flood tide stage (a) and mid ebb tide stage (b). From Carriker, M. R. 1961. Interrelation of functional morphology, behavior, and autecology in early stages of the bivalve *Mercenaria mercenaria*. *Journal of the Elisha Mitchell Science Society* 77:168-241.

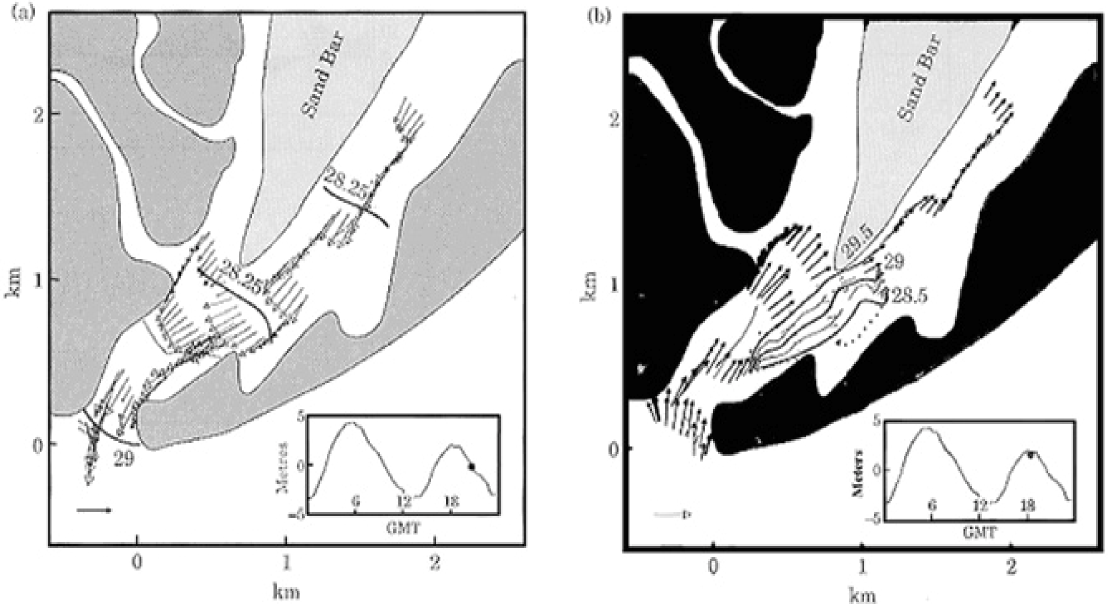


Figure 14. Synoptic current field during flood (a) and ebb (b) in lower Little Egg Harbor on May 7, 1996. Sea level data are plotted in the graph in the lower right corner of each panel with the time of the current vector estimates. The sand bar (light grey) is more exposed during low water. From Chant, R. J., M. C. Curran, K. W. Able, and S. M. Glenn. 2000. Delivery of winter flounder (*Pseudopleuronecttes americanus*) larvae to settlement habitats in coves near tidal inlets. *Estuarine, Coastal and Shelf Science* 51:529-541.

Coastal pumping, remotely forced by coastal sea level, drives more than 70% of the subtidal motion in the estuary (Chant, 2001). It is the major forcing factor responsible for the movement of seawater from Little Egg Harbor into Barnegat Bay, with local winds accounting for another 20% of the variance in the subtidal transport in the estuary. However, strong winds can completely alter the circulation patterns in this shallow, enclosed estuary over short periods of time.

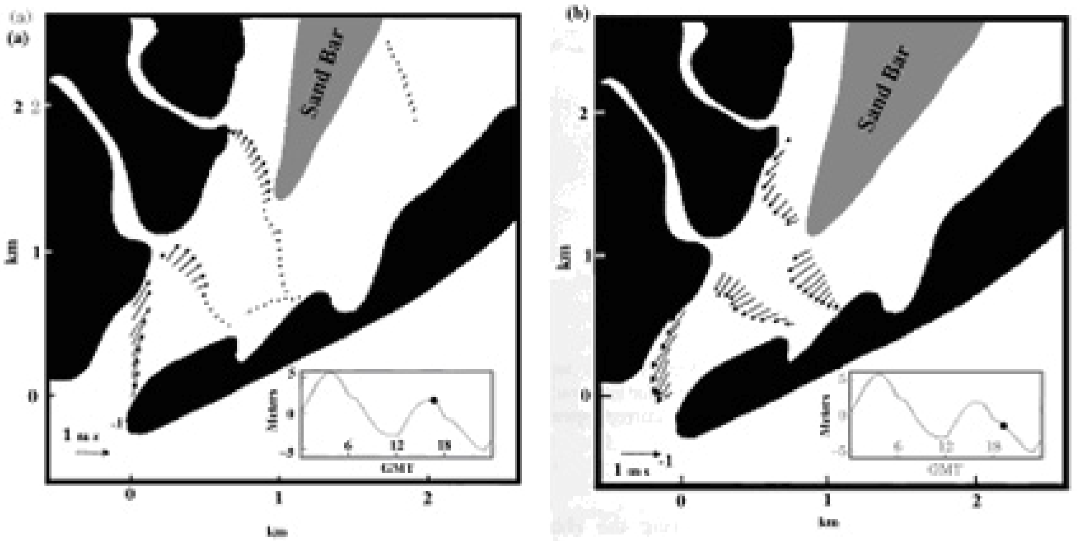


Figure 15. Current field and salinity during ebb (a) and flood (b) in lower Little Egg Harbor on April 29, 1997. Salinity record is contoured at 0.25 intervals. Sea level data are plotted in the lower right corner of each panel with the time of the current vector field estimate denoted by the dot. From Chant, R. J., M. C. Curran, K. W. Able, and S. M. Glenn. 2000. Delivery of winter flounder (*Pseudopleuronecttes americanus*) larvae to settlement habitats in coves near tidal inlets. *Estuarine, Coastal and Shelf Science* 51:529-541.

Water Quality

Extensive investigations of water quality conditions in the Mullica River-Great Bay Estuary have been conducted since the mid-1950s (Able et al., 1992, 1999). During the period from 1957-1986, Durand (1988) collected detailed physical-chemical data (temperature, salinity, dissolved oxygen, nitrogen, phosphorus, carbon, and chlorophyll) throughout the estuary and into the nearby waters of the Atlantic Ocean, while also focusing on primary production (Appendix 4). Since 1985, many water quality measurements have been made in the system as a component of targeted ecological studies (Able et al., 1999).

The most comprehensive database on water quality has been collected since 1996 as part of the System-wide Monitoring Program (SWMP) established by the National Estuarine Research Reserve System (NERRS). The goal of NERRS SWMP is to identify and track short-term variability and long-term changes in the integrity and biodiversity of representative estuarine ecosystems and coastal watersheds for the purpose of contributing to effective national, regional, and site specific coastal zone management. Data derived from NERRS SWMP can be used for the following purposes: (1) to address circulation problems in the estuarine systems; (2) to support site-specific, nonpoint source pollution control programs by implementing a network of continuous water quality monitoring stations; and (3) to develop a nationwide database on baseline environmental conditions in NERRS estuarine systems. A major initiative of SWMP is to collect long-term water quality and ecological data that will be of value for coastal resource management.

JCNERR Research and Monitoring Program

Since 1996, the NERRS has concentrated on (SWMP) monitoring of physical and chemical water quality parameters and local and regional weather conditions and impacts. Future efforts will also focus on monitoring environmental stressors,

mapping habitat change, assessing watershed land use, and investigating biodiversity (Greene and Trueblood, 1999; Kennish, 2003). One of the primary objectives of SWMP is to provide the baseline data necessary to systematically evaluate anthropogenic effects on estuarine ecosystems and to restore the functionality of these estuaries to their undisturbed conditions (Wenner et al., 2001).

During the past 13 years, SWMP has collected data semi-continously year-round on a series of physical-chemical parameters (i.e., temperature, salinity, dissolved oxygen, pH, turbidity, and depth) using automated data loggers (Yellow Springs Instrument Company, 6-series data loggers; YSI 6000® or YSI 6600®). These instruments operate at shallow depths, relaying water quality measurements to internal memory. They run unattended for protracted periods (i.e., weeks at a time). Some effort has been made to analyze NERRS data system-wide. Wenner et al. (2001), for example, have analyzed SWMP water quality data (temperature, salinity, dissolved oxygen (mg/l), dissolved oxygen (% saturation), pH, and depth) from NERRS reserves for the 1996-1998 period. The purpose of this analysis was to accomplish the following:

- Provide a characterization of water quality for each NERR site.
- Determine the degree to which SWMP is producing important scientific information on the water quality of the nation's estuaries.
- Ascertain if SWMP could be modified to make it more effective or efficient or to obtain more ecologically relevant water quality information.

More recently, Sanger et al. (2002) analyzed water quality data collected by the NERRS program over the 1995-2000 (Phase 1) period.

Analysis of the SWMP database is ongoing. It is hoped that this effort will yield important information for comparing estuarine water quality conditions both regionally and nationally. It is also hoped that analysis of the data will be vital for planning the next phases of the SWMP monitoring program.

The focus of the research and monitoring program of the JCNERR is to identify and track short-term variability and long-term changes in the physical-chemical characteristics, biotic resources, and integrity of estuarine and coastal marine waters of the reserve site, as well as nearby coastal watersheds, for the purpose of contributing to effective coastal zone management. Important components of the program are water quality monitoring, biomonitoring, ecosystem research, and the assessment of land use and land cover elements within the reserve boundaries. Monitoring data collected as part of the System-wide Monitoring Program (SWMP) of the NERRS help to define baseline conditions and establish data trends for waterbodies and aquatic resources of the reserve. JCNERR SWMP provides a critical delineation and coordination of water quality conditions within the reserve's estuarine waters, and it provides the platform for making systematic, long-term observations of vital ecosystem parameters. Research and monitoring activities of the JCNERR fall within three distinct areas: (1) water quality monitoring (abiotic factors); (2) habitat and biotic community characterization; and (3) watershed land use and land cover analysis. These activities foster greater understanding of the relationship between disturbance/change and physical, chemical, and biological processes required to sustain biotic communities and resources in the reserve.

The JCNERR research and monitoring program currently operates five SWMP monitoring stations: four semi-continuous, water quality monitoring (data logger) stations (Lower Bank and Chestnut Neck in the Mullica River and Buoy 126 and Buoy 139 in Great Bay) and one weather station at the Richard Stockton College Marine Field Station at Nacote Creek. A suite of environmental parameters is monitored every 15 minutes at these stations (i.e., temperature, salinity, DO concentration, DO percent saturation, depth, pH, and turbidity at the water monitoring stations; temperature, humidity, atmospheric pressure, wind speed and direction, solar radiation, and precipitation at the weather monitoring station). Nutrient chemistry is also monitored at each of the four SWMP water quality monitoring stations on a monthly basis. Two of these stations (Chestnut Neck and Buoy 126) have been equipped with telemetry equipment that broadcasts water quality data to a GOES satellite, which is then posted to the World Wide Web.

SWMP is part of a comprehensive national effort of NERRS to monitor the health and functionality of U.S. estuaries. It currently involves activities at the 27 reserve sites nationwide, encompassing estuarine waters, wetlands, and uplands in five major estuarine/coastal regions (i.e., Northeast and Great Lakes, Mid-Atlantic Coast, Southeast Coast, Caribbean, Gulf Coast, and West Coast) representing nearly every recognized climatic zone (Figure 2). Initiated in 1995, SWMP is comprised of three integrated components: (1) water quality; (2) biological communities and habitats (biomonitoring); and (3) watershed land use changes. These components are being implemented in phases at all reserve sites. Phase 1 (abiotic parameters) of the reserve program focuses on monitoring key physical and chemical parameters that help to define the health of the estuarine system. These parameters include basin water quality indicators (e.g., pH, dissolved oxygen, and turbidity), meteorological conditions, and specific processes (e.g., tidal action). Phase 2 (biodiversity) of the NERRS program addresses two fundamental features of the system: (1) basic community structure in major estuarine habitats (e.g., uplands, lowlands, wetlands, and open water); and (2) population trends of important "target species" or indicator organisms (e.g., SAV, salt marsh plants, and endangered species). Phase 3 (land use patterns) of the reserve examines patterns of change in human use of surrounding watersheds. Data are compiled on major patterns of habitat classification and use in the watersheds, which will be periodically resurveyed to detect and track changes in land use as reflected by land cover change and other alteration. Remote sensing techniques are being applied in these studies, and the resultant information will be used in local and regional planning and management efforts.

An array of priority research projects is ongoing in the JCNERR that accompanies water quality monitoring. These include an assessment of nutrient loading and estuarine eutrophication of the Barnegat Bay-Little Egg Harbor system, demographic analysis of submerged aquatic vegetation, examination of phytoplankon and zooplankton dynamics, characterization of benthic habitat and communities, studies of shellfish and finfish populations, and mapping of watersheds. Work products generated in support of estuarine research activities consist of grant-writing documents, written technical reports and journal publications, seminar presentations, staff field and laboratory investigations, undergraduate and graduate student research projects, and partner surveys.

Benthic Research

Benthic habitat characterization of estuarine environments in the JCNERR has been conducted since 2003, with the most extensive work being reported for the Barnegat Bay-Little Egg Harbor Estuary. This work consisted of collecting SAV (as part of a biomonitoring program) samples and sediment cores, utilizing quadrats, deploying sediment profile imaging camera systems, and using underwater videography to assess habitat condition. Several hundred benthic cores were taken in seagrass habitats to assess seagrass aboveground and belowground biomass, density, blade length, and areal cover in the system. Habitats were investigated to establish long-term databases.

Benthic habitat quality in the estuary was investigated employing a sediment profile imaging (SPI) camera to collect samples during summer 2006. This instrument was used to assess the condition of bottom habitats, analyzing degradation caused by hypoxia and other stressors. The long-term goal is to generate benthic habitat quality (BHQ) indices for different areas of the estuary for making comparisons over time. Benthic grab sampling using a Young-modified Van Veen Grab has been conducted in JCNERR waters and is also scheduled for future benthic community characterization work.

Bottom Sediments

Sediments have been collected and analyzed at numerous sampling sites in Great Bay and the Barnegat Bay-Little Egg Harbor Estuary as part of a larger effort to assess and characterize benthic environments in the JCNERR. Sediment size and percent organic matter are being collected throughout the reserve system to determine if and how sediments influence biotic communities. Grab samplers and corers are being used to collect sediment samples in SAV beds, algal flats, and unvegetated bay bottom areas.

Zooplankton

A number of field study sites have been established to monitor biofouling in the estuary. This work has also provided data useful for examining the dynamics of meroplankton, larval settlement, and epibenthic community structure. The goal is to develop a more complete database on zooplankton dynamics in JCNERR waters.

Submerged Aquatic Vegetation

Nitrogen over-enrichment can significantly impact seagrass habitat (Kennish et al., 2007a). The JCNERR research and monitoring group completed a three year (2004-2006) submerged aquatic vegetation study in the Barnegat Bay-Little Egg Harbor Estuary, which characterized the abundance and distribution of seagrass beds in the system (Kennish et al., 2007b, 2008). This study, which included estuarine waters of the JCNERR, is the most comprehensive *in situ* work ever conducted on seagrass habitat in New Jersey. It generated a large database on the demographic characteristics and habitat change of seagrass in estuarine waters of the JCNERR. It also yielded valuable information on the effects of nitrogen enrichment on the species composition, frequency of occurrence, and potential impacts of benthic macroalgae on the eelgrass beds in the estuary. The results can be found in a report submitted to ERD in January, and a recent publication in the scientific literature (Kennish et al., 2007b; Kennish et al., 2008).

Nitrogen Enrichment

Detailed research is being conducted on the eutrophication of the coastal bays in New Jersey. Nitrogen loading and its impact on submerged aquatic vegetation and fishery resources (e.g., shellfish populations) have been documented. Eutrophication is the most serious threat to the ecosystems of the New Jersey coastal bays (Kennish et al., 2007a). Nutrient data have been collected extensively in the Barnegat Bay-Little Egg Harbor Estuary since 2004 as part of benthic habitat characterization studies conducted by Rutgers University (Kennish et al., 2007b, 2008). Seagrass blades collected in the estuary in 2008 are being used to establish a nitrogen loading index for the Barnegat Bay-Little Egg Harbor Estuary.

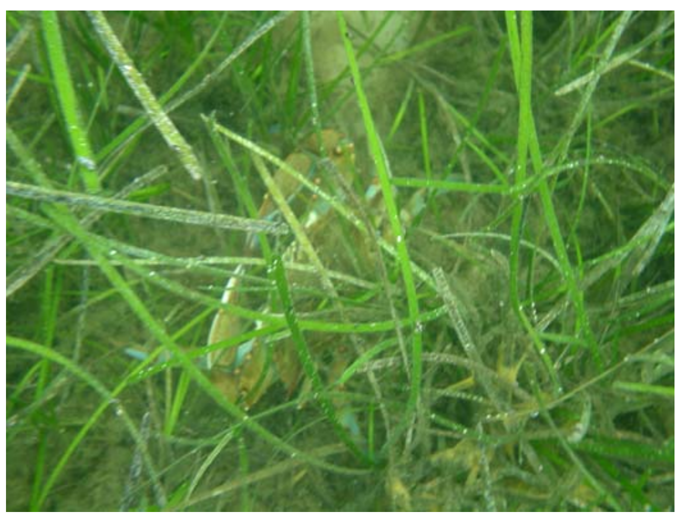
Fisheries

Comprehensive studies are being conducted at the Rutgers University Marine Field Station to determine the habitat needs of resource species such as summer flounder, striped bass, and bluefish. Acoustic tracking of these species is playing an important role in documenting their habitat requirements. The occurrence of bay scallops (*Argopecten irradians*) and other shellfish species has been investigated in JCNERR estuarine waters using underwater videographic imaging technology that has not been applied at other NERRS sites.

Finfish research has focused on acoustic tracking of recreational and commercial species, such as summer flounder (*Paralichthys dentatus*) and striped bass (Morone saxatilis). Research on the dynamics of other finfish species in the Great Bay and contiguous waters is ongoing. These studies have revealed detailed behavioral patterns of key finfish species in JCNERR waters.

Aquatic Habitat Assessment

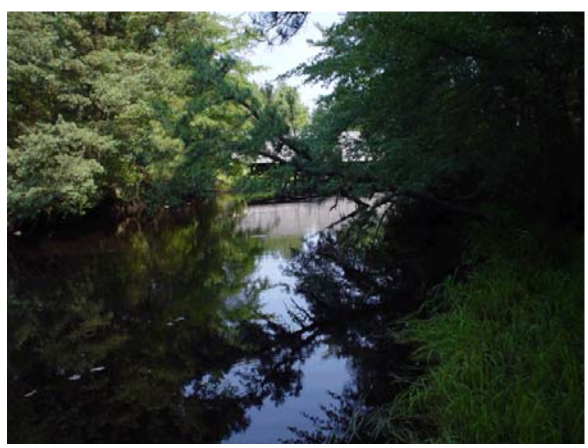
Studies are ongoing to determine habitat requirements of shellfish species (*Mercenaria mercenaria* and *Argopecten irradians*) under increasingly eutrophic conditions of the Barnegat Bay-Little Egg Harbor Estuary. Research is also ongoing to determine the dynamics of biofouling populations in the JCNERR. In addition, investigations are ongoing with



respect to assessing the environmental conditions necessary for the long-term success of seagrass populations in estuarine waters of the JCNERR, determining the impacts of nuisance and toxic algal blooms on seagrass beds and other critical habitat, and recommending to coastal managers the necessary measures for remediation of damaged environments.

Stream Water Quality

The water quality of bay tributaries is coupled to development in watershed areas. For example, in developed areas of the Barnegat Bay watershed, higher concentrations of nitrogen, phosphorus, sulfate, and other inorganic constituents, as well as elevated pH and specific conductance have altered water quality of influent systems (Hunchak-Kariouk et al., 2001). The size of a drainage basin and the type of land cover greatly influence the pollutant loads transported by streams and rivers in the watershed. Undeveloped rural areas with natural vegetative covers yield much lower constituent loads than urban centers and heavily developed residential zones.



Ayers et al. (2001) indicated that human activities associated with urban and agricultural land uses are the principal factors affecting water quality of streams and the health of aquatic life statewide. In areas where forest and wetland habitats are replaced by urban and suburban development, changes in natural flow of streams, habitat conditions, and biodiversity are evident. In addition, shifts toward species more tolerant of disturbance typically occur. Although pollutants that alter water quality of tributary streams may derive from both point and nonpoint sources, those originating from nonpoint sources are particularly problematic because they are so difficult to control. Nonpoint sources are diffuse and often extend throughout the watershed, whereas point sources are localized and heavily regulated.

U.S. Geological Survey investigations of water quality in New Jersey streams have commonly detected an array of chemical contaminants such as fertilizers, pesticides, and industrial and fuel-related compounds (volatile organic compounds or VOCs) (Nicholson et al., 2003). Analysis of streambed samples has frequently revealed the occurrence of environmentally persistent contaminants (e.g., DDT, PCBs, chlordane, dieldrin, polycyclic aromatic hydrocarbons, and trace metals). Impaired water quality in urban watersheds has been related to increases in impervious surfaces, which facilitate stormwater runoff and inputs of contaminants to tributary streams and estuarine basins. A similar suit of contaminants detected in ground water reflects the impact of human activities associated with developed land and upland agriculture. Especially noteworthy are elevated concentrations of nitrate in shallow ground water underlying agricultural areas in southern New Jersey. Other concerns are with the concentrations of volatile organic compounds and methyl tert-butyl ether (MTBE) which increase in regions of greater residential and industrial land use. Several major factors determine whether chemical contaminants in ground water will reach an estuary. Included here are the physical characteristics of aquifer systems, chemical characteristics of the contaminants, and the various processes taking place in the subsurface near the ground water and surface water interface that tend to reduce contaminant concentrations (e.g., adsorption, biodegradation, and denitrification).

It is clear, therefore, that human activities can play a significant role in the degradation of surface and ground water resources of New Jersey. The most commonly occurring contaminants associated with human activities that have been documented in New Jersey watersheds are pathogens (disease causing microorganisms), elevated nutrients, organic compounds (e.g., pesticides, PCBs, oil, grease, gasoline), trace elements, and sediments. The pathogens originate from various sources, such as malfunctioning septic systems, leaking sewer lines, improper boat sanitation disposal, and animal waste. Nutrients often derive from fertilizers used for domestic and agricultural purposes, although a substantial amount may also enter estuarine systems via atmospheric deposition. Similarly, trace element inputs are typically linked to atmospheric deposition, as well as acid rain drainage, and industrial waste discharges. Sediments eroded from roadways, construction sites, and farm fields can clog streams, alter stream flow, and degrade aquatic habitats (Kennish, 2001a).

A general pattern of decreasing water quality with increasing watershed development is evident in both the Mullica River watershed (Zampella, 1994; Dow and Zampella, 2000) and the Barnegat Bay watershed (Hunchak-Kariouk et al., 2001; Lathrop and

Conway, 2001). Along a watershed disturbance gradient of increasing development and agricultural land use intensity and wastewater flow in the Mullica River drainage basin, Zampella (1994) and Dow and Zampella (2000) found a gradient of increasing pH, specific conductance, and nutrients (i.e., total nitrate plus nitrite, total ammonia, and total phosphorus). Altered water quality along the watershed disturbance gradient coupled to increasing developed land and upland agricultural cover adversely affects the structure and function of biotic communities in wetland and aquatic systems (Morgan and Philipp, 1986; Zampella and Laidig, 1997; Zampella and Bunnell, 1998). More specifically, the biological consequences of water quality degradation in the impacted areas include invasion of the region's aquatic and wetland plant communities by non-native species and the elimination of native species (Zampella et al., 2001).

Lathrop and Conway (2001) assert that the percentage of impervious surface in a watershed is a strong indicator of the intensity of human land use and the amount of nonpoint source pollution, and it correlates closely with altered runoff patterns and water quality degradation. Watersheds with higher levels of nonpoint source pollution generally are those characterized by more intense development and a larger percentage of impervious surface cover. Over the 10-year period from 1986 to 1995, Lathrop and Conway (2001) calculated that the impervious surface cover in the Barnegat Bay watershed increased from 7% to 8%. In the Mill Creek/Westecunk Creek subwatershed and Tuckerton Creek subwatershed that drain into Little Egg Harbor, the percentage of urban land in 1995 amounted to 14% and 18%, respectively. One important approach to protect the water quality in a drainage basin is to minimize the amount of impervious cover and maximize the amount of undisturbed native vegetative cover.

The U.S. Geological Survey has analyzed surface water quality at more than 100 sites throughout the four physiographic regions of the state. Samples collected at each site four times a year have been analyzed for a number of physical-chemical properties, including nutrients, biological oxygen demand, major ions plus boron, organic carbon, suspended sediment, field parameters (pH, water temperature, specific conductance, dissolved oxygen concentration, and turbidity), pesticides, trace elements, and volatile organic compounds (Watt, 2001). The water quality data have been published annually in water resources data reports of the U.S. Geological Survey. Results of this sampling program indicate that surface water quality in streams of the Mullica River drainage basin is less degraded than that in more heavily developed watersheds in the densely populated northern counties of the state.

Estuarine Nutrient Dynamics

Several studies have examined nutrient concentrations in streams draining the Mullica River Basin (Durand and Nadeau, 1972; Zimmer, 1981; Durand, 1988, 1998; Zampella, 1994). Nitrogen has been the focus of most of these studies because it is the nutrient element principally limiting to primary production in Barnegat Bay, Little Egg Harbor, Great Bay and the other backbay waters of the JCNERR. The fractions of nitrogen measured include ammonium, nitrate, nitrite, and organic nitrogen forms. Phosphate levels have also been measured. Nitrogen concentrations recorded in the Mullica River by the aforementioned studies are as follows: ammonium (0-<10 µgat N/l), nitrate (0->70 µgat N/l), nitrite (0-<2 µgat N/l), and total organic nitrogen (0->60 µgat N/l)). Phosphate typically ranges from 0-<5 µgat P/l.

Durand (1984, 1998) has discussed the processes controlling nitrogen inputs to the Mullica River. The input of nitrogen at the upper drainage area is mainly as nitrate, with highest concentrations observed in streams draining agricultural and urban areas of the Pine Barrens and lowest levels in streams of relatively undisturbed areas of the drainage basin. Much nitrate derived from nitrification of ammonium in farmland soils is not utilized in the Mullica River, which is usually turbid. The nitrate that enters Great Bay and the other coastal bays fuels phytoplankton production. Even when nitrate enters the bays in low concentrations from influent systems, primary production is stimulated. However, primary production in the bays is often limited by low nitrogen concentrations. Light penetration is greater in the less turbid bay waters, where the compensation depth generally extends to the bottom. Benthic regeneration of inorganic nitrogen is an important process in the shallow backbays, but also plays a role in cycling of nitrogen in upriver areas. Phytoplankton nutrient uptake utilizes much of the inorganic nitrogen in the bays, thereby converting most of the nitrogen stocks there to organic form. As a result, the largest fraction of nitrogen transported to the coastal ocean from the bays exits in organic combination (Figure 16).

A conspicuous seasonal pattern of nitrogen concentrations is observed in upriver areas. Both ammonium and nitrate levels peak in these areas during the winter months. Higher concentrations of nitrate occur upriver than in the bay, where levels are reduced to near 0 during summer due to biotic uptake. An upriver to downriver decreasing gradient in nitrate levels is evident year-round. Nitrogen inputs to the coastal bays from the Mullica River and Barnegat Bay watersheds regulate primary production in the coastal bays. As summarized by Durand (1984, p. 49), "A balance between nitrogen input into the bays, cycling by regeneration, primary production, and light penetration exists such that nitrogen enters the system largely as nitrate in the upper drainage and leaves the estuary to the nearshore ocean as organic nitrogen."

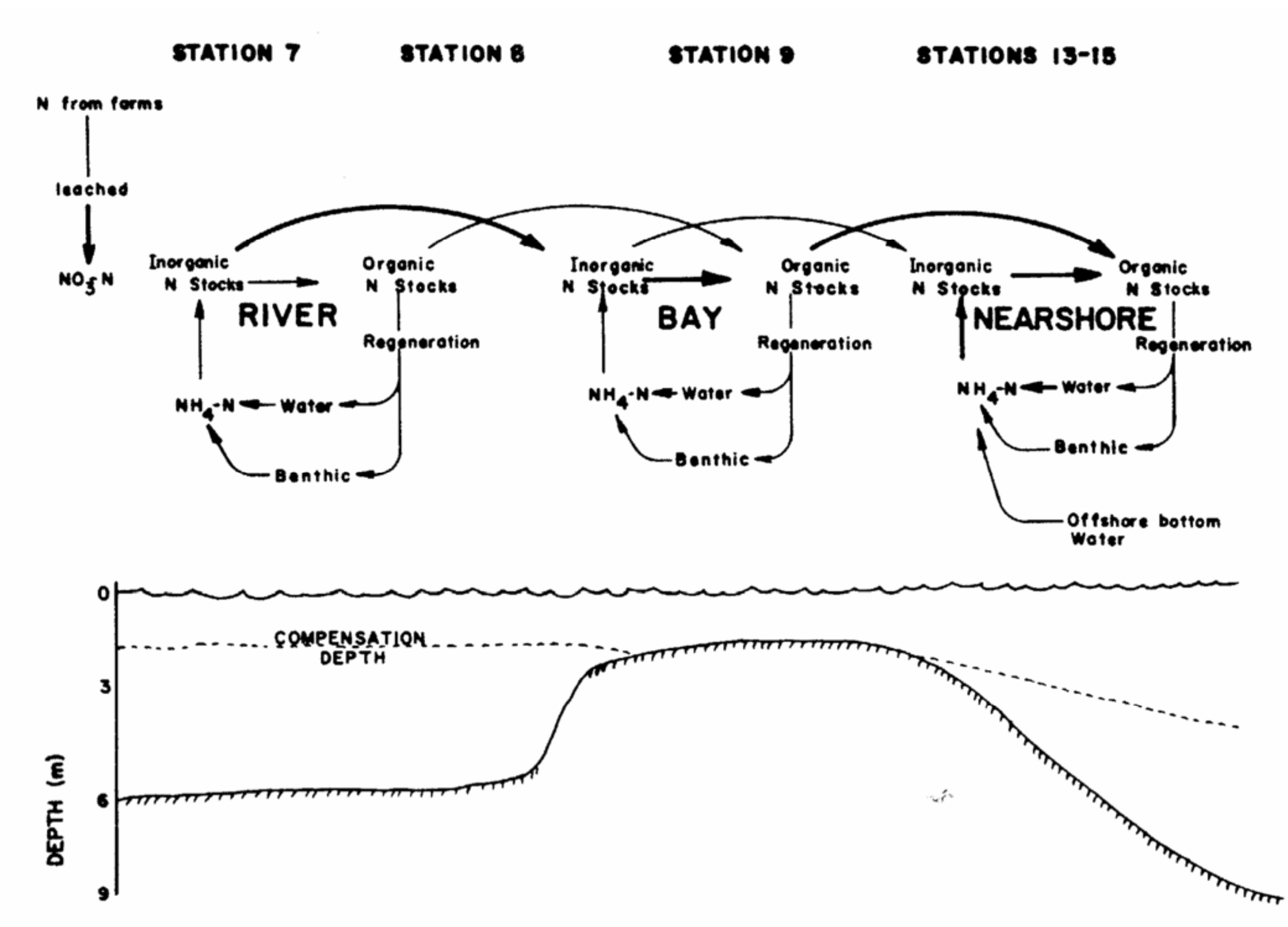


Figure 16. Schematic model of the Mullica River-Great Bay Estuary, exhibiting nitrogen dynamics through the system. From Durand, J. B. 1984. Nitrogen distribution in New Jersey coastal bays. In: M. J. Kennish and R. A. Lutz (eds.), *Ecology of Barnegat Bay, New Jersey*. Springer-Verlag, New York, pp. 29-51.

McGuirk Flynn (2008) examined how the biogeochemical processes and hydrological dynamics in the Mullica River-Great Bay Estuary influence the distribution, flux, and fate of DOM and DIN. In a study of nutrients in the estuary during the 2002 to 2004 period, she observed seasonal cycles for DOC, DON, and DOP, with concentrations increasing from spring to fall, and maximum concentrations occurring in the summer and early fall. The temporal distribution of DOC, DON, and DOP may be attributed to a combination of seasonal terrestrial sources and autochthonous primary production. Data from this study suggest seasonal watershed inputs of DOM may be significant in regulating the observed seasonal cycle of DOM within this estuarine system. Watershed inputs of DOM likely have a greater influence on the temporal distribution of DOM in the upper estuary and mid-estuary regions than in the lower estuary and coastal bay inlet. Autochthonous DOM production may be of greater importance in regulating the distribution of DOM in the lower estuary and coastal bay inlet than in the upper estuary and mid-estuary regions.

The annual mean export of DIN (15.7×10^6 mol yr^{-1}) and DON (17.4×10^6 mol yr^{-1}) from the lower estuary to the coastal area was approximately equal. During transport through the estuarine system, it appears that a portion of the DIN in the TDN pool is converted to DON, resulting in an equal export of DIN and DON to the coastal area. The annual mean export of DIP (0.76×10^6 mol yr^{-1}) and DOP (0.44×10^6 mol yr^{-1}) represented approximately 63% and 37%, respectively, of the total TDP exported from the lower estuary to the coastal area during this study period. The increase in the DIP fraction of the TDP pool may be attributed to release of DIP from particulate phosphorus during transport through the estuarine system.

The total estuarine system is a net source of DOC, DON, and DIP and a net sink of DIN on an annual time scale. In contrast, DOP is likely in balance within the total estuarine system. The upper estuary is a net sink of DIN, DON, and DIP, whereas the lower estuary is a net source. DOP in the upper estuary and lower estuary appears to be in balance on an annual time scale. In contrast, the mid-estuary region appears to be a clear sink of DOP. A LOICZ model estimates that this estuarine system is net heterotrophic, consuming 1.1 to 1.4 mol C m^{-2} yr^{-1}. Furthermore, the lower estuary is estimated as net heterotrophic, consuming an estimated 1.8 to 5.8 mol C m^{-2} yr^{-1}.

In summary, nitrate is the primary limiting nutrient in the Mullica River-Great Bay Estuary. On rare occasions, phosphate may be limiting. Based on the work of Durand and Nadeau (1972), nitrite never accounts for more than 3% of the total inorganic nitrogen in the system. Ammonium comprises most of the inorganic nitrogen present in Great Bay, and nitrate most of the inorganic nitrogen present upriver (i.e., in the Mullica River). Particulate carbon (i.e., detritus production) also appears to be greatest in upriver areas.

According to McGuirk Flynn (2008), the entire estuarine system is a net source of nutrients with the exception of DIN and DOP. The lower estuary acts as a net exporter of all dissolved organic and inorganic nutrients to the nearshore coastal area, serving as a potentially significant source of nutrients for primary production in the nearshore coastal region. This estuarine system appears to serve an important role in the cycling and processing of dissolved nitrogen and phosphorus, ultimately controlling the fraction of organic and inorganic nitrogen and phosphorus delivered to the coastal zone.

Estuarine Water Quality

Able et al. (1992) analyzed long-term measurements of temperature (Appendix 5), salinity (Appendix 6), tides (Appendix 7 and 8), and other hydrographic conditions at the Rutgers University Marine Field Station (RUMFS) on Great Bay over the 15-year period from 1976 through 1990. They showed that water temperature at the station ranged from 0.1-25.2°C and salinity from 23.6-34.5‰ during this period. Highest salinities were registered during the summer and fall seasons (Figure 17). Mean turbidity at RUMFS ranged from 4.9-17.9 NTU, although no seasonal trends were apparent (Appendix 9).

Commencing in August 1996, Rutgers University began an intense water quality monitoring effort by using data loggers to measure six physical-chemical parameters at two sites (Buoy 126 and Buoy 139 in Great Bay) as part of JCNERR program. Subsequently, data loggers were also deployed in the Mullica River at Chestnut Neck (September 1996) and Lower Bank (October 1996), as well as at Little Sheepshead Creek (April 1997), Nacote Creek (May 1997), and Tuckerton Creek (November 1998). The Nacote Creek monitoring site was discontinued in December 1998. A limited data logger deployment (March-June 2000) was conducted in Lake Pohatcong and at Mill Run. Data logger deployment was temporarily discontinued at Buoy 139 in Great Bay in July 1999, but was resumed in May 2002 and later discontinued again.

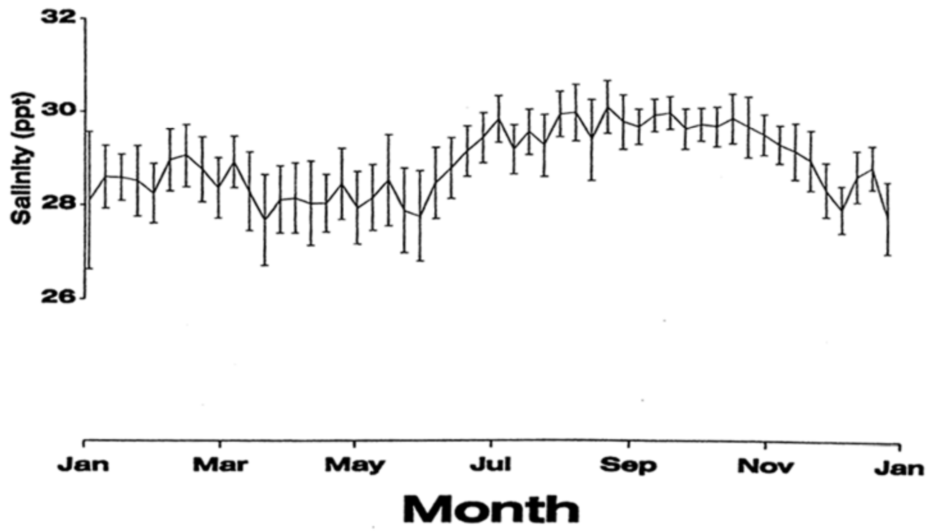


Figure 17. Mean monthly salinity recorded at the Rutgers University Marine Field Station on Great Bay during the period from 1976 through 1990.

JCNERR currently monitors physical-chemical parameters at four SWMP aquatic sites in the reserve system using YSI 6-series data loggers (Figure 18). These instruments are programmed to simultaneously record six physical-chemical parameters (i.e., water temperature, salinity, dissolved oxygen (mg/l and % saturation), pH, turbidity, and water depth). These measurements are recorded over a two-week period, and the data loggers are then switched out with newly programmed data loggers at the end of the deployment period. The monitoring sites cover a distance of ~33 km, extending from the freshwater/saltwater interface at Lower Bank, downriver to Chestnut Neck, into the polyhaline waters of Great Bay at Buoy 126 and Buoy 139 (Figure 18). As noted previously, physical-chemical data are also collected in nearshore ocean waters at LEO-15, although not with 6-series data loggers. Monitoring data in the program are available over the Internet at http://marine.rutgers.edu/rumfs/RUMFSdata.htm.

Each YSI data logger is inserted into a 3-6 m length of Schedule 40 PVC pipe when deployed in the field. The pipe is positioned vertically in the water column, being attached to a buoy, bridge piling, or other stabilized structure. Prior to deploying the PVC pipe, slots 2.5-cm wide and 20-cm long are cut 15 cm above the bottom such that they encircle the pipe. A 1.2-cm bolt is placed below the pipe slots to prevent the data logger from falling through the pipe to the estuarine floor when deployed. A PVC cap with a locking mechanism is then placed over the pipe. A rope is attached to the cap and the opposite end fastened to the bail of the data logger for retrieval of the instrument.

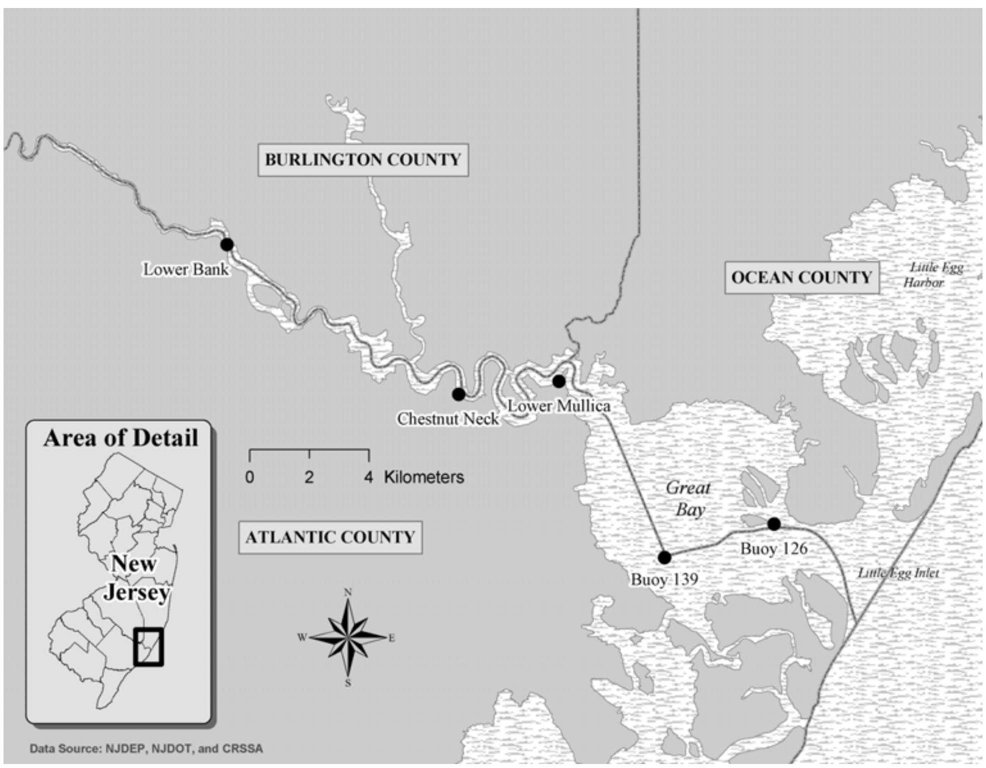


Figure 18. Map of the Jacques Cousteau National Estuarine Research Reserve showing the location of the System-wide Monitoring Program sites (closed circles) for water quality assessment in the Mullica River-Great Bay Estuary. The Lower Mullica River site was discontinued in 1998. Inset displays the location of the reserve with respect to the state of New Jersey.

Every 15 minutes during the deployment period, the programmed data loggers record temperature, salinity, dissolved oxygen (mg/l and % saturation), pH, turbidity, and water depth. At the end of the deployment period (~14 days), the data logger is removed from the PVC pipe, and then a YSI 600 data logger attached to a YSI 610-DM handheld unit is lowered into the pipe to record *in-situ* post-retrieval conditions at the same depth. These post-retrieval readings are compared to the last deployment values to provide "ground-truthing." Irregular and spurious data observed during this process are documented on deployment records. A newly calibrated and programmed YSI data logger is subsequently switched with the previously deployed instrument. The replaced data logger is returned to the laboratory for downloading of data, re-calibration, and re-programming prior to being exchanged at a different monitoring site.

The beginning and end of each data file are compared to the YSI 600 readings, and the data are checked for probe failure and fouling. The data loggers are programmed to start recording data a few hours before being deployed in the field. Records are maintained indicating which data loggers are used at each location and if any specific problems exist with the data loggers and their probes.

Uploading, cleaning, maintenance, and calibration are conducted as described in the YSI Operating Manual. Calibration standards required for pH and conductivity are purchased from a scientific supply house. A two-point calibration is used for pH, the first being pH 7 followed by pH 4. The lower pH standard is used because of the more acidic properties of the Mullica River. A standard of 20,000 us/cm is employed to calibrate for conductivity. The membrane on the oxygen probe is changed with every deployment, and it is carefully examined during the maintenance and calibration process. Servicing an instrument generally takes about two hours for each data logger plus the time involved with retrieval and deployment.

The longest monitored SWMP site in the JCNERR is Buoy 126, located at 39°30.478'N, 74°20.308'W on the eastern side of Great Bay ~100 m from the nearest land mass (i.e., natural marsh island). Semidiurnal tides (range = 0.68-1.55 m) characterize the site, and tidal currents range from ~3.5-5.5 km/hr. Bottom sediments consist of fine- to coarse-grained sands. Mean physical-chemical measurements recorded at this site during 2000 are as follows: temperature (13.5°C, with a range of -1.7-27.1°C); salinity (29.6‰, with a range of 22.5-33.3‰); dissolved oxygen (9.5 mg/l, with a range of 3.2-16.0 mg/l) (104.0% saturation, with a range of 42.8-159.8% saturation); pH (7.95, with a range of 7.0-8.4); turbidity (11.18 NTU, with a range of 0-196.0 NTU); and water depth (3.05 m, with a range of 0.59-4.29). Measurements of pH were highly variable between data logger deployments in 2000, possibly due to fouling of the original pin-hole-style pH probe on YSI 6000 units.

The Mullica River is ~65 km long with an average depth and width of 12.8 m and 590 m, respectively. The Chestnut Neck SWMP site is located in the Mullica River at 39°32.872'N, 74°27.676'W. The width of the river at this location is ~250 m. Tidal currents are less than 2 km/hr at this site during both ebb and flood tide. The data logger is attached to the dock of a small marina along the southern shore of the river adjacent to the main channel. Here, the bottom sediments consist of sand. Mean physical-chemical data recorded at this site during 2000 are as follows: temperature (14.8°C, with a range of -1.3-27.7°C); salinity (15.0‰, with a range of 4.1-26.9‰); dissolved oxygen (8.6 mg/l, with a range of 4.6-13.7 mg/l) (88.1% saturation, with a range of 61.3-115.3% saturation); pH (7.4, with a range of 6.6-8.1); turbidity (7.9 NTU, with a range of 0-107.0 NTU); and water depth (1.73 m, with a range of 0.27-2.63 m).

The other SWMP data logger site in the Mullica River is at Lower Bank (39°35.618'N, 74°33.091'W). At this location, the Mullica River is ~200 m wide, and a data logger is attached to the center of a bridge spanning the river. Semidiurnal tides characterize the Lower Bank site, with the tidal range being 0.46 m to 1.55 m. Here, tidal currents are ~2 km/hr. As a result, bottom sediments consist of cohesive fine sand. Mean physical-chemical measurements recorded at this site for 2000 are as follows: temperature (15.3°C, with a range of -0.7-29.6°C); salinity (2.1‰, with a range of 0-11.2‰); dissolved oxygen (9.2 mg/l, with a range of 3.1-14.9 mg/l) (88.0% saturation, with a range of 39.3-110.5% saturation); pH (6.2 mg/l, with a range of 4.5-7.7 mg/l); turbidity (24.3 NTU, with a range of 16.3-32.4 NTU); and water depth (1.73 m, with a range of 0.63-2.58 m).

In addition to these three SWMP sites, physical-chemical data are measured at Buoy 139 in Great Bay and periodically in nearshore ocean waters at LEO-15, about 9 km east of Little Egg Inlet. At LEO-15, continuous observations of coastal ocean processes are made at two instrumented platforms (known as Node A, 74°15.73'W, 39°27.70'N and Node B, 74°14.75'W, 39°27.41'N) anchored to the seafloor and spaced 1.5 km apart. Optical fibers transfer site data in 1-second intervals to computers at the

RUMFS. These data are fed to the Internet and are made immediately available at the Institute of Marine and Coastal Sciences at Rutgers University in New Brunswick, New Jersey.

Water quality has been monitored in Tuckerton Creek for extensive periods since November 1998, and the data loggers have periodically provided real time data to the visitors of the historic Tuckerton Seaport. Tuckerton Creek is a tidally influenced water body with freshwater inflow from nearby Lake Pohatcong. Similar to the Mullica River, Tuckerton Creek receives significant amounts of tannic acids leached from soils of the Pine Barrens. Lake Pohatcong and Mill Run were monitored with YSI data loggers in the spring of 2000 to obtain additional data for a potential fish stocking program and installation of a fish ladder on Lake Pohatcong. Both of these freshwater systems are characterized by low pH. Water quality has been sampled in Little Sheepshead Creek since April 1997 in support of long-term ichthyoplankton sampling, which has been conducted in the creek by RUMFS personnel for nearly two decades.

It is important to note that, while data loggers have provided near-continuous measurements of physical-chemical factors at the monitoring sites, data gaps do exist due to equipment failure, unusual environmental events, and adverse weather conditions. Another problem leading to potentially spurious data readings is an apparent systematic downward "drift" in dissolved oxygen measurements recorded by the data loggers 3-5 days after their deployment. Wenner et al. (2001) suggested that this drift may have been caused by fouling of living organisms on the membrane covering the oxygen probe. These data have been removed from the database. Despite these deficiencies, this long-term water quality monitoring program has effectively created a large database to assess environmental conditions at the NERRS system of estuaries.

Physical-chemical data collected in the JCNERR to date show that water quality varies considerably from the Lower Bank to LEO-15 monitoring sites. Although waters of both the Mullica River and Great Bay are relatively pristine, some fundamental differences in water chemistry are apparent. For example, the river contains high concentrations of tannins and humic compounds which discolor the water dark brown. These substances originate in the Pine Barrens. They tend to sorb to particulate matter and settle to the bay bottom. Thus, water clarity in the bay is greater than in the river.

Data collected at the monitoring sites also help to address issues related to estuarine circulation. For instance, because of the close proximity of the lower bay station (Buoy 126) to Little Egg Inlet, investigators have been able to examine tidal current flow into Great Bay. The upwelling of seawater from the coastal ocean into the Great Bay may significantly influence the transport of fish and shellfish larvae, as well as other organisms, upestuary. This colder ocean water that enters the bay can also have dramatic effects on the growth rates of organisms inhabiting the estuary. JCNERR data loggers provide the means to effectively track certain events within the estuary such as occurrences of upwelling, storms, and storm surges.

Meteorology

Meteorological data are collected at the Richard Stockton College Marine Science and Environmental Field Station at Nacote Creek. This meteorological station is unique in that it has two collection platforms (at 10 m and 19 m elevation) for wind speed and direction, and all data are available in real time at the Institute of Marine and Coastal Sciences website (http://marine.rutgers.edu). The weather station records wind speed and direction, air temperature, short wave radiation, photosynthetically active radiation, barometric pressure, and relative humidity. In addition, precipitation is also recorded. This station has been collecting SWMP meteorological data since September 2002.

The weather station is located approximately 14.3 km WSW of Little Egg Inlet, the primary saltwater influence of the JCNERR. The unit is mounted on a 13-m tower adjacent to the Nacote Creek, approximately 20 m from the high tide line. The elevations above the marsh surface are as follows: barometric pressure - 2.2 m, temperature and relative humidity - 2.9 m, PAR - 4.5 m, wind - 12.5 m, and the highest point on the tower (lightning rod) - 14 m. The rain gauge is approximately 2.1 m above the surface and 1.5 m north of the tower. The area is sparsely covered with clam shell debris and upland grasses.

Meterological parameters are measured every 5 seconds to produce 15-minute averages of air temperature, relative humidity, barometric pressure, rainfall, wind speed, wind direction, and PAR (Table 5). An instantaneous sample is taken every 15 minutes. Telemetry equipment was installed at the Nacote Creek Meteorological station on November 15, 2005, and it transmits data to the NOAA GOES satellite, NESDIS ID #3B00D112. The transmissions are scheduled hourly and contain four data sets reflecting 15-minute sampling intervals. By this process, the JCNERR effectively contributes to the Integrated Ocean Observing System (IOOS).

Data are uploaded from the CR1000 data logger to a Personal Computer (IBM compatible). Files are exported from LoggerNet in a comma-delimited format and uploaded to the CDMO where they undergo automated primary QAQC and become part of the CDMO's online provisional database. During primary QAQC, data are flagged if they are missing, out of sensor range, or outside 2 or 3 standard deviations from the historical seasonal mean. The edited file is then returned to the JCNERR where it is opened in Microsoft Excel and processed using the CDMO's NERRQAQC Excel macro. The macro inserts station codes, creates metadata worksheets for flagged data, and graphs the data for review. It allows the user to apply QAQC flags and codes to the data, append files, and export the resulting data file to the CDMO for tertiary QAQC and assimilation into the CDMO's authoritative online database.

Table 5. Monthly averages of select meterological parameters at the JCNERR during 2007.

Month (Avg.)	**Air Temp (°C)**	**RH (%)**	**BP (mb)**	**Wspd (m/s)**	**Wdir (degrees)**	**PAR (mmoles/m^2)**
JANUARY	4.0	69	1017	3.0	237	137.6
FEBRUARY	-1.7	58	1014	3.4	242	213.4
MARCH	5.9	63	1020	3.5	212	296.5
APRIL	9.4	69	1011	3.5	205	302.8
MAY	16.9	67	1019	3.1	192	458.9
JUNE	21.5	73	1013	2.8	204	411.7
JULY	23.5	74	1013	2.5	203	408.0
AUGUST	23.4	79	1014	2.5	187	302.4
SEPTEMBER	19.8	75	1020	2.4	199	386.5
OCTOBER	17.1	81	1019	2.8	200	259.6
NOVEMBER	7.3	74	1019	2.7	229	159.6
DECEMBER	3.3	79	1020	2.8	218	113.8
YEAR (avg)	**12.5**	**72**	**1016**	**2.9**	**211**	**287.6**
Std. dev. (YEAR)	8.82	6.67	3.25	0.39	17.40	114.78

Sensors on the weather station are inspected monthly for damage or debris. If any is found, it is repaired and/or cleaned. Sensors are removed and returned to Campbell Scientific for calibration at a minimum of every two years, depending on sensor specifications. Tables 5 and 6 show monthly averages recorded on specific meteorological parameters at the weather station during 2007.

Table 6. Monthly rainfall totals recorded by the JCNERR weather station during 2007.

Month (total)	**Precipitation (mm)**
JANUARY	98.1
FEBRUARY	73.9
MARCH	108.3
APRIL	138.5
MAY	23.6
JUNE	131.9
JULY	54.6
AUGUST	82.2
SEPTEMBER	54.2
OCTOBER	0.6
NOVEMBER	36.6
DECEMBER	180.4
YEAR	**982.9**

NERRS SWMP mandates that meteorological data collected by all reserves must be documented, edited, and submitted along with metadata to the CDMO on a regular schedule. These data, together with SWMP water quality data, constitute some of the most detailed measurements on physical-chemical parameters ever recorded in estuaries. They provide the basis for determining if environmental conditions in these coastal ecosystems are improving, deteriorating, or remaining unchanged through time.

Water Quality Monitoring - Data Years 1996-1998

Wenner et al. (2001) analyzed water quality data collected at 44 NERRS sampling sites nationwide, including those of the JCNERR. This analysis covered the data years between 1996 and 1998. The following discussion of water quality data on the JCNERR largely derives from the work of Wenner et al. (2001) based on water sampling conducted by reserve site personnel.

Focusing on two sampling sites in the JCNERR (i.e., Lower Bank and Buoy 126), Wenner et al. (2001) presented a suite of graphical data analysis techniques and statistical testing procedures to assess water quality conditions. At the Lower Bank site, temperature, salinity, and dissolved oxygen data recorded during 41 data logger deployments between August 1996 and November 1998 were analyzed statistically. The data loggers were deployed at a mean depth of 1.7 m below sea level and 0.3 m above the river bottom. Mean seasonal water temperatures at the site typically varied from 2-5°C in winter to 24-26°C in summer, with the minimum and maximum temperatures being 0.2°C (January 1997) and 30.1°C (July 1997), respectively. Tidal cycles were responsible for 60% of the temperature variance based on harmonic regression analysis.

Salinity at the Lower Bank site averaged 0-2‰ in winter and spring and 2-8‰ in summer and fall 1997-1998. The salinity ranged from a minimum of 0‰ to a maximum of 15.6‰. Nearly every month of data contained 0‰ salinity readings from this site.

During the 1996-1998 period, hypoxia was observed at all estuarine reserves in the Mid-Atlantic region except the JCNERR. Dissolved oxygen at Lower Bank typically ranged from 85-105% saturation year-round. Mean dissolved oxygen values were lowest in summer (80-100% saturation) and highest in winter (105-125%). Although hypoxia did not occur at the study site, supersaturation was documented periodically in the system. The percent saturation fluctuated 20-40% over daily and biweekly cycles during the year. Wenner et al. (2001) ascribed 38%, 34%, and 28% of the dissolved oxygen variance to diel cycles, tidal cycles, and tidal-diel cycle interaction, respectively.

Water temperature at Buoy 126 followed a similar seasonal cycle as at Lower Bank. Between 1996 and 1998, water temperature at Buoy 126 ranged from –1.4°C (January 1997) to 28°C (August 1998). Mean winter temperatures were typically 4-6°C, and mean summer temperatures, 22-24°C. Daily (1-2°C) and biweekly (3-10°C) temperature fluctuations were observed year-round. Tidal cycles accounted for 60% of the temperature variance as demonstrated by harmonic regression analysis.

Salinity at Buoy 126 ranged from 13‰ (May 1998) to 35.4‰ (April 1997). The mean salinity for the data set was 25-31‰, although strong daily and biweekly variations were documented. Tidal cycles were responsible for 82% of the salinity variance.

Mean dissolved oxygen at Buoy 126 regularly exceeded 100% saturation, with the range generally between 85-120% saturation. As at Lower Bank, hypoxia was never evident at Buoy 126. While moderate fluctuations (20-40%) in % saturation were discerned for daily and bi-weekly cycles, supersaturation was documented during eight months in the summer and fall of 1996-1998. Wenner et al. (2001) ascribed 41% of dissolved oxygen variance at this site to interaction between tidal and diel cycles, 34% of dissolved oxygen variance to tidal cycles, and 25% of dissolved oxygen variance to diel cycles. Based on observations at Buoy 126 and Lower Bank, the Mullica River-Great Bay Estuary appears to be a well-oxygenated system.

Water Quality Monitoring - Data Years 1999-2000

Appendix 10 provides summary statistics for environmental parameters monitored at three SWMP sites (i.e., Buoy 126, Chestnut Neck, and Lower Bank) in the JCNERR for data years 1999 and 2000 (covering the period from December 1998 to November 2000). The parameters of concern include temperature (°C), salinity (‰), dissolved oxygen (mg/L and % saturation), pH, turbidity (NTU), and water depth (m). Appendix 11 and Appendix 12 show statistical results of ANOVA applications on these data. Environmental parameters across sites are compared for 1999 (Appendix 11) and 2000 (Appendix 12). Appendix 13 provides the results of t-tests comparing environmental parameters between years (1999 and 2000).

Temperature

Water temperature followed a well-defined seasonal cycle at all three SWMP sites (Figure 19). Minimum (winter) and maximum (summer) temperatures during the 1999-2000 study period were 1.7°C and 27.9°C at Buoy 126, -1.3°C and 29.39°C at Chestnut Neck, and -0.7°C and 31.5°C at Lower Bank. The mean temperature was highest at Lower Bank for both 1999 (13.76°C) and 2000 (15.69°C). Analysis of variance

(ANOVA) models were run using the SAS statistical software package. The ANOVA determinations indicated no significant difference ($P > 0.05$) in mean temperatures among monitoring sites during 1999. However, a significant difference ($P < 0.05$) in mean temperatures among monitoring sites occurred in 2000. The application of standard statistical tests revealed a significantly higher ($P < 0.05$) mean temperature at Chestnut Neck and Lower Bank than at Buoy 126 in 2000.

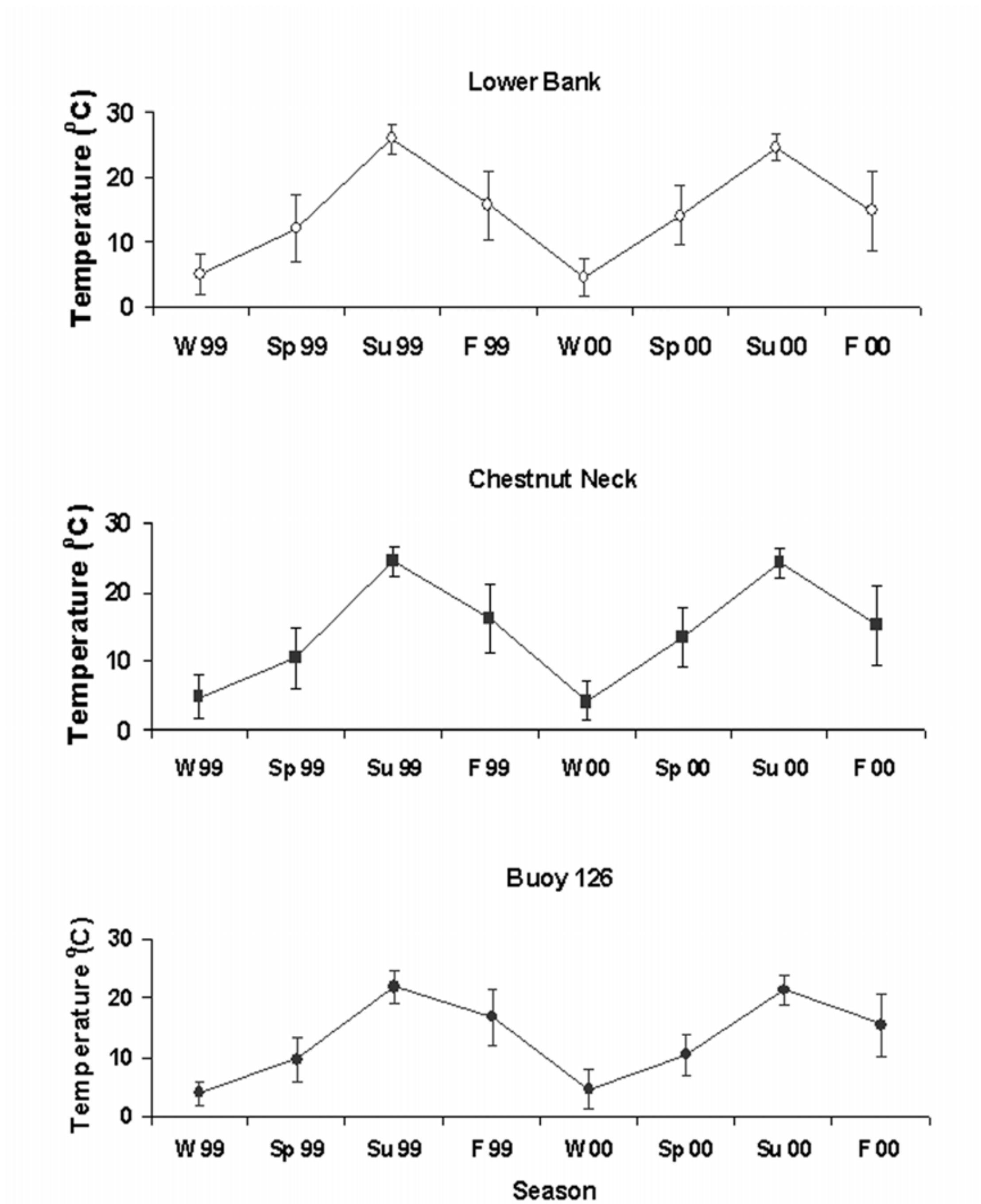


Figure 19. Mean seasonal water temperature and standard deviation values at three System-wide Monitoring Program sites in the Jacques Cousteau National Estuarine Research Reserve during the 1999 and 2000 monitoring period. From Kennish, M. J. (Ed.). 2003. *Estuarine Research, Monitoring, and Resource Protection*. CRC Press, Boca Raton, Florida.

The mean temperature at Chestnut Neck and Lower Bank was not significantly different ($P > 0.05$) between years (1999 and 2000). However, it was significantly different ($P < 0.05$) between years at Buoy 126 (Appendix 13). This difference may reflect the effect of coastal upwelling and other aperiodic factors at this site.

Salinity

A pronounced salinity gradient exists from the head to the mouth of the Mullica River-Great Bay Estuary, and this gradient is reflected in salinity measurements obtained at the SWMP sites (Figure 20). Salinity levels are lowest at Lower Bank (generally < 5‰), which marks the freshwater/saltwater interface ~25 km upstream of the Mullica River mouth. Intermediate salinity levels (~15‰) are found at Chestnut Neck located ~13 km upstream of the Mullica River mouth. Highest salinity levels (> 25‰) are recorded at Buoy 126 in the lower estuary.

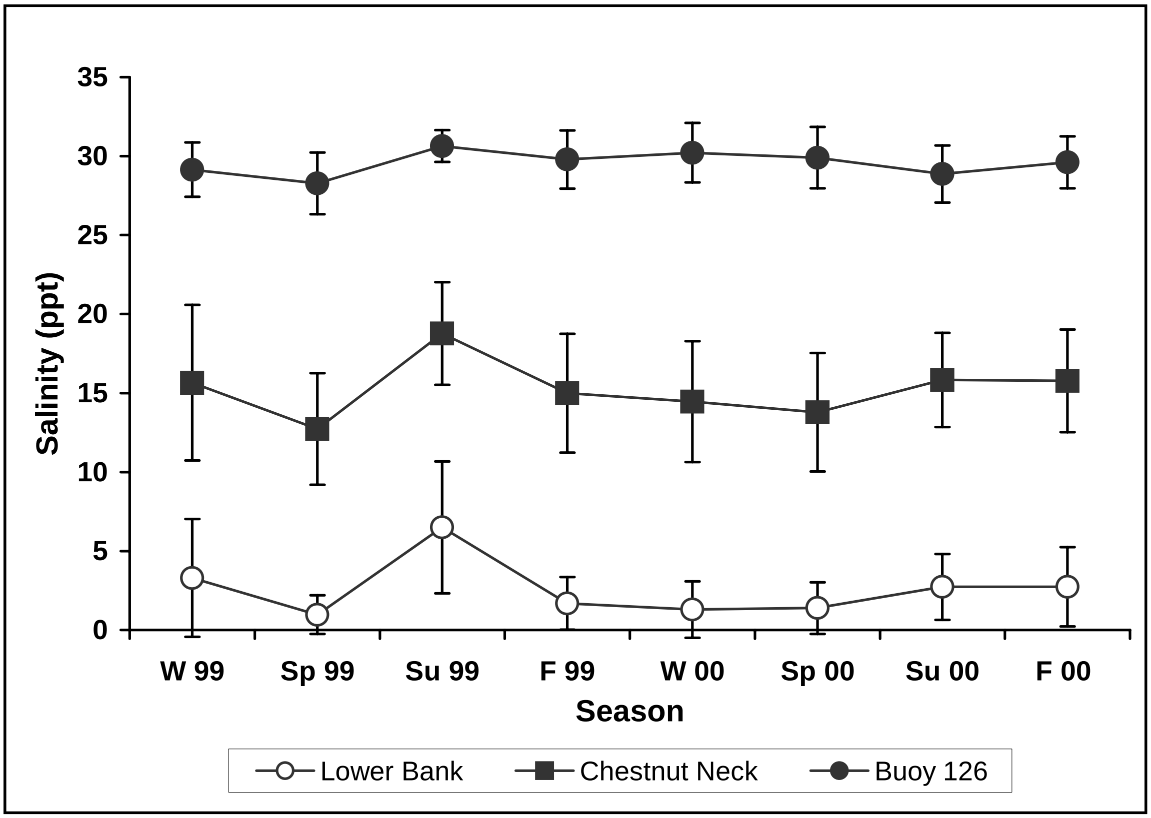


Figure 20. Mean seasonal salinity and standard deviation values at three System-wide Monitoring Program sites in the Jacques Cousteau National Estuarine Research Reserve during the 1999 and 2000 monitoring period. From Kennish, M. J. (Ed.). 2003. *Estuarine Research, Monitoring, and Resource Protection*. CRC Press, Boca Raton, Florida.

Lowest salinities at the SWMP sites during the two-year study period were recorded during spring 1999, with mean seasonal values amounting to 0.98‰ at Lower Bank, 12.73‰ at Chestnut Neck, and 28.27‰ at Buoy 126. Highest salinities, in turn, were observed during summer 1999 when drought conditions persisted throughout New Jersey. Mean salinities at this time were 6.49‰ at Lower Bank, 18.77‰ at Chestnut Neck, and 30.63‰ at Buoy 126 (Figure 20). Mean salinities at the three monitoring sites were significantly different ($P < 0.05$) for both 1999 and 2000. Using standard statistical tests, the mean salinity at Buoy 126 was shown to be significantly greater ($P < 0.05$) than that at Chestnut Neck and Lower Bank, and the mean salinity at Chestnut Neck was shown to be significantly greater ($P < 0.05$) than that at Lower Bank. Substantial differences in the salinity levels exert a major controlling influence on the composition, abundance, and distribution of estuarine organisms at these three SWMP sites.

The mean salinity at Buoy 126 was not significantly different ($P > 0.05$) between years (1999 and 2000). However, it was significantly different ($P < 0.05$) between years (1999 and 2000) at Chestnut Neck and Lower Bank. Variable runoff and freshwater input to the Mullica River between years may be responsible for the observed differences at the Mullica River sites.

Dissolved Oxygen

Consistently high dissolved oxygen levels were documented at the SWMP sites in 1999 and 2000, and hypoxia was not observed. Seasonal variation of dissolved oxygen was conspicuous, with highest values observed during the winter and lowest values during the summer (Figure 21). The highest dissolved oxygen concentrations for both years were registered at Buoy 126, with mean values being 9.63 mg/l and 9.51 mg/l for 1999 and 2000, respectively. Lowest dissolved oxygen levels were measured at Lower Bank in 1999 (mean = 8.98 mg/l) and at Chestnut Neck in 2000 (mean = 8.64 mg/l).

Mean dissolved oxygen concentrations were significantly different ($P < 0.05$) among the three SWMP sites for both 1999 and 2000. Standard statistical tests applied to these data revealed that the mean dissolved oxygen concentration at Chestnut Neck was significantly lower ($P < 0.05$) than that at Lower Bank and Buoy 126 in 1999. The mean dissolved oxygen levels at the latter two sites were also significantly different ($P < 0.05$). During 2000, the mean dissolved oxygen concentration was significantly higher ($P < 0.05$) at Buoy 126 than at Lower Bank and Chestnut Neck. The mean dissolved oxygen level at Lower Bank was significantly higher ($P < 0.05$) than at Chestnut Neck

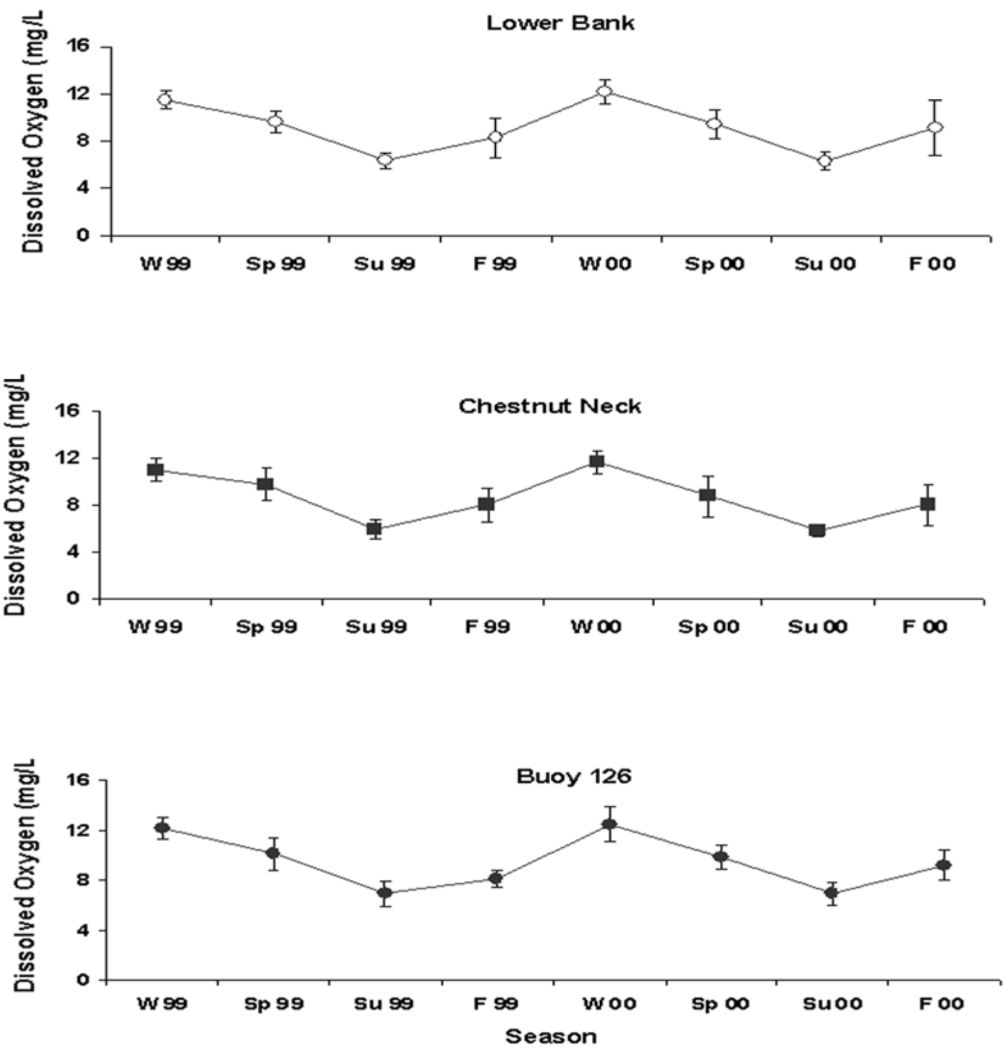


Figure 21. Mean seasonal dissolved oxygen concentrations (mg/l) at three System-wide Monitoring Program sites in the Jacques Cousteau National Estuarine Research Reserve during the 1999 and 2000 monitoring period. From Kennish, M. J. (Ed.). 2003. *Estuarine Research, Monitoring, and Resource Protection*. CRC Press, Boca Raton, Florida.

There was no significant difference ($P > 0.05$) in the mean dissolved oxygen (mg/l) concentration between the years 1999 and 2000 at Buoy 126. However, a significant difference ($P < 0.05$) in mean dissolved oxygen concentration between years was evident at Chestnut Neck and Lower Bank. The mean dissolved oxygen concentration was high both years, averaging 9.54 mg/l in 1999 and 9.51 mg/l in 2000.

Seasonal averages of dissolved oxygen (% saturation) for the three SWMP sites typically ranged from ~80-120% (Figure 22). Highest dissolved oxygen % saturation values were recorded at Buoy 126. Here, mean dissolved oxygen commonly exceeded 100% saturation. Supersaturation was periodically observed at all the SWMP sites during the summer and fall seasons.

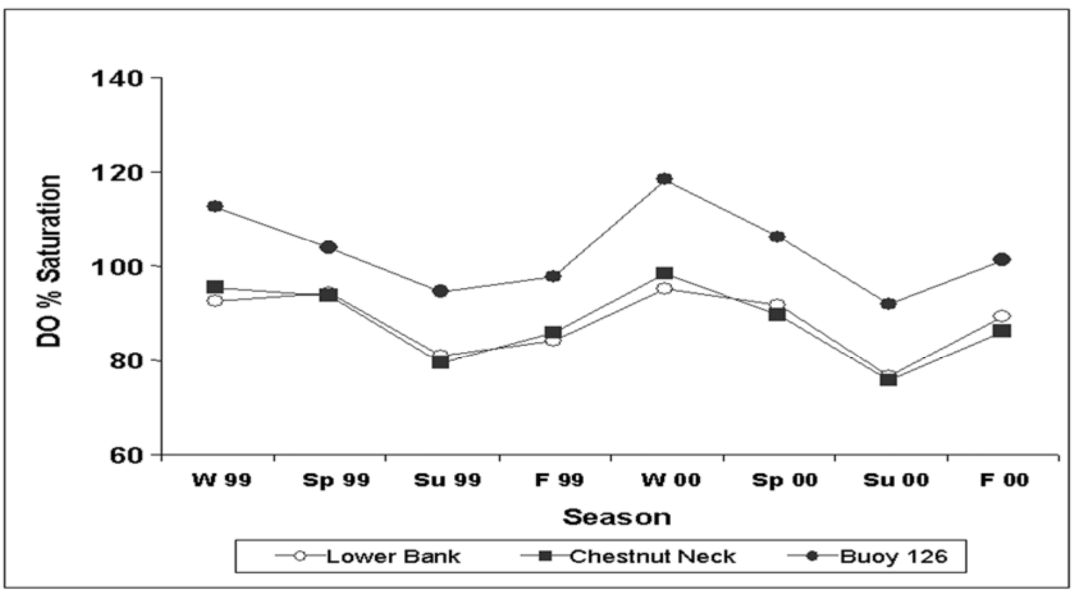


Figure 22. Mean seasonal dissolved oxygen levels (% saturation) at three System-wide Monitoring Program sites in the Jacques Cousteau National Estuarine Research Reserve during the 1999 and 2000 monitoring period. From Kennish, M. J. (Ed.). 2003. *Estuarine Research, Monitoring, and Resource Protection*. CRC Press, Boca Raton, Florida.

pH

Salinity and dissolved oxygen concentrations influence pH levels. High concentrations of tannins and humic acids in the Mullica River also affect pH. As a result, pH values at Lower Bank and Chestnut Neck are substantially lower than those at Buoy 126 (Figure 23). The pH values progressively increase from upriver areas to the open waters of Great Bay.

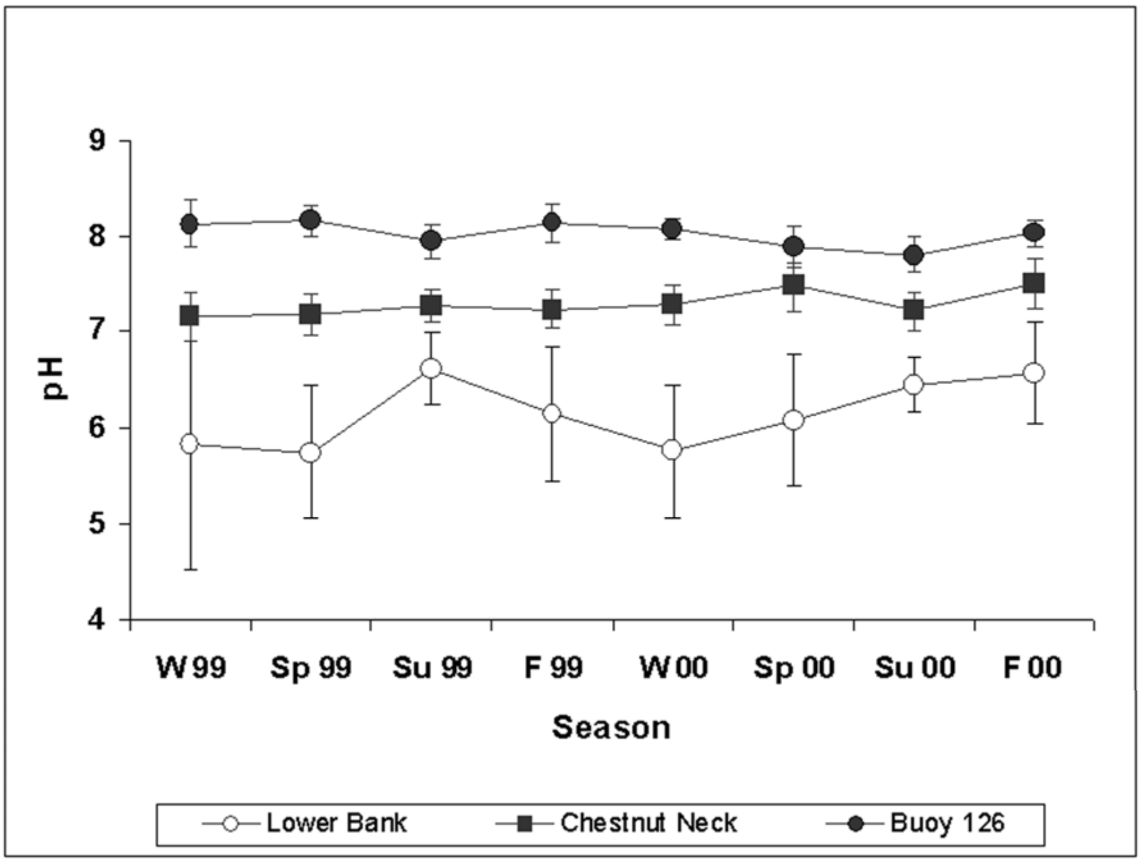


Figure 23. Mean seasonal pH and standard deviation values at three System-wide Monitoring Program sites in the Jacques Cousteau National Estuarine Research Reserve during the 1999 and 2000 monitoring period. From Kennish, M. J. (Ed.). 2003. *Estuarine Research, Monitoring, and Resource Protection*. CRC Press, Boca Raton, Florida.

In 1999, the mean values of pH recorded at the three SWMP sites were as follows: Lower Bank, 6.14; Chestnut Neck, 7.20; and Buoy 126, 8.10. In 2000, the mean values of pH registered at the three SWMP sites were as follows: Lower Bank, 6.24; Chestnut Neck, 7.37; and Buoy 126, 7.95. The mean pH values were significantly different ($P < 0.05$) among the three SWMP sites for both years of the study. Using standard statistical tests, the mean pH levels at Buoy 126 were found to be significantly greater ($P < 0.05$) than those at Lower Bank and Chestnut Neck for 1999 and 2000. At Chestnut Neck, the mean pH levels were also significantly greater ($P < 0.05$) than those at Lower Bank for both years.

The mean pH measurements at Lower Bank were not significantly different ($P > 0.05$) between years (1999 and 2000). However, the mean pH measurements were significantly different ($P < 0.05$) between years at both Buoy 126 and Chestnut Neck.

Turbidity

Mean turbidity levels at the SWMP sites were less than 35 NTU during the 1999 and 2000 study period. The highest annual mean turbidity values of 25.04 NTU and 24.27 NTU were documented at Lower Bank in 1999 and 2000, respectively (Figure 24). The mean turbidity measurements at the three sites typically ranged from 6-32 NTU. The mean turbidity levels were significantly different (P <

0.05) among the three SWMP sites for both 1999 and 2000. Standard statistical tests applied to these data indicate that the mean turbidity values at Lower Bank were significantly greater ($P < 0.05$) than those at Buoy 126 and Chestnut Neck for both 1999 and 2000. Similarly, the mean turbidity values at Buoy 126 were significantly greater ($P < 0.05$) than those at Chestnut Neck for both years. In addition, the mean turbidity levels were significantly different ($P < 0.05$) between years (1999 and 2000) at each of the SWMP sites.

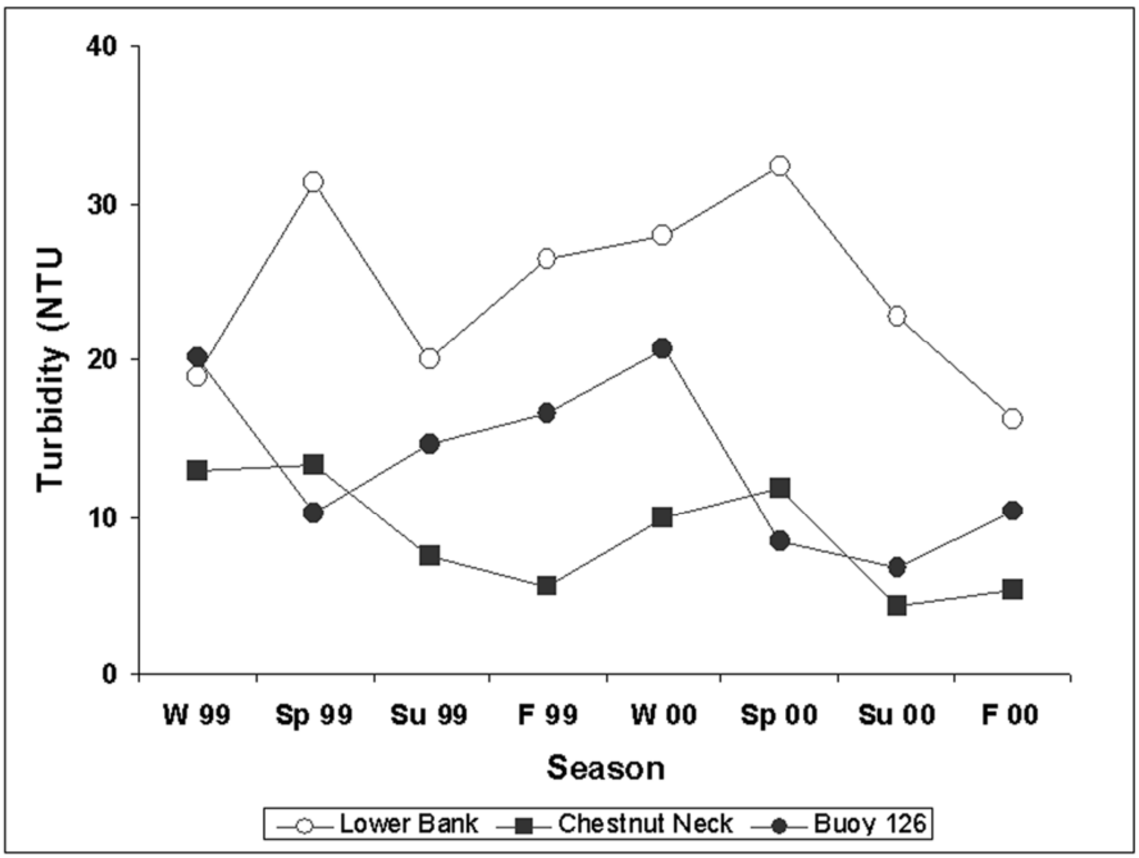


Figure 24. Mean seasonal turbidity values at three System-wide Monitoring Program sites in the Jacques Cousteau National Estuarine Research Reserve during the 1999 and 2000 monitoring period. From Kennish, M. J. (Ed.). 2003. *Estuarine Research, Monitoring, and Resource Protection*. CRC Press, Boca Raton, Florida.

Depth

Figure 25 shows water depths recorded at the three SWMP sites during 1999 and 2000. Water depths were greatest at Buoy 126, with mean values of 2.83 m and 3.05 m in 1999 and 2000, respectively. Water depths were more than 1 m shallower at Chestnut Neck and Lower Bank. At Buoy 126, mean depths were significantly greater ($P < 0.05$) than those at Chestnut Neck and Lower Bank for both years. At Lower Bank, the water depth was significantly greater ($P < 0.05$) than that at Chestnut Neck in 1999, but there was no significant difference ($P > 0.05$) in the mean water depths at both sites in 2000.

The mean depth at Chestnut Neck and Lower Bank was not significantly different ($P > 0.05$) between years (1999 and 2000). However, it was significantly different ($P < 0.05$) between years at Buoy 126.

Water Quality Discussion

Appendix 11 and Appendix 12 summarize results of ANOVAs for environmental parameters monitored at the three JCNERR SWMP sites. ANOVAs were run by year, 1999 (Appendix 11) and 2000 (Appendix 12), using data derived from semi-continuous recordings of 6-series data loggers. Data gaps in the database are mainly due to malfunctioning instruments (e.g., probe failure) and adverse weather conditions (e.g., icing problems). The most statistically significant differences are those related to salinity and pH.

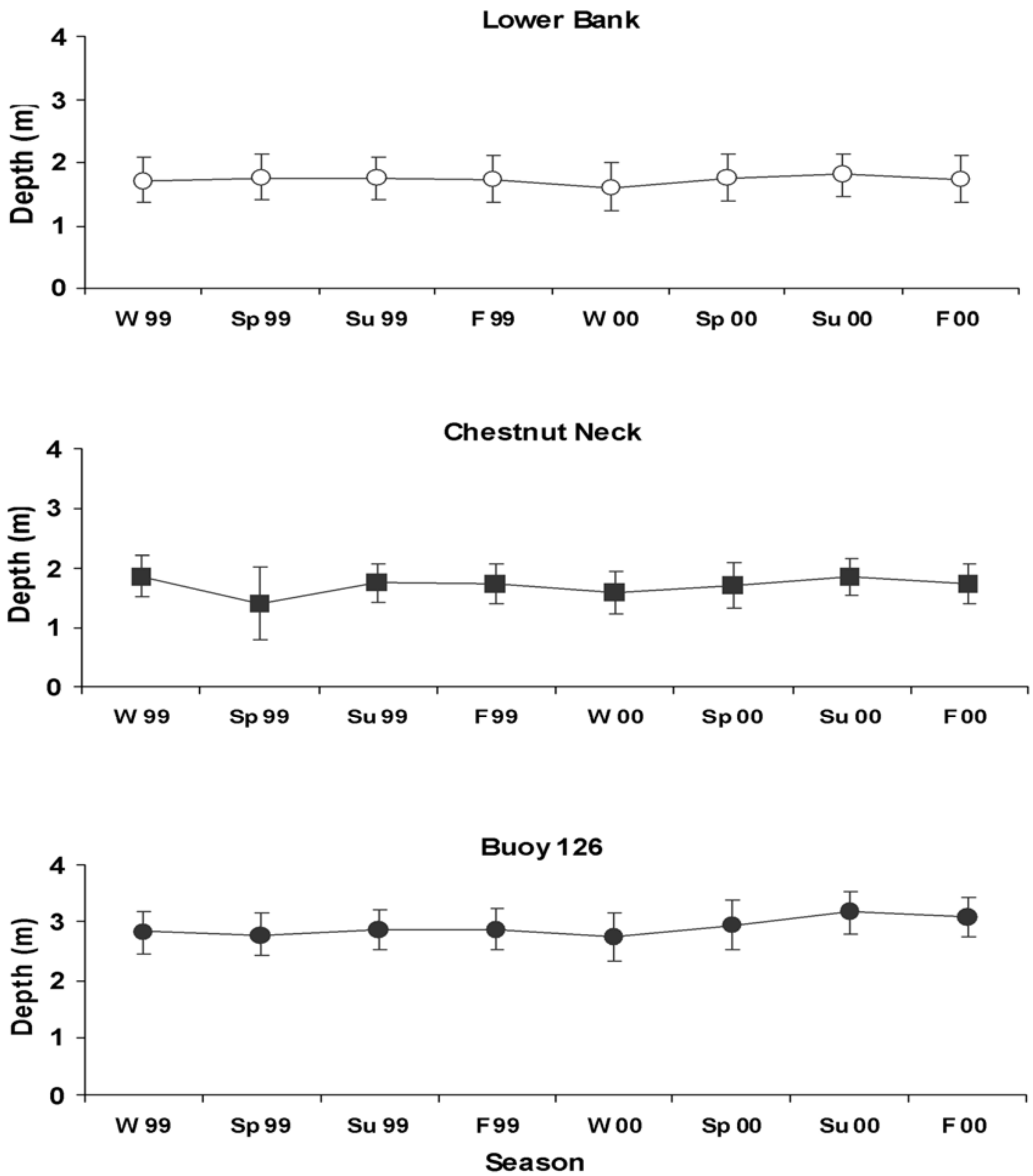


Figure 25. Mean seasonal depth and standard deviation values at three System-wide Monitoring Program sites in the Jacques Cousteau National Estuarine Research Reserve during the 1999 and 2000 monitoring period. From Kennish, M. J. (Ed.). 2003. *Estuarine Research, Monitoring, and Resource Protection*. CRC Press, Boca Raton, Florda.

Temperature

Because of the shallow depths in Great Bay, water temperatures closely follow air temperatures. Lowest water temperatures (< 0°C) typically occur in late January and February, and highest temperatures (> 25°C) in July and August. Seasonal temperatures are similar in the bay and river as is evident from data logger recordings at Buoy 126, Chestnut Neck, and Lower Bank. Freezing of the river and bay has been occasionally reported in late December, January, and February. During cold winters, the entire bay has been frozen.

From February to mid-June, water temperature generally increases linearly from ~1°C to ~20°C. Similarly, water temperature typically decreases linearly from ~25°C in August to ~1°C in January. According to Durand and Nadeau (1972), little thermal stratification exists in most areas of the system.

Wenner (2001), employing scatter plots, documented strong fluctuations (1-2°C) in daily water temperature at Buoy 126 and Lower Bank. Even stronger temperature fluctuations (3-10°C) were delineated over bi-weekly intervals at these sites. Harmonic regression analysis ascribed 60% of the temperature variance at both sites to 12.42-hour cycles and an additional 23% of the temperature variance to 24-hour cycles.

Salinity

The SWMP sites at Lower Bank, Chestnut Neck, and Buoy 126 lie along a well-defined salinity gradient of the Mullica River-Great Bay system. Lower Bank, which marks the upper end of the estuary ~25 km upstream from the head of Great Bay, is characterized by oligohaline conditions. Limnetic waters occur immediately upstream of

Lower Bank. Mesohaline salinities predominate at Chestnut Neck. Polyhaline conditions are found at Buoy 126. Salinity differences among these three sites are statistically significant ($P < 0.05$).

Salinity from Lower Bank to Deep Point at the mouth of the Mullica River varies in response to tidal action, frequency and intensity of precipitation, evaporation, and freshwater inflow. At Buoy 126, the principal factors affecting salinity levels are proximity to Little Egg Inlet, tidal currents, and winds. SWMP sites in the JCNERR experience semidiurnal tides, and hence salinities vary in response to tidal cycles. Other factors (e.g., spring-neap tidal cycles and freshwater pulses) account for much of the salinity variation at the time scale of days to weeks. Episodic events, which can cause marked changes in salinity within a short time span, include major storms and storm surges, floods, and periodic upwelling events. Seasonal variations in salinity are primarily ascribed to seasonal changes in precipitation and freshwater discharge as well as seasonal shifts in wind direction and velocity. During the period from December 1998 to November 1999, salinity at Buoy 126, Chestnut Neck, and Lower Bank ranged from 22.20-32.35‰, 2.89-26.80‰, and 0.0-18.5‰, respectively. During the period from December 1999 to November 2000, salinity at Buoy 126, Chestnut Neck, and Lower Bank ranged from 22.50-33.30‰, 4.10-26.90‰, and 0.0-11.20‰, respectively.

Salinity fluxes associated with episodic events can be substantial, approaching the annual variation in mean salinity. Durand (1988) recorded salinities as low as 1‰ in the Deep Point area near the mouth of the Mullica River after protracted periods of heavy rainfall. However, salinities as high as 25-27‰ were also observed at this site during dry periods in the summer months. Wenner et al. (2001) showed that salinity fluctuations exceeded 10‰ at the SWMP sites during episodic events in August and December 1996, March and May 1997, and from March to December 1998. Using harmonic regression analysis, they ascribed 82% of salinity variance at the sites to 12.42-hour cycles, 10% of salinity variance to 24-hour cycles, and 8% of salinity variance to interaction between 12.42-hour and 24-hour cycles.

Freshwater enters the Mullica River via surface runoff and groundwater influx from the Mullica River Basin, as well as from direct precipitation on the water surface. A positive correlation exists between periods of high river flow and reduced salinity levels at Lower Bank and Chestnut Neck sites. High river discharges also reduce salinities in upper Great Bay and along the southern perimeter. Salinity at Buoy 126 usually exceeds 25‰ because ocean water enters at Little Egg Inlet and flows along the northern part of the bay, directly affecting conditions at this monitoring site. While the predominant flow during flood tide is in the northern part of the bay, accounting for higher salinities in this area, the predominant flow during ebb tide is in the southern part of the bay. This current pattern creates a counterclockwise gyre in the central portion of the bay (Durand, 1988). Strong tidal currents and the shallowness of the bay produce well-mixed conditions, resulting in relatively uniform salinities in the water column.

Salinity differences between the three SWMP sites are not only statistically significant but also biologically significant. Planktonic, benthic, and nektonic communities differ considerably along the salinity gradient of the Mullica River, as well as in areas of Great Bay where salinity differences can be substantial (Durand and Nadeau, 1972; Durand, 1988). Salinity is a major factor affecting the species composition, abundance, and distribution of aquatic organisms in the system.

Dissolved Oxygen

The health of estuarine systems is closely coupled to dissolved oxygen concentrations. Oxygen depletion caused by organic loading and excessive biochemical oxygen demand can lead to hypoxia or anoxia and reduced habitat availability, greater susceptibility of organisms to disease and predation, and increased mortality (Pihl et al., 1992; Winn and Knott, 1992; Borsuk et al., 2001). The impacts of oxygen deficiency are often most conspicuous on benthic communities and habitats (Dauer et al., 1992; Diaz and Rosenberg, 1995). Aside from major shifts in the distribution and abundance of estuarine organisms attributable to severe oxygen depletion, more subtle effects may be manifested by altered behavioral, physiological, and reproductive activity of biota (Summers et al., 1997; Wenner et al., 2001). In addition to the biochemical oxygen demand, several other factors influence the severity of oxygen depletion in the bottom waters of estuaries, notably exchange of oxygen with the surface layer, vertical density stratification, and the intensity and frequency of mixing (Borsuk et al., 2001).

Oxygen deficiency is becoming a more serious problem in many estuaries due to greater loading of organic matter from nearby watersheds, as well as accelerated nutrient-driven phytoplankton and benthic algal production in embayments (Paerl et al., 1998). As a result, coastal resource programs in many states are emphasizing more intense monitoring of dissolved oxygen in estuarine and coastal marine waters. At NERRS sites nationwide, dissolved oxygen is the target of year-round monitoring efforts.

Oxygen deficiency was never a problem at the JCNERR during the monitoring period from August 1996 to December 2000, a condition that has continued through

December 2008. This is attributed primarily to the relatively strong currents, well-mixed condition, and general lack of thermal stratification of river and bay waters in the system. The mean dissolved oxygen values typically ranged from 85-105% saturation during the study period. A distinct seasonal cycle was apparent, with the highest mean % saturation (100-125%) occurring in winter and the lowest mean % saturation (75-100%) taking place in summer. Supersaturation was observed periodically during all seasons of the year.

Absolute values of dissolved oxygen (mg/l) were relatively high in the JCNERR, with annual mean dissolved oxygen levels exceeding 8.5 mg/l at the three SWMP sites. Highest dissolved oxygen values (mean > 11.0 mg/l) were registered during the winter, and lowest dissolved oxygen values (mean = 6.0-7.0 mg/l) during the summer.

Various factors affect the dissolved oxygen content of riverine and estuarine waters. Included here are temperature, organic carbon loading, salinity, turbulence, and atmospheric pressure. In the JCNERR, higher temperatures and greater loading of organic matter during summer depress dissolved oxygen levels due to accelerated microbial respiration associated with organic degradation processes. Lower temperatures and diminished loading of organic matter result in significantly higher dissolved oxygen levels in winter because chemical and biological oxygen consumption coupled to the decomposition of organic matter declines appreciably.

Although hypoxia has not been observed in the JCNERR, episodes of supersaturation may be a cause of concern. The formation of reactive oxygen species during supersaturation events may have a toxic effect on biota of the system (Dalton, 1995). However, supersaturation events in the reserve are characteristically ephemeral, and therefore their biotic effects are likely to be small.

Analysis of SWMP data from the JCNERR indicates that this reserve has not experienced the dissolved oxygen problems of many other estuarine systems in the U.S. Dissolved oxygen concentrations in the reserve, which are consistently above 6.0 mg/l, reflect the generally high water quality conditions in the system. However, monitoring must continue in order to assess seasonal variations of dissolved oxygen, which may be considerable.

pH

When proceeding along a salinity gradient from upriver areas to the open waters of Great Bay, pH progressively increases. The pH not only varies with salinity but also with dissolved oxygen concentrations. In addition, large amounts of tannins and humic acids in the Mullica River depress pH levels. Hence, the mean pH levels at Lower Bank and Chestnut Neck for the 1999-2000 period were significantly less ($p < 0.05$) than the mean pH values at Buoy 126 for the same time period. No significant seasonal trends in pH values were evident at the SWMP sites.

Zampella and Laidig (1997) and Dow and Zampella (2000) showed that there is an association between increases in pH and nutrient enrichment and watershed disturbance in the Pinelands due to agricultural land use, residential development, and wastewater flow. More specifically, pH is positively correlated with concentrations of NO_3^-, NH_4^+, total P, Ca^{2+}, and Mg^{2+}, and all of these variables parallel a Pinelands watershed disturbance gradient. Dow and Zampella (2000) proposed that pH is a potential indicator of Pinelands watershed disturbance and subsequent ecological effects that follow disturbance. Such effects may be manifested as major changes in the species composition, abundance, and distribution of organisms in the Mullica River.

Turbidity

Durand and Nadeau (1972) reported considerably greater water transparency in Great Bay than in the Mullica River. They also observed the highest degree of transparency in the bay during the summer and early fall. Areas upriver exhibited maximum transparency in the winter and minimum transparency in the summer. Reduced input of tannins, humic compounds, and particulate matter from the Pinelands in the winter causes greater transparency in the Mullica River during the colder months of the year.

Results of seasonal turbidity measurements by the JCNERR corroborate, in part, the findings of Durand and Nadeau (1972). For example, the highest annual mean turbidity among the SWMP sites in 1999 (25.04 NTU) and 2000 (24.27 NTU) occurred at Lower Bank. Chestnut Neck had the lowest annual mean turbidity in 1999 (9.69 NTU) and 2000 (7.85 NTU). Durand and Nadeau (1972) noted more turbid waters in the bay during winter apparently due to increased sediment loading, a condition supported by SWMP data of the reserve, which show highest mean turbidity levels at Buoy 126 during the winter of 1999 (20.09 NTU) and 2000 (20.64 NTU). The lowest seasonal mean turbidity (6.69 NTU) at Buoy 126 was reported in the summer of 2000. At Lower Bank, in turn, the lowest seasonal mean turbidity measurements were registered during the winter of 1999 (18.85 NTU) and fall of 2000 (16.13 NTU). The highest seasonal mean turbidity values at Lower Bank in both 1999 (31.30 NTU) and 2000 (32.39 NTU) were found in the spring. At Chestnut Neck, the seasonal mean turbidity was highest for both the spring of 1999 (13.25 NTU) and 2000 (11.77 NTU). The lowest seasonal mean turbidity at this site was documented in the fall of 1999 (5.54 NTU) and the summer of 2000 (4.28 NTU).

As is evident from the water quality database of the JCNERR, turbidity values vary seasonally and from year to year. Highest turbidity occurs in the Mullica River at Lower Bank based on the 1999 and 2000 database. Although the turbidity is seasonally variable, some trends are evident. Higher turbidity levels generally occur in the bay during winter and in the bay tributaries during summer. However, episodic events such as hurricanes, other major storms, and upwelling events can produce unusually high turbidity levels of relatively short duration, which can leave significant spikes in the database during any season.

Spatial variation in turbidity levels can also be substantial in the bay. Turbid waters discharging from the mouth of the Mullica River, for example, concentrate along the southern part of the bay. Clearer ocean water, in turn, can often be traced along the northeast perimeter. This spatial distribution of turbidity is a consequence of the cyclonic circulation pattern in the bay.

Depth

Tidal action accounted for much of the variation in depth at the SWMP sites. For example, Wenner et al. (2001) attributed 86% of the depth variance at Buoy 126 between August 1996 and November 1998 to 12.42-hour cycles. Only 7% of the depth variance at this location during the same period was ascribed to both 24-hour cycles and interaction between 12.42-hour and 24-hour cycles. Similar numbers were obtained at Lower Bank. Here 85% of depth variance between August 1996 and November 1998 was ascribed to 12.42-hour cycles. Only 6% of depth variance at this location was attributed to 24-hour cycles, and 9% of depth variance was ascribed to interaction between 12.42-hour and 24-hour cycles. According to Wenner et al. (2001), therefore, depth is an important factor for evaluating and interpreting temporal variability in parameters associated with tides.

Meteorological Monitoring

As part of the System-wide Monitoring Program, the JCNERR has a weather station located on Nacote Creek that collects data on air temperature, wind speed and direction, relative humidity, barometric pressure, rainfall and photosynthetically active radiation (PAR). Weather conditions can have a strong influence on water quality. For example, rainfall influences salinity in estuaries and can increase runoff of sediment and organic material that in turn may influence other parameters such as dissolved oxygen, turbidity, pH, and temperature.

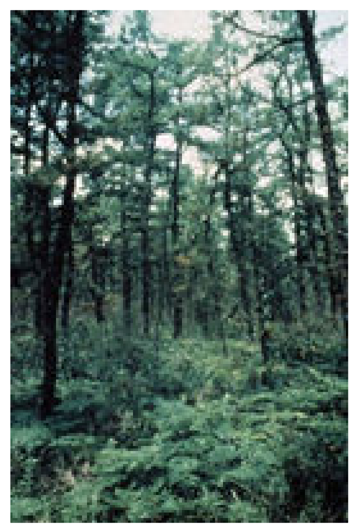
HABITATS

Watershed

Overview

The JCNERR contains a wide range of terrestrial and aquatic habitats. These include upland pine-oak forests, lowland Atlantic white cedar swamps, freshwater marshes, salt and freshwater tidal marshes, barrier islands (including sandy beaches and dune habitats), shallow bays, and the coastal ocean.

Upland forest areas in the JCNERR support two major vegetation types, namely pine-oak forest and oak-pine forests. The dominant tree is the pitch pine (*Pinus rigida*). In no other region in North America does the pitch pine cover such an extensive area. Other abundant species include short-leaf pine and oaks of several species: scrub, blackjack, black, red, white, and chestnut. The most common oak species north of the Mullica River is the black oak; in the south, the scarlet oak becomes prominent. The understory of these forests is a variety of shrubs, mostly of the oak and heath family, such as lowbush blueberry and black huckleberry. Typical ground cover includes lichens, mosses, bracken fern and members of the heath family (bearberry and teaberry).



Lowland forest areas of the JCNERR are composed of Atlantic white cedar, red maple, pitch pine, black gum, gray birch, sassafras, and sweetbay magnolia. Pitch pine lowlands are characterized by a dense canopy of pitch pine, often occurring in depressions and as narrow bands along stream and swamp banks. Secondary trees typically include red maple, blackgum and sweet bay magnolia.

Lowland forest understory growth tends to be more varied than upland growth, with sheep laurel, stagger-bush, dangleberry, black huckleberry, and sweet pepperbush as prominent shrubs. Sheep laurel is especially abundant in these areas, while leather-leaf occupies the margins of standing water. Ground cover layers are also quite diverse and well developed, with bracken ferns, teaberry, and moss lichen vegetation. Cedar swamps and sphagnum bogs are scattered throughout the pine lowlands, with the dominant tree being the Atlantic white cedar.

Salt marshes occur near the coast and along the lower Mullica River, consisting primarily of salt meadow grass (*Spartina patens*) and saltwater cordgrass (*Spartina alterniflora*), as well as spike grass (*Distichlis spicata*). High marsh areas that are flooded less regularly are characterized by salt meadow grass, spike grass, and black grass (*Juncus gerardii*). Species characteristic of salt pannes area include Bigelow's glasswort (*Salicornia bigelovii*), common glasswort (*S. europea*), and perennial glasswort (*S. virginica*), as well as marsh spearscale (*Atriplex patula*) and annual salt marsh fleabane (*Pluchea purpurascenes*).

Vegetation of the barrier islands include dune grass (*Ammophila*), which anchors the sand in the foredunes, and a mix of bayberry, heather and marsh elder dominating the back dune. The few freshwater pockets around the islands, are occupied by typical grasses, sedges, and flowering plants.

Upland Forests

A complex mosaic of contiguous forest and wetland vegetation occurs in the Pinelands, with discrete patches or corridors of cedar and hardwood swamps growing amidst a background matrix of upland pine and oak forests (Forman, 1998). In the uplands, a continuous gradient of forested vegetation is evident in some areas, from pure pitch pine (*Pinus rigida*) stands on one end grading into pure oak trees (*Quercus* spp.) at the other end (McCormick, 1998). Pitch pine (*P. rigida*) dominates in pine-oak forests, with various oak trees (i.e., scarlet oak, *Quercus coccinea*; white oak, *Q. alba*; black oak, *Q. velutina*; and chestnut oak, *Q. prinus*) playing a subsidiary role. In contrast, oak trees dominate in oak-pine forests and can account for more than 75% cover. Scrub oak (*Q. ilicifolia*), blueberries (*Vaccinium* spp.), huckleberry (*Gaylussacia* spp.), mountain laurel (*Kalmia latifolia*), inkberry (*Ilex glabra*), sweet fern (*Comptonia peregrina*) and other heath plants generally dominate the understory vegetation in these forests. Progressing toward lowland habitats, the upland forests gradually grade into pitch pine lowland forests.

The Wharton State Forest, Penn State Forest, Bass River State Forest, and Clarks Landing provide excellent examples of upland and lowland forests in the system. Pine-oak (*Pinus-Quercus*) trees form the predominant upland forest canopy, while Atlantic white cedar (*Chamaecyparis thyoides*) and various swamp hardwoods (e.g., *Acer, Magnolia, Nyssa*) colonize water courses and other poorly drained areas (McCormick, 1998; Tedrow, 1998). Pitch pine (*Pinus rigida*) colonizes ~50-80% of the uplands, and shortleaf pine (*P. echinata*) is also relatively abundant. Several species of oak trees are present, notably black oak (*Quercus velutina*), blackjack oak (*Q. marilandica*), southern red oak (*Q. falcata*), chestnut oak (Q. prinus), post oak (*Q. stellata*), scrub oak (*Q. ilicifolia*), white oak (*Q. alba*), and scarlet oak (*Q. coccinea*). Among these species, black oak is most common north of the Mullica River, and southern red oak, most common to the south (McCormick, 1998).

In pine-oak forests, pitch pine covers 30% or more of the ground, contributes 50% or more of the tree stems 2.5 cm or more in diameter, and constitutes 50% or more of the basal area. In contrast, larger treeform oaks dominate in oak-pine forests, covering 40% or more of the ground, contributing 50% or more of the stems, and comprising 35% or more of the basal area. Although broadleaf trees predominate in oak-pine forests, pitch pine is found in nearly all stands (McCormick, 1998). Oak-pine, chestnut oak, and scarlet oak-shortleaf pine are the principal constituents of the upland canopy layer of the oak-pine forests. Pine-blackjack oak, pine-post oak, and pine-black oak represent the primary components of the upland canopy of pine-oak forests. Two shrub types also occur among these two broad groupings of upland canopy: (1) heath-type dominated by lowbush blueberry (*Vaccinium vacillans*) and black huckleberry (*Gaylussacia baccata*); and (2) scrub-oak type. The heath-type understory, with plants growing about 30-60 cm high, forms nearly continuous cover throughout the uplands (McCormick, 1998). The scrub oak is ~1-5 m tall. Lichens, mosses, ferns, wintergreen (*Gaultheria procumbens*), and bearberry (*Arctostaphylos uva-ursi*) provide considerable ground cover in some upland forest areas. Cowwheat (*Melampyrum lineare*), goatsrue (*Tephrosia virginiana*), and several other herbs occur sporadically (McCormick, 1998).

Frequent fires and repeated cutting have played a significant role in determining the composition and physical structure of upland vegetation. Fires have occurred at a periodicity of ~10-30 years, and cutting was common during the first half of the 20th century. Pitch pine is more tolerant of fire than are oaks, and areas experiencing reduced fire frequency shift to oak-dominated habitats. However, both types of trees can resprout from dormant buds lying beneath the soil surface subsequent to fires. This enables the trees to recover; however, the rate of recovery varies among species. Species differences in resistance to fire damage, in shade tolerance, and in reproductive strategies are responsible for the selective action of fire observed on various types of plant species in the Pinelands.

Areas of the Pine Barrens subjected to frequent fires are dominated by low growing, dwarf pitch or pygmy pine (*Pinus rigida*) < 3 m high, and scrub oaks (*Quercus marilandica* and *Q. ilicifolia*). Species dominating the shrub and herb layers include mountain laurel (*Kalmia latifolia*), sheep laurel (*K. angustifolia*), sweet fern (*Comptonia* *peregrina*), and sand myrtle (*Leiophyllum buxifolium*), with ground covers comprised largely of bearberry (*Arctostaphylos uva-ursi*), broom crowberry (*Corema conradii*), trailing arbutus (*Epigaea repens*), and wintergreen (*Gaultheria procumbens*). There are three areas of pygmy pine in the Pine Barrens, which collectively cover ~4,950 ha (Good et al., 1998). These dwarf pitch pine communities are the most extensive in the world (U.S. Fish and Wildlife Service, 1996).

Lowland Vegetation

McCormick (1998) provided a detailed description of lowland vegetation in the Pinelands region. Ground water levels in lowland forests are near the surface, resulting in soil saturation for prolonged periods, which influences the vegetation patterns year-round. Wetland forests in the Pine Barrens consist primarily of Atlantic white cedar (*Chamaecyparis thyoides*), black gum (*Nyssa sylvatica*), and trident red maple (*Acer rubrum*). Pitch pine (*Pinus rigida*), gray birch (*Betula populifolia*), sweetbay magnolia (*Magnolia virginiana*), and sassafras (*Sassafras albidum*) are also present in many stands. In addition, basket oak (*Quercus michauxii*), fin oak (*Q. palustris*), willow oak (*Q. phellos*), water oak (*Q. nigra*), and sweet gum (*Liquidambar styraciflua*) grow on the periphery.

Six types of plant communities occur in the lowlands, forming swamp forests or relatively small freshwater marshes. These include: (1) Atlantic white cedar swamp forests; (2) broadleaf swamp forests; (3) herbaceous wetland communities; (4) shrubby wetland communities; (5) pitch pine lowland forests; and (6) pine transition forests (McCormick, 1998). Of these communities, Atlantic white cedar swamp forests and broadleaf swamp forests are most extensive. The Atlantic white cedar constitutes the principal canopy in the cedar swamp forests, along with sweetbay magnolia (*Magnolia virginiana*), black gum (*Nyssa sylvatica*), and trident red maple (*Acer rubrum*). Dangleberry (*Gaylussacia frondosa*), bayberry (*Myrica pensylvanica*), fetterbush (*Leucothoe racemosa*), swamp azalea (*Rhododendron viscosum*), sweet pepperbush (*Clethra alnifolia*), and several other shrubs form the understory. Among herbaceous ground cover are *Sphagnum* mosses, curly grass ferns (*Schizaea pusilla*), pitcherplants (*Sarracenia purpurea*), sundew (*Drosera* spp.), partridgeberry (*Mitchella repens*), and swamp pink (*Helonias bullata*).

Trident red maple (*Acer rubrum*) serves as the principal canopy in broadleaf forests. Pitch pine (*Pinus rigida*) and Atlantic white cedar (*Chamaecyparis thyoides*) are locally important components of the canopy. Secondary trees include black gum (*Nyssa sylvatica*), gray birch (*Betula populifolia*), sweetbay magnolia (*Magnolia virginiana*), and sassafras (*Sassafras albidum*). The shrub layer consists of black huckleberry (*Gaylussacia baccata*), dangleberry (*Gaylussacia frondosa*), fetterbush (*Leucothoe racemosa*), sheep laurel (*Kalmia angustifolia*), leatherleaf (*Chamaedaphne calyculata*), and swamp azalea (*Rhododendron viscosum*). Mosses and lichens provide the primary ground cover.

Pitch pine (*Pinus rigida*) is the dominant species in pitch pine lowland forests, comprising 90% of the canopy. Black gum (*Nyssa sylvatica*), trident red maple (*Acer rubrum*), and gray birch

(*Betula populifolia*) are of secondary importance. The undergrowth consists of more than 20 species of shrubs and woody vines; dangleberry (*Gaylussacia frondosa*), black huckleberry (*Gaylussacia baccata*), leatherleaf (*Chamaedaphne calyculata*), and sheep laurel (*Kalmia angustifolia*) are the predominant species. Wintergreen (*Gaultheria procumbens*), bracken fern (*Pteridium aquilinum*), turkeybeard (*Xerophyllum asphodeloides*), and *Sphagnum* mosses grow as ground cover over nearly 30% of the forest floor.

Pine transition communities are found between the broadleaf swamp forests or Atlantic white cedar swamp forests and upland forests. In these transition forests, pitch pine (*Pinus rigida*) is the dominant species of the canopy above an understory of smaller black gum (*Nyssa sylvatica*), trident red maple (*Acer rubrum*), and gray birch (*Betula populifolia*). Dominant species of the well-developed shrub layer include dangleberry (*Gaylussacia frondosa*) and sheep laurel (*Kalmia angustifolia*), with winterberry (*Ilex verticillata*), grouseberry (*Gaylussacia dumosa*), black huckleberry (*Gaylussacia baccata*), and bayberry (*Myrica pensylvanica*) also occupying this layer. Among the herbs and shrubs are bracken fern (*Pteridium aquilinum*), cinnamon fern (*Osmunda cinnamomea*), turkeybeard (*Xerophyllum asphodeloides*), wintergreen (*Gaultheria procumbens*), and *Sphagnum* mosses. The herbs and shrubs cover only ~2% of the ground in the pine transition forests.

Herbaceous wetland communities proliferate along the margins of ponds and streams in the Pine Barrens. As noted by McCormick (1998), white water lilies (*Nymphaea odorata*), bullhead lilies (*Nuphar variegatum*), spatterdocks (*Nuphar advena*), bladderworts (*Utricularia spp.*), and other submerged or floating leaf plants occur near pond margins and in stream coves. Sedges (*Carex* spp,), rushes (*Juncus* spp.), pipeworts (*Eriocaulon* spp.), chain ferns (*Woodwardia* spp.), other emergent plants, and *Sphagnum* mosses inhabit areas along the shore.

Zampella and Laidig (1997) and Zampella et al. (2001) reported on stream vegetation surveys conducted in the Mullica River Basin for the Pinelands Commission. They recorded a total of 305 vascular plants at 72 stream sites, including 232 herbaceous species and 73 woody species (Appendix 14). Twenty-nine species were deemed to be disturbance-indicator species in this basin (Table 7).

In flood plains of Pine Barrens streams, grass- and sedge-dominated wet meadow communites (savannas) commonly proliferate. Among the dominant vegetation in these communities are coast sedge (*Carex exilis*), button sedge (*Carex bullata*), golden crest (*Lophiola aurea*), Torrey's dropseed (*Muhlenbergia torreyana*), and lowland broomsedge (*Andropogon virginicus* var. *abbreviatus*). Savannas in the Pine Barrens cover a total area less than 400 ha. Through succession, they are replaced by shrub and forest swamps.

Table 7. Disturbance-indicator plant species.

Asclepias incarnata	swamp milkweed
Bidens connata	purple-stemmed beggar ticks
Bidens frondosa	beggar ticks
Boehmeria cylindrica	false nettle
Callitriche heterophylla	large water starwort
Carex lurida	sallow sedge
Cinna arundinacea	wood-reed
Cyperus strigosus	straw-colored cyperus
Dioscorea villosa	common wild yam
Echinochloa muricata	American barnyard grass
Erechtites hieracifolia	pilewort
Eupatorium dubium	eastern joe-pye weed
Galium tinctorium	stiff marsh bedstraw
Impatiens capensis	spotted touch-me-not
Lindernia dubia	short-stalked false pimpernel
Lobelia cardinalis	cardinal flower
Ludwigia palustris	water purslane
Microstegium vimineum	eulalia or japanese stiltgrass
Mikania scandens	climbing hempweed
Panicum clandestinum	deertongue grass
Polygonum arifolium	halberd-leaved tearthumb
Polygonum hydropiperoides	mild water pepper
Polygonum punctatum	dotted smartweed
Polygonum sagittatum	arrow-leaved tearthumb
Potamogeton epihydrus	Nuttall's pondweed
Potamogeton pusillus	small pondweed
Sambucus canadensis	common elder or elderberry
Thelypteris palustris	marsh fern
Typha latifolia	broad-leaved cattail

From Zampella, R. A., J. F. Bunnell, K. J. Laidig, and C. L. Dow. 2001. The Mullica River Basin. Technical Report, New Jersey Pinelands Commission, New Lisbon, New Jersey.

Vernal ponds (coastal plain intermittant ponds) are characterized by seasonally saturated soils and markedly fluctuating water levels. In addition to sedges *(Carex* spp., *Cladium mariscoides, Eleocharis microcarpa,* and *Scleria reticularis*), panic and muhly grasses (*Panicum capillare*, *P. mattamuskeettense*, *P. verrucosum*, and *Muhlenbergia torreyana*) commonly dominate vernal pond plant communities, although rare herbaceous species typically occur here as well. Some of the other plant species identified at vernal ponds in the Pinelands are the knotted spikerush (*Eleocharis equisetoides*), Pine Barrens boneset (*Eupatorium resinosum*), dwarf white bladderwort (*Utricularia olivacea*), awned meadow beauty (*Rhexia aristosa*), Long's bulrush (*Scirpus longii*), drowned beaked-rush (*Rhynchospora inundata*), Boykin's lobelia (*Lobelia boykinii*), Wright's panic grass (*Panicum wrightianum*), slender water-milfoil (*Myriophyllum tenellum*), rose tickseed (*Coreopsis rosea*), short-beaked bald-rush (*Rhynchospora nitens*), and floating heart (*Nymphoides cordata*). St. James Pond, Bill Henry Pond, Odd Pond, Chatsworth Goose Pond, and Woodbine Pond are examples of vernal ponds in the Pinelands (U.S. Fish and Wildlife Service, 1996).

Shrubby wetland communities have also been delineated in the channels of intermittent streams and along pond margins. Highbush blueberry (*Vaccinium corymbosum*) and leatherleaf (*Chamaedaphne calyculata*) are common, and staggerbush (*Lyonia mariana*) and sheep laurel (*Kalmia angustifolia*) also grow here. *Sphagnum* mosses provide extensive ground cover.

Sphagnum and cranberry bogs, as well as cedar swamps, are irregularly distributed throughout the pine lowlands. The Atlantic white cedar (*Chamaecyparis thyoides*) is the dominant tree in these areas, typically growing in dense stands along stream banks and locally within the broader lowlands. The *Sphagnum* mats are inhabited by various shade- and acid-tolerant herbaceous plants, including swamp azalea (*Rhododendron viscosum*), fetterbush (*Leucothoe racemosa*), dangleberry (*Gaylussacia frondosa*), and highbush blueberry (*Vaccinium corymbosum*). The herbaceous plants are best established in openings of the forest cover. Mosses (*Sphagnum* spp.) form the principal ground cover along with pitcher plants (*Sarracenia purpurea*), sundews (*Drosera* spp.), and bladderworts (*Ultricularia* spp.).

Ponds, lakes, bogs, and streams serve as habitat for many species of algae, both benthic and planktonic forms (Appendix 15). The acidic waters of the Pine Barrens strongly influence the composition of the algal flora. Moul and Buell (1998) identified more than 350 algal taxa in the Pine Barrens, with green algae (Chlorophyta), yellow-green algae (Chlorophyta), and euglenoids (Euglenophyta) being well represented. Diatoms are particularly abundant.

In summary, several wetland complexes occur in lowland areas of the Pine Barrens, notably Atlantic white cedar swamps, hardwood swamps, pitch pine lowland forests, and Pine Barrens savannas. Bass River, Oswego River, Batsto River, and the West Branch of the Wading River exhibit well-developed wetland complexes. Rare plants found in these complexes are the Pine Barrens boneset (*Eupatorium resinosum*), Pine Barrens gentian (*Gentiana autumnalis*), Pine Barrens reedgrass (*Calamovilfa brevipilis*), Pine Barrens smoke grass (*Muhlenbergia capillaris*), Barratt's sedge (*Carex barrattii*), Pickering's reedgrass (*Calamagrostis pickeringii*), Pickering's morning-glory (*Stylisma pickeringii* var. *pickeringii*), New Jersey *rush (Juncus caesariensis*), bog asphodel (*Narthecium americanum*), false asphodel (*Tofieldia racemosa*), sandplain fax (*Linum intercussum*), sand yellow-eyed grass (*Xyris caroliniana*), sheathed panic grass (*Panicum scabriusculum*), Canby's lobelia (*Lobelia canbyi*), yellow fringeless orchid (*Platanthera integra*), reversed bladderwort (*Utricularia resupinata*), curly grass fern (*Schizaea pusilla*), pale beaked-rush (*Rhynchospora pallida*), and Knieskern's beaked-rush (*Rhynchospora knieskernii*). Although relatively few species dominate forest wetlands in lowland areas of the Pine Barrens (e.g., Atlantic white cedar, black gum, pitch pine, red maple, and sweetbay), the understory may consist of 20 or more shrub species (e.g., blueberries, *Vaccinium* spp.; swamp azalea, *Rhododendron viscosum*; and sweet pepperbush, *Clethra alnifolia*). The unique wetland vegetation in the Pinelands includes various rare or endangered species (e.g., swamp pink, *Halonias bullata*; and Knieskern's beaked-rush, *Rhynchospora knieskernii*). The wetland complexes support a wide diversity of animal populations.

Marshes

Freshwater and Brackish Marshes

Freshwater tidal marshes occupy zones of tidal influence in the upper reaches of the Mullica and Wading Rivers. Three distinct zones of freshwater intertidal wetland vegetation are evident based on the degree of tidal influence. The low tidal marsh, characterized by sparsely vegetated intertidal flats, is exposed only at low tide. Plant species commonly found in this zone are the grass-leaved arrowhead (*Sagittaria graminea*), stiff arrowhead (*S. rigida*), and Hudson arrowhead (*S. subulata*), Parker's pipewort (*Eriocaulon parkeri*), bluntscale bulrush (*Scirpus smithii* var. *smithii*), and riverbank quillwort (*Isoetes riparia*). In the mid-tidal zone, the following species are encountered: arrow arum (*Peltandra virginica*), dotted smartweed *(Polygonum punctatum*), pickerel-weed (*Pontederia cordata*), spatterdock (*Nuphar advena*), three-square bulrush (*Scirpus pungens*), water hemp (*Amaranthus cannabinus*), and wild rice (*Zinzania aquatica*). Cattails (*Typha angustifolia* and *T. glauca*) dominate the upper tidal zone. Other plants observed in this zone include the orange jewelweed (*Impatiens capensis*), sweet flag (*Acorus calamus*), arrowheads (*Sagittaria* spp.), rose mallow (*Hibiscus moscheutos* var. *moscheutos*), smooth bur-marigold (*Bidens laevis*), halberd-leaved tearthumb (*Polygonum arifolium*), sensitive fern (*Onoclea senibilis*), swamp rose (*Rosa palustris*), button bush (*Cepahalanthus occidentalis*), knob-styled dogwood (*Cornus amomum*), purple loosestrife (*Lythrum salicaria*), and common reed (*Phragmites australis*).

Brackish tidal marshes occur along spatially restricted stretches of the Mullica River, Wading River, Bass River, Nacote Creek, and Landing Creek. Narrow-leaved cattail (*Typha angustifolia*), big cordgrass (*Spartina cyosuroides*), Olney three-square bulrush (*Scirpus americanus*), and common reed (*Phragmites australis*) dominate these marshes. Submerged aquatic vegetation reported in brackish tidal reaches typically consist of slender pondweed (*Potamogeton pusillus*), redhead grass (*P. perfoliatus*), horned pondweed (*Zanniuchellia palustris*), water celery (*Vallisneria americana*), naiad

(*Najas flexilis*), and widgeon grass (*Ruppia maritima*). Common submerged aquatic vegetation in freshwater tidal reaches are arrowheads (*Sagittaria latifolia, S. engelmanniana*, and *S. spatulata*), bulrush (*Scirpus* spp.), American mannagrass (*Glyceria grandis*), and Nuttall's pondweed *(Potamogeton epihydrus*).

Salt Marshes

Extensive salt marshes border Little Egg Harbor and Great Bay. Salt marshes also extend up the Mullica River to Lower Bank, and they occur along the perimeter of the lower Wading River. These salt marshes are characteristic of those in the northeastern U.S., being dominated by *Spartina alterniflora* (short form) and *Spartina patens* (salt-meadow cordgrass) (Rountree and Able, 1992). Salt marsh vegetation covers nearly 9,000 ha of wetland habitat in the Mullica River-Great Bay Estuary. Most salt marshes surrounding Great Bay occur in the Brigantine portion of the Forsythe National Wildlife Refuge and the Great Bay Boulevard Wildlife Management Area. In the Little Egg Harbor area, most of the salt marsh habitat occurs in the Barnegat portion of the Forsythe National Wildlife Refuge, the Holgate Unit of the Forsythe National Wildlife Refuge (located at the southern extremity of Long Beach Island), and the northern perimeter of the Great Bay Boulevard Wildlife Management Area. A series of bay islands in the southern portion of Little Egg Harbor also harbors considerable salt marsh habitat. Among these sites are West Sedge Island, East Sedge Island, Middle Sedge Island, Barrell Island, Bunting Sedge Island, Blake Whale Island, Goosebar Sedge Island, Johnny Sedge Island, Middle Island, Hither Island, Hester Sedge Island, Drag Sedge Island, Story Island, Goodluck Sedge Island, and Parker Island. A similar, albeit smaller, complex of salt marsh islands exists along the northeastern part of Great Bay in close proximity to RUMFS.

Smooth cordgrass (*Spartina alterniflora*) dominates low marsh areas inundated daily by the tide. The tall-form dominates along tidal creeks, and the short-form predominates in other low marsh areas (Smith and Able, 1994). Salt-meadow cordgrass (*Spartina patens*), spike grass (*Distichlis spicata*), and black grass (*Juncus gerardii*) predominate in high marsh areas flooded less regularly. Typical species encountered in salt pannes are saltwort grass (*Salicornia bigelovii*), perennial glasswort (*S. virginica*), samphir (*S. europea*), orach (*Atriplex patula*), and marsh fleabane (*Pluchea purpurascens*). Characteristic species along the marsh-upland border include *S. patens*, annual salt marsh pink (*Sabatia stellaris*), seaside goldenrod (*Solidago sempervirens*), marsh elder (*Iva frutescens*), and the common reed (*Phragmites australis*). The common reed is an invasive species which has totally replaced *S. alterniflora* and other species on the marsh surface in some areas (Able and Hagen, 2000). The effect of this invasion on natural marsh systems is a cause of concern and the subject of considerable controversy (Weinstein and Kreeger, 2000).

Barrier Islands

As noted above, Long Beach Island is heavily developed except for the Holgate Unit of the Forsythe National Wildlife Refuge, which is designated as a wilderness area. The North Brigantine State Natural Area is also protected, with the undeveloped land consisting of relatively remote and undisturbed habitat. Along the developed portions of the barrier island complex, the dune scrub/shrub and woodland communities fronting the estuary have been largely destroyed or substantially altered. The natural dunes have been decimated in many areas, leading to the demise of dune grass and shrub vegetation. This habitat-forming vegetation is extremely important because it stabilizes the dunes and protects beaches against wind and wave erosion. It also provides stopover habitat for numerous species of migrating birds flying along the Atlantic Coastal Flyway.

The undeveloped portions of the barrier islands are typified by extensive sand beaches and well-developed primary and secondary dune systems along the ocean side. Salt marshes and tidal flat habitats occur along backbarrier areas (U.S. Fish and Wildlife Service, 1996). The barrier beaches are typified by barren foredunes, and a primary dune plant community dominated by American beach grass (*Ammophila breviligulata*); the beach pea (*Lathyrus maritimus*), Japanese sedge (*Carex kobomugi*), seaside goldenrod (*Solidago sempervirens*), and sea rocket (*Cakile edentula*) are also observed here. Representative species identified in the secondary dune plant community include beach heather (*Hudsonia tomentosa*), bayberry (*Myrica pensylvanica*), beach plum (*Prunus maritima*), salt spray rose (*Rosa rugosa*), and pineweed (*Hypericum gentianoides*). Some rare species, such as the seabeach knotweed (*Polygonium glaucum*), inhabit the barrier beaches as well. In areas to the north (i.e., Island Beach State Park), well-developed thicket, edge, and freshwater wetland communities proliferate on the barrier (Kennish, 2001a).

In undisturbed areas of the barrier island system (e.g., Island Beach Northern Natural Area), an extensive coastal dune woodland community, or maritime forest, occurs behind the secondary dunes. In addition to the dominant red cedar (*Juniperus virginiana*), other trees comprising this community are the southern red oak (*Quercus falcata*), willow oak (*Quercus phellos*), black cherry (*Prunus serotina*), serviceberry (*Amelanchier canadensis*), sassafras (*Sassafras albidum*), and American holly (*Ilex opaca*). Sweet pepperbush (*Clethra alnifolia*), bayberry (*Myrica pensylvanica*), blueberries (*Vaccinium* spp.), hackberry (*Celtis occidentalis*), and multiflora rose (*Rosa multiflora*) form the secondary plant community. Open woodlands dominated by pitch pine exist in other areas. Trees associated with pitch pine are the Atlantic white cedar (*Chamaecyparis thyoides*), oak trees, and scattered holly. Sheep laurel (*Kalmia angustifolia*) and highbush blueberry (*Vaccinium corymbosum*) dominate the shrub layer (U.S. Fish and Wildlife Service, 1996).

Little Beach Island, located within the Brigantine National Wildlife Refuge, has vegetation typical of barrier beaches. American beach grass (*Ammophila breviligulata*) dominates the dune surface, with a mix of bayberry (*Myrica pensylvanica*), heather (*Calluna vulgaris*), marsh elder (*Iva frutescens*), and several other species concentrating in back dune areas. Various grasses, sedges, and flowering plants proliferate in low lying, freshwater pockets. The island is a major nesting, migration, and wintering area for waterfowl, marsh birds, and shorebirds.

Open Water

The Mullica River-Great Bay Estuary is characterized by a strong salinity gradient from limnetic conditions at its headwaters to full seawater at the LEO-15 site in the nearshore ocean. As a result, a wide array of freshwater, estuarine, and marine organisms inhabits this unique system, utilizing pelagic and benthic habitats. These organisms comprise complex planktonic, benthic, and nektonic communities.

Great Bay and Little Egg Harbor support numerous phytoplankton and zooplankton populations. Durand and Nadeau (1972) identified nearly 150 benthic invertebrate species in Great Bay alone. They showed that the benthic community here was dominated by the amphipod,

Ampelisca abdita. Benthic organisms inhabit both bare bottom habitats as well as areas covered by submerged aquatic vegetation (SAV). Vascular plants, notably seagrasses (e.g., eelgrass, *Zostera marina*), form important SAV habitat in Little Egg Harbor. Great Bay is essentially devoid of seagrass, while benthic macroalgae (e.g., sea lettuce, *Ulva lactuca*; hollow green weed, *Enteromorpha* sp.; and rockweed, *Fucus* sp.) are relatively abundant in some areas. Benthic infauna, epifauna, and fouling organisms are well represented in Little Egg Harbor, Great Bay, backbays to the south, and tributary systems.

More than 60 finfish species have been reported in the Mullica River-Great Bay Estuary. Other nektonic organisms observed here include sea turtles (e.g., Kemp's Ridley turtle, *Lepidochelys kempii*; leatherback turtles, *Dermochelys coriacea*; and green sea turtles, *Chelonia mydas*), snakes, and marine mammals (seals, whales, and porpoises). Several threatened or endangered nektonic species utilize the estuary at various times.

Many birds use the open water habitats and adjoining lands for feeding and other life processes. Both Little Egg Harbor and Great Bay are major migratory stopover and wintering areas for numerous waterfowl, shorebirds, and raptors. Water bird nesting colonies are common, such as those of terns (*Sterna* spp.), skimmers (*Rynchops* spp.), and egrets (*Casmerodius* spp.).

The following section provides a detailed description of the biotic communities of the estuarine and watershed areas in the JCNERR. These communities are generally characterized by having high species richness and abundance. The shelter and large food supply afforded by the backbarrier lagoon system support teeming concentrations of animal and plant life.

Barnegat Bay-Little Egg Harbor Estuary

Shallow lagoonal estuaries in New Jersey are subject to ongoing multiple anthropogenic impacts from an expanding population in adjoining coastal watersheds. Eutrophication poses the most serious threat to the long-term health and function of these systems, impacting essential habitats (e.g., seagrass and shellfish beds) as well as finfish nursery areas. Nutrient and organic carbon loading in the Barnegat Bay-Little Egg Harbor Estuary has been linked to an array of cascading environmental problems such as increased micro- and macroalgal growth, harmful algal blooms (HABs), bacterial and viral pathogens, high turbidity/benthic shading, altered benthic invertebrate communities, and impacted harvestable fisheries (Kennish et al., 2007a, b). These problems are causing the deterioration of sediment and water quality, loss of biodiversity, and disruption of ecosystem health and function. Human uses of estuarine resources are also being

impaired. The net insidious effect of progressive eutrophication may be the permanent alteration of biotic communities and habitats in the system.

The Barnegat Bay-Little Egg Harbor Estuary is classified as a highly eutrophic system based on application of NOAA's National Estuarine Eutrophication Assessment model (Kennish et al., 2007a). Because the Barnegat Bay-Little Egg Harbor Estuary is shallow, poorly flushed, and bordered by highly developed watershed areas, it is particularly susceptible to nutrient loading. Most of this load (~54%) derives from surface water inflow, but substantial fractions also originate from atmospheric deposition (~34%), and direct groundwater discharges (~12%) (Kennish, 2001a).

Other adverse effects on these estuarine waters include nonpoint source inputs of chemical contaminants, as well as the physical alteration of habitat due to bulkheading, diking and ditching, dredging, and lagoon construction. Power-plant (Oyster Creek Nuclear Generating Station) point-source impacts (i.e., biocidal releases, thermal discharges, impingement, and entrainment) have increased mortality of estuarine and marine organisms in Barnegat Bay. Human activities in watershed areas, notably deforestation and infrastructure development, partition and disrupt habitats while also degrading water quality and altering biotic communities. Ongoing land development (~35% of the Barnegat Bay watershed is now developed) raises turbidity and siltation levels in tributaries of the estuary, creating benthic shading problems. Management actions, including the purchase of open space, improved stormwater controls, and smart development are being pursued to remediate some of the aforementioned insidious effects and restore vital estuary functions; however, evidence indicates that remediation efforts have not resulted in significant mitigation of ecosystem impacts.

Significant data gaps exist in the Barnegat Bay-Little Egg Harbor Estuary. Hence, the following studies are recommended for the estuarine waters in the JCNERR.

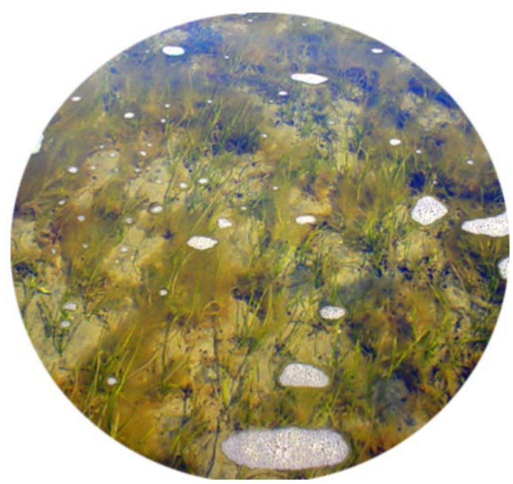
- Seagrasses are key indicators of water quality and condition of the Barnegat Bay-Little Egg Harbor Estuary. Therefore, the monitoring of seagrass abundance, shoot density, biomass, areal cover, and distribution in this system must be conducted consistently at regular intervals to establish a reliable bioassessment program and track the effects of nutrient enrichment.
- The development of a seagrass nutrient pollution indicator is strongly recommended to identify the early stages of eutrophication in the system. Because detailed surveys of SAV beds are labor intensive, costly, and time consuming, the development of an innovative nutrient pollution indicator based on assessment of nitrogen levels in seagrass tissues would be extremely useful for this system. By applying this indicator in the estuary, management mediated intervention could be significant in mitigating nutrient impacts on SAV beds.
- There is an indication of significant loss of seagrass beds in the estuary since the mid-1970s, although differences in mapping methods make it difficult to unequivocally establish the occurrence of a major dieback and loss of eelgrass area. Results of a GIS

spatial comparison analysis of SAV surveys reported by Lathrop et al. (2001a) and Lathrop and Bognar (2001) showed that there appears to have been loss of eelgrass in the deeper waters of the estuary culminating in the contraction of the beds to shallower subtidal flats (< 2 m depth) during the period between the 1960s and 1990s. The loss appears to have been most severe in Barnegat Bay north of Toms River and in southern Little Egg Harbor.

- A two-pronged seagrass monitoring and assessment program is recommended. This entails the application of aerial photography, airborne digital scanning systems, or satellite-based remote sensing to map and monitor the seagrass beds, in conjunction with *in situ* sampling to corroborate the aerial observations. Airborne scanning systems yield high spatial resolution imagery, and analog aerial photography enables investigators to visually interpret and map expanses of the beds. Groundtruthing efforts in concert with this remote sensing work should consist of establishing a series of sampling transects, with an array of quadrat, core, and hand sampling sites. These field applications should be conducted at least every five years and preferably at greater frequency.
- Seagrasses are also excellent bioindicators of estuarine sediment quality, as well as overall ecosystem health. By monitoring the distribution and abundance of seagrasses in the Barnegat Bay-Little Egg Harbor Estuary and establishing quantitative measures of acceptable limits as biocriteria, effective bioassessment of estuarine condition can be conducted. A major goal is to establish nutrient criteria and TMDL's that will remediate the impacts of nutrient enrichment in the estuary. This can only be achieved through careful monitoring and assessment of

seagrass habitat in the system. Delineating the distribution and abundance of seagrasses in this lagoon-type, coastal-bay system to track escalating eutrophic impacts is highly recommended. Since changes in seagrass distribution and abundance can occur over periods as short as weeks or months, rapid and cost effective tools are needed to accurately determine seagrass condition within seasonal constraints and to quantify cause-and-effect relationships.

- Chlorophyll diagnostic photopigment analysis is needed for identifying and quantifying phytoplankton functional groups. Phytoplankton community composition is an effective indicator of phytoplankton activity/response, including blooms, that has been linked to nutrient enrichment and other environmental stressors.
- Regular surveys of algal blooms (both phytoplankton and macroalgae) must be conducted in the estuary to identify key autotrophic responses to nutrient stressors. Surveys for brown tide (*Aureococcus anophagefferens*) are a primary target of phytoplankton bloom surveys.



- Benthic community studies must be conducted to determine if significant changes have occurred over time. The last comprehensive investigation of the benthic community in the estuary was conducted by Robert Loveland and his students at Rutgers University from 1968 to 1974. By re-sampling the same areas of the estuary, it will be possible to compare the benthic community 40 years after the Loveland investigations. Data that must be collected to assess the benthic community include species composition, abundance, biomass, diversity, and evenness. Metrics recorded on the benthos will be used to document changes in the benthos over the period from low development to high development in the coastal watershed.

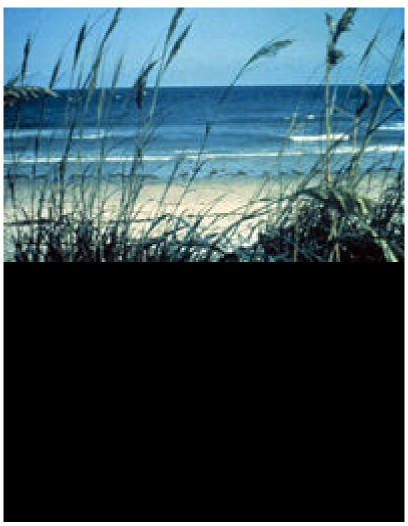
- The development of indices of benthic community condition is another valuable tool in bioassessment of estuarine ecosystems. In estuarine systems impacted by nutrient enrichment and bottom-up effects, such as the Barnegat Bay-Little Egg Harbor Estuary, the application of benthic index development for seagrass as well as other benthic habitats in the system is thus strongly recommended for effective biotic assessment. Metric measurements of targeted benthic assemblages will be used to effectively discriminate anthropogenically-stressed assemblages from non-stressed assemblages. These measurements can be used to generate numeric scores and indices of biotic integrity that can be important for developing biocriteria for this estuarine system. These data are necessary for accurate evaluation of ecosystem health useful for management decision making and resource protection. Benthic community sampling must be conducted at regular intervals (~five-year periods) to document changes in benthic condition through time.
- Shellfish stock assessment surveys must be conducted in the estuary, most notably targeting the hard clam (*Mercenaria mercenaria*) resource. The last hard clam

stock surveys in Little Egg Harbor and Barnegat Bay were completed in 2001 and 1986, respectively.

- Population surveys are necessary to document the distribution and abundance of sea nettles (*Chrysaora quinquecirrha*) in the estuary. Population eruptions of sea nettles in the estuary have occurred in several years since 2000.

FAUNAL COMMUNITIES

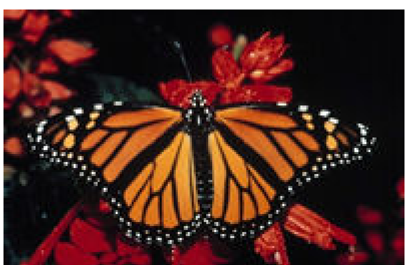
Overview



Mullica River-Great Bay Estuary

Great Bay is a major migratory stop and wintering area for many waterfowl, shorebirds and raptors. During the winter, the waterfowl population in the area is over 70,000 individuals. There are at least 44 distinct water bird nesting colonies for 15 different species. These include egrets, gulls, terns, and skimmers. Other birds of the reserve include herons, egrets, ospreys, eagles, owls, hawks, warblers and sparrows.

The Mullica River-Great Bay area



also supports numerous species of finfish. Major anadromous fish include striped bass, alewife, and blueback herring which spawn in tributaries. Shellfish populations are also extensive in the form of clams, mussels, and oysters (historically more abundant). Amphibians of the reserve include the elusive and protected Pine Barrens treefrog, and several other frog and salamander species. A diversity of reptiles are found within the reserve, represented by a variety of terrestrial and aquatic turtles, and several lizard and snake species, including the northern pine snake and the timber rattlesnake.

Watershed Faunal Communities

The Pinelands provide valuable habitat for numerous terrestrial organisms, notably reptiles, amphibians, mammals, birds, and insects. In addition, several fish species are relatively abundant in Pine Barrens streams and creeks, although the species richness is low. Many animal populations are characteristic of the Pine Barrens, and some of them are of recreational or commercial importance (e.g., ruffed grouse, *Bonasa umbellus*; eastern cottontail, *Sylvilagus floridanus*; and white-tailed deer, *Odocoileus virginianus*).

Amphibians and Reptiles

Conant (1998) reported that eight species of amphibians and reptiles only occur within the boundaries of the Pine Barrens, including the carpenter *frog (Rana virgatipes*), Pine Barrens treefrog (*Hyla andersonii*), rough green *snake (Opheodrys aestivus*), northern scarlet snake (*Cemophora coccinea*), northern red-bellied snake (*Storeria occipitomaculata occipitomaculata*), corn snake (*Elaphe guttata guttata*), eastern kingsnake (*Lampropeltis getulus getulus*), and northern pine snake (*Pituophis melanoleucus melanoleucus*). Other species observed in the Pine Barrens are widely distributed across southern New Jersey. In total, nearly 60 species of herpetofauna have been identified in the Pine Barrens, with most of them also found outside of its borders. Among these species are 11 salamanders, 14 frogs and toads, 11 turtles, 3 lizards, and 19 snakes (Table 8). Other widely distributed species include the Fowler's toad (*Bufo woodhousii fowleri*), southern leopard frog *(Rana utricularia*), northern water snake (*Natrix sipedon sipedon*), spotted turtle (*Clemmys guttata*), common snapping turtle (*Chelydra serpentina*), and the red-bellied turtle (*Chrysemys rubriventris*).

Table 8. Status of amphibians and reptiles in the New Jersey Pine Barrens.

Group	Species Name	Status in Pine Barrens
Salamanders		
	Spotted salamander	Uncertain
	Marbled salamander	REL, locally common
	Eastern tiger salamander	BOR, endangered
	Red-spotted newt	REL, few records
	Northern dusky salamander	BOR, rare
	Red-backed salamander	Abundant
	Slimy salamander	Uncertain
	Four-toed salamander	REL, numerous records
	Eastern mud salamander	Uncertain
	Northern red salamander	Abundant
	Northern two-lined salamander	BOR, rare
Toads and Frogs		
	Eastern spadefoot	Locally common
	Fowler's toad	Abundant
	Northern cricket frog	BOR, scattered records
	Pine Barrens treefrog	PBO, declining
	Cope's gray treefrog	PER, not present
	Northern spring peeper	Abundant
	Barking treefrog	INT, possibly extirpated
	Gray treefrog	BOR, scattered records
	New Jersey chorus frog	BOR, numerous records

Bullfrog	BOR, scattered records
Green frog	Abundant
Pickerel frog	BOR, few records
Wood frog	BOR, few records
Southern leopard frog	Abundant
Carpenter frog	PBO, common

Turtles

Common snapping turtle	Common
Stinkpot	Abundant
Eastern mud turtle	Numerous records
Spotted turtle	Abundant records but declining
Wood turtle	BOR, few records, threatened
Bog turtle	BOR, endangered
Eastern box turtle	Numerous records but declining
Northern diamondback terrapin	PER, not present
Map turtle	PER, not present
Eastern painted turtle	Abundant
Red-bellied turtle	Common
Eastern spiny softshell	INT, at western edge only

Lizards

Northern fence lizard	Abundant
Ground skink	PBO, uncommon
Five-lined skink	REL, few records

Snakes

Queen snake	PER, not present

Northern water snake	Abundant
Northern brown snake	Scattered records
Northern red-bellied snake	PBO, numerous records
Eastern ribbon snake	Numerous records but uncommon
Eastern garter snake	Numerous records
Eastern earth snake	Uncertain
Eastern hognose snake	Locally common but declining
Northern-southern ringneck snake	Scattered
Eastern worm snake	REL, common
Northern black racer	Locally common but declining
Rough green snake	PBO, common
Corn snake	PBO, scattered records
Black rat snake	Locally common
Northern pine snake	PBO, locally common
Eastern king snake	PBO, locally common
Eastern milk snake - scarlet king snake (intergrading population)	Numerous records
Northern scarlet snake	PBO, scattered records
Timber - canebrake rattlesnake (integrading population)	PBO, threatened

PBO, Pine Barrens only; BOR, border entrant; REL, relict in Pine Barrens; PER, peripheral to Pine Barrens; INT, introduced.

From Conant, R. 1998. A zoogeographical review of the amphibians and reptiles of southern New Jersey, with emphasis on the Pine Barrens. In: R. T. T. Forman, Ed., *Pine Barrens: Ecosystem and Landscape*. Rutgers University Press, New Brunswick, pp. 467-488.

Amphibian and reptilian species, which are common or abundant in the upland region, include the Pine Barrens tree frog (*Hyla andersonii*), eastern tiger salamander (*Ambystoma tigrinum tigrinum*), northern pine snake (*Pituophis melanoleucus melanoleucus*), timber rattlesnake (*Crotalus horridus horridus*), and wood turtle (*Clemmys insculpta*). In the lowland forest region, the eastern mud salamander (*Pseudotriton montanus montanus*), long-tailed salamander *(Eurycea longicauda longicauda*), and bog turtle (*Clemmys muhlenbergii*) are frequent inhabitants. Broad, undisturbed areas of the Pine Barrens serve as ideal habitat for many herpetofaunal species.

Zampella et al. (2001) identified 12 anuran species in the Mullica River Basin (Table 9). Bunnell and Zampella (1999) and Zampella et al. (2001), investigating 14 acid water ponds within publicly owned forest lands along the northwestern boundary of the Mullica River Basin, classified anurans (frogs and toads) in three groups: (1) forms restricted to the Pinelands, notably the Pine Barrens treefrog (*Hyla andersonii*) and the carpenter frog (*Rana virgatipes*); (2) forms with a widespread distribution in southern New Jersey such as the northern spring *peeper (Pseudacris crucifer crucifer*), Fowler's toad (*Bufo woodhousii fowleri*), southern leopard frog (*Rana utricularia*), green frog (*Rana clamitans melanota*), eastern spadefoot toad (*Scaphiopus holbrooki holbrooki*);

and (3) those forms normally unable to enter the Pinelands except in habitats disturbed by human activities. The latter border-entrant species are exemplified by the gray treefrogs (*Hyla versicolor* and *H. chrysoscelis*), New Jersey chorus frog (*Pseudacris triseriata kalmi*), northern cricket frog (*Acris crepitans crepitans*), wood frog (*Rana sylvatica sylvatica*), pickerel frog (*Rana palustris*), and bullfrog (*Rana catesbeiana*). The border-entrant species occur less frequently in the Pinelands than do the Pine Barrens species and the wide-ranging forms. They normally occupy Pinelands habitat disturbed by anthropogenic activity, and avoid the low pH of surface waters in undisturbed areas (Zampella et al., 2001).

Table 9. Taxonomic list of anuran species found in the Mullica River Basin.

Common Name	Scientific Name
Northern cricket frog	*Acris crepitans crepitans*
Pine Barrens treefrog	*Hyla andersonii*
Gray treefrog	*Hyla chrysoscelis* *Hyla versicolor*
Fowler's toad	*Bufo woodhousii fowleri*
Northern spring peeper	*Pseudacris crucifer crucifer*
New Jersey chorus frog	*Pseudacris triseriata kalmi*
Bullfrog	*Rana catesbeiana*
Green frog	*Rana clamitans melanota*
Pickerel frog	*Rana palustris*
Southern leopard frog	*Rana utricularia*

Wood frog	*Rana sylvatica*
Carpenter frog	*Rana virgatipes*

Modified from Zampella, R. A., J. F. Bunnell, K. J. Laidig, and C. L. Dow. 2001. The Mullica River Basin. Technical Report, New Jersey Pinelands Commission, New Lisbon, New Jersey.

Zampella and Bunnell (2000) compared the distribution of anuran populations in the Wading River Basin to those in the more intensely developed and farmed Mullica River Basin. Four non-native Pinelands species (i.e., bullfrog, *Rana catesbeiana*; pickerel frog, *R. palustris*; northern cricket frog, *Acris crepitans crepitans*; and gray treefrog, *Hyla versicolor*) normally distributed outside the region were recorded only in the Mullica River system, where sites were associated with the presence of upland agriculture and developed land. In contrast, six native Pinelands species (i.e., Pine Barrens treefrog, *Hyla andersonii*; carpenter frog, *R. virgatipes*; southern leopard frog, *R. utricularia*; Fowler's toad, *Bufo woodhousii fowleri*; northern spring peeper, *Pseudacris crucifer crucifer*; and green frog, *R. clamitans melanota*) were widely distributed in both river systems. Bullfrogs generally occurred at sites devoid of the Pine Barrens treefrogs and carpenter frogs. The bullfrogs occurred in proximity to developed land and upland agriculture, whereas the carpenter frogs preferred unaltered sites.

Zampella et al. (2001, p. 86) discussed the use of anuran assemblages as indicators of watershed disturbance in the Pinelands. They concluded the following:

- The presence of individual border-entrant species and assemblages dominated by these species is associated with adjacent developed land and upland agriculture.

- The general absence of the two Pine Barrens species at sites with bullfrogs indicates that the presence of bullfrogs may adversely affect native anuran diversity.
- On-stream anuran communities may be better indicators of overall watershed conditions compared to off-stream communities because most of the sites that support border-entrant species are stream sites.

In a study of the nearby Barnegat Bay watershed, Zappalorti and Sykes (1998) identified nine anuran species that are generally widespread and stable. These include the northern spring peeper (*Psuedacris crucifer crucifer*), northern gray treefrog (*Hyla versicolor*), New Jersey chorus frog (*Psuedacris triseriata kalmi*), bullfrog (*Rana catesbeiana*), green frog (*Rana clamitans melanota*), wood frog (*Rana sylvatica*), southern leopard frog *(Rana utricularia*), pickerel frog (*Rana palustris*), and Fowler's toad (*Bufo woodhousii fowleri*). The status of two other anuran species in the watershed, the carpenter frog (*Rana virgatipes*) and northern cricket frog (*Aris crepitans crepitans*), is undetermined. One anuran species, the eastern spadefoot toad (*Scaphiopus holbrooki holbrooki*) is declining. The southern gray treefrog (*Hyla chrosocelis*) is a State endangered species. The Pine Barrens treefrog (*H. andersonii*), another problematic species, was removed from the State endangered species list in May 2003.

The acid water and low concentrations of dissolved solids in Pinelands streams and ponds unaffected by upland land uses create harsh conditions for many herpetofauna and thus influence their distribution and abundance. The low pH of streams and ponds in the Pinelands can adversely affect embryonic and larval development and survival of less tolerant anuran species (Freda and Dunson, 1986). The native anurans (i.e., *Hyla* *andersonii* and *Rana virgatipes*) appear to be the species most tolerant of these conditions in the Pinelands. Other species residing in the Pine Barrens, but whose natural distribution is outside of this region, can successfully reproduce only in areas of the Pinelands that have been altered by human activity (Bunnell and Zampella, 1999). The Pine Barrens tree frog deserves special consideration because of its restrictive habitat requirements.

Three species of salamanders are relatively abundant in the Pine Barrens: the red-backed salamander (*Plethodon cinereus*), northern red salamander (*Pseudotriton ruber*), and four-toed salamander (*Hemidactylium scutatum*). In addition, the marbled salamander (*Ambystoma opacum*) is locally common. The northern two-lined salamander (*Eurycea bislineata*) and northern dusky salamander (*Desmognathus fuscus*) are rare, and the eastern tiger salamander (*Ambystoma tigrinum tigrinum*) is endangered. The amphibious salamanders breed in the water and usually inhabit moist areas beneath rotting stumps, logs, leaves, and other decaying debris.

Of the three species of lizards occupying Pine Barrens habitats, the most abundant is the northern fence lizard (*Sceloporus undulatus hyacinthinus*). The ground skink (*Scincella lateralis*) is uncommon. The five-lined skink (*Eumeces fasciatus*) represents the least abundant form, with only a few records of its occurrence in the Pine Barrens. While ground skinks inhabit open sandy wooded areas, fence lizards prefer open pine and pine-oak uplands where they are often observed on pine trees, wood piles, or fallen logs. Five-lined skinks, in turn, occupy moist or wet woodland areas such as hardwood swamps.

Most turtles in the Pine Barrens occur in brackish or freshwater habitats, the notable exception being the eastern box turtle (*Terrapene carolina*). Abundant species of turtles in the Pinelands are the stinkpot (*Sternotherus odoratus*) and eastern painted turtle (*Chrysemys picta*), with the snapping turtle *(Chelydra serpentina*), spotted turtle (*Clemmys guttata*), and red-bellied turtle (*Chrysemys rubriventris*) being common. Numerous records also exist for the eastern mud turtle *(Kinosternon subrubrum subrubrum*) and eastern box turtle (*T. carolina*). The wood turtle (*Clemmys insculpta*), a threatened species, and the bog turtle (*Clemmys muhlenbergi*), a State endangered and a federal threatened species, have also been recorded in the Pine Barrens.

The northern diamondback terrapin (*Malaclemys terrapin terrapin*) is found in the lower watershed, particularly in tidal salt marsh habitat. It nests on sandy uplands adjacent to tidal creeks and salt marshes (U.S. Fish and Wildlife Service, 1996; Hoden and Able, 2003). This year-round resident species has been declining in recent years. Various organisms prey on adult diamondback terrapins, particularly raccoons, bald eagles, and most notably, humans. Other predators attack the nests of diamondback terrapins (e.g., gulls, crows, muskrats, foxes, and skunks). Burger (1977) reported that 73% of terrapin nests on small islands in Barnegat Bay were destroyed within a single year by predators. Many individuals are also killed by vehicular traffic on roadways (Hoden and Able, 2003).

Several species of snakes occur in upland forest and wetland habitats of the Pine Barrens. Species commonly found in upland forests are the northern pine snake (*Pituophis melanoleucus melanoleucus*), eastern hognose snake (*Heterodon platyrhinos*), eastern worm *snake (Carphophis amoenus amoenus*), northern black racer (*Coluber* *constrictor constrictor*), northern scarlet snake (*Cemophora coccinea*), rough green snake (*Opheodrys aestivus*), eastern garter snake (*Virginia valeriae valeriae*), and corn snake (*Elaphe guttata guttata*). Those observed in wetland areas are the eastern ribbon snake *(Thamnophis sauritus sauritus*), northern water snake (*Nerodia sipedon*), and eastern king snake (*Lampropeltis getula getula*). The endangered timber rattlesnake (*Crotalus horridus horridus*) requires both upland and wetland forest habitat during different times of the year. Both the timber rattlesnake and corn snake are listed as State endangered species, and the northern pine snake is listed as a State threatened species.

Timber rattlesnakes in the Pine Barrens hibernate along cedar streams. They commonly position themselves in underground flowing water at the base of cedar trees where the root systems afford protection (Zappalorti and Reinert, 1989). When emerging from hibernation, the snakes quickly migrate to upland foraging sites. Abundance of the timber rattlesnake has declined over most of the snake's range during the past several decades (Tyning, 1992).

Pine snakes hibernate in a group and often with other snake species, including black racers and corn snakes (Kennish, 2001a). The snakes inhabit hibernation chambers until the spring thaw when they emerge to pursue prey. Pine snakes and corn snakes are non-venomous constrictors that primarily feed on warm-blooded prey.

Habitat loss and alteration pose a threat to various reptilian and amphibian populations in the Mullica River and Barnegat Bay watersheds. The most serious threats are associated with habitat partitioning, degradation, and destruction in the more heavily developed Barnegat Bay watershed. Other factors that may be contributing to the decline of some herptiles in watershed habitats are pollution of wetland and upland habitats, road mortality, illegal collecting and wanton killing by humans, as well as predation by domestic and feral animals.

Mammals

Wolgast (1998) has described the land-dwelling mammals inhabiting the Pine Barrens. More than 30 species reside in various parts of this system. They have been grouped into three categories based on size: small, intermediate, and large species. Most of the mammalian species (n = 22) are small (adult body length, excluding tail, < 26 cm). Among the small-sized mammals are the masked shrew (*Sorex cinereus*), least shrew (*Cryptotis parva*), short-tailed shrew (*Blarina brevicauda*), eastern mole (*Scalopus aquaticus*), star-nosed mole (*Condylura cristata*), little brown myotis (*Myotis lucifugus*), big brown bat (*Eptesicus fuscus*), eastern pipistrelle (*Pipistrellus subflavus*), eastern chipmunk (*Tamias striatus*), gray squirrel *(Sciurus carolinensis*), red squirrel (*Tamiasciurus hudsonicus*), southern flying squirrel (*Glaucomys volans*), rice rat (*Oryzomys palustris*), white-footed mouse (*Peromyscus leucopus*), red-backed vole (*Clethrionomys gapperi*), meadow vole (*Microtus pennsylvanicus*), pine vole (*Microtus pinetorum*), southern bog lemming (*Synaptomys cooperi*), Norway rat (*Rattus norvegicus*), house mouse (Mus musculus), meadow jumping mouse (*Zapus hudsonius*), and long-tailed weasel (*Mustela frenata*).

The body lengths of intermediate-sized mammals range from 26-76 cm (excluding tail). Eleven species comprise this group, including the opossum (*Didelphis virginiana*), woodchuck (*Marmota monax*), eastern cottontail (*Sylvilagus floridanus*), beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), red fox (*Vulpes vulpes*), gray fox (*Urocyon cinereoargenteus*), raccoon (*Procyon lotor*), mink (*Mustela vison*), striped skunk (*Mephitis mephitis*), and river otter (*Lutra canadensis*). The white-tailed deer (*Odocoileus virginianus*) and humans (*Homo sapiens*) constitute the largest mammals (adult body size > 1 m).

The aforementioned mammalian species have a broad distribution, ranging beyond the boundaries of the Pine Barrens. They are well-established species, some of which are threatened or endangered. Many of the species have distinct habitat preferences (Wolgast, 1998).

Mammalian species which prefer wetland habitats and nearby waterways include the least shrew, southern log lemming, muskrat, beaver, river otter, and mink. While the river otter resides in tidal marshes, bay islands, and Pine Barrens streams, the beaver is restricted to freshwater areas of tributary systems. The muskrat occurs in both freshwater and brackish marshes. The red-backed vole is essentially confined to wetland forests and bogs. Mammals associated with shrubland and grassland habitats include the eastern cottontail, woodchuck, meadow vole, and meadow jumping mouse. Species of rodents that dwell in upland forests are the pine vole, white-footed mouse, southern flying squirrel, gray squirrel, red squirrel, and eastern chipmunk. Larger upland forest species consist of white-tailed deer, opossum, striped skunk, long-tailed weasel, raccoon, gray fox, and red fox.

Birds

The JCNERR provides habitat for thousands of shorebirds, seabirds, songbirds, raptors, and waterfowl. The location of the reserve on the Atlantic Flyway enables numerous migrating birds to utilize coastal habitats as staging and overwintering areas. As a result, the avifauna observed in the Pine Barrens also includes rare species of both southern and northern affinities.

Colonial nesting waterbirds censused within the reserve boundaries are beach nesting birds (e.g., black skimmers, *Rynchops niger,* and least terns, *Sterna antillarum*), long-legged wading birds (e.g., herons, egrets, and ibises) nesting among trees and shrubs, and gulls and terns nesting on salt marsh islands (U.S. Fish and Wildlife Service, 1996). The Holgate Unit is one of the most important locations in New Jersey for nesting least terns. Other species of terns observed in the area are the common tern (*Sterna hirunda*), Forster's tern (*S. forsteri*), and gull-billed tern (*S. nilotica*). Laughing gulls (*Larus atricilla*), herring gulls *(L. argentatus*), and great black-back gulls (*L. marinus*) comprise significant nesting bird colonies. Salt marshes and beach bars along the Great Bay Boulevard Wildlife Management Area and on bay islands (e.g., Tow Island, Fish Island, and Seven Islands) are favored nesting locations for terns, gulls, and other colonial nesting waterbirds. Surveys revealed as many as 200 black skimmers nesting on Tow Island in 1995.

Appendix 16 contains a list of nearly 170 species of birds that have been identified along an intertidal mudflat (39°31'N, 74°10'W) located at the end of Great Bay Boulevard near RUMFS. This 1.56-ha mudflat terminates at the entrance to Little Egg Inlet and the Atlantic Ocean. More than 700 censuses conducted on a weekly basis year-round between November 1976 and August 1989 recorded a total of 28 species of shorebirds, gulls, and geese and nearly 185,000 individuals along Great Bay Boulevard and the open waters of the JCNERR. Overall abundance was greatest during the spring migration period, with a single peak in abundance occurring during mid-May, which averaged 1000 birds. Fall migration showed a significant peak in abundance during November. The mean number of species observed per week ranged from 14 in the spring, to four through the summer, and 11 during the fall migration. Total bird abundance did not change significantly over the 13-year study period. Only three species exhibited significant change in abundance over time: the American oystercatcher, sanderling, and yellowlegs.

Among the most commonly reported nesting long-legged wading birds are the black-crowned night heron (*Nycticorax nycticorax*), yellow-crowned night heron (*N. violaceus*), tri-colored heron (*Egretta tricolor*), little blue heron (*E. caerulea*), snowy egret (*E. thula*), great egret (*Casmerodius albus*), cattle egret (*Bubulcus ibis*), and glossy ibis (*Plegadis falcinellus*). A less conspicuous wading bird is the green-backed heron (*Butorides striatus*), a fish-eating species which nests in riparian habitats (Leck, 1998). Some bay islands, such as the Goosebar Sedge and Story Island, have supported significant heronies. In 1985, a small heronry existed on one of the Seven Islands; nesting birds consisted of cattle egrets, great egrets, black-crowned night-herons, and glossy ibises. A small great blue heron (*Ardea herodias*) heronry has been documented in the Pomona Woods in the eastern Pinelands (U.S. Fish and Wildlife Service, 1996).

Among the most abundant colonial waterbirds using the Brigantine Bay and marsh complex are gulls (laughing gulls, herring gulls, and great black-backed gulls) and terns (common terns, Forster's terns, and gull-billed terns). Long-legged waders nesting in this complex, in descending order of abundance, include the snowy egret, glossy ibis, great egret, black-crowned night-heron, tri-colored heron, cattle egret, little blue heron, and yellow-crowned night-heron. Aerial colonial waterbird surveys conducted in the Barnegat Bay-Little Egg Harbor estuarine system registered 500 long-legged waders in seven heronies in 1989, and 435 waders in 14 heronies in 1995. The most abundant species of waders for both survey years, in declining order of abundance, were the snowy egret, great egret, glossy ibis, black-crowned night heron, little blue heron, tri-colored heron, and yellow-crowned night heron (U.S. Fish and Wildlife Service, 1996).

Burger et al. (2001) has investigated the colonial waterbirds of the Barnegat Bay-Little Egg Harbor Estuary (Table 10). She followed population trends of several species of colonial-nesting birds (i.e., common tern, Forster's tern, black skimmer, and herring gull) in the estuary based on yearly censusing from 1976 to 1999. Her data indicate a significant increase in the number of colonies of herring gulls and a significant decrease in the number of colonies of common terns and black skimmers over this time interval. Aerial surveys conducted in 1977, 1978, 1979, 1983, 1989, and 1995 revealed a significant decline in the number of colonies of least terns and a significant increase in the number of colonies of great black-backed gulls, great egrets, black-crowned night herons, and glossy ibises. The number of adult herring gulls

decreased from 1976 to 1999, as did the number of adult snowy egrets and least terns from 1977 to 1995. A few colonial waterbirds in the Barnegat Bay-Little Egg Harbor Estuary are listed as State endangered and threatened species. For example, the least tern and black skimmer are listed as State endangered, whereas the yellow-crowned night-heron is listed as State threatened.

Table 10. Colonial waterbirds of the Barnegat Bay-Little Egg Harbor Estuary.

Group	Common Name	Scientific Name
Gulls, Terns, Skimmers		
	Common tern	*Sterna hirundo*
	Least tern	*Sterna antillarum*
	Forster's tern	*Sterna forsteri*
	Roseate tern	*Sterna dougalli*
	Caspian tern	*Sterna caspia*
	Gull-billed tern	*Sterna nilotica*
	Laughing gull	*Larus atricilla*
	Herring gull	*Larus argentus*
	Great black-backed gull	*Larus marinus*
	Black skimmer	*Rhynchops niger*
Long-legged Wading Birds		
	Great egret	*Casmerodius albus*
	Snowy egret	*Egretta thula*
	Cattle egret	*Bubulcus ibis*
	Great blue heron	*Ardea herodias*
	Green-backed heron	*Butorides striatus*
	Little blue heron	*Egretta caerulea*

Tri-colored heron	*Egretta tricolor*
Yellow-crowned night-heron	*Nycticorax violaceus*
Black-crowned night-heron	*Nycticorax nycticorax*
Glossy ibis	*Plegadis falcinellus*

From Burger, J., C. D. Jenkins, Jr., F. Lesser, and M. Gochfeld. 2001. Status and trends of colonially-nesting birds in Barnegat Bay. *Journal of Coastal Research*, Special Issue 32, pp. 197-211.

Many shorebirds also use the barrier beach-backbarrier lagoon system, as well as fringing habitat of the Mullica River-Great Bay Estuary, particularly during spring and fall migrations. They roost and forage in tidal salt marshes and feed on sandflats and mudflats of Great Bay and neighboring estuaries (U.S. Fish and Wildlife, 1996). Nesting species of note include the piping plover (*Charadrius melodus*), American oystercatcher (*Haematopus palliatus*), and willet (*Catoptrophorus semipalmatus*). All inhabit beaches and dunes, although oystercatchers and willets have broader habitat preferences and often frequent open marshes and marsh islands. The American oystercatcher, for example, nests on broad sand flats, open beaches, and sparsely vegetated areas of islands. A favored nesting area of the piping plover is the stretch of beach along the Holgate Unit, where an average of 13 pairs of piping plovers were documented from 1985 to 1995 (U.S. Fish and Wildlife Service, 1996). The piping plover typically nests in exposed or sheltered areas at the base of a clump of dune grass or other vegetation. Important natural predators are gulls (*Larus* spp.), crows (*Corvus* spp.), raccoons (*Procyon lotor*), and foxes (*Vulpes vulpes*) (Jenkins et al., 1998). Most of these shorebirds migrate from the region during the fall to overwinter along the southeast Atlantic, Gulf of Mexico, and Caribbean coasts (Kennish, 2001a). Aside from shorebirds, other groups of birds that use the Atlantic coastal corridor as a major migratory route include passerines, raptors, and waterfowl.

Nearly 300 species of birds have been recorded at the Edwin B. Forsythe National Wildlife Refuge, with more than 100 of them found to be actively breeding during the past few years. Shorebird species consistently observed in the refuge are the dunlin (*Calidris alpina*), semipalmated sandpiper (*C. pusilla*), western sandpiper (*C. mauri*), least sandpiper (*C. minutilla*), white-rumped sandpiper (*C. fuscicolis*), short-billed dowitcher (*Limnodromus griseus*), semipalmated plover (*Charadrius semipalmatus*), greater yellowlegs (*Tringa melanolueca*), black-bellied plover (*Pluvialis squatorola*), lesser golden plover *(P. dominica*), marbled godwit (*Lemosa fedoa*), Hudsonian godwit (*L. haemastica*), ruddy turnstone (*Arenaria interpres*), willet (*Catoptrophorus semipalmatus*), and American oystercatcher (*Haematopus palliatus*). Other shorebirds found in the region are the sanderling (*Calidris alba*) and red knot (*Calidris canutus*) (U.S. Fish and Wildlife Service, 1996).

Rails (e.g., clapper rail, *Rallus longirostrus*; Virginia rail, *Rallus limicola*; and sora rail, *Porzana carolina*) are common marsh-nesting birds. The Virginia rail, sora, and marsh wren breed in brackish and freshwater marshes along the Mullica and Wading Rivers. Human disturbance can greatly disrupt the breeding and nesting behavior of these birds.

A number of raptors utilize barrier beach and tidal marsh environments. Among these birds are the osprey (*Pandion haliaetus*), peregrine falcon (*Falco peregrinus*), merlin (*F. columbarius*), American kestrel (*F. sparverius*), northern harrier *(Circus cyaneus*), sharp-shinned hawk (*Accipiter striatus*), and short-eared owl (*Asio flammeus*).

The osprey, peregrine falcon, and northern harrier are the primary raptors. While the peregrine falcon and northern harrier nest year-round in the region, the osprey migrates to the Southeast U.S., Central America, and South America, where it overwinters. The peregrine falcon and the osprey are listed as a State threatened species. The northern harrier, in turn, is a State endangered species.

The osprey, peregrine falcon, and northern harrier all feed near the top of the estuarine food chain. The osprey primarily consumes fish. The peregrine falcon, in contrast, prefers other birds as prey such as shorebirds, small waterfowl, and gulls. Northern harriers also ingest small birds, but commonly hunt the marsh landscape for rodents and other small mammals (Kennish, 2001a).

The peregrine falcon and northern harrier nesting populations are relatively stable. The number of nesting ospreys, however, has increased dramatically during the past 25 years. Between 1975 and 1998, osprey nests increased more than five-fold, from 50 nests to over 250 nests statewide. In the study region, the osprey nests on platforms in salt marsh habitats. The northern harrier also utilizes salt marshes, as well as brackish marshes, for nesting and foraging. The merlin likewise feeds in the marshes. In recent years, the bald eagle has been observed nesting along the Mullica River as well as roosting and foraging in the tidal reaches of the Mullica and Wading Rivers (U.S. Fish and Wildlife Service, 1996). It is clearly evident that a range of habitats in the JCNERR are critically important to the health and viability of these raptor populations.

Other predatory birds are largely limited to upland forest habitats. Examples are the broad-winged hawk (*Buteo platypterus*), which nests in tall oak trees, as well as the eastern screech owl (*Otus asio*) and great horned owl (*Bubo virginianus*), which inhabit oak-pine forests. Impressive flights of hawks (e.g., sharp-shinned hawk, *Accipiter striatus*) are occasionally observed in the Pinelands (Leck, 1998).

Barnegat Bay-Little Egg Harbor Estuary and the Mullica River-Great Bay Estuary serve as important migration and wintering habitat for waterfowl. Midwinter aerial surveys indicate that an average of more than 12,000 waterfowl occur in the estuarine system, with the most abundant species being, in descending order, the American black duck (*Anas rubripes*), brant (*Branta bernicla*), greater and lesser scaup (*Aythra marila* and *A. affinis*), mallard (*Anas platyrhynchos*), and bufflehead (*Bucephala albeola*). Less abundant species are the tundra swan (*Cygnus colombianus*), Canada goose (*Branta canadensis*), gadwall (*Anas strepera*), red-breasted merganser (*Mergus serrator*), common merganser (*M. merganser*), hooded merganser (*Lophodytes cucullatus*), common goldeneye (*Bucephala clangula*), oldsquaw (*Clangula hyemalis*), American widgeon (*Anas americana*), northern pintail (*Anas acuta*), canvasback (*Aythra valisneria*), and green-winged teal (*Anas crecca*) (U.S. Fish and Wildlife Service, 1996; Casttelli et al., 1997).

Peak numbers of waterfowl are found in the reserve during the winter, although wintering waterfowl species vary considerably in abundance from year to year. The severity of winter weather conditions, especially the amount of freezing, strongly influences waterfowl abundance. Winter flocks in the system have been historically dominated by the American black duck; however, the mallard has increased dramatically in recent years (Leck, 1998).

During harsh winters when extensive areas freeze, many waterfowl concentrate in areas near Little Egg Inlet. Sea ducks, for example, prefer the inlet area. Diving ducks are mainly observed in open waters of Great Bay and Little Egg Harbor. Bufflehead and dabbling ducks utilize the shorelines and tidal creeks of the estuary. One of the largest wintering populations of tundra swans in the Mid-Atlantic region inhabits the Wading River, averaging as many as 2,500 individuals. The American black duck, mallard, Canada goose, and gadwall breed in the estuary. A breeding population of the American black duck also occurs in the Mullica River.

Mid-winter aerial surveys have revealed greater numbers of waterfowl in the Brigantine Bay and marsh complex, as well as the Barnegat Bay complex, than in the Mullica River-Great Bay estuarine system. For example, in the Brigantine Bay and marsh complex, mid-winter aerial waterfowl counts have documented an average of more than 70,000 birds. The most abundant species in these surveys are, in descending order, the brant, American black duck, snow goose (*Chen caerulescens*), greater and lesser scaup, Canada goose, bufflehead, scoters (*Melanitta* spp.), and mallard. These species are not evenly distributed in the complex. In the Barnegat Bay system, mid-winter aerial waterfowl counts average ~50,000 birds; the most abundant species are, in descending order, the greater and lesser scaup, brant, American black duck, bufflehead, canvasback, mallard, and Canada goose. The diversity of waterfowl frequenting the estuary in spring and fall is significant (Castelli et al., 1997; Table 11). These species are typically rafted in concentrated areas; thus, they are not evenly distributed in the system. The most abundant waterfowl species identified in fall (November) migrations are, in declining order, the brant, American black duck, scaup, mallard, bufflehead, Canada goose, and merganser (U.S. Fish and Wildlife Service, 1996). Because numerous waterfowl inhabit the coastal bays of New Jersey, these water bodies and adjacent land areas are important waterfowl hunting areas (Nichols and Castelli, 1997).

A number of seabird populations migrate along the coast. Species of note include the northern gannet (*Sula bassanus*), cormorants (*Phalacrocorax* spp.), sooty shearwater (*Puffinus griseus*), loons (*Gavia* spp.), and Wilson's storm petrel (*Oceanites oceanicus*). Aerial surveys conducted in Cape May County documented more than 900,000 seabirds migrating along the coast during the period from July through December 1995 (U.S. Fish and Wildlife Service, 1996).

Many songbirds also feed, nest, and breed in the Pine Barrens. Abundant breeding songbird populations in the Pinelands include the rufous-sided towhee (*Pipilo erythrophthalmus*), a member of the sparrow family found throughout the Pinelands but particularly at upland sites in areas of scrubby undergrowth, and the gray catbird (*Dumetella carolinensis*), which commonly nests in dense thickets. The Carolina chickadee (*Parus carolinensis*), Carolina wren (*Thyrothorus ludovicianus*), and mockingbird (*Mimus polyglottus*) are southern bird species also conspicuous in upland areas (Leck, 1998).

Within oak-pine woodlands, the red-eyed vireo (*Vireo olivaceus*), black-and-white warbler (*Mniotilta varia*), and the ovenbird *(Seiurus aurocapillus*) are frequently observed. Insectivores tend to be more abundant among oak-dominated stands. Species showing a preference for mixed pine-oak vegetation include the pine warbler (*Dentroica pinus*) and prairie warbler (*D. discolor*). The pine warbler concentrates in tall pine woodlands, and the prairie warbler, in shrub undergrowth. Pine forests harbor the greatest diversity of breeding birds (U.S. Fish and Wildlife Service, 1996).

Table 11. Waterfowl species occurring by month in federal surveys of Barnegat Bay, 1985-1993 (excluding 1988).

	Months						
SPECIES	OCT	NOV	DEC	JAN	FEB	MAR	APR
Mallard	x	x	x	x	x	x	x
American black duck	x	x	x	x	x	x	x
Gadwall	-	-	-	-	0	0	x
American wigeon	-	-	0	+	0	0	0
Greem-winged teal	x	+	x	x	x	x	x
Blue-winged teal	-	0	0	-	0	0	0
Northern shoveler	0	0	-	0	0	+	+
Northern pintail	+	+	x	x	x	x	x
Wood duck	0	0	0	0	0	0	0
Redhead	0	-	0	0	0	0	0
Canvasback	0	-	-	0	0	0	0
Scaup spp.	+	x	x	+	x	x	+
Ring-necked duck	0	0	0	0	0	0	0
Goldeneye	-	x	x	+	x	x	+
Bfufflehead	+	x	x	x	x	x	x
Ruddy duck	-	0	+	-	0	0	0
Merganser spp.	+	x	x	x	x	x	x
Common eider	0	0	0	0	0	0	0
Scoters spp.	0	0	-	-	0	0	0
Oldsquaw	0	+	x	x	x	x	+
Atlantic brant	x	x	x	x	x	x	x
Greater snow geese	-	-	-	0	0	0	+
Canada geese	-	+	x	x	x	x	x
Tundra swan	0	0	-	-	0	0	0
Mute swan	+	+	+	+	x	x	+

x species observed every year
+ species observed > 50% of the time
- species observed < 50% of the time
0 species not observed

From Castelli, P. M., D. Olson, and V. Turner. 1997. Aerial surveys of Barnegat Bay and Little Egg Harbor, New Jersey 1956-1996. In: G. E. Flimlin and M. J. Kennish (eds.), *Proceedings of the Barnegat Bay Ecosystem Workshop*. Rutgers Cooperative Extension of Ocean County, Toms River, New Jersey, pp. 329-344.

Insectivorous species dominate in cedar swamp habitats of the Pine Barrens. Representative species are the eastern wood pewee (*Contopus virens*), gray catbird (*Dumetella carolensis*), wood thrush (*Hylocichla mustilina*), white-eyed vireo (*Vireo griseus*), northern parula warbler (*Parula americana*), yellow warbler (*Dendroica petechia*), yellowthroat (*Geothylypis trichas*), redstart (*Setophaga ruticilla*), and song sparrow (*Melospiza melodia*). These birds are mainly present in summer. Other species also observed along swamps, lakes, and other waterways include the red-winged blackbird (*Agelaius phoeniceus*), purple martin (*Progne subis*), and tree swallow (*Iridoprocne bicolor*) (Leck, 1998).

The seaside sparrow (*Ammospiza maritima*), sharp-tailed sparrow (*A. caudacuta*), and marsh wren (*Cistothorus palustris*) are three songbird species that nest and breed in tidal and freshwater marshes. The seaside sparrow and sharp-tailed sparrow build their nests in cordgrass and salt-meadow marshes at ground level and up to about a meter above the ground. The marsh wren, in turn, constructs nests above the ground level attached to the stems of emergent vegetation such as cordgrass, common reed, and cattails (Kroodsma and Verner, 1997).

Some 25 neotropical migrant species breed in forest and scrub-shrub habitats of the Barnegat Bay-Little Egg Harbor Estuary, and another 17 neotropical migrants of various habitat affinity breed in the system as well. These species belong to several landbird groups, notably tanagers, buntings, grosbeaks, New World sparrows, vireos, flycatchers, swallows, cuckoo, nightjars, swifts, and hummingbirds. Habitats in the Pine Barrens provide high quality migratory stopovers for foraging, nesting, and cover from predators. Species generally occur on breeding grounds in watershed areas for three months or less (DeGraaf and Rappole, 1995; Kennish, 2001a).

Fish

McCormick (1970) reported that 24 freshwater fish species occur in the Pine Barrens, although Hastings (1998) noted that only 16 of these species are indigenous to the acidic waters of the region (if peripheral and introduced forms are excluded). Hence, the fish fauna of the Pine Barrens is relatively depauperate. Five groups of Pine Barrens fish are recognized: (1) characteristic species; (2) peripheral species; (3) introduced species; (4) anadromous species; and (5) marine species. The distribution of Pine Barrens fish species depends on three principal factors: (1) the requirement for sluggish streams or standing water with dense vegetation; (2) competition from similar or related species; and (3) tolerance of highly acidic waters (Hastings, 1984, 1998).

Several species of sunfish are important characteristic forms commonly found in the Pine Barrens. Included here are the blackbanded sunfish (*Enneacanthus chaetodon*), banded sunfish (*E. obesus*), bluespotted sunfish (*E. gloriosus*), and the mud sunfish (*Acantharchus pomotis*). The swamp darter (*Etheostoma fusiforme*), ironcolor shiner (*Notropis chalybaeus*), pirate perch (*Aphredoderus sayanus*), and yellow bullhead (*Ameiurus natalis*) are also characteristic species. Other more widespread species which belong to this group include the redfin pickerel (*Esox americanus*), chain pickerel (*Esox *niger*), American eel (*Anguilla rostrata*), brown bullhead (*Ameiurus nebulosus*), creek chubsucker (*Erimyzon oblongus*), eastern mudminnow (*Umbra pygmaea*), tesselated darter (*Etheostoma olmstedi*), and tadpole madtom (*Noturus gyrinus*).

Peripheral species are those forms relatively intolerant of acid waters, which typically occur in weakly acid or nonacid waters in marginal areas of the Pine Barrens. For example, in the lower reaches of the Mullica and Great Egg Harbor Rivers where saline waters buffer acid waters draining the Pinelands, the commonly occurring species are the yellow perch *(Perca flavescens*), white perch (*Morone americana*), white sucker (*Catostomus commersoni*), golden shiner (*Notemigonus crysoleucas*), spotted shiner (*Notropis hudsonius*), redbreasted sunfish (*Lepomis auritus*), mummichog (*Fundulus heteroclitus*), and banded killifish (*F. diaphanus*). Other species which may appear in peripheral waters of the Pine Barrens, but are relatively rare except in nonacid waters, are the comely shiner (*Notropis amoenus*), briddled shiner (*N. bifrenatus*), common shiner (*N. cornutus*), satinfin shiner (*N. analostanus*), gizzard shad (*Dorosoma cepedianum*), bluntnose minnow (*Pimephales notatus*), silvery minnow (*Hybognathus nuchalis*), margined madtom (*Noturus insignis*), fallfish (*Semotilus corporalis*), creek chub (*S. atromaculatus*), blacknose dace (*Rhinichthys atratulus*), and American brook lamprey (*Lampetra lamottei*).

A number of introduced species have also been documented in peripheral areas of the Pine Barrens. Examples are the black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), goldfish (*Carassius auratus*), carp (*Cyprinus carpio*), and largemouth bass (*Micropterus salmoides*). Three salmonid species, notably the rainbow trout (*Salmo gairdneri*), brown trout (*S. trutta*), and brook trout *(S. fontinalis*), also occur in these peripheral areas. The channel catfish (*Ictalurus punctatus*), black bullhead (*I. melas*), and flathead minnow (*Pimephales promelas*) may have been stocked in past years in Pine Barrens streams (U.S. Fish and Wildlife Service, 1996).

Several marine species migrate into the Mullica River and its tributaries to spawn. Anadromous fishes recorded in these waters are the striped bass (*Morone saxatilis*), American shad (*Alosa sapidissima*), hickory shad (*A. mediocris*), blueback herring (*A. aestivalis*), and alewife (*A. pseudoharengus*). They are generally confined to the tidal portion of the rivers and creeks (Hastings, 1998). Spawning runs were more common in past years when fewer dams obstructed upstream movements. Anadromous fish spawning is now largely confined to the lower reaches of the rivers due to human obstructions. The installation of fish ladders (e.g., at Lake Pohatcong) is a strategy to mitigate these impacts.

Various estuarine and marine species have also been found in other Pine Barrens river basins. Examples are the bay anchovy (*Anchoa mitchilli*), Atlantic menhaden (*Brevoortia tyrannus*), hogchoker (*Trinectes maculatus*), two-spined stickleback (*Gasterosteus aculeatus*), three-spined stickleback (*Apeltes quadracus*), weakfish (*Cynoscion regalis*), kingfish (*Menticirrhus saxatilis*), and Atlantic croaker (*Micropogonias undulatus*) (Patrick et al., 1998). These species utilize a variety of habitats in the river basins.

Zampella et al. (2001) collected 22 fish species in streams and impoundments of the Mullica River Basin (Table 12). Based on the work of Hastings (1984), the native Pinelands species can be categorized as restricted-characteristic or widespread-characteristic forms. The restricted-characteristic species are those forms mostly limited to the Pinelands and include the blackbanded sunfish (*Enneacanthus chaetodon*), banded sunfish (*Enneacanthus obesus*), mud sunfish (*Acantharchus pomotis*), pirate perch (*Aphredoderus sayanus*), yellow bullhead (*Ameiurus natalis*), and swamp darter (*Etheostoma fusiforme*). The widespread-characteristic species include those forms typically found in other parts of the state. This list includes the bluespotted sunfish (*Enneacanthus gloriosus*), chain pickerel (*Esox niger*), redfin pickerel (*Esox americanus*), creek chubsucker (*Erimyzon oblongus*), ironcolor shiner (*Notropis chalybaeus*), tadpole madtom (*Notorus gyrinus*), eastern mudminnow (*Umbra pygmaea*), and American eel (*Anguilla rostrata*).

Zampella et al. (2001) observed that the most frequently encountered native species in Pinelands streams were the eastern mudminnow, chain pickerel, swamp darter, and banded sunfish. The most frequently occurring non-native forms in Pinelands streams were the pumpkinseed (*Lepomis gibbosus*), bluegill, tessellated darter, largemouth bass, brown bullhead, golden shiner, and yellow perch. The banded sunfish, blackbanded sunfish, and bluespotted sunfish were the native species that dominated the impoundment assemblages. There was greater relative abundance of three non-native species (largemouth bass, bluegill, and pumpkinseed) in the impoundments than in the streams (Zampella et al., 2001).

Fish species that typically inhabit the Pine Barrens are rather sedentary forms associated with abundant vegetation. They are also predominantly acid-tolerant forms (Hastings, 1998). Fishes of the Pine Barrens have become well adapted to the artificial lakes, mill ponds, cranberry bogs and other human-made impoundments occurring in this unique environment (U.S. Fish and Wildlife Service, 1996).

Table 12. Taxonomic list of fish collected in the Mullica River Basin.

Common Name	Scientific Name
Mud sunfish	*Acantharchus pomotis*
Yellow bullhead	*Ameiurus natalis*
Brown bullhead	*Ameiurus nebulosus*
American eel	*Anguilla rostrata*
Pirate perch	*Aphredoderus sayanus*
Blackbanded sunfish	*Enneacanthus chaetodon*
Bluespotted sunfish	*Enneacanthus gloriosus*
Banded sunfish	*Enneacanthus obesus*
Creek chubsucker	*Erimyzon oblongus*
Redfin pickerel	*Esox americanus*
Chain pickerel	*Esox niger*
Swamp darter	*Etheostoma fusiforme*
Tessellated darter	*Etheostoma olmstedi*
Banded killifish	*Fundulus diaphanus*
Pumpkinseed	*Lepomis gibbosus*
Bluegill	*Lepomis macrochirus*
Largemouth bass	*Micropterus salmoides*
golden shiner	*Notemigonus crysoleucas*
Tadpole madtom	*Noturus gyrinus*
Yellow perch	*Perca flavescens*
Black crappie	*Pomoxis nigromaculatus*
Eastern mudminnow	*Umbra pygmaea*

From Zampella, R. A., J. F. Bunnell, K. J. Laidig, and C. L. Dow. 2001. The Mullica River Basin. Technical Report, New Jersey Pinelands Commission, New Lisbon, New Jersey.

Insects

Hundreds of insect species inhabit the Pine Barrens region, including a number of rare and threatened forms. Among the rare insect species in the Mullica River watershed are the rare skipper (*Problema bulenta*), occurring along Turtle Creek, and the precious underwing moth (*Catocala pretiosa pretiosa*) and Lemmer's pinion moth (*Lithophane lemmeri*), occupying areas along the upper tidal Mullica River. Other rare moth species observed in the Pinelands are the Pine Barrens underwing (*Catocala herodias gerhardi*), jair underwing (*Catocala jair* ssp. 2), Doll's merolonche (*Merolonche dolli*), coastal swamp metarranthis (*Metarranthis pilosaria*), spanworm moth (Itame sp. 1), notodontid moth (*Heterocampa varia*), and noctuid moths (*Ampharetra purpurea*, *Chytonic sensilis*, and *Zanclognatha* sp. 1). Two moth species, *Agrotis buchholzi* and *Crambus daeckellus*, are endemic to the Pine Barrens. Immediately upriver of the tidal influence in the Batsto watershed, numerous rare Lepidoptera (moths and butterflies) have been recorded (U.S. Fish and Wildlife Service, 1996).

Salt marshes in the JCNERR support a wide diversity of insects such as various species of aphids, beetles, leafhoppers, spiders, and mites. The northeastern beach tiger beetle (*Cincindela dorsalis dorsalis*), a federal threatened species, occupies parts of the Great Bay Boulevard Wildlife Management area and the Holgate Unit of the Forsythe National Wildlife Refuge. Wolf spiders (Lycosidae) are widespread in marsh and interior Pinelands zones (Boyd, 1991). Greenhead flies (*Tabanus nigrovittatus*), sand flies (*Culicoides* spp.), and stable flies (*Stomoxys calxitrans*) are ubiquitous pests in tidal salt marshes. Damselflies and dragonflies (*Odonata*) are also abundant in tidal wetland areas of the reserve. Five species of mosquitos breed in the coastal salt marshes, notably *Aedes* *sollicitans*, *A. cantator*, *A. taeniorhynchus*, *Anopheles bradleyi*, and *Culex salinarius*. Among these species, *A. sollicitans* is most abundant (Kennish, 2001a).

Arthropods are the most numerous fauna in the Pinelands. Boyd and Marucci (1998) subdivided the arthropods of the Pine Barrens into seven major groups: (1) arthropods other than insects; (2) insects found on vegetation in pine and oak woods; (3) insects inhabiting shrub and semi-open areas with scattered vegetation; (4) insects of open, sandy areas; (5) insects more often heard than seen; (6) insects living under bark and in dead trees and old stumps; and (7) insects living in aquatic and semi-aquatic habitats.

Arthropods other than insects are comprised of a number of important groups, including spiders (Arachnida), wood ticks (Acarina), and harvestment or Daddy-Long-Legs (Phalangida). Other significant members are harvest mites, chiggers, or redbugs (Acarina); sowbugs and pillbugs (Isopoda); millipedes (Diplopoda); and centipedes (Chilopoda). These organisms are often seen searching for food and habitat on or under all types of vegetation.

Among the insects found on vegetation in pine and oak forests, seven major groups are recognized. These include the grasshoppers (Orthoptera), walking sticks (Orthoptera), long-horned beetles (Coleoptera), weevils or snout beetles (Coleoptera), pine sawflies (Hymenoptera), gall wasps (Hymenoptera), and moths (Lepidoptera). A wide variety of moths inhabit the Pine Barrens, notably gypsy moths, underwing moths, as well as giant silkworm and royal moths. Many provide forage for birds particularly during the nesting season.

Insects predominating in shrub and semi-open areas with scattered vegetation are grasshoppers (Orthoptera), leafhoppers (Homoptera), froghoppers or spittlebugs (Homoptera), plant bugs and stink bugs (Hemiptera), ladybird beetles and leaf beetles (Coleoptera), butterflies (Lepidoptera), ichneumons (Hymenoptera), leaf-cutting ants (Hymenoptera), social wasps (Hymenoptera), as well as honey bees (Hymenoptera), bumble bees, and carpenter bees. Bees, especially honey bees, play a significant role in the pollination of plants. While carpenter bees build nests by boring holes and tunnels in wooden structures, bumble bees construct nests in cavaties in the ground, and honey bees occupy hives or may nest in hollow cavities in trees and other protected habitat.

Four major groups of insects prefer open, sandy areas. They are the antlions (Neuroptera), tiger beetles (Coleoptera), robber flies (Diptera), and velvet ants (Hymenoptera). Many of these insects are voracious predators (e.g., antlions and tiger beetles) consuming ants and other prey.

Insects more often heard than seen are the northern true katydid (Orthoptera), crickets (Orthoptera), and dog-day cicadas or harvestflies (Homoptera). All of these insects make acute audible sounds that can be heard over considerable distances. The katydids are most easily detected by the sounds they emit at night. Similarly, crickets are mainly noticed at night due to their high-pitched sounds. Cicadas, however, are commonly heard during the day by the loud and piercing sounds they emit from nearby shrubs or trees.

Wood cockroaches (Orthoptera), termites (Isoptera), ants (Hymenoptera), as well as click beetles and darkling or bark beetles (Coleoptera) are the main groups of insects found under bark and in dead trees and old stumps. Ants live in colonies of variable size, and they are prey of various predaceous arthropods. Although termites cause considerable destruction of domestic wooden structures, they convert dead trees and other vegetation to humus and thus play an important role in the natural breakdown process of dead organic matter. Wood cockroaches, click beetles, and bark beetles congregate under the bark of dead trees, fallen logs, and old stumps.

Among the most important arthropods observed in the JCNERR are insects found in aquatic and semi-aquatic habitats. For example, mosquitoes, black flies, horse flies, and deer flies (all Diptera) are very abundant in the region, persistently annoying humans and other mammals. In addition, dragonflies and damselflies (Odonata); water boatmen, blackswimmers, water bugs, waterscorpions, and water striders (all Hemiptera); as well as predaceous diving beetles, water scavenger beetles, and whirligig beetles (all Coleoptera) are representative members of this group. These organisms are found in an array of watershed habitats such as white cedar swamps, hardwood swamps, *Sphagnum* bogs, abandoned cranberry bogs, streams, and lakes.

ESTUARINE BIOTIC COMMUNITIES

Investigators from Rutgers University have periodically conducted studies of biotic communities in estuarine waters of the JCNERR since the 1950s. Studies by state and federal government agencies (e.g., New Jersey Department of Environmental Protection, U.S. Fish and Wildlife Service, and National Marine Fisheries Service), research laboratories (e.g., Academy of Natural Sciences of Philadelphia and Woods Hole Oceanographic Institution), and other academic institutions (Richard Stockton College) have augmented this work. Appendix 17 provides a list of publications, technical reports, and theses dealing with research and monitoring activities as well as ancillary investigations in the reserve. The following discussion gives an overview of the structure and dynamics of the biotic communities based on this earlier work.

Estuarine waters within the JCNERR support rich and diverse communites of estuarine and marine organisms (nekton, plankton, benthic flora and fauna, and marine mammals). The composition and distribution of these organisms in Great Bay, Little Egg Harbor, Little Bay, and contiguous waters are similar to those in other New Jersey coastal bays. The backbay systems of the JCNERR provide food, habitat, and shelter for hundreds of plant and animal species. Some of these species (e.g., blue crab, *Callinectes sapidus*; hard clam, *Mercenaria mercenaria*; bluefish, *Pomatomus saltatrix*; summer flounder, *Paralichthys dentatus*; winter flounder, *Pseudopleuronectes americanus*; weakfish, *Cynoscion regalis*; and white perch, *Morone americana*) are recreationally or commercially important. The following discussion details the floral and faunal communities inhabiting estuarine waters of the reserve.

Phytoplankton

The principal primary producers of the open estuarine waters of the reserve system are microscopic, free-floating plants (i.e., phytoplankton) - unicellular, filamentous, or chain-forming species - dominated by diatoms (Bacillariophyceae) and dinoflagellates (Dinophyceae). Although Durand and Nadeau (1972) and Durand (1988) conducted numerous field measurements of phytoplankton production in the Mullica River-Great Bay Estuary during the 1960s and 1970s, most investigations of phytoplankton species composition have been completed in Little Egg Harbor and Barnegat Bay to the north (Martin, 1929; Mountford, 1965, 1967, 1969, 1971; Olsen, 1989; Olsen and Mahoney, 2001). However, seasonal phytoplankton surveys have also been performed in Great Bay (Olsen and Mahoney, 2001).

Martin (1929) indentified 41 dinoflagellate species in Barnegat Bay, with the dominant forms being *Cymnodinium splendens*, *Prorocentrum micans*, and *P. triangulatum* (*P. minimum* var. *triangulatum*). Mountford (1967, 1969, 1971) reported 186 phytoplankton species in the Barnegat Bay-Little Egg Harbor Estuary, and he also documented red-tide blooms of *Gonyaulax spinifera* and *Prorocentrum triangulatum* in the system. Mountford (1971) noted that ultraplankton (spherical cells 2-4 µm in diameter mainly consisting of *Nannochloris atomus*) dominated the phytoplankton community in his studies, with concentrations up to 8 x 10^5 cells/ml in summer.

Olsen and Mahoney (2001) recorded a total of 132 phytoplankton species in the Barnegat Bay-Little Egg Harbor Estuary (including a supplementary sampling site in Great Bay) during seasonal phytoplankton surveys conducted between 1987 and 1998 (Table 13). Nonmotile coccoid picoplankters were numerically dominant. Aside from

Nannochloris atomus, the most widely distributed species within the embayment were *Skeletonema costatum*, *Cylindrotheca closterium*, *Nitzschia* spp., *Cyclotella* sp., *Prorocentrum minimum*, *Katodinium rotundatum*, *Heterosigma carterae*, *Euglena/Eutreptia* spp., *Chroomonas vectensis*, *C. amphioxiea*, *C. minuta*, *Pyramimonas* spp., *Calycomonas ovalis*, and *Chlorella* sp. Neritic or coastal forms predominated near inlet areas and primarily included centric diatoms (e.g., *Skeletonema*, *Thalassiosira*, *Cerataulina*, and *Chaetoceros* spp.) and the larger, thecate dinoflagellates (e.g., *Prorocentrum*, *Dinophysis*, *Protoperidinium*, and *Ceratium* spp.). Of the 132 phytoplankton species identified by Olsen and Mahoney (2001), 57 (~41% of the total) were dinoflagellates and 43 (31%) were diatoms. To date, 242 phytoplankton species have been chronicled in the estuary.

Table 13. List of phytoplankton species identified in the Barnegat Bay-Little Egg Harbor estuarine system from 1987 to 1998. An "X" before the species name indicates those not previously listed for the bay, by either Martin (1929) or Mountford (1971). Species followed by a slash (/) appeared frequently in low numbers, or were occasionally abundant. A plus (+) indicates those which were often abundant, attaining cell concentrations $>10^3$ ml^{-1}, with occasional mild blooms. An asterisk (*) denotes species which attained dominance or subdominance in seasonal blooms, exceeding 10^4 cells ml^{-1}. For *Nannochloris* and *Aureococcus* this criterion is an order of magnitude higher (to 10^5), since they typically appeared in substantially greater concentrations than other species. Two asterisks denote heavy blooms ($>5 \times 10^5$). The order of taxa generally follows that presented in Olsen and Cohn (1979), after Hendy (1974) for Bacillariophyceae; Butcher (1961) for Euglenophyceae; and Parke and Dixon (1976) for the other classes. In cases of synonyms or nomenclatural changes, species names with former priority are indented in parentheses under the respective names currently in usage.

CYANOPHYCEAE

X *Synechococcus* Nageli (sp.) (*)

CHRYSOPHYCEAE

HAPTOPHYCEAE

X *Chrysochromulina* Lackey (sp.) (/)

C. minor Parke and Manton (+)

Ochromonas Wyssotzki (sp.)

Caylcomonas Lohmann

C. gracilis Lohmann (/)

(*C. wulfi* Conrad and Kufferath)

X *C. ovalis* Wulff (*)

X *Apedinella* Throndsen

A. radians (Lohmann) Campbell

Distephanus Stohr

D. speculum (Ehrenbeg) Haeckel

Ebria Borgert

E. tripartita (Schumann Lemmermann)

RAPHIDOPHYCEAE [1]

X *Heterosigma* Ashakiwo

H. carterae (+)[2] Hulbert

(*Olisthodiscus luteus* Carter)

(*Heterosigma ashakiwo* Hada)

PELAGOPHYCEAE[1]

X *Aureococcus* Hargraves et Sieburth (**)

A. anophagefferens Hargraves

Cerataulina Schütt

C. pelagica (Cleve) Hendey (/)

(C. bergonii (Peragallo) Schütt)

Chaetoceros Ehrenberg (spp.) (/)

C. decipiens Cleve

X *C. sociale* Lauder

X *Pavlova* Butcher (sp.)

P. gyrans Butcher

P. lutheri (Droop) Green

(*Monochrysis lutheri* Droop)

BACILLARIOPHYCEAE

Melosira Agardh (sp.)

Leptocylindrus Cleve

L. danicus Cleve (/)

L. minimus Gran (+)

Skeletonema Greville

S. costatum (Greville) Cleve (+)

Cyclotella (Kutzing) DéBrebisson

X *C. caspia* Grunow

C. meneghiniana Kützing (+)

Thalassiosira Cleve

T. gravida Cleve (/)

T. nordenskioldii Cleve (/)

T. rotula Meunier

Coscinodiscus Ehrenberg (spp.)

Gyrosigma Hassall (sp.)

Amphiprora Ehrenberg (sp.)

Amphora Ehrenberg (sp.)

X *Phaeodactylum* Bohlin

P. tricornutum Bohlin (/)

Rhizosolenia Brightwell

R. alata Brightwell

R. delicatula Cleve (/)

R. setigera Brightwell

Guinardia Peragallo

G. flaccida (Castracane) Peragallo

Ditylum Bailey

D. Brightwelli (West) Grunow

(Triceratium brightwelli West)

Fragilaria Lyngbye (sp.)

Synedra Ehrenberg (sp.)

Asterionella Wm. Smith

A. glacialis Castracane (/)

(*A. japonica* Cleve and Müler)

Thalassiothrix Cleve and Grunow

T. frauenfeldii Grunow

Thalassionema (Grunow) Hustedt

T. nitzschioides Hustedt (/)

Licmophora Agardh (sp.)

Achnanthes Bory (sp.)

(Nitzschia closterium forma)

(*Nitzchia minutissima* Allen & Nelson)

Nitzschia Hassall (spp.) (+)

X *N. elegans* Hustedt

X *N. longissima* (deBrébisson) Ralfs

X *N. proxima* Hustedt

Pseudonitzschia Cleve

P. seriata (Cleve) Peragallo

(*Nitzschia seriata* Cleve)

Cylindrotheca Rabenhorst

C. closterium (Ehrenberg) Leiman Lewis (+)

(*Nitzschia closterium* Ehrenberg)

X *Minutocellus* Hasle[3]

M. polymorphus Hargraves et Guillard (*)

CHLOROPHYCEAE

Chlamydomonas Ehrenberg (sp.)

X *C. vectensis* Butcher (+)

X *Chlorella* Beijerinick (sp.) (*)

Scenedamus Meyen

S. quadricauda (Turpin) de Brébission

Cocconeis Ehrenberg (sp.) (/)

Navicula Bory (spp.) (/)

Caloneis Cleve (sp.)

Mastogloia Thwaite (sp.)

Pleurosigma Wm. Smith (sp.) (/)

Bipedinomonas Carter

X *B. pyriformis* Carter (/)

(*Heteromastix pyriformis* Carter)

Pyraminomonas Schmarda (sp.) (+)

X *P. grossii* Parke (/)

X *P. micron* Conrad and Kufferath (+)

X *Tetraselmis* Stein (/)

T. gracilis (Kylin) Butcher

T. maculata Butcher

EUGLENOPHYCEAE

Eutreptia Perty

X *E. lanowii* Steuer (/)

X *E. viridis* Perty (/)

Euglena Ehrenberg (sp.)

X *E. deses* Ehrenberg

X *E. proxima* Dangeard (/)

DINOPHYCEAE

Prorocentrum Ehrenberg

P. aporum (Schiller) Dodge

(*Exuviella apora* Schiller)

P. lima (Ehrenberg) Dodge (/)

Nannochloris Naumann

N. atomus Butcher (**)

PRASINOPHYCEAE

X *Pedinomonas* Korshikov

P. minor Korshikov

Dinophysis Ehrenberg

D. acuminata Claparède and Lachmann

D. acuta Ehrenberg

X *D. lachmanii* Paulsen

Amphidinium Claparède and Lachmann (sp.)

X *A. crassum* Lohmann

A. fusiforme Martin (/)

Gymnodinium Stein (spp.) (/)

X *G. amplinucleum* Campbell

X *G. danicans* Campbell (/)

X *G. galesianum* Campbell

X *G. gracilentum* Campbell

X *G. lazulum* Hulburt

G. nelsoni Martin (/)

G. punctatum Pouchet

G. splendens Lebour

X *G. subroseum* Campbell

X *G. transluciens* Campbell

Gyrodinium Kofoid and Swezy (spp.)

X *G. cf aureolum* Hulburt

G. dominans Hulburt

(*E. marina* Cienkowski)

P. micans Ehrenberg (/)

P. minimum (Pavillard) Schiller (+)

P. minimum var. *triangulatum* (Martin) Hulbert (/)

(*P. triangulatum* Martin)

P. scutellum Schröeder

P. triestinum Schiller (/)

(*P. redfieldi* Bursa)

Polykrikos Bütschli

P. kofoidii Chatton

Diplopsalis Meunier

D. lenticula Bergh

Glenodiniun Ehrenberg

G. danicum Panslen

Heterocapsa Stein

H. triquetra (Ehrenberg) Stein (/)

(*Peridinium triquetrum* (Stein) Meunier)

Oblea Balech

O. rotunda (Lebour) Balech (/)

(*Peridiniopsis rotunda* Lebour)

Protoperidinium Bergh (spp.)

X *G. estuariale* Hulburt (+)

X *G. metum* Hulburt (/)

G. pellucidum Wulff (/)

Katodinium Fott

X *K. asymmetricum* (Massart) Loeblich III

(*Massartia asymmetrica* (Massart) Schiller)

X *K. rotundatum* (Lohmann) Loeblich III (+)

(*M. rotundata* (Lohmann) Schiller)

G. scrippsae Kofoid

G. spinifera (Claparede and Lachmann) Diesing (/)

X *Alexandrium* Halim (sp.)

A. tamarense (Lebour) Balech

Ceratium Schrank

C. fusus (Ehrenberg) Dujardin

C. minutum Jorgensen

C. tripos (Muller) Nitzsch

CRYPTOHYCEAE

X *Hemiselmis* Parke

H. virescens Droop (/)

Chroomonas Hansgirg (sp.) (+)

	(*Peridinium* Ehrenberg)	X	*C. amphioxiea* (Conrad and Kufferath)
X	*P. achromaticum* Levander		Butcher (/)
	P. brevipes Paulsen		(*Rhodomonas amphioxiea* Conrad)
X	*P. aciculiferum* Lemmermann	X	*C. caroliniana* Campbell (/)
	P. excavatum Martin	X	*C. minuta* (Skuja) Campbell (+)
	Scrippsiela Balech et Loeblich III		(*R. minuta* Skuja)
	S. trochoidea (Stein) Loeblich III (/)	X	*C. vectensis* Carter (+)
	(*Peridinium trochoideum* (Stein)		*Cryptomonas* Ehrenberg (sp.) (/)
		X	*C. testacea* Campbell
	Gonyaulax Diesing (sp.)		
X	*G. diacantha*		

[1] Taxa of uncertain position; these genera formerly included under Chrysophyceae

[2] *H. carterae* has been misidentified in the region as *O. luteus*

[3] Species of uncertain position

From Olsen, P. S. and J. B. Mahoney. 2001. Phytoplankton in the Barnegat Bay-Little Egg Harbor estuarine system: species composition and picoplankton bloom development. *Journal of Coastal Research*, SI 32: 115-143.

Olsen and Mahoney (2001) also described widespread and prolonged phytoplankton blooms in the Barnegat Bay-Little Egg Harbor Estuary between 1985 and 2000, with the greatest prevalence (> 10^6 cells/ml) in the southern part of the system (i.e., Little Egg Harbor). *Nannochloris atomus* dominated these blooms. In addition, the coccoid picoplankter, *Aureococcus anophagefferens*, has been responsible for repeated brown-tide blooms in Little Egg Harbor; concentrations of this organism have exceeded 10^6 cells/ml during some bloom events. Brown-tide blooms in the estuary were documented in 1995, 1997, and 1999-2002, and they may have adversely affected SAV and hard clam (*Mercenaria mercenaria*) beds (Mary Gastrich, NJDEP, personal communication, 2004).

Chronic phytoplankton blooms can adversely affect estuarine systems in several ways. In the Barnegat Bay-Little Egg Harbor Estuary, for example, phytoplankton blooms have reduced aesthetic water quality by discoloring the water a murky greenish and yellowish-brown hue in the summer as picoplankton numbers escalate. *Aureococcus* blooms inhibit the feeding and growth of bivalves, notably the hard clam. Shading effects of the blooms may also be responsible for a decline in faunal habitat in some areas due to persistent light attenuation.

Moser (1997) showed that phytoplankton production in the estuary amounted to ~480 g C/m^2/yr, and phytoplankton biomass, ~10 mg chlorophyll *a*/m^3. Because nutrient inputs are highest in the more heavily developed northern estuary, phytoplankton production and biomass peak in this region. Nitrogen is the primary limiting nutrient to phytoplankton growth, with organic nitrogen being the dominant form. The highest concentrations of organic nitrogen (~40 μM) occur during summer. Inorganic nitrogen forms are present in low concentrations. Mean ammonium levels are < 2.5 μM, and mean nitrate plus nitrite levels are ~2.0 μM. Highest ammonium concentrations occur in summer, whereas peak nitrate plus nitrite levels exist from late fall to spring. Total nitrogen levels in the estuary generally range from ~20 to 80 μM. Phosphate concentrations in the system are much lower, being < 1 μM (Seitzinger et al., 2001).

Durand and Nadeau (1972) discussed seasonal phytoplankton production in Great Bay. They noted that phytoplankton production peaks in the summer months, declines in the fall, and remains low until late winter (February-March) when a phytoplankton bloom develops. Phytoplankton production gradually increases from the spring into the summer.

Chlorophyll *a*, a measure of phytoplankton biomass, also attains highest levels during the summer. Chlorophyll *a* minima are evident during the winter when temperature, light intensity, and light duration decline dramatically. Intermediate chlorophyll *a* values usually take place during the spring and fall.

Durand (1984) examined the relationship between phytoplankton production, nitrogen supply, and light penetration/depth in the Mullica River-Great Bay system. He showed that highest concentrations of nitrate (1-7 μg-at/L) and ammonium (~10-30 μg-at/L) in Great Bay and the backbays to the south occur in the late summer and fall. Appendix 18 provides measurements of gross primary productivity and phytoplankton nitrogen requirements at the lower end of the Mullica River in 6 m of water, at the head of the bay in 3 m of water, and at a down-bay site in 1.7 m of water. The productivity values are generally higher at the down-bay site, ranging up to 1,362 mg C/m^2/day. At the head of the bay, productivity ranges from 419-958 mg C/m^2/day. At the lower Mullica River site, productivity values range from 422-1,081 mg C/m^2/day.

The Mullica River averages ~5-9 m in depth from its mouth to the Lower Bank site ~25 km upriver. Great Bay is shallower, averaging ~2 m in depth at mean low water. The compensation depth in the system averages ~1.5 m. However, turbidity is higher in the river due to tannins and humic compounds, which restricts phytoplankton production to only the upper ~25% of the water column. With much clearer conditions in the bay, phytoplankton production occurs throughout the water column. Nutrients are underutilized in the river because of the limited light penetration. The greater water clarity in the bay enables the phytoplankton to utilize the nutrients more effectively, thereby resulting in significantly higher production.

Zooplankton

The zooplankton community consists of numerous diminutive species that drift passively in the water column due to limited capability of locomotion. They comprise the principal herbivorous component of estuaries in the reserve. As such, they represent important intermediate food-web constituents, consuming phytoplankton and serving as forage for numerous benthic and nektonic organisms. While most zooplankton consume phytoplankton, some species are carnivores, detritivores, and omnivores. Zooplankton ingest food principally via filter feeding, although raptorial feeding is also common.

Zooplankton communities in estuarine and coastal marine waters are often dominated by protozoans, cnidarians, mollusks, annelids, arthropods, echinoderms, chaetognaths, and chordates (Omori and Ikeda, 1984). Zooplankton may be classified by three principle criteria: size, taxonomy, or length of planktonic life. On the basis of size, three zooplankton groups are recognized: (1) microzooplankton (< 64 µm); mesozooplankton (64-250 µm); and (3) macrozooplankton (> 250 µm). On the basis of duration of planktonic life, zooplankton are subdivided into the following groups: (1) holoplankton (which spend their entire life in the plankton); (2) meroplankton (which occur in the plankton for only a portion of their life cycle); and (3) tychoplankton (which primarily include benthic organisms temporarily translocated into the water column by currents, behavioral activity, or other means).

Protozoans (e.g., foraminiferans, radiolarians, rotifers, and tintinnids) dominate the microzooplankton of estuaries. Among the mesozooplankton, the predominant forms are copepods, cladocerans, rotifers, and meroplankton of various taxa (e.g., bivalves, gastropods, polychaetes, barnacles, and cyphonautes). The macrozooplankton consists mainly of the jellyfish group (i.e., hydromedusae, comb jellies, and true jellyfishes) and crustaceans (i.e., amphipods, isopods, mysid shrimp, and true shrimp).

Durand and Nadeau (1972) conducted the most detailed study of the zooplankton community of the Mullica River-Great Bay system. Loveland et al. (1969), Mountford (1971, 1980), and Tatham et al. (1977, 1978) examined the zooplankton of the Barnegat Bay-Little Egg Harbor Estuary. Sandine (1984) and Kennish (2001b) provided an overview of zooplankton research in the Barnegat Bay-Little Egg Harbor system; most of this work has focused on Barnegat Bay, with the zooplankton community of Little Egg Harbor being largely uncharacterized.

Although Durand and Nadeau (1972) registered a large number of zooplankton species during a seasonal sampling period, only two or three forms dominated the community in terms of absolute abundance, accounting for ~80% of all organisms collected. Species diversity was generally greater in the bay than at upriver sites due in large part to the influx of populations from the nearshore ocean, notably copepods. The total counts of zooplankton at the four sampling stations in the system (i.e., Lower Bank, French Point, Graveling Point, and RUMFS) peaked during the March through September period, averaging 6,371 organisms/100 L (Table 14). Much lower zooplankton abundance occurred during the October through February period, averaging 1,075 organisms/100 L or less. Minimum abundance was recorded in December and January. Fall and winter reduction in zooplankton abundance was greatest in the Mullica River. Highest zooplankton abundance was observed in the lower-river to mid-bay region.

Copepods were particularly important members of the zooplankton community. For example, copepod nauplii comprised 36.6-53.8% of the total zooplankton counts each year. In the lower river to mid-bay region, they constituted 50-70% of the total zooplankton numbers. Both calanoid and harpacticoid species were abundant, with nine calanoid and five harpacticoid species being identified. The most dominant copepod species in terms of total numbers appeared to be *Acartia tonsa*, *Eurytemora affinis*, and *Oithona similis*. Of these three species, *A. tonsa* dominated in the bay, and *E. affinis* dominated in the river. The coastal form, *O. similis*, reached highest concentrations near Little Egg Inlet. Other copepod species identified in the bay included *Paracalanus crassirostris*, *P. parva*, *Centropages hamatus*, *C. typicus*, *Temora longicornis*, *Pseudocalanus minutus, Pseudodiaptomus coronatus*, *Tortanus discaudatus*, and *Labidocera aestiva*.

Table 14. Monthly mean abundance of zooplankton in the Mullica River-Great Bay Estuary.[1]

Month	Lower[2] Bank	French[3] Point	Graveling[4] Point	Rutgers Marine Field Station[5]
October	--	4.59	2.71	5.27
November	--	--	3.12	0.85
December	12.29	4.08	0.18	0.78
January	1.46	2.47	1.27	4.50
February	5.17	3.69	6.78	--
March	57.87	10.93	34.49	13.49
April	25.65	335.44	48.94	24.50
May	39.02	54.06	35.68	--
June	126.28	118.78	33.60	32.07
July	82.42	64.70	41.72	30.47
August	214.52	56.87	36.08	32.84
September	15.31	46.60	96.47	45.28
October	5.47	19.39	3.64	39.00
November	5.67	7.62	18.11	--
December	11.06	1.42	0.35	--
January	2.46	1.95	55.85	--
February	1.90	3.17	23.20	--
March	43.55	14.18	171.94	--
April	53.72	35.61	102.56	26.51
May	517.45	18.71	42.77	--
June	103.40	9.51	25.44	4.73

[1]Number/liter

[2]25 km upriver

[3]Mouth of the Mullica River

[4]Head of Great Bay

[5]Near Little Egg Inlet

From Durand, J. B. and R. J. Nadeau. 1972. Water resources development in the Mullica River Basin. Part I. Biological evaluation of the Mullica River-Great Bay Estuary. Technical Report, New Jersey Water Resources Research Institute, Rutgers University, New Brunswick, New Jersey.

Rotifers and cladocerans attained maximum abundance at the Lower Bank site. Peak numbers of rotifers (> 4,000 organisms/100 L) occurred in March and highest numbers of cladocerans (19,000 organisms/100 L), in August. Very low abundances of cladocerans were registered at the other three sampling sites.

In previous studies of the Barnegat Bay-Little Egg Harbor Estuary, calanoid copepods (notably *Acartia tonsa, A. hudsonica, and Oithona colcarva*) dominated the microzooplankton. During the summer months, *A. tonsa* and *O. colcarva* were most abundant, and during the winter months, *A. hudsonica* predominated. Abundance of microzooplankton peaked during the spring and summer months, when maximum mean monthly densities exceeded 1 x $10^5/m^3$ (Tatham et al., 1977, 1978; Sandine, 1984; Kennish, 2001b).

Microzooplankton can attain very high abundances. For example, Tatham et al. (1977, 1978) documented maximum mean monthly densities of microzooplankton in the Barnegat Bay-Little Egg Harbor Estuary exceeding $100,000/m^3$. They reported the maximum density of rotifers (3.8 x $10^5/m^3$) and tintinnids (1.6 x $10^5/m^3$) during the September 1975 to August 1977 sampling period. Pulses of meroplankton added greatly to the spring and summer microzooplankton maxima. Peak numbers of bivalve larvae were obtained during the spring, although the larvae occurred year-round. Highest reported monthly densities of bivalve larvae approached 20,000/m^3. Gastropod larvae also occurred in the estuary year-round, with maximum mean monthly densities ranging from ~1,000-10,000/m^3 during the May through September period. The maximum mean monthly densities of both barnacle and polychaete larvae were recorded in the spring, when they exceeded 10,000/m^3.

Various crustacean and coelenterate taxa dominate the macrozooplankton in the Barnegat Bay-Little Egg Harbor Estuary. Among the most abundant macrozooplankton are *Rathkea octopunctata, Neomysis americana, Neopanope texana, Panopeus herbstii, Crangon septemspinosa, Jassa falcata, Sarsia* spp., and *Sagitta* spp. For example, the hydromedusae, *R. octopunctata*, has attained maximum mean monthly densities greater than 200/m^3 (Tatham 1977, 1978; Sandine, 1984). During night sampling, *N. americana* has reached maximum densities of nearly 120/m^3 and *N. texana*, densities of nearly 58,000/m^3.

Some macrozooplankton, such as arrow worms (*Sagitta* spp.) and ctenophores (*Mnemiopsis leidyi* and *Beroe* sp.), are major predators of other zooplankton (Mountford, 1980). For instance, *M. leidyi* consumes large numbers of microzooplankton, especially copepods, and reaches maximum densities above 100/m^3. Beroe sp., in turn, preys heavily on *M. leidyi*.

Ichthyoplankton comprise a significant fraction of the total zooplankton in the Barnegat Bay-Little Egg Harbor Estuary. Eggs and larvae of bay anchovy (*Anchoa mitchilli*) and larvae of gobies (*Gobiosoma* spp.) are the most abundant ichthyoplankton forms during the warmer months of the year from June through September. Sandine (1984) reported larval densities of bay anchovy and gobies amounting to $52/m^3$ and $18/m^3$, respectively. Other relatively abundant ichthyoplankton observed during the warmer months of the year include larvae of the Atlantic menhaden (*Brevoortia tyrannus*), American eel (*Anguilla rostrata*), cunner (*Tautogolabrus adspersus*), hogchoker (*Trinectes maculatus*), and northern pipefish (*Syngnathus fuscus*) (Kennish, 2001b). Bay anchovy eggs are extremely abundant, accounting for more than 90% of all fish eggs sampled in the bay. During the January through April period, larvae of the winter flounder (*Pseudopleuronectes americanus*) and sand lance (*Ammodytes* sp.) dominate the ichthyoplankton. Significant winter flounder larval densities ($> 60/m^3$) have been recorded in the estuary. Elvers of the American eel are also common during this winter-spring period (Sandine, 1984).

Benthic Communities

The benthic communities of Great Bay, Little Egg Harbor, and the small back-bays to the south (i.e., Little Bay, Reeds Bay, and Absecon Bay) consist of a wide array of flora and fauna. Dominant benthic flora in estuarine waters of the reserve include eelgrass (*Zostera marina*), widgeon grass (*Ruppia maritima*), various species of macroalgae (e.g., *Ulva lactuca, Ceramium fastigiatum,* and *Gracilaria tikvahiae*), and microalgae (e.g., diatoms). In addition to their role as primary producers, benthic flora, particularly seagrasses, are important habitat formers in the system. Submerged aquatic vegetation (SAV), *Z. marina* and *R. maritima*, provides habitat for epibiota (on leaves and stems), infauna, and nekton. Some commercially important species (e.g., *Callinectes* *sapidus*, *Argopecten irradians*, and *Tautoga onitis*) use seagrasses during early development or as adult habitat (Bologna et al., 2000). SAV serves as vital spawning, nursery, and feeding grounds for many estuarine organisms in the reserve.

Benthic invertebrates are classified taxonomically, and can also be differentiated on the basis of size, life habits, and adaptations, as well as mode of obtaining food. Based on taxonomy, most major phyla are represented by the estuarine benthos of the reserve, with members of the Mollusca, Annelida, Arthropoda, Echinodermata, Cnidaria, Ctenophora, and Chordata predominating. Based on size, four classes of benthic invertebrates are recognized: microfauna, meiofauna, macrofauna, and megafauna. Microfauna (mainly protozoans) are diminutive forms that pass through sieves of 0.04-0.1 mm mesh. Meiofauna (e.g., nematodes, ostracods, gastrotrichs, mystacocarids, tardigrades, and turbellarians) pass through 0.5 mm mesh, but are retained by sieves of 0.04-0.1 mm mesh. Larger invertebrates captured by sieves of 0.5-2 mm mesh constitute the macrofauna. The largest invertebrates (e.g., adult bivalves, gastropods, and crabs), most frequently collected by nets and dredges rather than bottom grab samplers, comprise the megafauna.

Although the most conspicuous members of the benthic invertebrate community are epibenthic and infaunal forms, many others are interstitial, boring, swimming, and commensal-mutualistic types. Four categories of benthic fauna are also delineated based on their mode of obtaining food. These are deposit feeders, suspension feeders, herbivores-scavengers, and parasites.

Benthic Fauna

Durand and Nadeau (1972) conducted the most detailed investigations of the benthic invertebrate community in Great Bay, collecting samples throughout much of the bay in 1968 with a Petersen dredge and a modified oyster dredge (Figures 26 and 27). A large database exists on the benthic faunal and floral communities of Barnegat Bay as reported by Loveland and Vouglitois (1984), Loveland et al. (1984), and Kennish (2001a). However, most of this work was conducted during the 1969-1972 period. More recent studies of benthic organisms in the Barnegat Bay-Little Egg Harbor Estuary include those of McLain and McHale (1997), Moser (1997), Lathrop et al. (2001a, b), Wootton and Zimmerman (2001), Kennish et al. (2004a, b, 2007a, b, 2008). With exception to recent work on SAV, the benthic communities of Little Egg Harbor remain poorly characterized. Much of the following discussion on the benthic fauna in Great Bay and Little Egg Harbor derives from the surveys of Durand and Nadeau (1972) and Moser (1997), respectively.

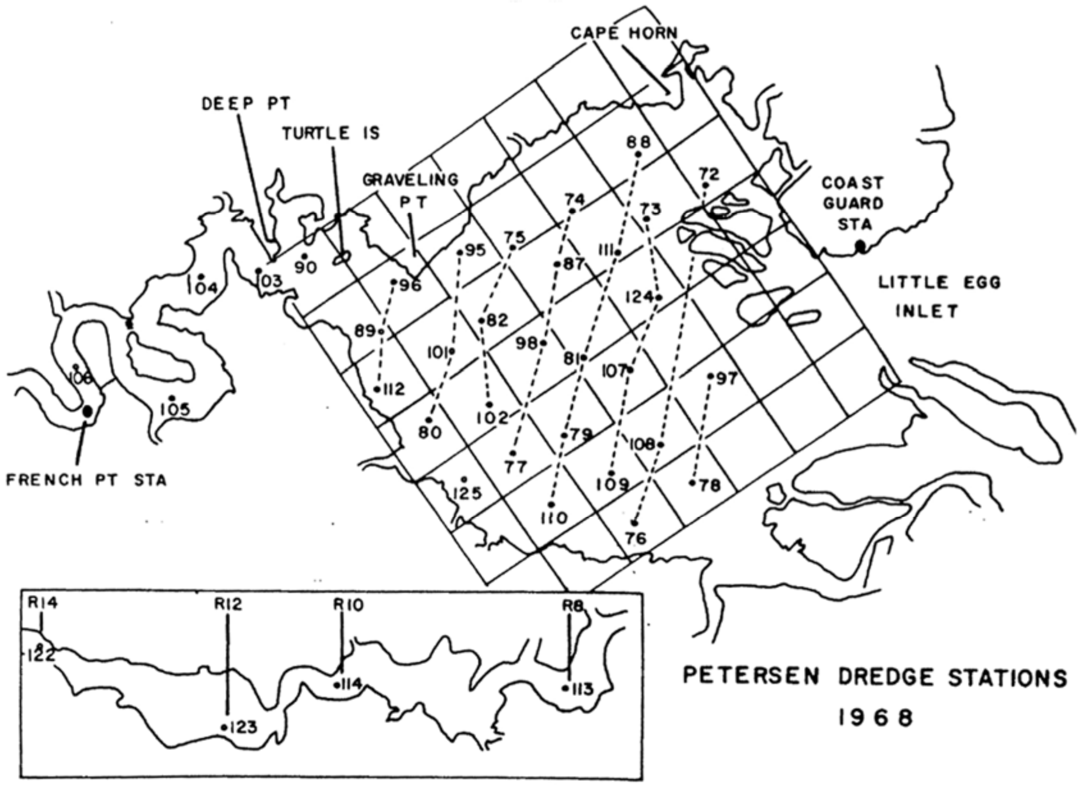


Figure 26. Benthic invertebrate sampling stations of Durand and Nadeau in the Mullica River-Great Bay Estuary. Modified from Durand, J. B. and R. J. Nadeau. 1972. Water Resources Development in the Mullica River Basin. Part I. Biological Evaluation of the Mullica River-Great Bay Estuary. Technical Report, New Jersey Water Resources Research Institute, Rutgers University, New Brunswick, New Jersey. 138 p.

Durand and Nadeau (1972) recorded 143 benthic invertebrate species in Petersen dredge samples collected in Great Bay (Appendix 19). This species list may be compared to the taxonomic list of benthic invertebrates reported for Barnegat Bay for the 1969 to 1973 period (Loveland and Vouglitois, 1984) (Table 15). It contains more than 200 benthic invertebrate species.

Table 15. Taxonomic list of benthic invertebrates found in Barnegat Bay.

Phylum Porifera	
Class Demospongiae	*Cliona celata* (Grant)
	Halichondria bowerbanki (Burton)
	Halichondria Panicea (Pallas)
	Haliclona sp.
	Microciona prolifera (Ellis and Solander)
Phylum Cnidaria	
Class Hydrozoa	
Order Athecata	*Hydractinia echinata* (Fleming)
	Pennaria tiarella (Ayres)
	Tubularia crocea (L. Agassiz)
Order Thecata	*Campanularidae* sp.
	Obelia commissuralis (McCrady)
	Thuiaria argentea (Linnaeus)
Class Anthozoa	

Order Actiniaria	*Diadumene leucolena* Verrill
	Edwardsia elegans Verrill
	Halcampoides sp.
	Haliplanella luciae Verrill
	Haloclava producta (Stimpson)
	Metridium senile (Linnaeus)
	Haliplanella luciae (Verrill)
	Actinothoe modesta(Verrill)
Order Ceriantharia	*Cerianthus americanus* Verrill
Phylum Platyhelminthes	
Class Turbellaria	*Euplana gracilis* (Girard)
	Stylochus ellipticus (Girard)
Phylum Nemertinea	
Class Anopla	*Carinoma tremaphoros* (Leidy)
	Cerbratulus lacteus (Leidy)
Phylum Sipunculida	*Golfingia improvisum* Theel
	Golfingia sp.

Phylum Annelida

Class Polychaeta

Order Phyllodocida

Family Phyllodocidae	*Eteone heteropoda* Hartman
	Eteone lactea Claparede
	Eulalia viridis (Linnaeus)
	Eumida sanguinea (Oersted)
	Paranaitis speciosa (Webster)
	Phyllodoce arenae (Webster)
	Phyllodoce maculata (Linnaeus)
Family Polynoidae	*Harmothoe imbricata* (Linnaeus)
	Harmothos oerstedi (Malmgren)
	Lepidonotus squamatus (L.)
Family Sigalionidae	*Stenelais boa* (Johnston)
Family Chrysopetalidea	*Dysponetus pygmaeus* Levinsen
Family Glyceridae	*Glycera americana* Leidy

	Glycera capitata Oersted
	Glycera dibranchiata Ehlers
Family Goniadidae	Glycinde solitaria Webster
	Goniada maculata Oersted
	Ophioglycera gigantean Verrill
Family Nephtyidae	*Nephtys incisa* Malmgren
	Nephtys picta Ehlers
Family Syllidae	*Autolytus cornutus* (A. Agassiz)
Family Hesionidae	*Gyptis vittata* Webster and Benedict
	Podarke obsura Verrill
Family Nereidae	*Nereis arenaceodonta* Moore
	Platynereis dumerilii (Verrill)
	Nereis pelagica Linnaeus
	Nereis succinea (Frey and Leukart)
	Nereis virens Sars
Order Capitellida	
Family Capitellidae	*Capitella capitata* (Fabricius)

	Notomastus latericeus Sars
Family Maldanidae	*Clymenella torquata* (Leidy)
	Clymenella zonalis (Verrill)
	Maldane sarsi Malmgren
	Maldinopsis elongata (Verrill)

Order Spionida

Family Spionidae	*Polydora ligni* Webster
	Scolecolepides viridis (Verrill)
	Scolelepis squamata (O. F. Muller)
	Spio filicornis (O. F. Muller)
	Spio setosa Verrill
Family Chaetopteridae	*Spiochaetopterus oculatus* Webster
Family Sabellariidae	*Sabellaria vulgaris* Verrill

Order Eunicida

Family Onuphidae	*Diopatra cuprea* (Bosc)
Family Eunicidae	*Marphysa sanguinea* (Montagu)
Family Arabellidae	*Arabella iricolor* (Montagu)

Family Dorvilleidae	*Stauronereis ruda* (Della Chiaje)

Order Ariciida

Family Orbiniidae	*Orbinia norvegica* (Sars)
	Scoloplos fragilis (Verrill)
	Scoloplos robustus (Verrill)

Order Cirratulida

Family Cirratulidae	*Cirratulus grandis* Verrill
	Tharyx acutus Webster and Benedict

Order Terebellida

Family Pectinariidae	*Pectinaria gouldii* (Verrill)
Family Ampharetidae	*Asabellides oculata* (Webster)
Family Terebellidae	*Amphitrite cirrata* O.F. Muller
	Amphitrite johnstoni Malmgren
	Amphitrite ornata (Leidy)
	Pista cristata (O.F. Muller)

	Pista palmata (Verrill)
	Polycirrus eximius (Leidy)
	Polycirrus medusa Grube
	Terebellides stroemi Sars
Order Flabelligerida	
Family Flabelligeridae	*Pherusa plumose* (O. F. Muller)
Order Sabellida	
Family Sabellidae	*Sabella crassicornis* Sars
	Sabella microphthalma (Verrill)
Family Serpulidae	*Hydroides dianthus* (Verrill)
Phylum Arthropoda	
Class Xiphosurida	*Limulus polyphemus*Linnaeus
Class Pycnogonida	*Callipallene brevirostris* (Johnston)
	Tanystylum orbiculare (Wilson)

Class Crustacea

Order Thoracica	*Balanus balanoides* (Linné)
	Balanus eburneus (Gould)
	Balanus imprvisus (Darwin)
Order Mysidacea	*Heteromysis formosa* (Smith)
	Neomysis americana (Smith)
Order Cumacea	*Oxyurostylis smithi* (Calman)
Order Tanaidacea	*Leptochelia savignyi* (Kroyer)
Order Isopoda	*Cyathura polita* (Stimpson)
	Edotea triloba (Say)
	Erichsonella attenuata (Harger)
	Erichsonella filiformis (Say)
	Idotea baltica (Pallas)
	Lironeca ovalis (Say)
Order Amphipoda	
Family Lysianassidae	*Lysianopsis alba* Holmes

Family Ampeliscidae	*Ampelisca abdita* Mills
	Ampelisca Macrocephala Liljeborg
	Ampelisca vadorum Mills
	Ampelisca verrilli Mills
Family Calliopiidae	*Calliopius laeviusculus* (Kroyer)
Family Gammaridae	*Elasmopus laevis* Smith
	Gammarus lawrencianu Bousfield
	Gammarus mucronatus Say
	Maera danae Stimpson
	Melita nitida Smith
Family Bateidae	*Batea catharinensis* Muller
Family Pontogeneidae	*Pontogeneia inermis* (Kroyer)
Family Hyalidae	*Hyale* sp.
Family Corophiidae	*Cerapus tubularis* Say
	Corophium tuberculatum Shoe-maker
	Erichthonius sp.

	Unciola irrorata Say
Family Ampithoidae	*Ampithoe longimana* Smith 1873
	Ampithoe rubricate Montagu 1813
	Cymadusa compta Smith
Family Ischyroceridea	*Jassa falcate*a (Montagu) 1818
	Isochyroceros anguipes Kroyer 1838
Family Aoridae	*Lembos smithi* Holmes 1905
	Microdeutopus gryllotal Costa 1853
Family Caprellidae	*Aeginella longicornis* Kroyer
	Caprella geometrica Say
	Caprella linearis Say
Order Decapoda	
Family Hippolytidae	*Hippolyte zostericola* (Smith)
Family Crangonidae	*Crangon septemspinosa* Say
Family Palaemonidae	*Palaemonetes pugio* Holthuis

	Palaemonetes vulgaris (Say)
Family Majidae	*Libinia dubia* Milne-Edwards
Family Cancridae	*Cancer irroratus* Say
Family Xanthidae	*Eurypanopeus depressus* (Smith)
	Neopanope texana (Smith)
	Panopeus herbstii H. Milne-Edwards
	Rhithropanopeus harrisii (Gould)
Family Portunidae	*Callinectes sapidus* Rathbun
	Carcinus maenus (Linnaeus)
	Ovalipes ocellatus (Herbst)
Family Paguridae	*Pagurus longicarpus* Say
	Pagurus pollicaris Say
Phylum Mollusca	
Class Gastropoda	
Order Mesogastropoda	*Bittium alternatum* (Say)

	Crepidula convexa Say
	Crepidula fronicata (Linnaeus)
	Crepidula plana Say
	Epitonium rupicola Kurtz
	Littorina saxatilis (Olivi)
	Polinices duplicatus (Say)
	Triphora nigrocincta (Adams)
Order Neogastropoda	*Anachis avara* (Say)
	Busycon canaliculatum (Linnaeus)
	Busycon carica (Gmelin)
	Eupleura caudata (Say)
	Mitrella lunata (Say)
	Ilyanassa obsoleta (Say)
	Nassarius trivittatus (Say)
	Nassarius vibex (Say)
	Urosalpinx cinerea (Say)
Order Cephalaspidea	*Acteon punstostriatus* (C. B. Adams)
	Haminoea solitaria (Say)
	Turbonilla interrupta (Totten)
	Acteocina canaliculata (Say)

Order Nudobranchia	*Doridella obscura* (Verrill)
	Doridella sp.
	Cratena pilata (Gould)
	Cratena sp.
	Cuthona concinna (Alder and Hancock)

Class Bivalvia

Order Protobranchia	*Nucula proxima* Say
	Solemya vellum Say
	Yoldia limatula (Say)
Order Prionodontia	*Anadara ovalis* (Bruguiere)
Order Pteroconchida	*Argopecten irradians* (Lamarck)
	Crassostrea virginica (Gmelin)
	Geukensia demissa (Dillwyn)
	Modiolus modiolus Linnaeus
	Mytilus edulis (Linné)
Order Heterodontida	*Chiona cingenda* Dillwyn
	Ensis directus Conrad
	Gemma gemma (Totten)

	Laevicardium mortoni Conrad
	Macoma balthica (Linné)
	Macoma tenta (Say)
	Mercenaria mercenaria (Linné)
	Mulinia lateralis (Say)
	Mya arenaria (Linné)
	Petricola pholadiformis Lamarck
	Pita morrhuana (Linsley)
	Spisula solidissima (Dillwyn)
	Tagelus divisus (Spengler)
	Tellina agilis Stimpson
	Tellina versicolor Dekay
Order Eudesmodontida	*Lyonsia hyalina* Conrad
Phylum Ecotoprocta	*Amathia vidovici* (Heller)
	Bowerbankia gracilis Leidy
	Bugula turrita (Desor)
	Electra hastingsae Marcus
	Membranipora sp.
Phylum Echinodermata	
Class Asteroidea	*Asterias forbesii* (Desor)

Class Ophiuroidea	*Amphipholis squamata* (Delle Chiaje)
Class Echinoidea	*Arbacia punctulata* (Lamarck)
Class Holothuroid	*Cucumaria pulcherrima* (Ayres)
	Leptosynapta tenuis (Ayres)
	Leptosynapta roseola (Verrill)
	Thyone briareus (Lesueur)
Phylum Hemichordata	*Saccoglossus kowalevskyi* (A. Agassiz)
Phylum Chordata	
Class Ascidiacea	*Botryllus schlosseri* (Pallas)
	Molgula manhattensis (Dekay)
	Perophora viridis Verrill
Phylum Chaetognata	*Sagitta elegans* Verrill

From Loveland, R. E. and J. J. Vouglitois. 1984. Benthic fauna. In: M. J. Kennish and R. A. Lutz (eds.), *Ecology of Barnegat Bay, New Jersey*. Springer-Verlag, New York, pp. 135-170.

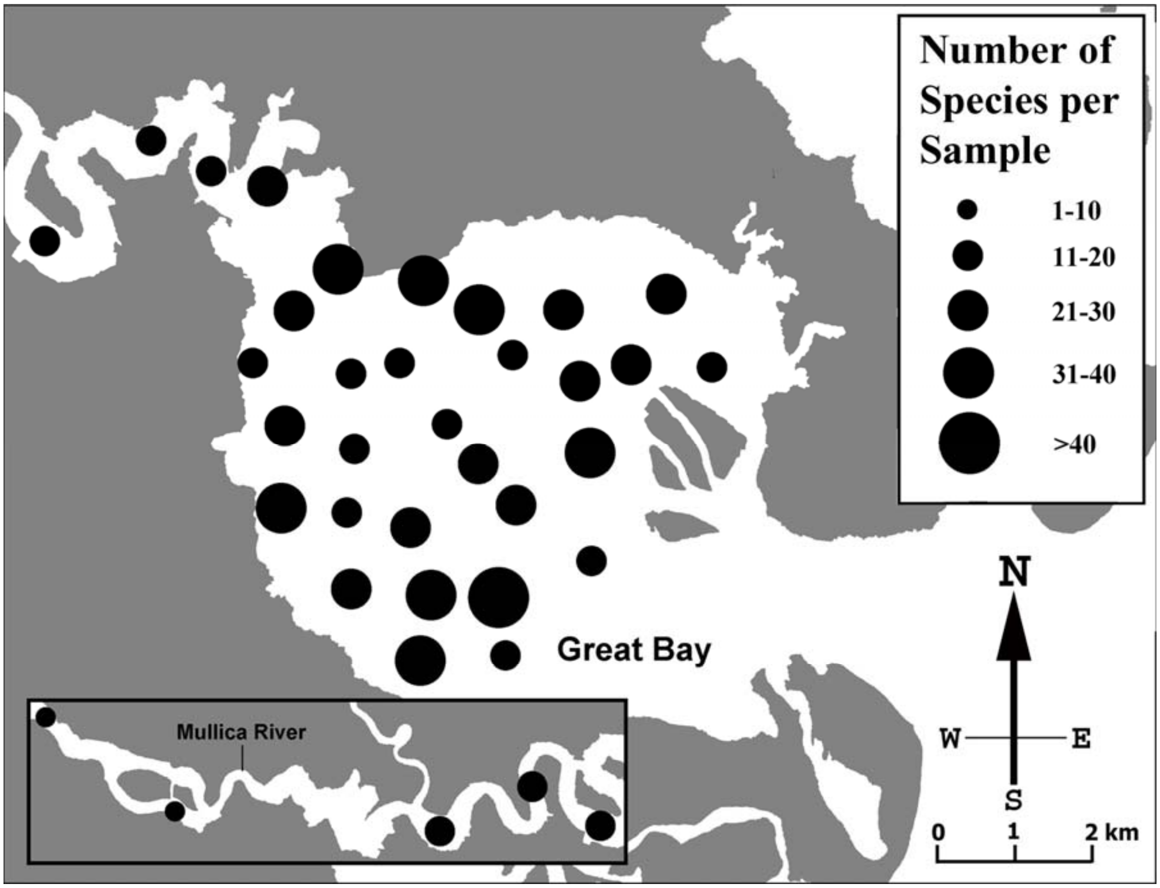


Figure 27. Species richness (number of species/sample) of benthic organisms collected by Petersen dredge in the Mullica River-Great Bay Estuary. Modified from Durand, J. B. and R. J. Nadeau. 1972. Water Resources Development in the Mullica River Basin. Part I. Biological Evaluation of the Mullica River-Great Bay Estuary. Technical Report, New Jersey Water Resources Research Institute, Rutgers University, New Brunswick, New Jersey. 138 p.

The benthic faunal communities of Great Bay and Barnegat Bay are similar in that most species belong to only a few phyla. For example, nearly 90% of the benthic fauna collected by Durand and Nadeau (1972) were about equally divided among the annelids, mollusks, and arthropods (Table 16). Species richness varied considerably across the bay (Figure 27). The most abundant organism collected was *Ampelisca abdita*, a tube-forming amphipod that covered extensive areas of the estuarine bottom, reaching densities >5,000 individuals/m^2 in some areas (Figure 28). The tubes produced by these amphipods stabilize fine sediments on the bay bottom. In addition, *A. abdita* is an important forage species for various benthic and nektonic organisms.

The benthic invertebrates in the estuary exhibit a distinct spatial distribution when proceeding from Lower Bank in the Mullica River to Little Egg Inlet. Four species types are recognized: (1) river-dominant forms; (2) bay-dominant forms; (3) lower-bay dominant forms; and (4) estuary-wide forms (Table 17). Seven species are considered to be true estuarine forms, occurring along the length of the estuary. Included here are *Ampelisca abdita, Corophium cylindricum, Cyathura polita, Notomastus latereus, Polydora ligni, Scoloplos robustus,* and *Turbonilla* sp. These seven species are not only widely distributed but also very abundant. Durand and Nadeau (1972) found that they comprised 71% of the total assemblage of benthic organisms collected at 75% of the sampling sites. The dominant forms in the estuary, therefore, can tolerate a rather wide salinity range.

The distribution of some benthic invertebrates appears to be closely linked to the amount of silt-clay in the bottom sediments. For example, Durand and Nadeau (1972) showed that *Acteocina canaliculata*, *Lumbrinereis tenuis*, *Maldinopsis elongata*, *Tellina agilis*, *Turbonilla* sp., and *Unciola irrorata* occurred only in sediments with more than 38% silt-clay. Other species (e.g., *Ampelisca verrilli, Ensis directus, Haustorius arenarius, Pygospio elegans, and Oxyurostylis smithi*) were observed only in sediments with less than 20% silt-clay. The bay exhibits marked bands of sediment with high percentages of sand (e.g., sand bars in the western bay) giving way to adjacent areas with higher percentages of silt and clay (Figure 11). This sediment distribution clearly affects the spatial distribution of benthic invertebrates.

Table 16. Taxonomic breakdown of benthic invertebrates collected with a Petersen Dredge in the Mullica River-Great Bay Estuary.

	Number of species	Cumulative %
Polychaeta	49	34.3
Crustacea	45	65.7
Gastropoda	20	79.7
Bivalvia	14	89.5
Ectoprocta	4	92.3
Coelenterata	4	95.1
Nemertea	3	97.2
Porifera	2	98.6
Platyhelminthes	1	99.2
Ascidacea	1	99.9

From Durand, J. B. and R. J. Nadeau. 1972. Water resources development in the Mullica River Basin. Part I. Biological evaluation of the Mullica River-Great Bay Estuary. Technical Report, New Jersey Water Resources Research Institute, Rutgers University, New Brunswick, New Jersey.

Table 17. Spatial distribution of benthic invertebrates along a salinity gradient of the Mullica River-Great Bay Estuary.

River-Dominant Forms

Cerebratulus lacteus

Chiridotea almyra

Gammarus locusta

Glycera dibranchiata

Hypaniola grayi

Lyonsia hyalina

Melita nitida

Neopanope texana

Nereis succinea

Ptilocherirus pinquis

Sagartia modesta

Scolecolepides viridis

Scoloplos fragilis

Streblospio benedicti

Sympleustes glaber

Bay-Dominant Forms

Acteocina canaliculata

Ampelisca verrilli

Amphitrite cirrata

Arca pexata

Brania clavata

Crepidula convexa

Elasmopus laevis

Glycera americana

Glycinda solitaria

Leucon americanus

Lumbrineris tenuis

Maldinopsis elongata

Mulinia lateralis

Oxyurostylis smithi

Polycirrus eximus

Tellina agilis

Triphora nigrocincta

Unciola irrorata

Lower-Bay Dominant Forms

Caprella geometrica

Cirratulus grandis

Crangon septemspinosa

Cylichna alba

Ensis directus

Haustorius arenarius

Idotea balthica

Nassarius vibex

Nephtys picta

Pagurus longicarpus

Pygospio elegans

Stenothoe cypris

Estuarine Forms (Entire Range)

Ampelisca abdita

Corophium cylindricum

Cyathura polita

Notomastus latereus

Polydora ligni

Scolopos robustus

Turbonilla sp.

From Kennish, M. J., S. M. Haag, G. P. Sakowicz, and J. B. Durand. 2004. Benthic macrofaunal community structure along a well-defined salinity gradient in the Mullica River-Great Bay Estuary. *Journal of Coastal Research*, SI 45: 209-226.

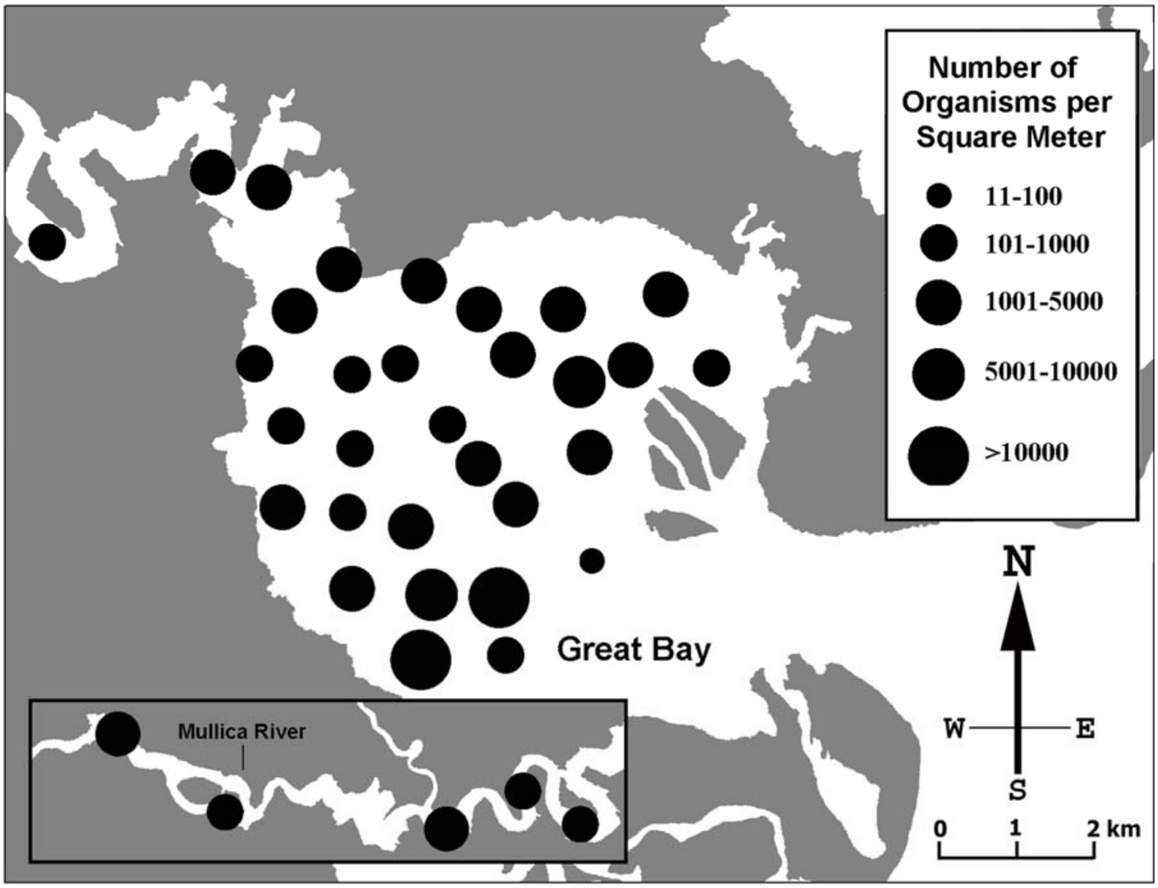


Figure 28. Density (number of organisms/m^2) of benthic organisms collected by Petersen dredge in the Mullica River-Great Bay Estuary. From Kennish, M. J., S. M. Haag, G. P. Sakowicz, and J. B. Durand. 2004. Benthic macrofaunal community structure along a well-defined salinity gradient in the Mullica River-Great Bay estuary. *Journal of Coastal Research*, SI 45: 209-226.

While some benthic fauna were present in very low numbers in a patchy distribution, others exhibited a broader distribution across sections of the estuarine floor. For example, *Ampelisca verrilli* and *Gemma gemma* occurred in high abundances in the lower end of Great Bay. *Acteocina canaliculata* and *Glycinde solitaria* were only observed on the southwestern side of the bay. *Nassarius obsoletus* and *Unciola irrorata* attained peak numbers near the mouth of the Mullica River and the western perimeter of the bay. *Ptilocheirus pinquis* was common along the Mullica River bottom, but was rarely found along the bay bottom. Salinity appears to be a major controlling factor restricting species to the riverine habitats.

Benthic faunal assemblages have also been investigated on Beach Haven Ridge (39°28'18"N, 74°15'10"W) at the site of the Long-term Ecosystem Observatory of Rutgers University on the inner continental shelf and nearby areas. Hales et al. (1995), using a 2-m beam trawl, examined the species composition of epibenthic invertebrate assemblages on Beach Haven Ridge, deeper waters of the inner continental shelf, and estuarine habitats of Great Bay. Viscido et al. (1997), also using a 2-m beam trawl, studied the abundance and spatial distribution patterns of epibenthic decapod crustacean assemblages along Beach Haven Ridge (i.e., landward of the ridge, on the ridge top, and seaward of the ridge) (Figure 29). Results of the investigation by Hales et al. (1995) indicate that echinoderms (i.e., sea urchins, *Arbacia punctulata*; sand dollars, *Echinarachnius parma*; and sea stars, *Asterias forbesi*) predominated at deeper sites on the inner continental shelf. Gastropods (*Busycon* spp., *Euspira heros*, and *Nevirita duplicata*), bivalves (*Spisula solidissima*), and polychaetes (*Diopatra cuprea*) were abundant around the Beach Haven Ridge. Other taxa (hard clams, *Mercenaria mercenaria*; American oysters, *Crassostrea virginica*; and grass shrimp, *Palaemonetes vulgaris*) occurred only in estuarine samples from Great Bay. Most of the aforementioned species attained peak abundance in summer and lowest abundance in winter.

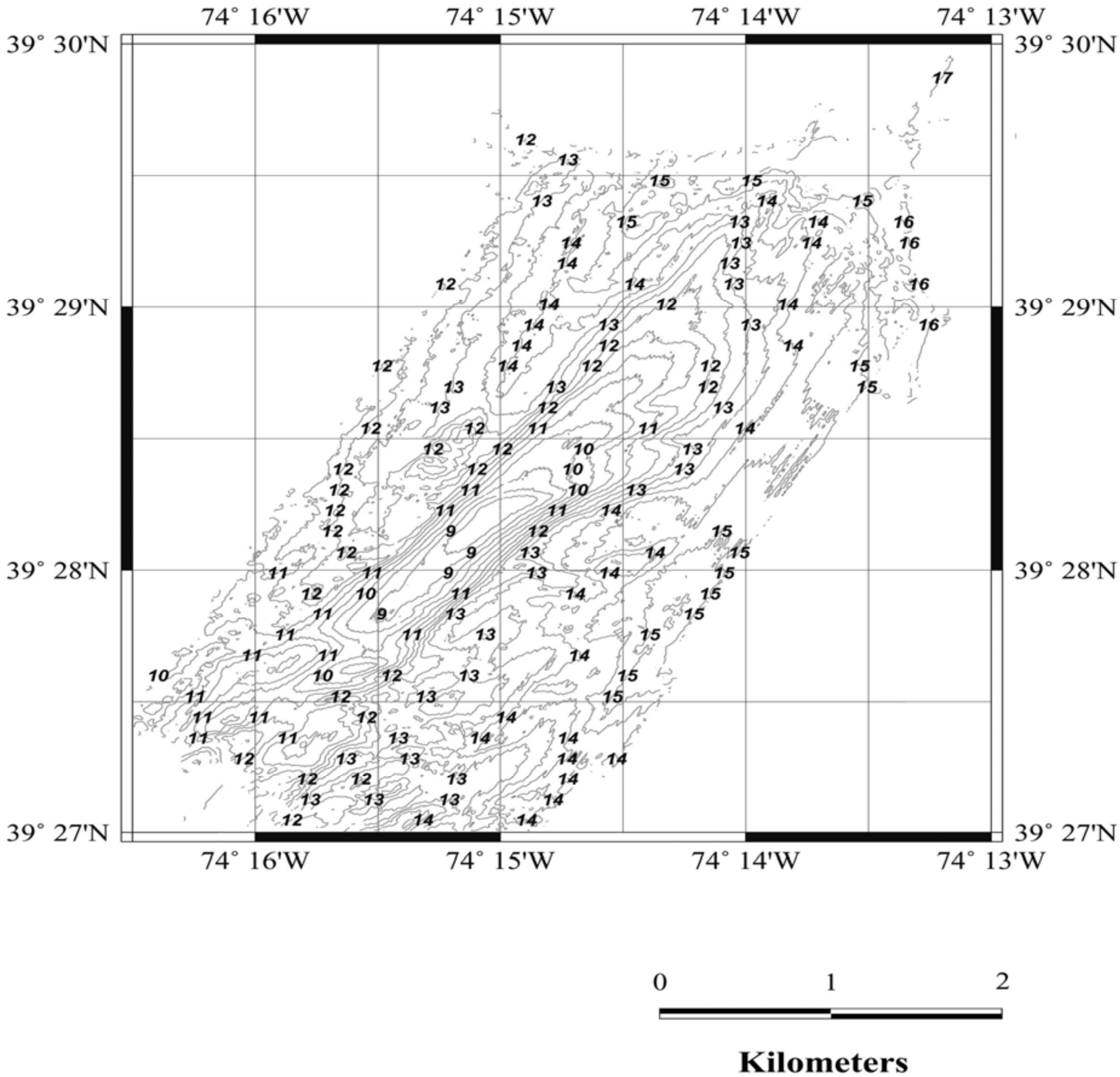


Figure 29. Topographic structure of the Beach Haven Ridge marking the location of the Long-Term Ecosystem Observatory (LEO-15) site of Rutgers University within the Jacques Cousteau National Estuarine Research Reserve. From Viscido, S. V., D. E. Stearns, and K. W. Able. 1997. Seasonal and spatial patterns of an epibenthic decapod crustacean assemblage in northwest Atlantic continental shelf waters. *Estuarine, Coastal and Shelf Science* 45:377-392.

Viscido et al. (1997) reported that nine principal species comprise the epibenthic decapod crustacean assemblage of the Beach Haven Ridge. Four of these species (i.e., Atlantic rock crab, *Cancer irroratus*; spider crab, *Libinia emarginata*; lady crab, *Ovalipes ocellatus*; and sevenspine bay shrimp, *Crangon septemspinosa*) numerically dominated the assemblage, accounting for more than 98% of all decapods collected. Among these species, *C. irroratus, L. emarginata,* and *C. septemspinosa* were much more abundant landward and seaward of the ridge. *Ovalipes ocellatus* was not as spatially variable as these three species. Together with *C. irrorata, O. ocellatus* reached maximum abundance in the summer. *Crangon septemspinosa* and *Libinia emarginata* attained peak abundance in spring and fall. Viscido et al. (1997) concluded that Beach Haven Ridge not only has a strong influence on the abundance and distribution of decapod crustaceans but also affects the structure of the entire community of marine benthic organisms in the area.

Benthic Flora

Eelgrass (*Zostera marina*) and benthic macroalgae are important elements of the benthic floral community of the reserve. Eelgrass and widgeon grass (*Ruppia maritima*) are essentially confined to Little Egg Harbor and Barnegat Bay. Benthic macroalgae are more broadly distributed in the system, occurring in Little Egg Harbor, Great Bay, and the shallow back-bays to the south. Sea lettuce*, Ulva lactuca*, is an abundant macroalgal species in these bays. Other common benthic macroalgal forms include *Gracilaria tikvahiae*, *Ceramium fastigiatum,* and *Agardhiella subulata*.

Eelgrass and widgeon grass occur along the shallow margins of Little Egg Harbor primarily along the eastern side of the embayment in waters less than ~1.5 m (Figure 30). In past years, eelgrass has grown in dense beds along the margins of the estuary to maximum depths of ~2 m, although the beds have become more spatially restricted in some areas in recent years. The abundance of eelgrass in a given year depends on the amount of seeds set the previous year and the successful germination of the seeds. The temporal and spatial shifts in the distribution of SAV in Little Egg Harbor may be the result of natural cycles (Loveland et al., 1984), although anthropogenic factors such as excessive nutrient loading, dredging, and prop scarring of motorized watercraft has been detrimental (Kennish 2001a).

Nutrient-induced phytoplankton blooms and excessive growth of benthic macroalgae can cause a decline in seagrass distribution. Wasting disease caused by *Labyrinthula zosterae* is also destructive during some years. McClain and McHale (1997) reported that wasting disease destroyed about 400 ha of eelgrass beds in Barnegat Bay during 1995. In addition, as much as 50% of the eelgrass leaves examined in 1996 exhibited evidence of wasting disease.

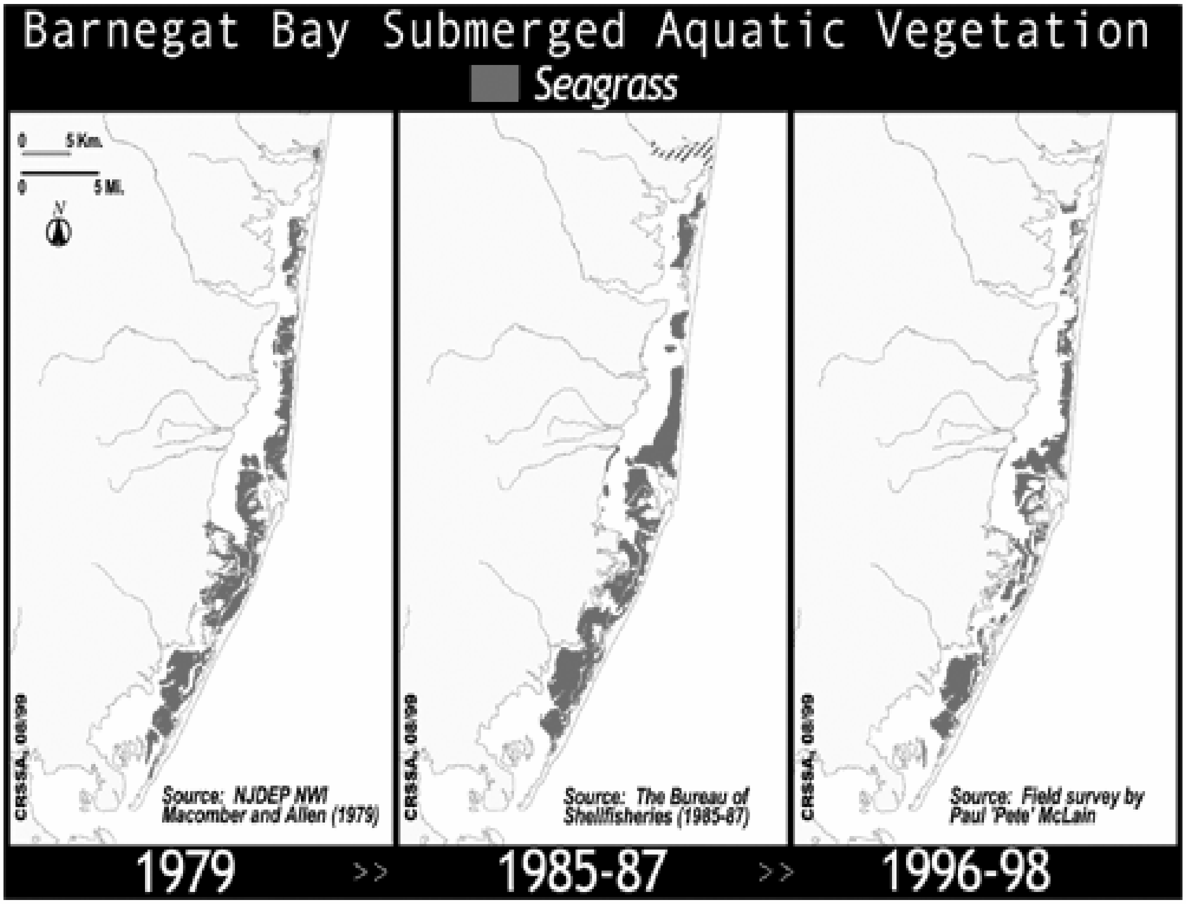


Figure 30. Seagrass distribution in the Barnegat Bay-Little Egg Harbor Estuary covering the period from the 1970s to the 1990s. From Richard G. Lathrop, Center for Remote Sensing and Spatial Analysis, Rutgers University, New Brunswick, New Jersey.

The loss of eelgrass beds during the past several decades may have been considerable, although different mapping techniques applied in past surveys have made data comparisons tenuous. Between the 1960s and 1990s, the overall decrease of areal coverage of eelgrass beds in the Barnegat Bay-Little Egg Harbor Estuary may have been as much as 3000 ha or nearly one-third of the total beds in the system. A GIS spatial comparison analysis of SAV surveys by Lathrop (2001b) suggests a contraction of the eelgrass beds to shallow subtidal areas (< 2 m) during this period.

There has been clear evidence of the loss of beds in southern Little Egg Harbor. Bologna et al. (2000) revealed that the total SAV coverage in Little Egg Harbor decreased by 62% between 1975 and 1999, with the most significant reductions associated with the loss of *Zostera marina* beds. However, there was no significant change in the areal coverage of *Ruppia maritima* during this 25-year period. Wasting disease was present in less than 10% of *Z. marina* samples collected, and it was most prevalent in July and August. During these months, the effect of the wasting disease could have contributed substantially to the loss of some *Z. marina* beds in the estuary. Light attenuation may have been a more important factor in eelgrass decline. While there appears to have been appreciable reduction of *Z. marina* in Little Egg Harbor since the 1970s, evidence indicates that the recolonization of previous SAV habitat is taking place adjacent to the Sedge Islands in the southern part of the estuary.

There is great concern regarding the relatively recent decline of eelgrass beds in the coastal bays of New Jersey because of the significant functional roles that they play. For example, eelgrass beds provide refuge and food resources for many species.

In addition, they stabilize the benthic habitat by baffling waves and currents and mitigating substrate erosion (Kennish, 2001a). Wootton and Zimmerman (2001) reported that aboveground biomass and belowground biomass values of eelgrass beds at Forked River, Sands Point, and Sedge Island sampling sites in Barnegat Bay during 1998 ranged from 8.73-141.23 g/m^2 and 58.33-270.58 g/m^2, respectively. Maximum biomass occurred during summer, as it had for eelgrass biomass in Little Egg Harbor, when a peak biomass of 230 g FDW/m^2 was recorded (Bologna et al., 2000). Sogard and Able (1991) showed that sites where *Zostera marina* was the dominant vegetation in the JCNERR had higher densities of most fish species than did sites where *Ulva lactuca* was the dominant vegetation. However, *U. lactuca* was an important habitat for decapods in areas lacking *Z. marina*. Since eelgrass beds strongly influence the abundance and distribution of many benthic and nektonic organisms, the loss of the beds is a serious concern to the reserve program and the subject of ongoing biomonitoring investigations.

Benthic macroalgae provide refuge for amphipods, shrimp, and other estuarine organisms of the reserve. *Ulva lactuca* has been shown to reduce predation rates on blue crabs (*Callinectes sapidus*) in the system (Wilson et al., 1990). This green alga is part of a widely distributed drift community of macroalgal forms in Great Bay and other estuarine waters. The macroalgae are also important nursery habitat for certain species (e.g., *C. sapidus*).

Kennish et al. (2007b) conducted an estuary-wide investigation of seagrass abundance, biomass, and areal coverage during the 2004-2006 period. This investigation of the Barnegat Bay-Little Egg Harbor Estuary yielded a number of important findings. For example, the biomass of eelgrass beds in the Barnegat Bay-Little Egg Harbor Estuary during the three-year study period exhibited important temporal and spatial patterns. The density as well as the aboveground and belowground biomass of eelgrass varied considerably during the spring to fall period, but was generally highest during the June-September period. This temporal pattern is attributed to more favorable light conditions during the late spring and summer. Aboveground and belowground biomass also varied spatially due to a wide range of physical-chemical conditions over small spatial scales, including marked differences in shading, light availability, macroalgae cover, and other factors. Of most concern is the low aboveground and belowground biomass of *Zostera marina* recorded along transects during 2006 compared to those in 2004 and 2005, indicating a 50-87.7% decline. Diminishing seagrass biomass and percent cover (also observed) in 2006 appear to signal an ecosystem problem in the estuary, likely coupled to ongoing nutrient enrichment.

Although considerable temporal and spatial variation of eelgrass biomass was observed, eelgrass blade length was very consistent across sampling sites and sampling periods. For example, in 2004 there was only a slight decrease in mean eelgrass blade length in Little Egg Harbor from June-July (34.02 cm), August-September (32.21 cm), and October-November (31.83 cm) despite the gradually declining photoperiod and variable water temperature over the six-month study period. The maximum blade length did not vary substantially between the two different eelgrass beds. In 2005, the mean eelgrass blade length in Barnegat Bay was more variable, with the highest measurement (32.71 cm) obtained for the June-July period, the lowest measurement (25.89 cm) for the August-September period, and an intermediate measurement (28.47 cm) for the October-November period. In 2006, the mean eelgrass blade length was substantially lower, amounting to 19.37 cm in June-July, 18.65 cm in August-September, and 18.61 cm in October-November. The reduced eelgrass blade length also correlated with reduced aboveground biomass values.

The percent cover of seagrass decreased from 2004 to 2006 in concert with the decline of biomass. In 2004, there was decreasing cover of seagrass from spring to fall in Little Egg Harbor. The highest mean percent cover of seagrass in June-July (45%) was significantly greater than that in August-September (38%) and October-November (21%). In contrast, the percent cover of macroalgae was lower and more seasonally variable than the percent cover of seagrass. For example, the mean percent cover of macroalgae

increased from 13% in June-July to 21% in August-September and then declined to 14% in October-November. The highest percent cover of macroalgae in August-September probably reflects the greater growth and abundance of different algal species at this time.

In 2005, the percent cover of seagrass during June-July, August-September, and October-November sampling periods in Barnegat Bay amounted to 37%, 43%, and 16%, respectively. The percent cover by macroalgae during these periods was 14% (June-July), 7% (August-September), and 2% (October-November). Once again, the percent cover of both seagrass and macroalgae declined rapidly from summer into the fall.

The percent cover of seagrass was much reduced estuary-wide in 2006, concomitant with declining biomass measurements. It amounted to 32% in June-July, 23% in August-September, and 19% in October-November. The percent cover of macroalgae was similarly reduced in 2006, being 2% in June-July, 7% in August-September, and 7% in October-November. The percent cover of both seagrass and macroalgae in 2006, as well as in 2004 and 2005, was generally highest in interior areas of the seagrass beds than in marginal areas.

Most of the macroalgal species in the Barnegat Bay-Little Egg Harbor Estuary belong to a drift community. However, macroalgal blooms and patches that blanket the estuarine floor can be particularly detrimental to seagrass beds and associated benthic fauna. They hinder seagrass growth by shading or blocking sunlight and can render the estuarine floor unsuitable for regrowth of seagrass for extended periods. Hence, excessive growth of macroalgae in the estuary can be extremely damaging to seagrass habitat, a finding corroborated by studies conducted in other coastal bays in the Mid-Atlantic region and elsewhere.

In 2004, 32 macroalgal species were documented in the Little Egg Harbor survey area. Red algae (n = 19) accounted for 59% of the species collected, with green algae (n = 11) comprising 34% and brown algae only 6%. *Ulva lactuca* was the most common algal species, being found in 59% of the samples. Sheet-like species, such as *U. lactuca*, appear to pose the most serious threat to seagrass beds because they often form extensive patches that blanket and damage the seagrass plants. In 2005, 21 macroalgal species were recorded in Barnegat Bay with most species (16) being red algae. *Gracilaria tikvahiae* (present in 70% of samples), *Bonnemaisonia hamifera* (56%), *Spyridia filamentosa* (46%), and *Champia parvula* (19%) were the most abundant forms.

While brown tide (*Aureococcus anophagefferans*) blooms may be equally detrimental to seagrass beds due to their shading effects, no blooms were observed during the 2004 and 2005 sampling periods. The maximum cell counts of *A. anophagefferans* reported in the estuary during 2004 and 2005 amounted to 4.9 x 10^4 cells ml^{-1} and 4.7 x 10^4 cells ml^{-1}, respectively. These numbers are far less than those recorded during the bloom years of 2000-2002 (>1 x 10 cells ml^{-1}). Thus, it is very unlikely that *A. anophagefferans* had any adverse impact on the eelgrass beds in the estuary during these two survey years.

The three-year SAV investigation (2004-2006) generated a large database on the demographic characteristics and habitat change of *Zostera marina* in the Barnegat Bay-Little Egg Harbor Estuary. It also yielded valuable information on the species composition, frequency of occurrence, and potential impacts of benthic macroalgae on the eelgrass beds in bay waters. Data collected in this study serve as a platform for further investigations of seagrass dynamics and restoration programs in this critically important coastal bay system.

Nekton

Fish and Crabs

The fish faunas of the Mullica River-Great Bay Estuary are among the most intensely studied of any estuary along the East Coast of the U.S., with particular focus on the life history and ecology of young-of-the-year forms. This is largely attributed to the research efforts of RUMFS (Able et al., 1999). More than 60 finfish species have been documented in the estuary, and this assemblage is enriched by regular visitors and strays from more northern and (particularly) southern waters that use the estuary as a nursery and feeding area. Some species that utilize the estuary as a nursery area include the Atlantic menhaden (*Brevoortia tyrannus*), weakfish (*Cynoscion regalis*), bluefish (*Pomatomus saltatrix*), and spot (*Leiostomus xanthurus*). Other species use the estuary for its spawning habitat. Among summer spawners are the bay anchovy (*Anchoa mitchilli*), Atlantic silverside (*Menidia menidia*), gobies (*Gobiosoma* spp.), northern pipefish (*Syngnathus fuscus*), and wrasses (*Labrida*e spp.); examples of winter spawners are the winter flounder (*Pseudopleuronectes americanus*) and sand lance (*Ammodytes americanus*) (U.S. Fish and Wildlife Service, 1996). Jivoff and Able (2001) reported similar fish assemblages for Little Egg Harbor.

The oyster toadfish (*Opsanus tau*), fourspine stickleback (*Apeltes quadracus*), and winter flounder are resident species in estuarine waters of the JCNERR. Northern forms that occur are the threespine stickleback (*Gasterosteus aculeatus*) and the grubby (*Myoxocephalus aenaeus*). Numerous species spawned in the southern Mid-Atlantic Bight and farther south can be abundant (e.g., northern puffer, *Sphoeroides maculatus*; butterflyfishes, *Chaetodon* spp., and spot). Other fishes are present during the summer as a result of inshore-offshore migrations (e.g., black sea bass, *Centropristis striata*; tautog, *Tautoga onitis*; and summer flounder, *Paralichthys dentatus*). Among the most common pelagic species are the bay anchovy, Atlantic silverside, and Atlantic herring (*Clupea harengus*). Major diadromous forms consist of the alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*), which spawn in tributaries, and the American eel (*Anguilla rostrata*), which grows in the estuary but spawns in the Sargasso Sea. At the LEO-15 site, the typically dominant species are the bay anchovy, silver hake (*Merluccius* *bilinearis*), spotted hake (*Urophycis regia*), smallmouth flounder (*Etropus microstomus*), and windowpane flounder (*Scophthalmus aquosus*).

Although more than 60 species of fish have been registered in the Mullica River-Great Bay Estuary, only 20 of these species have comprised more than 99.9% of all fish collected in field surveys (Durand and Nadeau, 1972). Forage species (e.g., bay anchovy and Atlantic silverside) are by far the most abundant forms. The absolute abundance of fish in the estuary is highest from May through November due to the arrival of warm-water migrants and recruitment from spawning populations in the estuary. In terms of relative abundance, the top ranked species recorded in fish surveys of the 1970s were the bay anchovy (*Anchoa mitchilli*), striped anchovy (*Anchoa hepsetus)*, Atlantic silverside, northern puffer, silver perch, alewife, oyster toadfish, striped killifish (*Fundulus majalis*), sea herring (*Clupea harengus*), and white perch *(Morone americana*). In later trawl surveys of Great Bay and Little Egg Harbor, Szedlmayer and Able (1996) found that the bay anchovy was the dominant species (50.5% of the total number of fish), followed by spot (10.7%), Atlantic silverside (9.7%), fourspine stickleback (5.9%), blue crab (*Callinectes sapidus*) (4.6%), and northern pipefish (4.2%).

Some fish species are habitat specific. For example, Jivoff and Able (2001), in a habitat study of Little Egg Harbor, noted that the threespine stickleback, Atlantic menhaden, and naked goby (*Gobiosoma bosc*) preferred subtidal creek habitats. Four-spine stickleback, silver perch, and lizardfish (*Synodus foetens*) were associated with eelgrass. The small-mouth flounder, windowpane, skate (*Raja eglanteria*), and hakes (*Urophysis* spp.) predominated in deep channels.

Finfish abundance in Little Egg Harbor is similar to that in the Mullica River-Great Bay Estuary, being highest from May through November. Far fewer individuals are present during the winter in both systems, although an increase in abundance is evident as early as March or April. Larvae and juveniles attain maximum numbers in the spring and summer months. Annual variations in absolute abundance of 50-100% are not unusual. Fluctuations in environmental conditions that influence reproductive success may be responsible for such large variations in abundance. More research must be conducted to address these uncertainties (Kennish, 2001a).

The community structure, seasonal patterns, and population trends of the finfish community in the Mullica River-Great Bay Estuary parallels that in the Barnegat Bay-Little Egg Harbor Estuary and other neighboring coastal bays. Forage fishes and juveniles numerically dominate these communities, utilizing the systems primarily as nursery areas. Adult marine forms spawn or feed in the bays, but typically inhabit oceanic waters. Warm-water and cool-water migrants appear seasonally, being occasionally present in greater numbers than resident species. Examples of warm-water migrants are the summer flounder, northern pipefish, black sea bass, and striped searobin (*Prionotus evolans*). The winter flounder is an example of a cool-water migrant. Warm-water migrants are more abundant than cool-water migrants and account for large numbers of fish in the bays from July through November. At this time, young of residents and warm-water migrants coexisting in the estuary reach maximum population sizes. The finfish community of the coastal bays, therefore, is characterized by: (1)

numerical dominance of a few species; (2) forage fishes and juveniles; (3) seasonal occurrence of warm-water and cool-water migrants; and (4) large fluctuations in abundance of populations (Tatham et al., 1984; Kennish, 2001a).

A species list of finfish compiled for Little Egg Harbor includes most of those species also found in the Mullica River-Great Bay Estuary and neighboring coastal bays to the south (Appendix 20) (Jivoff and Able, 2001). Able et al. (1996) noted that the fish fauna of Great Bay and Little Egg Harbor is phylogenetically diverse. They identified 58 species from 35 families and 11 orders represented across all estuarine shoreline habitats. In late summer, frequent visitors from southern regions (e.g., *Chaetodon ocellatus*, *Hypochamphus meeki*, and *Lutjanus griseus*) increase the faunal diversity. In late winter or early spring, visitors from more northern areas (e.g., *Myoxocephalus aenaeus*) likewise increase the diversity.

More recently, Martino and Able (2003) studied the large-scale fish assemblage structure across the estuarine-ocean ecotone of the reserve. Their field collections over a 3-year study period showed that species richness and abundance appeared greatest in the nearshore ocean, decreased in Great Bay, and then increased again towards the uppermost stations in the Mullica River. Members of the Percichthyidae and Ictaluridae characterized the river assemblages, whereas representatives of the Triglidae and Stromateidae characterized the ocean and bay assemblages. Some species (e.g., *Anchoa mitchilli* and *Cynoscion regalis*) were found ubiquitously across the sampling area. Both small- and large-scale patterns were evident in the structure of the estuarine fish assemblage. The small-scale patterns, which are probably driven by foraging, competition, and/or predation, appear to be the result of habitat associations. The large-scale patterns are primarily the result of the responses of individual species to dominate environmental gradients such as salinity.

A number of finfish species are of recreational or commercial importance in JCNERR waters. Included here are the American eel, alewife, blueback herring, bluefish, summer flounder, winter flounder, weakfish, white perch, black sea bass, spot, tautog, northern puffer, striped bass (*Morone saxatilis*), kingfish *(Menticirrhus saxatilis*), and Atlantic croaker (*Micropogonias undulatus*). Among shellish species, the blue crab is of paramount importance. A description of some of these species follows.

Recreational and Commercial Species

American eel (*Anguilla rostrata*)

The American eel requires estuarine habitat to complete its life cycle. This species is catadromous, meaning spawning is in the ocean (in this case the Sargasso Sea, in midwinter), and later stages are found in estuaries or freshwater systems. The eggs hatch into leptocephali (ribbon-like, transparent larvae) that drift with ocean currents for a year or so toward the North American coast. As they approach coastal waters, the larvae metamorphose into "glass eels," that have the typical eel form but are still transparent. Shortly after entering estuaries, the glass eels acquire pigmentation and transform into elvers. In the Delaware Estuary, 5- to 8-cm long elvers appear in February-March, when they concentrate in tidal creeks of the lower estuary. They reach the middle estuary in April-May and the upper estuary in May-June. Females travel farther toward freshwater than do males. Both sexes tend to occur in deeper or fresher water in the colder months, returning to coastal areas in the spring.

Except for the aforementioned seasonal movements, eels are quite sedentary and usually remain in home territories. Males mature at 28 to 30.5 cm in length, and rarely exceed 60 cm in length. Females mature at about 46 cm, often attaining lengths of 60 to 90 cm (Bigelow and Schroeder, 1953). In estuaries, juveniles and adults primarily feed on crustaceans, bivalves, and polychaetes. At 5 to 20 years, adults leave the estuary and return to the Sargasso Sea to spawn in the spring, after which they die. Stone et al. (1994) reported that elvers are common in the Barnegat Bay-Little Egg Harbor Estuary from February through April. Later juveniles are common year-round, while adults are rare.

Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalis*)

These two species are collectively called "river herring." They are anadromous, entering brackish to freshwater to spawn and then migrating back to coastal areas. The alewife ranges from Labrador to South Carolina, and is most abundant in Mid-Atlantic and New England waters. The blueback herring occurs from Nova Scotia to Florida, but is most common from Chesapeake Bay south. The alewife usually spawns in mid-spring at water temperatures of 16-19˚C. The blueback herring spawns later in spring at temperatures of ~5˚C warmer. Both species enter the Delaware River Estuary as early as February and begin spawning runs. They also spawn in tributaries of Great Bay. Adult forms are reportedly abundant in the Barnegat Bay-Little Egg Harbor Estuary, and they spawn there in April and May, a time when eggs and larvae are also numerous. Adults are common in March and June, and juveniles are abundant year-round.

Adult blueback herring are observed from March through June. Spawning takes place from April through June, with eggs and larvae generally observed during these months. Juveniles are common year-round (Stone et al., 1994).

Spawning usually begins at age 3, preferably in shallow areas. The blueback herring favors areas with hard substrates and fast currents, whereas the alewife uses a variety of habitats, typically with slower currents. Many historical spawning areas are not presently available due to dams and/or pollution. Loss of these spawning and nursery grounds has undoubtedly been a major factor in the decline of herring stocks. However, where upstream habitats are suitable (e.g., good water quality), the installation of fish ladders at dams can effectively enhance the stocks of these important forage species. Alewifes live as long as 10 years and reach a maximum length of 36 cm. Blueback herring, in turn, live 7 to 8 years and reach a maximum length of 33 cm (Bigelow and Schroeder, 1953).

Larvae of both species transform to juveniles at ~2 cm in length. The juveniles become similar in appearance to adults at ~3 cm. Larval river herring are planktivores, feeding selectively on small copepods and cladocerans. Juveniles consume larger plankton. The diet of adults includes fish eggs, small fish, plankton, bottom invertebrates (such as amphipods), and insects. When abundant, all life stages of river herring are important in food webs. Adults are a preferred prey of birds, whales, and many fish species, notably bluefish, striped bass, and weakfish.

Bluefish (*Pomatomus saltatrix*)

In the western Atlantic, the bluefish ranges from Nova Scotia to Argentina. Bluefish occurring off the Mid-Atlantic and southeast U.S. coasts may belong to a single genetic stock. These fish spawn in offshore waters from March through August. Most bluefish are capable of spawning by age 2. Eggs and larvae generally remain in oceanic waters. Early juveniles (2 to 5 cm) move toward coastal and estuarine nursery areas by active swimming and/or passive movement with currents. The numbers of larvae reaching these nursery areas are quite variable and may be a key determinant of the subsequent abundance of larger juveniles and adults. Early-spawned fish enter Mid-Atlantic estuaries in late May to mid-June, at an average length of 6 cm. Fish spawned in summer either remain in coastal waters or enter estuaries in August when they are ~4.5 cm in length.

Bluefish are fast growing. Young-of-the-year fish may be 25-cm long by fall, and ultimately comprise the popular “snapper” fishery. Maximum size is ~1.1 m in length and 12.3 kg in weight. Maximum age is ~12 years. This predatory fish is usually found in schools of similar-sized individuals. There are seasonal migrations, with movement into Mid-Atlantic coastal and estuarine waters in the spring, and a return southward or offshore in the fall. The larger fish tend to move farther north in summer but perhaps not as far south in winter. Adults are common and juveniles are abundant in Great Bay and the Barnegat Bay-Little Egg Harbor Estuary from about May to November (Stone et al., 1994).

Larval bluefish mainly consume copepods. Fish appear in the bluefish diet when the larvae are slightly over 2.5-cm long, and soon become the main staple. However, young bluefish may prey more on invertebrates, such as crustaceans and polychaetes, in some areas or seasons. The Atlantic menhaden (*Brevoortia tyrannus*) is a very important prey species for larger individuals. Mature bluefish, in turn, are consumed by sharks, tunas, and billfish. Oceanic birds are major predators of young-of-the-year bluefish. Some cannibalism has been reported.

The importance of specific estuarine habitats to bluefish stocks is not known. Since the egg and larval stages develop at sea, estuarine dependence is undoubtedly less than for species in which these sensitive stages occur inshore. The pelagic bluefish is also not closely tied to particular water depths, bottom types, or aquatic vegetation, though young-of-the-year fish tend to congregate in shallow nearshore areas. It does not appear to use marsh surfaces. Estuaries, and specific estuarine features such as marsh creeks, probably provide benefits in terms of shelter and abundant forage that leads to rapid growth, especially among young-of-the-year fish.

Striped Bass (*Morone saxatilis*)

The striped bass, one of the largest fish species inhabiting estuaries, is a very popular gamefish. It also is highly valued commercially. Although this species has a natural range from the Gulf of St. Lawrence to the Gulf of Mexico, it has been successfully introduced elsewhere, such as San Francisco Bay. Being anadromous, the striped bass lives in coastal and estuarine areas and enters fresh or low salinity waters for spawning, as well as egg and larval development. There are both migratory and nonmigratory stocks, with the former predominating in the Mid-Atlantic. Most of the Mid-Atlantic fish originate in Chesapeake Bay. The Hudson River also has an important spawning stock. Migrating stripers move north in the spring; many find their natal estuary to spawn, and then resume their northward coastal migration. The return migration occurs in the fall, with individuals overwintering in coastal areas from New Jersey to North Carolina, and in Chesapeake Bay.

Striped bass are not very abundant in Great Bay, Little Egg Harbor, and the back-bays to the south (i.e., Little Bay, Reeds Bay, Absecon Bay). Stone et al. (1994) reported that adults and juveniles are rare in Barnegat Bay from March through December. There are reports of stripers overwintering in the Barnegat Bay-Little Egg Harbor Estuary and in areas just outside of this system, as well as in Great Bay. Some striped bass have been counted in fish kills at the Oyster Creek Nuclear Generating Station.

There are no records of striped bass spawning in the Mullica River watershed. In the Delaware River Estuary, spawning is from early April to June at temperatures of 10-25^{o}C, with peak activity generally from late April to early May at temperatures of 15-18°C. The semi-buoyant eggs are released over various substrates in shallow waters (< 6 m) with moderate flow rates ($\geq$ 0.3 m/s). Eggs and larvae are often concentrated in channels, whereas juveniles disperse throughout the estuary and use all depths as nursery areas, moving toward deeper, more saline areas as they grow. Most young-of-the-year fish (and some adults) overwinter in the estuary; however, individuals greater than 2 years of age often spend the winter in adjacent coastal waters. Most stripers reach sexual maturity at age 5 (Bigelow and Schroeder, 1953).

Striped bass may grow to ~10 cm in length by the end of their first summer and 30 cm or more by their second summer. They can grow to great sizes, with the maximum on record being over 1.8 m in length and 56 kg in weight. Most fish larger than 13.5 kg are females (Bigelow and Schroeder, 1953). The diet of small stripers is often dominated by amphipods and shrimp, whereas larger bass consume a wide variety of fish as well as worms, crustaceans, squid, and clams (Bigelow and Schroeder, 1953).

Commercial and recreational catches of striped bass declined drastically in the Mid-Atlantic region during the mid-1970s (Clark, 1998). The decrease in abundance was largely due to the very low production of juveniles in Chesapeake Bay from the early 1970s through the late 1980s. After declaration of a coastwide moratorium on commercial harvesting, juvenile production increased. This led to 1993 and 1996 juvenile indices that were the highest on record. When the moratorium ended, commercial landings had rebounded to 2.2 million kg in 1996. The stock was declared restored in 1995, and it is now considered fully exploited. There are no data on recreational landings of striped bass in the JCNERR.

Summer Flounder (*Paralichthys dentatus*)

The summer flounder (or fluke) is one of the most popular sportfish in the Mid-Atlantic region, and it is commercially important. The species ranges from Nova Scotia to at least as far south as Florida. It is found in estuaries to the outer continental shelf. The center of abundance of the summer flounder occurs from Cape Cod (MA) to Cape Hatteras (NC). It is unclear if summer flounder in the Mid-Atlantic region constitute a single stock; there may be a separate stock in the vicinity of Cape Hatteras and another in the South Atlantic Bight. There are pronounced seasonal migrations, with most adults inhabiting inshore waters during the warmer months and wintering well offshore to depths as great as 150 m. In subsequent years, individuals tend to return to the same estuary or move north and east. Older fish may remain offshore year-round. Females reach sexual maturity at a size of ~28 cm, and males at a size of ~25 cm. The median age of sexual maturity in both sexes is 1.5 years (Packer and Greisbach, 2003). The species attains a maximum size of ~0.9 m and 6.7 kg. The largest individual on record is 11.7 kg.

Spawning takes place offshore, peaking in October and November, with females capable of producing more than 4 million eggs. The total number of eggs produced is size- and age-dependent. Eggs are pelagic and buoyant, and early larvae are planktonic. Later stage larvae and postlarvae migrate to coastal and estuarine nursery areas from October to May, where they complete metamorphosis to the typical flatfish form. Metamorphosis involves the migration of the right eye across the top of the head, and the widening and flattening of the body. It typically occurs when the larvae are between 0.64 cm and 1.91 cm long. After this transformation, they move to the bottom, bury in the sediment, and complete development to the juvenile stage. According to Stone et al. (1994), juveniles and adults are common in the Barnegat Bay-Little Egg Harbor Estuary from May through September, and juveniles are present but rare the remainder of the year. These life stages are common in the Mullica River-Great Bay Estuary. Larvae are rare, occurring in these systems from October through May.

Great Bay and Little Egg Harbor are valuable sources of shelter and food for intermediate stages of the species, especially metamorphosing larvae and early juveniles

(Rountree et al., 1992). Juveniles usually are found in sandy areas, adjacent eelgrass beds, among macroalgae, and in marsh creeks. Since these areas are vulnerable to perturbations, they have been identified by the Mid-Atlantic Fishery Management Council as habitat of particular concern in summer flounder management (Packer and Hoff, 1999).

The larval diet is dominated by immature copepods, and also includes tintinnids, bivalve larvae, and copepod eggs and adults. Toward the end of metamorphosis, the diet shifts toward benthic invertebrates. Small juvenile flounder less than ~10 cm long feed opportunistically on whatever suitable prey is available, consuming mostly crustaceans and polychaetes. Fish are more prominent in the diet of larger juveniles. For young-of-the-year summer flounder in marsh creeks of Great Bay and Little Egg Harbor, the most important prey are silversides, followed by mummichogs, grass shrimp, and sand shrimp. In other estuaries, mysid shrimp are also commonly consumed. Adults may forage on larger fish such as spot and pipefish. The likely predators of larval flounder include mummichogs and sand shrimp. Juvenile and adult flounder are probably consumed by the blue crab, spiny dogfish, goosefish, cod, sea raven, longhorn sculpin, fourspot flounder, as well as silver, red, and spotted hake.

Winter Flounder (*Pseudopleuronectes americanus*)

The winter flounder is a small-mouthed, right-eyed flatfish. It is valuable in both commercial and recreational fisheries of northwest Atlantic estuaries and continental shelf areas. The species prefers cool temperatures; its range is from Labrador to Georgia, with highest abundances in Canadian waters. The Federal Fishery Management Plan for winter flounder considers the species to consist of three stocks: Gulf of Maine, Southern New England/Middle Atlantic, and Georges Bank stocks.

Except for Georges Bank fish, adults migrate inshore in fall and early winter, and spawn in late winter and early spring. In the Mid-Atlantic, the peak of spawning is February and March. Most adults return to offshore waters after spawning. Migrating adults sometimes travel long distances. In one tagging study, the average distance was ~65 km, and in another study, a fish tagged in the inner New York Bight was recovered ~315 km away near Nantucket, Massachusetts. South of Cape Cod, females become sexually mature at 3 years of age and an average length of 27.7 cm, and males at 3.3 years of age and an average length of 29.0 cm (Bigelow and Schroeder, 1953). Maximum length is ~63.5 cm, and the maximum age is more than 15 years. Stone et al. (1994) state that in the Barnegat Bay-Little Egg Harbor Estuary adults are abundant from November through April, and spawning occurs from January through March, with eggs and larvae being abundant at this time. Juveniles are abundant year-round. The winter flounder is also relatively abundant in Great Bay.

Except for the Georges Bank stock, the species is estuarine-dependent, requiring shallow, lower-salinity waters to spawn. Eggs adhere to various substrates including mud, sand, gravel, and vegetation. Eggs are ~0.3 cm in diameter when they hatch, typically in two to three weeks, with faster hatching times occurring at higher temperatures. Larvae are negatively buoyant. This probably enables them to be retained in greater numbers in suitable estuarine nursery areas rather than being swept out to sea. As they approach metamorphosis (which usually occurs 5 to 8 weeks after hatching), the larvae become increasingly bottom-oriented, feeding on copepods, copepod and barnacle nauplii, polychaetes, and invertebrate eggs. Metamorphosing larvae settle on the bottom when they are ~1.3 cm in length.

Young-of-the-year winter flounder inhabit shallow waters of New Jersey's coastal bays, feeding on polychaetes and crustaceans, especially amphipods. Here, they may grow to 10 to 18 cm in length during the first year. Most of these fish overwinter in estuaries, but they are also commonly found in adjacent coastal waters. In some estuarine areas, there are restrictions on dredging from January 1 through May 31 to protect spawning and early life stages in these important habitats. Since winter flounder are visual feeders, they may be adversely affected by natural or anthropogenic factors that reduce water clarity. Large docks and other platforms may also impair feeding, perhaps by blocking or decreasing available light (Duffy-Anderson and Able, 1999

Weakfish (*Cynoscion regalis*)

The weakfish ranges from Nova Scotia to Florida, with its center of abundance in Chesapeake Bay and Delaware Bay. It is estuarine-dependent, since all life stages are found in this environment. Spawning begins at water temperatures of ~15ºC and generally peaks from mid-May through mid-June. Spawning occurs in 1-3 batches per season on sand and hard substrates throughout the lower estuary. Some spawning also occurs in coastal waters. Young-of-the-year weakfish appear by June and occupy nursery habitats in a wide range of temperatures and salinities in both the mainstem estuary and smaller tributaries and creeks.

The diet of young-of-the-year forms includes mysid shrimp, crabs, worms, and clams. Most weakfish mature by their second summer, when males are 12.7 to 15.2-cm long and females 15.2 to 20.3-cm long. A 30.5-cm long fish is probably 2 years of age, and a 61-cm individual may be 9 years old. The largest weakfish on record is 7.9 kg, but fish heavier than 5.4 kg or longer than 1 m are rare (Bigelow and Schroeder, 1953). Adults are most abundant in lower estuarine areas at salinities $\geq$ 15‰. Weakfish tend to occur in schools of like-sized individuals. Juveniles begin to migrate out of New Jersey estuaries in August, and by mid-November both juveniles and adults have left for offshore areas. They travel south to overwinter off Virginia and North Carolina. In the Barnegat Bay-Little Egg Harbor Estuary and Mullica River-Great Bay Estuary, adults are common from April through October, and then rare through November. Eggs and larvae are rare from May to August. Juveniles are common from May to November (Stone et al., 1994).

Blue Crab (*Callinectes sapidus*)

The blue crab is an abundant and ubiquitous member of estuarine nektonic communities along most of the East Coast of the United States (Millikin and Williams, 1980). It is a recreationally and commercially important species in the estuarine waters of the JCNERR. The life cycle of the blue crab is approximately 2 years from egg to adult, with an average lifespan of about 3 to 4 years. In the Mid-Atlantic region, mating occurs during the summer (June-September) throughout estuaries. Males may mate more than once within a mating season and may go through at least two seasons. In contrast, females have a single opportunity to mate, immediately after their final (terminal) molt to maturity (Van Engel, 1958), and most of them mate with only a single male (Jivoff, 1997). After mating, females migrate to higher salinity waters near the estuary mouth to overwinter and eventually spawn (Van Engel, 1958; Schaffner and Diaz, 1988; Tankersley et al., 1998). Adult males and immature crabs remain in brackish waters of estuaries, burying in bottom sediments during the winter.

In the Mid-Atlantic region, spawning typically begins the following spring and may continue into the early fall, with females producing what appears to be two or three broods of eggs (McConaugha et al., 1983; Epifanio et al., 1984). However, if mating occurs in the late spring or early summer, females may be able to produce one brood of eggs later that same summer or fall (Millikin and Williams, 1980). Individual females can produce between 700,000 and 2,000,000 eggs per brood, with larger females typically exhibiting greater fecundity (Hines, 1982; Prager et al., 1990). Larvae are released into the water column and are transported out of the estuary by tidal currents to develop offshore over the continental shelf (McConaugha et al., 1983; Johnson and Hester, 1989; Epifanio, 1995).

On the continental shelf, blue crab larvae from different estuaries may mix (Cole and Morgan, 1978; McMillen-Jackson et al., 1994) before being transported back to the estuaries by wind and water circulation patterns (Epifanio et al., 1984, 1995; Johnson and Hester, 1989; Boylan and Wenner, 1993; Morgan et al., 1996). Once the first-stage crabs settle onto the bottom, they seek protective habitats such as seagrass beds (Heck and Thoman, 1984; Ryer et al., 1990; Morgan et al., 1996; Perkins-Visser et al., 1996). Juvenile crabs molt and grow rapidly, migrating away from high salinity waters into brackish waters, where they eventually mature (after 12-18 months) and mate.

Sea Turtles and Marine Mammals

The JCNERR also supports several species of sea turtles such as the loggerhead turtle (*Caretta caretta*) and green turtle (*Chelonia mydas*), both federal-listed threatened species, as well as the Kemp's Ridley turtle (*Lepidochelys kempii*) and leatherback turtle (*Dermochelys coriacea*), both federal-listed endangered species. These sea turtles occur in inshore waters from late winter through early spring. Marine mammals including the right whale (*Eubalaena glacialis*) and humpback whale (*Megaptera novaenangliae*), both federal-listed endangered species, and the finback whale (*Balaenoptera physalus*), a state-listed endangered species, have been reported off the coast throughout the year. The harbor porpoise (*Phocoena phocoena*), which has been proposed for listing as a threatened species, may also occur in JCNERR waters.

Avissar (2001) investigated the population structure of the northern diamondback terrapin (*Malaclemys terrapin terrapin*) in an unaltered subtidal creek (Schooner Creek) adjacent to Great Bay Boulevard in Tuckerton, New Jersey, during summer 2001. She also compared her results with those of Rountree and Able (1992) who surveyed the northern diamondback terrapin population in the same creek during the 1988-1989 period. Avissar (2001) estimated that the population size of the northern diamondback terrapin was 119 individuals in Schooner Creek. In addition, she showed that the mean carapace length of the terrapins captured and measured in the 2001 survey (118.4 mm) was significantly less than that registered by Rountree et al. (1992) (154.3 mm) in their 1988-1989 survey. The largest individual recorded by Avissar (2001) was 190 mm compared to a maximum size of 250 mm registered by Rountree et al. (1992). This species is susceptible to vehicular mortality. For example, Hoden and Able (2003) documented a total of 77 adult female road-kill events along Great Bay Boulevard between 1993 and 2000. The loss of females due to such events is a cause of concern for the terrapin population structure in the area.

Szerlag and McRobert (2006) conducted extensive pit tagging of northern diamondback terrapins in marsh habitat and border areas of the JCNERR. They investigated the movements of the terrapins, and their susceptibility to mortalilty from vehicular traffic along Great Bay Boulevard to the edge of the estuarine habitat of Little Egg Harbor. They found that mortality of the terrapins from vehicular traffic was significantly greater in the first 4-km segment of the roadway east of the JCNERR Education Center, where the volume of vehicular traffic is greatest. Their study showed the potentially significant impact that human activities can have on terrapin populations in the reserve.

ENDANGERED AND THREATENED SPECIES

Overview

Appendix 21 provides a list of state- and federal-designated endangered and threatened species identified in the Mullica River-Great Bay Estuary and adjoining watershed areas. The federally-listed threatened plant, swamp pink (*helonias bullata*) is found within the reserve. Several occurrences of the federally-listed threatened plant, Knieskern's beaked-rush (*Rhynchospora knieskernii*), have also been documented within the reserve boundaries, as well as those of the sensitive joint-vetch (*Aeschynome*), Seabeach Amaranth (*Amaranthus pumulis*), and American chaffseed (*Schwalbea americana*), all federally-listed as threatened plants.

The piping plover (a federally-listed threatened species) builds nests within JCNERR habitat, as do the protected bald eagle and the peregrine falcon. A state endangered reptile, the Timber rattlesnake, and several threatened and endangered sea turtles and other marine mammals also utilize land and waters protected within the reserve boundaries.

Reserve Species

The Endangered Species Act of 1973 affords protection for endangered and threatened species, as well as their habitats. Since enactment of the Endangered Species Act, many animal and plant species have been protected; in some cases (e.g., bald eagle, *Haliaeetus leucocephalus*; peregrine falcon, *Falco peregrinus*; and alligator, *Alligator* *mississippiensis*), impacted species have shown remarkable recovery. Candidate species, in addition to species of concern, are also a focus of state and federal programs to facilitate the conservation and protection of plant and animal species in the Mullica River watershed and elsewhere in New Jersey. Most species that become endangered do so as a result of anthropogenic factors, most notably the loss and alteration of habitat, overfishing and overhunting, introduced/invasive species, and interaction with domestic animals. Of these factors, habitat loss and alteration are most serious; hence, preservation of habitat remains the principal means of protection of these impacted species. Species may become rare in the watershed and estuarine habitats of the JCNERR due to both natural events and anthropogenic activities (Fairbrothers, 1998). Habitat loss and alteration associated with anthropogenic impacts are particularly troubling because the environment may be changed to such a degree that prospects for survival of some species may diminish significantly.

Because most areas within the Mullica River watershed are pristine or relatively undisturbed, suitable habitat exists for a diversity of fauna and flora. The New Jersey Natural Heritage Program recognizes several priority sites for biodiversity within the Mullica River-Great Bay system. The Batsto area and Little Egg Inlet are macrosites that are recognized as having outstanding or very high biodiversity. Ballangers Creek, Clark's Landing Bog, Dan's Island, and Port Republic have also been recognized as sites of high biodiversity. These areas support an abundance and diversity of rare and federally-listed endangered, threatened, and candidate species in New Jersey, including plants, amphibians, reptiles, mammals, birds, fish, insects and other invertebrates. The Pinelands Comprehensive Management Plan also lists endangered and threatened species specific to the Pinelands region. Appendix 22 contains a list of federal-designated endangered and threatened species for the entire State of New Jersey.

The New Jersey Department of Environmental Protection (Endangered and Nongame Species Program), examining the status of rarity and endangerment, has compiled the following definitions of categories:

- Endangered Species: those species whose prospects for survival within the state are in immediate danger due to one or several factors, such as loss or degradation of habitat, over-exploitation, predation, competition, disease, disturbance, or contamination. Assistance is needed to prevent future extinction in New Jersey.
- Threatened Species: those species which may become endangered if conditions surrounding them begin to or continue to deteriorate. Thus, a threatened species is one already vulnerable due to small population size, restricted range, narrow habitat affinities, significant population decline, or some other factor.
- Species of Special Concern: those species that warrant special attention because of inherent vulnerability to environmental deterioration or habitat modification that would result in their becoming threatened. This category would also be

applied to species that meet the foregoing criteria and for which there is little understanding of their current population status in the state.

- Candidate Species: those species that appear to warrant consideration for addition to the federal list of endangered and threatened species.
- Stable Species: those species that appear to be secure in New Jersey and not in danger of falling into any of the preceding categories in the near future.
- Undetermined Species: those species for which there is not enough information available to determine the status.

The New Jersey Natural Heritage Program maintains information on state-listed species. It also chronicles the most up-to-date information on candidate species in New Jersey. The U.S. Fish and Wildlife Service reviews and evaluates the candidate species list which is regionally maintained.

Section 7(a)(2) of the Endangered Species Act 16 U.S.C. 1531 *et. seq.* requires federal agencies, in consultation with the U.S. Fish and Wildlife Service and the National Marine Fisheries Service (NMFS), to ensure that any action authorized, funded or carried out by the agencies is not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of critical habitat. NOAA consults with the U.S. Fish and Wildlife Service and the National Marine Fisheries Service with regard to species listed under the Endangered Species Act.

SUMMARY AND CONCLUSIONS

The JCNERR is one of the least disturbed coastal areas in the densely populated urban corridor of the northeastern United States, encompassing terrestrial, wetland, and

aquatic habitats almost entirely in public ownership. The upland portion of the reserve consists of extensive pine-oak forest, which serves as a protective buffer for the coastal habitats. Freshwater tidal marshes border tributary streams and headwaters of the Mullica River. Brackish marshes occupy zones in the estuary where fresh and saltwater mix. Finally, extensive salt marshes dominated by cordgrass (*Spartina alterniflora*) occur along the margins of Little Egg Harbor, Great Bay, and lower Mullica River.

The seaward segment of the reserve consists of dunes, barrier islands, and open estuarine and nearshore ocean waters. These coastal regions serve as major migratory stopovers and wintering areas for many species of waterfowl, shorebirds, wading birds, raptors, and songbirds. Subtidal waters support thriving communities of plankton, benthos, finfish, and marine mammals. The open water boundary of the reserve extends nearly 10 km offshore, incorporating the Long-Term Ecosystem Observatory (LEO) of Rutgers University.

SWMP Water Quality Monitoring

The JCNERR collects physical water quality and meteorological data using guidelines established by NERRS SWMP. The Institute of Marine and Coastal Sciences (IMCS) of Rutgers University manages the JCNERR, and Rutgers personnel have been conducting research within this system since the 1950s. After acquisition of the RUMFS site on Great Bay in 1972, Rutgers compiled extensive data sets on physical-chemical and biological conditions of estuarine waters and surrounding watershed areas of the reserve.

The meteorological conditions of the region have been monitored continuously with measurements of air and water temperature, wind speed and direction, and rainfall at nearby Atlantic City from 1888 to the present. In addition, Rutgers has been monitoring water quality parameters (temperature, salinity, turbidity) at the RUMFS site within the JCNERR since 1976. Prior to designation of the JCNERR in October 1997, Rutgers Univesity broadened its monitoring of water quality parameters in the Mullica River-Great Bay Estuary using 6-series YSI data loggers to record salinity, water temperature, dissolved oxygen, pH, turbidity, and depth. Since 1997, data loggers have recorded measurements on the parameters in 15-minute increments at four monitoring sites within estuarine waters of the reserve. This information has been helpful in asessing short-term and long-term episodic events in the system, including patterns of circulation and the effects of upwelling events detected on the inner continental shelf. These data have also been valuable for investigating the effects of upwelling on larval fish transport into estuarine waters of the reserve as well as the general patterns of species distribution within the system.

A suite of environmental parameters is monitored every 15 minutes at these stations (i.e., temperature, salinity, DO concentration, DO percent saturation, depth, pH, and turbidity at the water monitoring stations; temperature, humidity, atmospheric pressure, wind speed and direction, solar radiation, and precipitation at the weather monitoring station). Nutrient chemistry is also monitored at each of the four SWMP water quality monitoring stations on a monthly basis. Two of these stations (Chestnut Neck and Buoy 126) have been equipped with telemetry equipment that broadcasts water quality data to a GOES satellite, which is then posted to the World Wide Web.

Meteorological data are collected by a Campbell Weather Station located at the Richard Stockton College Marine Science and Environmental Field Station at Nacote Creek. This meteorological station is unique in that it has two collection platforms (at 10 m and 19 m elevation) for wind speed and direction, and all data are available in real time at the Institute of Marine and Coastal Sciences website (http://marine.rutgers.edu). This station has been collecting SWMP meteorological data since September 2002.

Meteorological parameters are measured every 5 seconds to produce 15-minute averages of air temperature, relative humidity, barometric pressure, rainfall, wind speed and wind direction. An instantaneous sample is taken every 15 minutes. Telemetry equipment was installed at the Nacote Creek Meteorological station on November 15, 2005, and it transmits data to the NOAA GOES satellite, NESDIS ID #3B00D112. The transmissions are scheduled hourly and contain four data sets reflecting 15-minute sampling intervals. By this process, the JCNERR effectively contributes to the Integrated Ocean Observing System (IOOS).

A major goal of JCNERR SWMP is to identify and track short-term variability and long-term changes in the integrity and biodiversity of estuarine waters and coastal watersheds for the purpose of contributing to effective site specific coastal zone management. Data collected in SWMP can be used to: (1) support state-specific non-point source pollution control programs by establishing local networks of continuous water quality monitoring stations in representative protected estuarine ecosystems; and (2) to help develop a nationwide database on baseline environmental conditions in the NERR system of estuaries.

The JCNERR program currently submits data to the CDMO for 4 sites within its system (Lower Bank, Chestnut Neck, Buoy 139, and Buoy 126). The long-term water quality monitoring sites in the Mullica River-Great Bay Estuary extend from the freshwater/saltwater interface at Lower Bank, down the Mullica River to the polyhaline waters of the lower estuary, covering a distance of nearly 35 km.

Physical-chemical data are also collected at LEO located on the inner continental shelf. Continual observations of coastal ocean processes are collected via two instrumented platforms (known as Node A, 74°15.73'W, 39°27.70'N and Node B, 74°14.75;W, 39°27.41'N) anchored to the sea floor and spaced 1.5 km apart. Optical fibers transfer data to computers at the Rutgers University Marine Field Station in 1-second intervals. These data are fed to the Internet and immediately made available at the

Rutgers University Coastal Ocean Observation Laboratory. The nodes support sensors that monitor an array of parameters such as temperature, salinity, dissolved oxygen, and chlorophyll.

Mullica River-Great Bay Estuary

The estuarine waters of Great Bay have been traditionally pristine and free of excessive nutrient loading and chemical contaminants from anthropogenic sources. This is due to the fact that there is very little development or industry within the watershed drainage basins and their tributaries. The lower part of Great Bay had received significant nutrient loading from a menhaden fish-processing factory, which operated along the northern perimeter of the bay from the early 1930s to the early 1960s. However, this area is no longer influenced by nutrient enrichment.

The Mullica River is relatively deep, ranging from 5 to 9 m in depth in the section that is monitored by JCNERR data loggers. Great Bay averages about 2 m in depth at mean low water. The river also has a dark coloration due to naturally occurring tannins and humic acid compounds originating in the New Jersey Pine Barrens. The depth of the river and the dark color of the water limit light penetration, and therefore nutrients entering the river upstream are not effectively utilized by phytoplankton. Light begins to penetrate where the river and bay waters converge, enabling the phytoplankton to thrive and increase in

production in the bay.

Inorganic nitrogen levels are low relative to those of organic nitrogen, which reach 40 µM or more during the summer months. Phytoplankton production in Barnegat Bay approaches 500 gC /m^2/yr, reaching maximum levels in summer. This production is high relative to other coastal bay systems. More than 240 species of phytoplankton have been identified in the Barnegat Bay-Little Egg Harbor Estuary. Phytoplankton blooms are common in JCNERR estuaries, with significant diatom and dinoflagellate blooms occurring during most years. Picoplankton, brown-tide (*Aureococcus anophagefferens*) blooms, which occurred during most summers between 1995 and 2002, may be more problematic because of their potentially adverse effects on vital seagrass and shellfish beds.

Production of benthic flora is also significant in JCNERR waters. For example, SAV beds consisting of eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*) are extensive in Little Egg Harbor. Great Bay and the back-bays to the south are devoid of seagrass but support prolific populations of macroalgae, such as *Ulva lactuca, Agardhiella subulata, Ceramium fastigiatum,* and *Gracilaria tikvahiae*. Both the seagrass and benthic macroalgae provide habitat for numerous benthic and nektonic organisms.

Zooplankton communities in the system consist of large populations of microzooplankton, macrozooplankton, and icthyoplankton. Copepods (*Acartia hudsonica, A. tonsa, Eurytemora affinis*, and *Oithona similis*) dominate the microzooplankton, whereas hydromedusae, comb jellies, and true jellyfishes dominate the macrozooplankton. Meroplankton and ichthyoplankton comprise significant components of the total zooplankton, particularly during the warmer months of the year from June through September.

More than 140 benthic invertebrate species have been recorded in the Mullica River-Great Bay Estuary. Higher species richness (>200 benthic invertebrate forms) have been identified in the Barnegat Bay-Little Egg Harbor Estuary. While nearly all phyla are represented, the most abundant taxa include the polychaetes, bivalves, gastropods, and crustaceans. Along a well-defined salinity gradient of the Mullica River-Greatt Bay Estuary, four distinct assemblages of benthic invertebrates are evident, notably river-dominated, bay-dominated, lower-bay dominated, and estuary-wide forms. The relative concentrations of silt-clay and sand in bottom sediments strongly influence the local distribution of benthic invertebrates in JCNERR estuaries.

More than 60 species of fish have been identified in Great Bay compared to more than 100 species of fish in the Barnegat Bay-Little Egg Harbor system. Five fish assemblages are recognized, including resident species, warm-water migrants, cool-water migrants, marine strays, and freshwater strays. Species richness and absolute abundance peak during the summer months, primarily due to the influx of warm-water migrants. Estuarine habitats in the New Jersey coastal bays are heavily utilized by fish as spawning, nursery, and feeding grounds. A number of fish species are recreationally or commercially important, such as summer and winter flounder, bluefish, striped bass, and weakfish.

JCNERR estuaries and coastal waters also support a wide variety of sea turtles (e.g., loggerhead-, leatherback-, and Kemp's Ridley turtles) and marine mammals (e.g, humpback-, finback-, and right whales; harbor porpoises, and harbor seals). Several turtles and marine mammals occurring in JCNERR waters are listed as threatened or endangered species. The northern diamondback terrapin (*Malaclemys terrapin terrapin*) is susceptible to road kill and other anthropogenic impacts.

The JCNERR lies along the Atlantic Flyway and thousands of migrating birds utilize habitats in the reserve as staging and overwintering areas. Gulls, terns, waders, rails, and raptors are well represented in reserve habitats. Songbirds, waterfowl, and seabirds have been censused from upland watershed areas to the barrier islands along the seaward boundary. Nearly 170 species of birds were registered along Great Bay Boulevard and the adjacent open estuarine waters of the JCNERR over a 13-year study period.

Current Research

The JCNERR is conducting a number of studies on nutrient processes in its estuarine waters. For example, studies have compared atmospheric nitrogen data with results of water column nitrogen levels to demonstrate that both sources may contribute to seasonal algal blooms in the Mullica River-Great Bay Estuary. An atmospheric sampling platform located at RUMFS is providing atmospheric deposition data for the immediate area of Great Bay with the long-term goal to establish a nutrient budget for the Mullica River-Great Bay Estuary.

Innovative studies of phytoplankton biomass are being conducted using experimental deployment of a HOBI Labs Hydroscatt-2 backscatter fluorometer at moored sites in Great Bay. The use of a spectral backscatter-fluorometer enables chlorophyll *a* levels to be measured in a more automated manner and to be related to phytoplankton rate processes. The objective is to generate an optical, nearly continuous time series of measurements on phytoplankton biomass at specific estuarine sites that can be correlated with changes in water quality (e.g., nutrients) measured by the aforementioned methods.

Investigations are also being conducted on larval settlement and dynamics of the epibenthic organisms in estuarine waters of the JCNERR and neighboring systems. Artificial substrates of different composition are being deployed at various sites to determine the development and structure of the epibenthic community. The deployment of aluminum, plastic, and PVC settling plates are yielding considerable data on the settlement, recruitment, and post-recruitment success of epibenthic organisms in estuarine waters of the JCNERR.

Soft-bottom benthic community sampling is also being conducted in the JCNERR to assess the benthos in the system. Both sediment and biotic samples are being collected using a Van Veen grab. More than 50 permanent benthic sampling stations have been established in Great Bay and lower Mullica River to examine the benthic habitats and community of organisms. Results of this sampling program will be compared to those of earlier investigations on the benthos conducted during the 1960s. The purpose is to delineate changes in the sediment regime and benthic community over the past 40 years.

Side-scan sonar imaging of the seabed in Great Bay has been completed using an autonomous underwater vehicle. This project was initiated to document the complex and multi-scaled bedforms and associated benthic habitats in the bay. Small-, medium-, and large-scale bedforms (i.e., ripples, dunes, and sand waves) have been imaged and assessed as potential habitat for benthic invertebrate and finfish populations.

Shellfish are likewise being targeted, particularly the recreationally and commercially important blue crab (*Callinectes sapidus*) and hard clam (*Mercenaria mercenaria*). Studies are focusing on the effects of habitat quality in JCNERR estuaries on the dynamics of these species. This work is designed to better understand how different habitats affect the abundance, population characteristics, and mortality of these economically important species. Anthropogenic influences on the shellfish populations are being examined.

Biomonitoring projects are being conducted in Little Egg Harbor to determine the changes that occur in demographic characteristics of SAV populations (*Zostera marina* and *Ruppia maritima*) during an annual growing period. This work is addressing the following questions to document variability of SAV beds in this important JCNERR coastal bay:

- What quantitative changes take place in aboveground and belowground biomass, shoot or stem density, and maximum canopy height of SAV beds over a growing season?
- How variable is the percent cover by seagrass and macroalgae within the field survey areas? Is seasonal dominance evident among the species? Are shifts in spatial distribution of the SAV species significant within a growing season?

- Do the SAV bed boundaries expand, contract, or remain unchanged over a seasonal sampling period?
- Where is the maximum species abundance observed in the sampling segments and can this abundance be related to specific environmental factors?
- Can the surveys differentiate natural variability of the SAV from that induced by anthropogenic activities?

The project has been designed to respond to multiple coastal management needs. SAV beds are recognized as essential biotic habitats that receive special consideration in New Jersey.

Much of RUMFS research in the JCNERR is focused on the study of the early life history and ecology of fishes, many of which are important to commercial and recreational fisheries in the region. Using plankton nets during evening flood tides, RUMFS has monitored ichthyoplankton occurrence and abundance within the reserve since 1989. Long-term monitoring of juvenile fishes in the Mullica River-Great Bay Estuary began with the use of traps in 1990, and otter-trawls in 1988. These data have proved invaluable to fisheries managers and scientists for determining habitat preferences of fish and decapod crustaceans and annual fluctuations in abundance.

Researchers at RUMFS have investigated the migration dynamics of striped bass, an anadromous species of substantial ecological, recreational and commercial importance to the Middle Atlantic Bight, by providing information on their rate, seasonality, path of movement and behavior during movement. Striped bass tagged with individually coded acoustic transmitters are being monitored with strategically located hydrophone receivers that complement existing instrument packages which measure various physical parameters in the coastal ocean and adjacent estuaries of the JCNERR. This study has important consequences for the implementation of a unified, coast-wide census of marine life, and the management of this keystone species at a period of maximum stock size.

RUMFS scientists and staff are also involved in studies evaluating essential fish habitat and juvenile fish recruitment on the inner continental shelf and in the estuarine waters of the JCNERR. Research approaches to these topics include submersible dives, habitat mapping with multibeam and side-scan acoustic systems, and otolith extraction. The adjacent Mid-Atlantic Bight has likewise been the focus of intensive surveys for all fish life history stages by the National Marine Fisheries Service (NMFS) during the last 25 years.

Two research projects completed within the reserve in 2000 included a three-year assessment of the effects of sea scallop fishing gear on juvenile fish habitat on the continental shelf off New Jersey, and a study on bluefish habitats and movement in the coastal ocean off New Jersey. In 2000, researchers began investigating the impacts of docks and piers on submerged aquatic vegetation. A variety of benthic data has been amassed including annual surveys of surf clam population densities, length/frequency analysis, and juvenile recruitment at stations within the 4.8-km limit along the New Jersey coast.

In addition to monitoring activities in the reserve, investigators are involved in restoration activities along Delaware Bay. This research parallels initiatives of NERRS that focuses on restoration in estuarine ecosystems. Projects have included monitoring and evaluation of fish and decapod use of former salt hay farms, which have recently been exposed to tidal inundation, and *Phragmites comminus* dominated marshes, which have been treated to restore natural vegetation. The latter was complemented with work in the brackish reaches of the JCNERR addressing the invasion of *Phragmites* on these undisturbed marshes.

The IMCS Division of Pinelands Research and the Pinelands Commission have engaged in multidisciplinary studies dealing with applied research problems in the area, including mycorrhizal community functioning, soil biodiversity, and forest fire frequency effects on habitat nutrient sustainability. The Richard Stockton College of New Jersey, one of the Mullica River landowners, has monitored harbor and gray seals that have been frequenting Great Bay in recent years.

Investigations of land use/land cover change in the Mullica River watershed are also being conducted. These investigations are providing documentation via a Geographic Information System (GIS) on how the terrestrial land within the watershed draining into the reserve is being changed/developed. Some of the parameters of study include impervious surface, population, and amount of altered land. Future investigations will deal with assessment of the amount of marsh that has been developed or diked for mosquito control. The amount of change in the physical structure of the marsh habitat will also be examined. Finally, applications of remote sensing to detect harmful algal blooms in the reserve are also under investigation.

An analysis to quantify the amount of development at build-out has been completed for the Mullica River watershed at the Center for Remote Sensing and Spatial Analysis at Rutgers University. A similar project for the Barnegat Bay watershed was previously completed. The build-out analysis uses a GIS-based approach, enabling investigators to create a spatially explicit model to examine potential changes in specific areas of the watershed.

To create a base layer of commercial and urban areas for the build-out analysis, land use for the Mullica River watershed has been updated using spot aerial photography and compared to existing land use and land cover data from 1995. Areas of new growth have been documented, and a large percentage of data has been field-checked for accuracy.

Several new data layers have been incorporated into the JCNERR GIS database, including 1930 black and white aerial photography for Ocean County, a 10-meter digital elevation model from the New Jersey Department of Environmental Protection (NJDEP), environmentally sensitive index data, and NJDEP brown-tide data. In addition, SWMP data collection points, 2000 land cover data, spot satellite imagery (from NOAA Coastal Services Center), 2000 census data, historical topographic maps from 1890, and many more data sources have been processed.

Future development in the Mullica River watershed has been determined based on the location of existing development, land permanently protected as open space, municipal zoning rules, the Pinelands Management Plan, and wetlands and coastal zone regulations. The potential impacts of the predicted development on the water resources have been identified using the number of dwelling units and population as indicators of residential water demand and impervious surface as an indicator of non-point source pollution. By understanding potential changes in these indicators, investigators can better identify key actions needed to protect resources in the watershed. This work will enable coastal decision makers to improve the management of natural resources in the reserve.

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Zimmer, B. J. 1981. Nitrogen Dynamics in the Surface Water of the New Jersey Pine Barrens. Ph.D. Thesis, Rutgers University, New Brunswick, New Jersey. 317 p.

Appendix 1. List of Graduate Research Fellows awarded in the Jacques Cousteau National Estuarine Research Reserve.

Tenley Conway (2001) Integrating land use change models and stakeholder models into a framework for coastal management.

Jennifer Haag (2004) Atmospheric deposition of nitrogen at Great Bay, New Jersey.

Inga La Puma (2007) Assessment of land use and disturbance scenarios in the Jacques Cousteau National Estuarine Research Reserve watersheds using spatial modeling.

Edward Martino (2002) Spatial variation in fish and decapod crustacean abundance and diversity within tidal creeks along an estuarine physicochemical gradient at the Jacques Cousteau NERR in Mullica River-Great Bay Estuary.

Amanda McGuirk (2003) Bioavailability of particulate phosphorus in estuarine systems: a comparison between pristine and polluted sites in Jacques Cousteau National Estuarine Research Reserve.

Melissa Neuman (1997) Effects of upwelling on larval occurrence and abundance in the Mullica River-Great Bay Estuary.

Dana Rowles (2003) An evaluation of summer flounder (*Paralichthys dentatus*), coastal habitat use, and dynamics comparison between migration and summer residence in the Jacques Cousteau National Estuarine Research Reserve.

Gregg Sakowicz (2001) Essential fish habitat for marsh fishes: behavioral ecology of larval and juvenile *Fundulus heteroclitus* and *Cyprinodon variegates.*

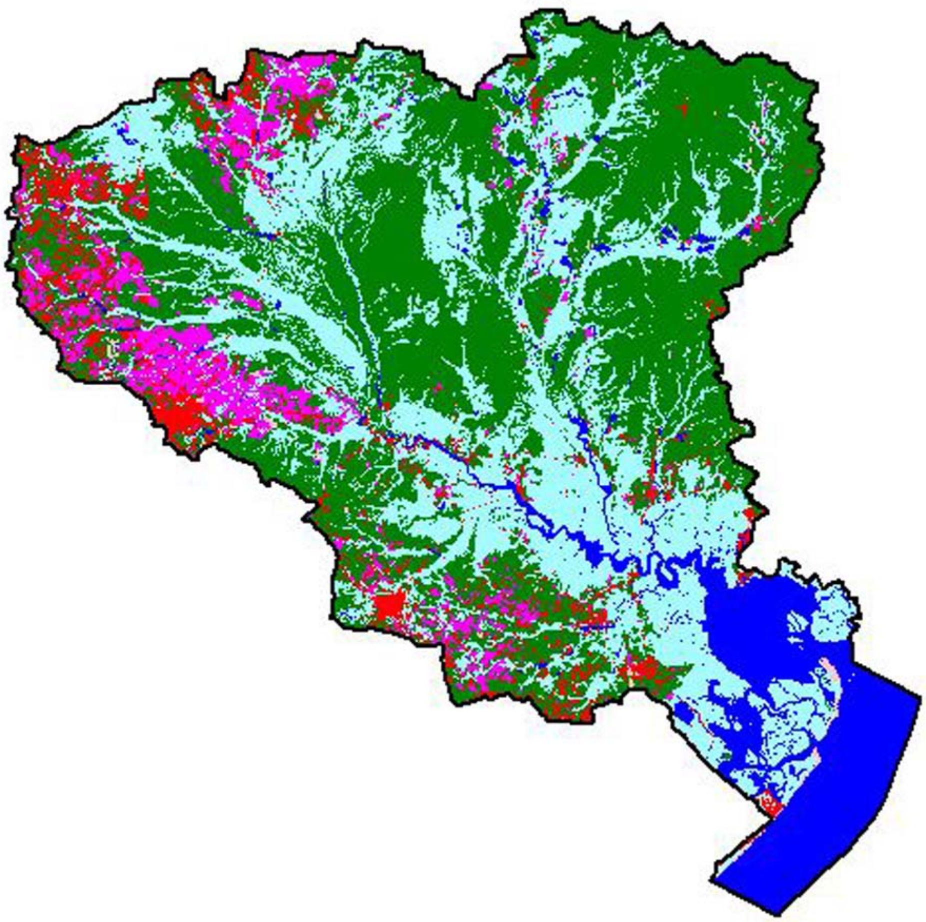
Jamie Tirado (2005) Biomass changes in seagrass epiphytes in a New Jersey shallow coastal bay system.

Jason Turnure (2007) Delineating habitat resources for weakfish, *Cynoscion regalis*: biotelemetry and passive acoustic approaches.

Tracy Wiegner (1999) Organic nitrogen from freshwater wetlands in the Jacques Cousteau NERR at Mullica River and Great Bay.

Appendix 2. A Build-out Analysis of the Mullica River Watershed

Changing Land Use in the Mullica River Watershed: Past and Future Trends.
1986 – 1995 – 2000 – Buildout



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Jacques Cousteau National Estuarine Research Reserve

ABSTRACT

The Mullica River Watershed is located in the Pinelands ecosystem and currently contains a high percentage of unaltered land. However, due to its close proximity to the Atlantic City, Philadelphia, and New York City metropolitan areas there is great potential for further development. We were interested in determining the potential impact of past and future development on water resources. The project has three parts: (1) identifying past land use; (2) determining the potential of future development; and (3) using indicators to asses the impacts of the past and potential future development on water demand and urban non-point source pollution. While there is currently little development in the watershed, our analysis indicates that a substantial portion of the land is available for future development. However, if growth is limited to the designated Pinelands' growth areas, the impacts to water resources will be minimized.

INTRODUCTION

The Mullica River Watershed, located in southeastern New Jersey (Figure 1), is part of the Pinelands ecosystem. The Pinelands are characterized by highly sandy acidic soils, a frequent fire regime, and a pine-oak dominated upland forest. Approximately 940,000 acres in size, the Pinelands' stretch from the northern reaches of Ocean County to Cape May County. The Pinelands became the first National Reserve in 1978 and received international attention in 1983 when it was designated as an International Biosphere Reserve. Today, the Pinelands Commission regulates new development within the administrative boundaries of the New Jersey Pinelands Management Areas, approximately two-thirds of the Pinelands region. Eighty-two percent of the 420,000 acre Mullica River Watershed is within the Pinelands Management Areas. However, much of the watershed is potentially prime residential and commercial land due to the close proximity of Atlantic City, Philadelphia, and New York City. Additional development would not only alter the terrestrial ecosystem, but also has the potential to negatively impact groundwater and the downstream estuary.

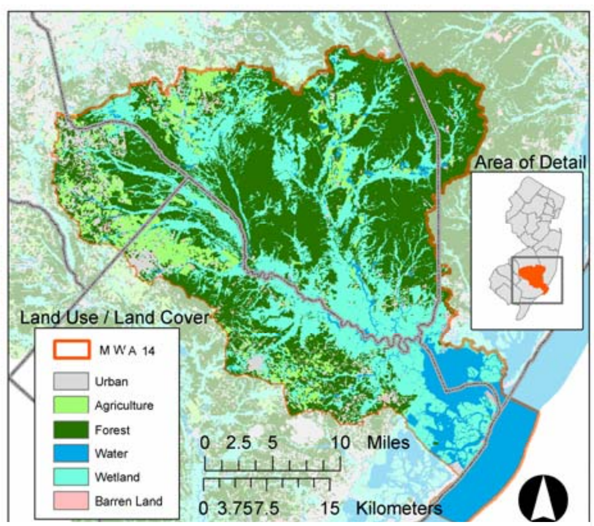

Figure 1. WMA 14 NJDEP Land Use / Land Cover 1995.

The goal of this project was to identify land use trends and determine the potential impact of past and future development on water resources. There were three parts to the analysis. First, past land use was identified from existing datasets and updates completed using satellite imagery. Second, future growth potential was determined through a build-out analysis, based on the location of existing development, permanently protected open space, and applicable regulations. Several different scenarios were examined, including low constraint and high constraint analyses. The third part of the project examined the potential impacts past and future urban development might have on water resources using the number of dwelling units and population as indicators of residential water demand and impervious surface as an indicator of urban non-point source pollution. By understanding potential changes in these indicators, we can better identify actions needed to protect the water resources of the Mullica River Watershed.

METHODS

To map land use and future developmental pressures in the Mullica River Watershed we used a Geographic Information System (GIS). GIS enables the creation, manipulation, and analysis of digital spatial data, allowing us to examine the location of past and future change. The Mullica River Watershed boundary used by the New Jersey Department of Environmental Protection (NJDEP) defined the spatial extent of the analysis.

Past Land Use

The NJDEP dataset of land use and land cover (LULC) was used to determine land use in 1986 and 1995 (Appendix 1). The LULC dataset is based on the interpretation of one meter color infrared photography, allowing a minimum mapping unit (MMU) of one acre and fine scale differentiations between LULC classes based on Anderson levels one through four. To update this dataset, we created a GIS data layer of land use in 2000, by comparing SPOT satellite panchromatic images (10 meter ground resolution cell) obtained in 2000 with the 1995 -1997 color infrared aerial photography flown by the United States Geological Service. Areas of change were on-screen digitized using ESRI GIS software. The large pixel size for the satellite sensor dictated a MMU of 1000 sq meters, approximately one quarter of an acre. A much simpler method was used to categorize altered or changed areas as compared to the NJDEP approach. Polygons were coded as urban, agriculture, or barren/ grassland. Urban areas identified included all new commercial and residential structures. Using only the satellite data, distinctions between multiple houses and single houses could be determined based on the relative size and shape of the development (Appendix 2), but differentiating between residential and commercial areas was not possible without ancillary data. New agriculture represents all new areas that are actively being farmed, determined by shape, size, and relative proximity to existing agriculture. Barren and managed grassland were grouped together because of the difficulty in differentiating between them using the satellite imagery (Appendix 2).

Build-out Analysis

Once we identified past land use, we were interested in examining the potential for future development. We used a build-out analysis to map potential future development across the landscape under specific sets of constraints. The scope and location of future urban development is identified in this type of analysis, although timing of development is not predicted. The build-out was created using a grid environment, with a five-meter grid cell length, due to ease of computation. Appendix 1 lists the data layers used.

To locate developable land we excluded land already developed, wetlands, preserved open space, parcels with severed developmental rights, and buffer zones around water bodies and wetlands. The buffer zone width was determined based on our interpretation of NJDEP regulations and the Pinelands Management Plan. The buffer ranges from no buffer to 300 feet, depending on the size of the wetland, surrounding land uses, whether threatened or endangered species are present, and if the wetland is locate within a Pinelands Management Area. The remaining land was assumed to be available for development in this analysis.

Four build-out scenarios were created:

1. Low constraint scenario (LC) representing current regulations. The current regulations included in this scenario were (1) limitation on development in wetlands or buffer zones around freshwater and tidal areas as specified under the NJDEP's Freshwater Wetlands and Coastal Programs, (2) municipal zoning regulations, and (3) Pinelands Area regulations.

2. High constraints scenario one (HC1) is the same as LC except that areas without sewer service are forced to have a minimum lot size of 3.2 acres. This lot size was chosen as the Pinelands Commission determined 3.2 acres was the smallest lot that could support a septic system without negative impacts in the region (Pinelands Commission 1982). This scenario does not take into account the Pinelands' pilot septic program that is testing new technologies that would make it possible to support septic systems on smaller lots. However, HC1 is similar to current activities guided by Executive Order 109 (Springer 2002), and the recently defeated Watershed Management Rules (NJDEP 2001a) meant to replace the temporary situation of the Executive Order.

3. High constraints scenario two (HC2) is the same HC1 with an additional constraint on the maximum impervious surface allowed based on the 2000 Coastal Zone Management Rules (NJDEP 2001b). These rules use the state planning designations to define limits on the maximum impervious surface in a given area (Table 2). Current centers and zone designations were included in the HC2 scenario. Only a small percentage of the watershed area (3%) is affected by the CAFRA rules because most of the watershed is in the Pinelands Management Area, which is not covered under these rules.

4. High constraints scenario three (HC3) is the same as the HC2 scenario except maximum impervious surface limits were applied using current and proposed town centers.

Table 2. Maximum impervious surface cover allowed in the CAFRA planning areas.

Planning Area	Maximum Impervious Surface Cover	Percent of Watershed in Each Planning Area
Metropolitan	80 %	0.02 %
Suburban, Sewer Service	30 %	0.87 %
Suburban, No Sewer Service	5 %	0.37 %
Rural	5 %	0.60 %
Environmentally Sensitive	3 %	2.18 %

*For the percent equation the total area of the Mullica River Watershed was 373,471 acres. Water areas were not included.

Indicator Analysis

To assess the impacts of future development on water resources, two indicators were used. The number of dwelling units and population were calculated as indicators of residential water demand, while impervious surface was used as an indicator of urban non-point source pollution. Indicator values for past conditions were calculated to compare with build-out estimates.

Dwelling Units and Population A growing population can negatively impact the region's water resources, as a larger population requires a larger supply of freshwater. We focused on residential water demand in this analysis because most land use conversions have been and are predicted to be from forest to residential uses. If the population continues to increase, the demand for potable freshwater could exceed the sustainable supply. Thus, it is important to understand the potential size of the population at build-out.

To determine the past population of the Mullica River Watershed census block data from 1990 and 2000 were used. The census block data were combined with the NJDEP LULC data for 1995. If the census block was completely within the Mullica River Watershed all of the population was counted. For census blocks that overlapped the watershed boundaries, a percentage of the population was added relative to the percentage of total residential area of the specific block that falls within the Watershed. For example, census block number 3879 has a 2000 population of 184 people. Eight-four percent of the residential areas of this census block in 1995 were located within the Watershed's boundaries, so 84.2 percent (155 people) of 182 people are considered within the watershed.

Build-out population estimates were based on the number of dwelling units. To estimate the number of dwelling units, areas that could be developed were combined with digital zoning density information supplied by the Pinelands Commission and the municipalities with land outside the Pinelands Management Areas (Appendix 1). We assumed that only 80 percent of the land in each polygon could be used for building lots to account for land needed for public infrastructure. While 80 percent is the value currently used by planners in the region (McKeon, 2001), it is likely that in areas with low density zoning a smaller percentage of the land must be reserved for infrastructure. The building lot area was then divided by the maximum zoning density to determine the number of dwelling units per polygon. The number of dwelling units was then rounded down to reflect the impossibility of building a fraction of a dwelling unit. The number of predicted dwelling units was multiplied by the average number of people in a dwelling unit based on the 2000 census for the Watershed to determine the total predicted increase in population at build-out. Transfer of development rights, which could results in higher density development in certain areas, was not considered. However, the ability to transfer development rights does exist in the Pinelands Management Area, and may impact the density of future development.

In order to assess the validity of the build-out scenarios, the same methods used to calculate the number of dwelling units at build-out were applied to estimate dwelling units in 2000. The calculation was only completed for the census blocks that were completely within the Mullica River Watershed. The number of predicted dwelling units was then multiplied by average number of people per dwelling unit in 2000 (2.46 people per dwelling unit) to get an estimated population. This number was compared to the 2000 census numbers, and is discussed in the results section.

Impervious Surface When land is converted to urban uses, there are physical, chemical, and biological impacts on water quality (Zandbergen 1998). Impervious surface has been proposed as an accurate measure of non-point source pollution from urban run-off and a general indicator of watershed health (Soil Conservation Service 1975; Klein 1979; Arnolds and Gibbons 1996; Wang 2001). Impervious surface refers to streets, sidewalks, driveways, roofs, patios, and other impenetrable surfaces. Areas that are more intensely developed tend to have a larger percentage of impervious surface cover, contributing more non-point source pollution to the water in the watershed. Thus, impervious surface is an important environmental indicator of the intensity of human land use and closely correlates with water quality degradation and altered runoff patterns in urban and urbanizing areas (Novotny and Chesters 1981; Brown 1988; Driver and Troutman 1989; Ferguson and Suckling 1990; Arnold and Gibbons 1996; Charbeneau and Barrett 1998).

In compiling data from a number of watersheds, Arnold and Gibbons (1996) developed a set of impact thresholds: (1) less than 10 percent impervious surface cover can be considered non- impacted; (2) between 10 and 30 percent cover can be considered impacted; and (3) greater than 30 percent cover is generally considered degraded. While these thresholds should not be considered 'hard and fast' breakpoints, they do provide a useful guide in evaluating the comparative risk of water quality degradation at a watershed scale.

The NJDEP estimated impervious surface for 1986 and 1995 based on the LULC dataset. Build-out estimates were determined by calculating the average amount of land covered by impervious surface for each zone. There is an inverse relationship between lot size and the percent of the lot covered by impervious surface. However, large lot development creates more per capita impervious cover. For the largest lot size (70 acres) the impervious surface cover was estimated at one percent, while the smallest lot size (0.08 acres) had an average impervious cover of 43 percent. The average amount of impervious surface by zoning density was applied to the build-out scenarios to determine the potential impervious surface at build-out.

RESULTS

Past Land Use

Table 3 shows land use in 1986, 1995, and 2000. A total of 370,571 acres, 88 percent of the watershed, was in a natural or unaltered state in 1986, making the Mullica River Watershed one of the most pristine watersheds in New Jersey. Since 1986, little change has occurred on the unaltered lands. Although 2,400 acres of forest and 300 acres of wetlands were lost between 1986 and 2000, this represents only 0.7 percent of the total watershed. Of this loss, most conversions from natural to altered land were from forest to urban land uses.

Table 3. Land use/ land cover in 1986, 1995, and 2000.

Land Cover	Acres 1986	Acres 1995	***Acres 2000***	**Percent change 1986 to 2000**
Agriculture	25,753	24,358	24,389	-5.3 %
Barren Land	2,666	2,459	2,799	+5.0 %
Forest	188,988	187,735	186,581	-1.3 %
Urban	20,926	23,824	24,736	+18.2 %
Water	46,311	46,444	46,441	-0.2 %
Wetlands	135,276	135,096	134,970	-0.3 %

Traditionally the Pinelands were thought of as a wasteland due the poor nutrient content and high acidity of the soil which hindered agricultural efforts. Today specialized agriculture exists mainly through the domestication and cultivation of indigenous plant species (cranberry and blueberry) that are adapted to these adverse conditions. In 1986, 25,753 acres of land in the Mullica River Watershed were actively being farmed, approximately six percent of the total watershed. Agriculture decreased by 1,395 acres between 1986 and 1995. Most of the land was converted to forest, with approximately 54 percent left fallow. Forty-three percent of the converted agriculture can be attributed to urban and commercial growth. It is difficult to accurately quantify the change in agricultural land between 1995 and 2000 due to the nature of satellite land use updates. Never the less, it appears that the loss of farmland may be slowing, with an increase of 30 acres of farmland between 1995 and 2000 identified.

In 1986, urban land comprised 5.84 percent of the watershed and by 1995 had increased to 6.6 percent of the watershed. Between 1995 and 2000, urban areas continued to increase to 6.9 percent. Most new development is occurring along the southwest edge of the watershed, in the areas designated for growth. This trend indicates that Pinelands regulations are effectively keeping new development away from the core areas of the region.

Build-out Scenarios

The percent of urban land was compared to the amount of land available for development (Table 4). In general the sub-watershed areas that have the most development in 2000 (Figure 2; Upper and Lower Mullica River) have the greatest potential to increase in development. Sub-watersheds that are least developed in 2000 (Great Bay and Bass River) have less land available for development in the future. Bass River has so little land available for development because most of the land is protected open space (Wharton State Forest), while most of the Great Bay sub-watershed is open water and wetlands.

Figure 2. Sub-watersheds (USGS HUC 11) in the Watershed.

Table 4. Existing urban land and land available for future development, as a percent of entire watershed.

HUC-11	Urban 1986	Urban 1995	Urban 2000	***Available for Development***
Bass River	0.79	0.90	0.94	10.90
Basto River	4.40	5.46	5.68	11.85
Oswego River	0.86	0.97	1.02	17.77
Upper Mullica River	10.79	11.86	12.11	19.56
Mullica and Wading River	5.68	7.12	7.83	17.36

Lower Mullica River	6.84	7.52	7.76	18.20
Great Bay	5.54	6.05	6.21	4.71
Brigantine	38.35	39.84	39.84	13.68
Total Watershed	5.84	6.66	6.92	16.68

Indicator Results

The population was 76,383 and 83,501 in 1990 and 2000 respectively, representing a nine percent increase over the ten-year period. The build-out population was calculated as 110,363 to 124,334 (Table 5), an increase of 32 to 49 percent predicted. The LC scenario allowed the highest number of dwelling units, while the three high constraint models (H1, H2, H3) all allowed approximately the same number of dwelling units. However, all scenarios represent a substantial increase over the 2000 watershed population.

The quality check of the build-out methodology predicts a 2000 population of 55,300 for the census blocks completely within the Mullica River Watershed. The total census population for these blocks was 72,000 people, with the build-out analysis potentially underestimating predicted population by about 23 percent. The disparity is most likely due to differences in the existing zoning file and the density pre regulation development, primarily in areas of older development and the differences in the # of people per dwelling unit across the different residential development types. This may not be a problem for the model as new growth is expected to more consistently conform to the zoning information used in this analysis. But, if the model under predicts by 23 percent, however, the population and impervious surface could be significantly higher at build-out.

Table 6 shows impervious surface estimates for 1986, 1995, and the build-out scenarios. Impervious surface for the Mullica River Watershed in 1986 was 1.34 percent. Between 1986 and 1995 impervious surface increased by 741 acres to 1.53 percent. Both values are substantially less than the 10 percent threshold of Arnolds and Gibbons (1996). The build-out analysis aggregated across the entire Mullica River basin, predicted a range of impervious surface between 2.50 and 2.83 percent, with the low constraints scenario having the highest value. These values are also well below Arnold and Gibbons (1996) 10 percent threshold for impacted areas.

To highlight localized areas of potentially high impact from non-point source pollution, impervious surface was also analyzed using the USGS HUC 14 sub-watersheds. For 1986 and 1995, no sub-watersheds were over the 10 percent impervious surface threshold (Figure 3). The build-out scenarios predict anywhere from four to seven sub-watersheds over the 10 percent mark (Figure 4), with the potentially impacted sub-watersheds located in the Regional Growth Areas or outside the Pinelands Management Area. The LC scenario had the highest number of sub-watersheds over 10 percent. In addition, 19 sub-watersheds, approximately one-third of the total, are located downstream and are hydrologically connected to impacted areas in the LC scenario (Figure 5). The build-out scenarios based on the Coastal Zone Management Rules maximum impervious surface limits (HC2 and HC3) had the lowest levels of impervious surface predicted, indicating that enforcement of these rules could reduce the impact of future development on water quality.

Table 5. Estimated dwelling units and population.

	1990	2000	LC	HC1	HC2	HC3
DU increase	30,587	33,916	50,249	45,306	44880	44984
Total Population	76,383	83,501	123,680	111,520	110,472	110,728

Table 6. Estimated impervious surface in 1986, 1995, and build-out.

	1986	1995	LC	HC1	HC2	*HC3*
Acres	5,005	5,746	10,556	9828	9,372	9,563
Percent*	1.34 %	1.53 %	2.83 %	2.63 %	2.50 %	2.56 %

*For the percent equation the total area of the Mullica River Watershed was 373,471 acres. Water areas were not included.

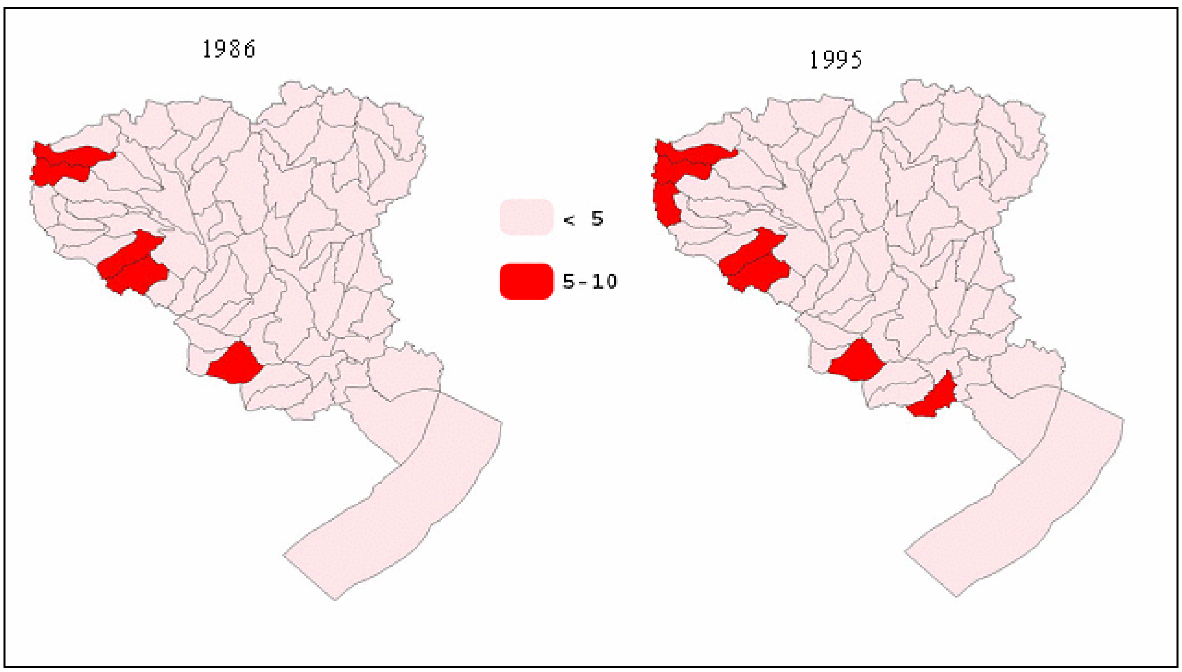

Figure 3. Impervious surface estimates by USGS HUC 14.

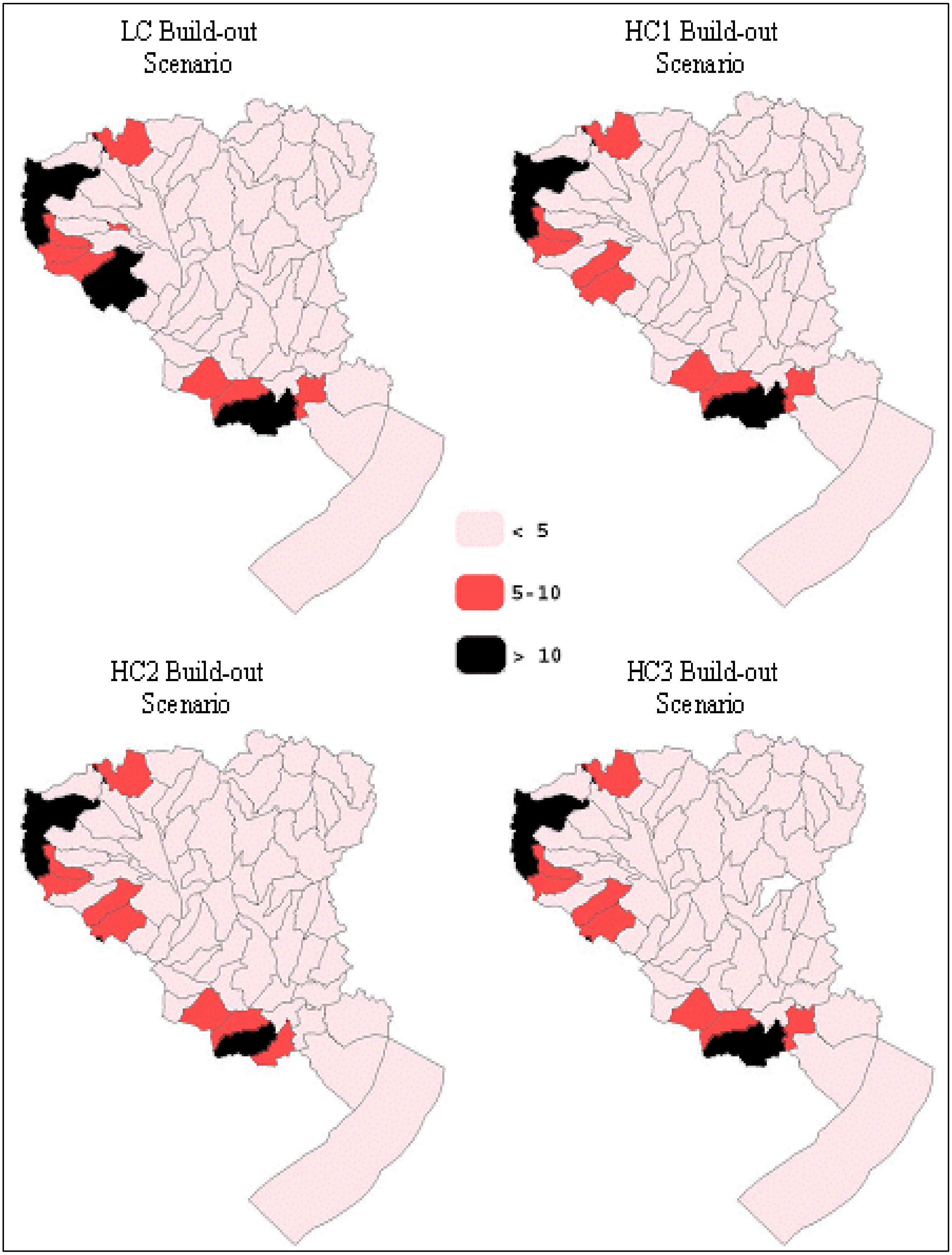

Figure 4. Build-out impervious surface estimates for USGS HUC 14.

CONCLUSIONS

Based on our analysis, there has been an 18 percent increase in urban land in the Mullica River Watershed between 1986 and 2000. Conversely this can be seen as a real loss of around 1% of the watershed to development between 1986 and 2000. These results highlight the strength of the Pinelands regulations in limiting overall growth and steering new development towards designated growth areas. Additionally, the slowing conversion rate of agricultural land indicates that another Pinelands management goal, preserving traditional agriculture, is being met.

While regulatory, social, and economic conditions are likely to change between now and build-out, there is the potential for a substantial increase in urban development to occur that could negatively impact the water supply and quality of the downstream estuary. Again, the Pinelands regulations should help limit the impacts, with most new development concentrated in a few sub-watersheds. By concentrating the areas of high impervious surface, mitigation of urban non-point source pollution can be made more feasible by the adoption of best management storm water runoff plans. However, if the Pinelands regulations are relaxed or not enforced, then there is the potential for more widespread development, greatly impacting water quality throughout the watershed and increasing the need for mitigation activities.

Of the build-out scenarios considered, the two high constraint models based on the Coastal Zone Management Rules (HC2 and HC3) are most effective at reducing the potential impacts of impervious surface. These rules take an approach similar to the Pinelands Management Area, trying to concentrate urban development in specific areas, while minimally impacting most of the land. Again, enforcement of these rules, or ones similar, will reduce overall impacts and increase the effectiveness of mitigation actions against non-point source pollution.

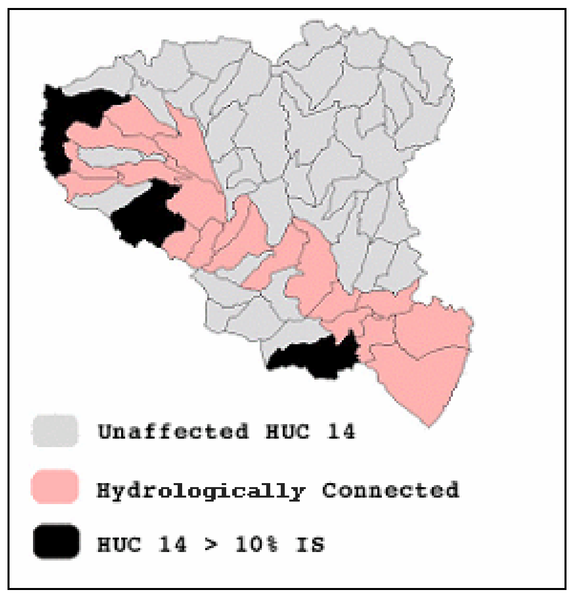

Figure 5. Hydrological connectivity for the LC build-out scenario.

While the indicator analysis highlights the need for mitigation activity limiting impacts of impervious surface in the southwest portion of the watershed, the potential increase in population suggests that sufficient water supply is also a concern, particularly as many households rely on shallow wells. Future work should consider the location of the potential new growth and the supply of water to develop a water supply management plan to help ensure there is a sufficient supply of potable water to meet future demand.

ACKNOWLEDGEMENTS

The Pinelands Commission, Brigantine City, Galloway Township, and Port Republic Township provided essential zoning data for the project. Discussions with Chris Krupka (Pinelands Commission) in the early stages of the project provided necessary direction. John Bognar and Jim Trimble provided technical support.

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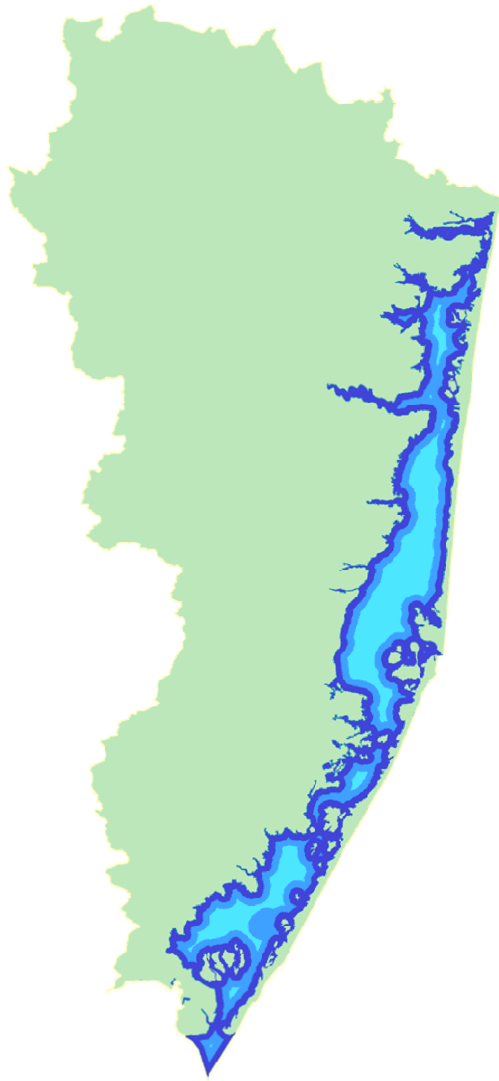
Appendix 3. A Build-out Analysis of the Barnegat Bay Watershed



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May 2001

CRSSA Technical Report 2001-02

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Introduction

As part of the National Estuary Program, the Barnegat Bay region has been the focus of an ambitious scientific characterization and data synthesis process. This effort has recently culminated in the development a Comprehensive Conservation and Management Plan (CCMP) for the bay and its watershed (Barnegat Bay Estuary Program, 2000a). The goal of the CCMP is to balance the competing demands of human uses of the region while promoting the long term sustainability of the bay and its diverse natural resources. In implementing the CCMP and targeting conservation efforts, a prospective look at future development patterns was deemed necessary. In response, we have completed a build-out analysis of the watershed. A build-out analysis maps the expected location of future development and estimates the number of new dwelling units when all land available for development is developed at the highest intensities possible. However, a build-out analysis does not project when build-out will occur. A build-out analysis is useful in long-term planning efforts as a way to understand the potential future growth. The goal of this Barnegat Bay watershed build-out study is to provide information to local decision-makers on the scope and magnitude of future development patterns based on several different scenarios of zoning and land use management policies.

In this study, we use the number of dwelling units, population, and percent of impervious surface cover as ways to quantify the amount of development possible at build-out. The number of dwelling units and population are indicators of residential water demand, while impervious surface is an indicator of non-point source pollution. By understanding the potential changes of these indicators, we can better identify actions needed to protect the resource in the Barnegat Bay.

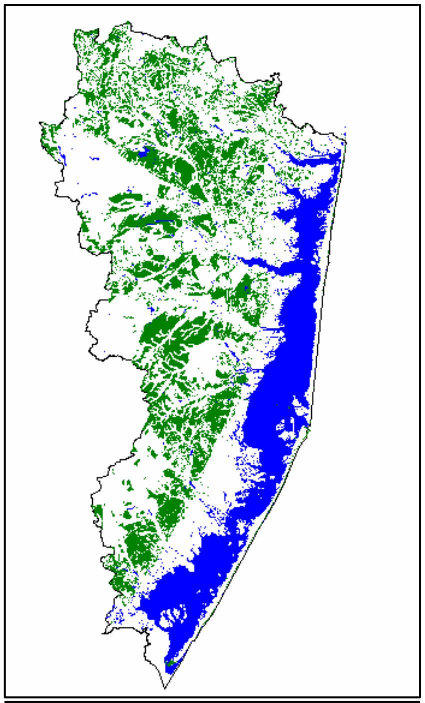

Figure 1. Land available for development.

Methods to Create Build-out Scenarios

We created the build-out model using a Geographic Information System. This is a computer based tool used to manage, manipulate, and analyze digital data. The approach allowed us to create a spatially explicit model so we could examine potential changes in specific areas of the watershed.

The first step in creating the build-out model was identifying land that is available for development. Already developed areas, permanently protected open space, and land that is undevelopable for environmental reasons (e.g., consists of wetlands or adjacent buffer lands) were excluded from this category. The remaining land in the watershed was deemed available for development (Figure 1). The next step was to identify the type of development that could occur on the available land. Municipal zoning regulation and the Pinelands Comprehensive Management Plan were used to determine potential future land uses. Sewer service areas were included in the analysis, as lower development densities are often required in places that do not have sewer service. Once the potential land uses of the developable areas were determined, we were able to map potential land uses at build-out.

Three build-out scenarios were considered:

1. Baseline: This is based on current regulations, with down zoning to 3.2 ac outside sewer service areas. We believe this is the most likely prediction of future build-out. The 3.2 acre figure was derived as an average of the existing zoning regulations for non-sewered areas in the Pinelands Reserve and other Ocean County municipalities.

2. No down zoning: This scenario is based on current regulations but with no down zoning outside sewer service areas.

3. Century Plan Implemented: This scenario is based on current regulations with down zoning outside sewer service areas to 3.2 ac. Under this scenario, the tracts of land the Trust for Public Land identified in the Century Plan (Blanchard, 1997; Blanchard and Herpetological Associates, 1995) as important to protect as open space are removed from future development.

Indicators Used to Determine Potential Impacts of Build-out

Dwelling Unit and Population Increase

The population living in the watershed will increase as more areas in the watershed are developed. A growing population can negatively impact the regions water resources as a larger population requires a larger supply of freshwater. At present, increase in water demand has lowered the aquifers under the watershed, leading to saltwater intrusion from the Barnegat Bay in certain locations (Barnegat Bay Estuary Program, 2000b). This salt water intrusion threatens the freshwater supply, while potentially negatively impacting the watershed's biological resources. If the population continues to increase, the demand for potable freshwater could exceed the sustainable supply. Thus, it is important to understand the potential size of the population at build-out.

To estimate the increase in population in the watershed we began by estimating the number of new dwelling units. For each patch of land available for development, the number of new dwelling units was calculated by determining the number of units that could be built on that patch based on the minimum lot size requirements for the area as specified in the existing zoning maps. As new development requires public infrastructure (roads, new schools, etc.) we used the 80-20 rule of thumb to calculate the number of new dwelling units. This rule of thumb states that generally 80 percent the of land will be used for residential homesites, while the remaining 20 percent is reserved for infrastructure (e.g., roads).

Once the predicted number of potential new dwelling units was determined, we multiplied new dwelling unit by the average number of people per dwelling unit based on 1990 census data for Ocean County. The resulting number is the predicted population growth at build-out. Adding the predicted new growth to the existing numbers, we then estimated the potential number of total dwelling units and population of the watershed at build-out.

As a means of validating the above build-out modeling methods, we compared predicted vs. observed results for our baseline year of 1995. The predicted number of dwelling units was approximately 16% greater than the observed number in 1995. The over prediction can be explained several ways. First, development does not always occur at maximum density as zoned, which is assumed in the build-out model. In many cases residential lots are larger than the zoned minimum lot size. The second major factor may be the 1995 digital mapped land use/land cover (LULC) data (NJDEP, 2000). The LULC data set was used to map existing development and these data are not mapped on an ownership parcel basis. Areas mapped as developable do not necessarily represent a complete parcel, or may be composed of several partial parcels that have been placed into one contiguous tract that meets the development criteria. Because of the data limitations and unpredictable nature of residential development, the number of new dwelling units is given as a range. The initial model prediction of new dwelling units represents the high end and adjusted prediction (down-weighted by 16%) represents the low end of the range of possible new dwelling units in the watershed.

Impervious Surface

Dominated by sandy soils, the upland and wetland systems of Barnegat Bay’s watershed (known locally as the Pinelands) act as a single hydrologic unit. Human development readily impacts the region's surface waters, associated wetlands (Morgan and Good,1988; Zampella, 1994) and groundwater aquifers (Vowinkel and Siwiec, 1991). Previous work in the Mullica River basin, under similar Pinelands conditions, revealed a gradient of increasing pH, specific conductance, and nutrients that paralleled a watershed-disturbance gradient of increasing developed and agricultural land-use intensity and wastewater flow (Zampella 1994; Dow and Zampella 2000). This same general pattern of decreasing water quality with increasing watershed development is also evident in the Barnegat Bay watershed (Hunchak-Kariouk et al., 2001). This degraded water quality, in turn, has also impacted the ecological structure and function of the region's freshwater aquatic and wetland communities (Morgan and Philipp 1986; Ehrenfeld and Schneider 1991; Zampella and Laidig, 1997; Zampella and Bunnell, 1998). Continuing downstream, Barnegat Bay is on the receiving end of this nutrient enriched runoff and has experienced negative impacts associated with eutrophication (Kennish et al., 1984; Seitzinger and Styles, 1999). Thus, there is a close connection between the forcing factors of human-mediated watershed disturbance and the resulting impacts to downstream freshwater and estuarine systems.

Impervious surface is an important environmental indicator of the intensity of human land use and closely correlates with water quality degradation and altered runoff patterns in urban and urbanizing areas (Novotny and Chesters, 1981; Brown, 1988; Driver and Troutman, 1989; Ferguson and Suckling, 1990; Arnold and Gibbons, 1996; Charbeneau and Barrett, 1998). Impervious surface refers to roads, sidewalks, roofs, patios, and other surfaces that water can not penetrate. The percent of impervious surface cover is a good indicator of the amount of non-point source pollution. As non-point source pollution is a leading cause of water quality degradation, understanding potential increases is important for understanding impacts on water quality. Areas that are more intensely developed tend to have a larger percentage of impervious surface cover, contributing more non-point source pollution to the water in the watershed. In compiling data from a number of watersheds, Arnold and Gibbons (1996) developed a set of impact thresholds: 1) < 10% impervious surface cover can be considered non-impacted; 2) between 10-30% cover can be considered impacted; and 3) > 30% cover is generally considered degraded. While these thresholds should not be considered 'hard and fast' breakpoints, they do provide a useful guide in evaluating the comparative risk of water degradation on a watershed scale.

To estimate the percent impervious surface in the watershed at build-out, we used the New Jersey's Department of Environmental Protection's impervious surface estimates from the 1995 digital mapped LULC data (NJDEP, 2000). Build-out impervious surface values were determined by assigning the average values of areas with similar zoning classes that were already developed in 1995. Impervious surface information was then summarized at the catchment level. Summarizing the data by catchments, which average 9 sq. miles, allowed us to identify localized areas where the amount of non-point source pollution is potential quite high.

Results from the Build-out Analysis

In 1995, 25 percent of the watershed was urban land, while 27 percent is available for development (Table 1). The remaining land is either permanently protected open space or unavailable for development for environmental reasons (e.g., wetlands). It is important to remember that not all land available for development can be converted to urban land uses. Some of the land, particularly in the Pinelands Management Area, is limited to rural land uses. Areas designated for low density residential development or agriculture are not urban but they are built-out based on land use regulations.

Dwelling Unit and Population Increase

In 1995, the model estimates 246,817 dwelling units in the Barnegat Bay Watershed. At build-out 73,087 to 84,985 potential new dwelling units are predicted. Based on regulations they would be built-out at a density of 1.2 to 1.4 dwelling units per acre.

Table 1. Existing Urban and Land Available for Development.

Sub-watershed	Total Acres	% Urban	% Developable
Metedeconk River	22,064	41	27
Toms River	15,425	19	41
Union Branch	16,111	16	22
Kettle Creek	4,433	50	26
Silver Bay	8,504	66	17
Wrangle Brook/ Jakes Branch	12,552	30	32
Potters Creek	2,359	36	16
Cedar Creek	14,064	7	27
Stouts Creek	1,955	22	5
Forked River	6,525	15	32
Oyster Creek	10,060	16	28
Mill Creek/ Westecunk Creek	19,026	14	24
Tuckerton Creek	8,316	18	24
TOTAL	**171,606**	**25**	**27**

The potential new development is associated with a estimated total population of between 812,556 and 842,777 people (these figures represent year-round residents and do not take into account part-time summer residents and visitors). This is an increase of 30 to 34 percent over the baseline year of 1995. If the Century Plan land is removed from possible development through preservation as public open space, then predictions are reduced to a potential 25 to 29 percent increase. However, if there is no down zoning outside sewer service areas, then as much as a 37 to 43 percent increase in dwelling units and population could occur.

Table 2 Predicted number of dwelling units and population.

Scenario	Dwelling Units	Population	% Increase
1995	246,817	626,914	-
Baseline build-out scenario	319,904 - 331,802	812,556 - 842,777	30 - 34
Build-out, no down zoning scenario	338,236 - 353,118	859,119 - 896,920	37 - 43
Century Plan scenario	308,359 - 318,377	783,231 - 808,678	25 - 29

Impervious Surface

In 1986, the watershed land area consisted of approximately seven percent impervious surface cover. In 1995, the percent impervious surface cover increases to approximately eight percent. Thirty-two percent of the catchments were above the 10 percent impervious surface threshold identified by previous studies to be the point where water quality begins to be impacted (Arnold and Gibbons, 1996). In 1995, no catchments were above 30 percent impervious surface threshold that can be considered degraded (Arnold and Gibbons, 1996). At build-out, the model predicts impervious surface will rise to 12 percent, with 46 percent of the catchments over 10 percent. Figure 2 clearly illustrates how the existing and future development is concentrated in the northern third of the bay's watershed. The total percent impervious surface cover is predicted at 13 percent if there is no down zoning and 12 percent if the Century Plan land is removed from development. Fifty-seven percent of the catchments are above the 10 percent threshold in the no down zoning scenario, while only 42 percent are predicted as above the 10 percent threshold in the Century Plan scenario. Five percent of the catchments are predicted as above the 30 percent threshold in all three build-out scenarios. Examining the amount of change within each catchment, the baseline scenario has fewer catchments covering more than 10 percent of the land with impervious surface than the no down zoning scenarios (Table 3).

Table 3. Percent of additional land covered by impervious surface, by catchment .

Percent Increase	1986 to 1995	1995 to Build-out (Baseline)	1995 to Build-out (no down zoning)	1995 to Build-out (Century Plan Removed)
No Change	35*	14	12	16
1 - 5	40	40	36	44
6 – 10	1	17	20	13
11 – 15	0	2	5	2
16 - 20	0	2	2	0
21 - 25	0	1	1	1

* Three catchments reduced the estimated amount of impervious surface by 1 percent from 1986 to 1995.

One advantage of this GIS-based modeling technique is the ability to highlight areas of greatest potential change, allowing greater targeting of planning or mitigation efforts to the locations that need them the most. Four of the five catchments that will cover an additional 10 percent of the land with impervious surface in the baseline scenario are contiguous to each other. This hot spot of potential impervious surface increase straddles the Toms River, Union Branch, and Kettle Creek Sub-watersheds. These catchments represent the area of greatest changes in all scenarios, with the alternative scenarios differing by only one or two percent. The other catchment predicted to have an additional 10 percent of its land under impervious surface is located along the Barnegat Bay shoreline in the Oyster Creek sub-watershed. Only eight percent of land was covered by impervious surface in 1995 while 20 percent is predicted to be impervious at build-out. A substantial area of land in this catchment is targeted for protection as open

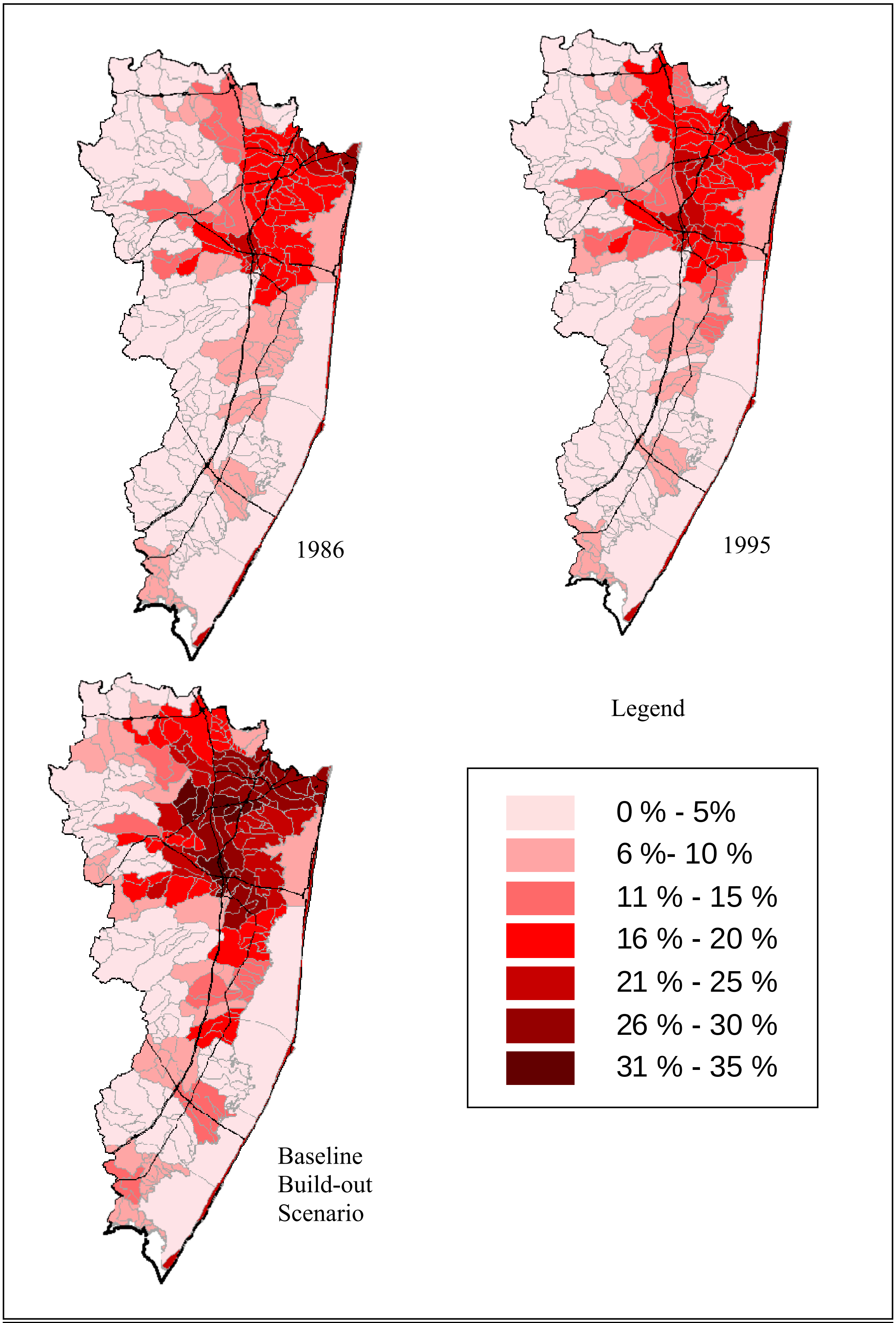

Figure 2. Percent impervious surface cover.

space by the Century Plan. If the land is purchased as open space as proposed, the impervious surface is predicted to increase to only 10 percent of the total catchment land. This type of spatial analysis underscore the advantage of this GIS-based approach to evaluate site-specific scenarios.

Summary and Recommendations

We completed a build-out analysis of the Barnegat Bay Watershed to gain a better understanding of the potential future growth in the watershed. The potential number of dwelling units, residential population, and amount of impervious surface were estimated at build-out under several different scenarios. The build-out model estimates that the number of dwelling units and population could increase 30 to 34 percent in the baseline scenario. An additional four percent of the land area, up from eight percent, in the watershed is predicted to be covered by impervious surface at build-out; this represents an increase in impervious surface cover of 50 percent. Approximately 50 percent of the catchments will have more than 10 percent impervious surface cover, suggesting that water quality will be impacted. Unfortunately estuarine and watershed-related science is not sufficiently advanced to allow us to definitively predict how much the water quality will decrease and what the precise impacts will be on Barnegat Bay proper. Whereas we may know enough to predict a general trend towards increasing eutrophication, we are unsure of the exact details. Previous experience in other eutrophic water bodies suggests that we should be prepared for unexpected surprises.

While protecting open space in the Barnegat Bay watershed is important, the results of the Century Plan build-out scenario suggest that this approach alone is not sufficient to ensure protection of water resources. Under the Century Plan scenario, approximately 89,000 acres of open space would be purchased, reducing the overall amount of developable land by 32 percent. However, as these open space tracts are generally zoned as low density residential, their removal from development reduces the total number of dwelling units by only 11,500 or 16 percent and only minimally reduces the overall impervious surface cover. These results suggest several important points: 1) aggressive purchase of open space as outlined in the Century Plan will still allow considerable room for additional growth in the Barnegat Bay watershed; and 2) to protect the bay's water resources, the adverse impacts of this additional development should be mitigated.

Although the exact amount of additional development may vary based on the amount of land protected as open space, zoning and other regulations, and socioeconomic factors, the build-out analysis indicates that significant additional development will occur in the watershed. This build-out analysis reinforces the idea that comprehensive watershed scale planning is needed to address future development impacts. The Barnegat Bay Comprehensive Conservation and Management Plan identifies a number of actions that new and existing residents can adopt to help protect the water quality and supply. For example, new construction should minimize the amount of impervious surface and maximize the amount of undisturbed native vegetation cover to promote water infiltration. Low impact lawn/garden care techniques should be promoted to reduce nutrient inputs in runoff and conserve water supply. Riparian buffers should be retained and in many places restored to help filter runoff and inhibit soil erosion. Storm water management systems need proper design and maintenance to effectively reduce storm peak flows and associated non-point source pollution. These types of activities, along with a number of other recommendations, are outlined in the CCMP.

It is our hope that this build-out analysis can be used to highlight 'hotspots' of future change and thereby aid in local planning and management decision making. Rather than generic best management practices, using GIS-based decision support modeling techniques we can more readily and effectively customize recommendations to address the specific circumstances of individual sites. For example, watershed managers could target high risk locations for mitigation actions such as riparian buffer restoration in a more cost effective manner. Only by incorporating both watershed, municipal, and site level actions will we meet the Estuary Program's goals of protecting the public water supply and maintaining and restoring ecological conditions in the Barnegat Bay.

GIS Data Availability

The GIS data (in an ArcView .shp file format) used to develop the build-out analysis as well as the resulting scenario outputs will be made available for free download at the following web site: http://www.crssa.rutgers.edu/projects/runj/bbay.html.

Acknowledgements

Dave McKeon and staff at Ocean County Planning offered insight and aided in the data gathering process. Scott Haag and Steve Lennartz provided valuable assistance during the digitizing and analysis phases. Funding was provided by the US EPA through the Barnegat Bay National Estuary Program.

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Appendix 4. Summary of nutrient, productivity, and hydrographic monitoring in the Mullica River-Great Bay estuarine system and the adjacent Atlantic Ocean between 1957 and 1979. Parameters measured include chlorophyll (C), nitrogen (N), phosphorus (P) and carbon (*), and standard hydrographic data (H) including Secchi, water temperature, salinity, and dissolved oxygen.

	Year																						
Station	**1957**	**1958**	**1959**	**1960**	**1961**	**1962**	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**
CL				HCP	HNP	HCNP	HCNP	HCN														HCNP*	HNP
R17					HNP	HCNP						HCN	H									HCNP*	
R14					HNP	HCNP						HC	H		HCN*							HCNP*	
R12												HCN	H		HCN*	HCN*	HCN*					HCNP*	
R11					HNP	HCNP																H	
R6	HCP	HCP	HCP	HCP	HCNP	HCNP	HCNP	HC	HC	HC	HCN	HCN	H	H	HCN*	HCN*					HCN*	HCN*	
TI	H	HCP	HCP	HCP	HCNP	HCNP	HCNP	HCN	HCN	HCNP	HCN	HCN	HCN*	HCN*	HCN*	HCN*	HCN*	HCN*	HCN*	HCN*	HCN*	HCN*	
GP						HCNP		H				H	H										
PC	H	HP	HCP	HCP	HCNP				H	H	H	H	H	H									
MB					HNP	HCNP	HCNP	HC	HC	HC	HCN	HCN			HCN*								
CH			HCP	HCP	HCNP	HCNP	HCNP	H	H	H	H	HCN	H	H									
M2O												H					HCN*	HCNP*	HCNP*	HCN*	HCNP*	HCNP*	
CG												HCN	H		HCN*	HCN*	HCN*	HCNP*	HC	HCN*	HCNP*	HCNP*	
F																	HCN*	HCNP*	HCNP*				
C																	HCN*	HCNP*	HNCP*	HCN*	HCNP*		
Site																	HCN*	HCNP*	HCNP*	HCN*	HCNP*	HCNP*	
BRG																		HCNP*	HCNP*	HCN*			
BH																	HCN*	HCNP*					
½																	HCN*	HCNP*		HCN*	BCNP*		
Off																		HCNP*					

Stations

CL	Crowley Landing	GP	Graveling Point	C	Buoy C in Little Egg Inlet
R17	Green Bank	OC	Oyster Creek	Site	Little Egg Inlet Buoy
R14	Lower Bank	MB	Mid Bay	BRG	off Brigantine
R12	Hog Island	CH	Cape Horn	BH	Beach Haven
R11	River Mile 11	M2O	Intercoastal Waterway	1/2	6.5 miles off Little Egg Inlet
R6	French Point	CG	Rutgers Marine Field Station	Off	13 miles off Little Egg Inlet
TI	Turtle Island	F	Marker Buoy F in Little Egg Inlet		

Able, K. W., R. Hoden, D. Witting, and J. B. Durand. 1992. Physical Parameters of the Great Bay-Mullica River Estuary (With a List of Research Publications). Technical Report, Contribution No. 92-06, Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, New Jersey. 38 p.

Appendix 5. Mean monthly water temperature (˚C) recorded at the Rutgers University Marine Field Station on Great Bay, New Jersey.[a]

	Year														
MONTH	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	**1989**	**1990**	**ALL**
JAN	No Data	-0.40	0.09	2.20	3.63	-0.75	0.76	4.92	1.75	1.50	1.21	3.03	0.60	4.00	3.57	2.11
FEB	No Data	0.33	-0.14	-0.38	1.78	2.43	2.53	4.36	5.84	2.01	1.71	1.22	3.11	3.99	5.96	2.64
MAR	No Data	7.16	4.03	6.18	4.87	4.72	6.13	7.00	5.42	6.87	6.37	5.83	6.69	5.81	7.62	6.09
APR	No Data	12.36	9.73	9.31	10.73	11.79	9.87	10.09	10.81	11.40	10.16	9.64	9.80	11.04	10.88	10.55
MAY	No Data	15.80	13.66	16.18	15.31	15.39	16.14	15.10	14.46	16.70	16.38	14.07	15.40	15.02	15.71	15.37
JUN	20.89	19.48	19.05	18.87	18.89	20.01	20.17	20.33	20.16	20.62	20.89	20.23	19.76	21.08	20.28	19.98
JUL	No Data	23.27	21.90	23.50	21.93	24.31	23.80	25.08	21.15	24.34	24.68	24.31	21.05	24.06	23.75	23.29
AUG	No Data	24.36	24.96	24.58	23.75	22.65	22.51	23.46	24.86	25.25	23.59	24.72	21.70	24.16	24.65	23.89
SEP	20.77	22.00	21.02	21.13	22.32	21.13	20.25	21.86	21.09	23.19	21.23	22.47	20.13	22.37	21.65	21.48
OCT	14.34	14.83	15.95	15.48	15.59	14.77	16.53	16.97	17.33	18.48	16.24	15.18	14.03	16.57	17.97	16.06
NOV	6.57	10.75	11.31	11.75	8.98	10.41	12.83	10.79	11.18	13.44	11.03	10.90	10.96	11.68	10.65	10.93
DEC	3.01	4.75	6.27	6.25	3.43	4.40	7.59	5.32	7.35	5.17	6.54	6.47	4.89	2.62	7.31	5.60
ALL	12.49	13.92	12.89	13.04	12.90	12.76	13.34	13.64	13.53	13.56	12.83	13.64	12.41	13.77	14.06	13.29

[a]1976 to 1990 Period.

Able, K. W., R. Hoden, D. Witting, and J. B. Durand. 1992. Physical Parameters of the Mullica River-Great Bay Estuary (With a List of Research Publications). Technical Report, Contribution No. 92-06, Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, New Jersey. 38 p.

Appendix 6. Mean monthly salinity recorded at the Rutgers University Marine Field Station on Great Bay, New Jersey.[a]

	Year														
MONTH	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	**1989**	**1990**	**ALL**
JAN	No Data	29.60	25.19	25.76	29.46	30.73	27.58	28.59	27.83	29.98	28.21	26.25	26.75	30.05	29.76	28.48
FEB	No Data	27.73	27.69	No Data	31.26	30.65	25.94	26.47	27.65	29.31	29.94	28.62	28.30	29.63	28.80	28.75
MAR	No Data	27.69	26.53	No Data	29.86	29.22	26.55	25.05	25.75	30.47	30.28	28.14	27.83	28.22	30.64	28.20
APR	No Data	27.96	27.07	No Data	27.61	28.70	27.65	28.63	24.05	30.30	30.29	25.25	29.70	27.65	29.52	28.13
MAY	No Data	28.59	26.16	23.62	27.75	29.05	27.48	31.60	26.61	28.27	29.62	26.22	28.90	25.59	30.05	28.00
JUN	28.43	29.91	27.05	27.08	28.71	30.30	27.56	32.48	26.64	30.78	30.43	28.43	30.24	26.91	28.16	28.89
JUL	No Data	31.07	27.07	28.81	29.81	29.68	28.10	32.07	28.01	31.53	30.31	28.33	31.47	27.70	29.10	29.44
AUG	No Data	29.86	27.41	28.97	29.82	30.29	29.26	34.50	27.83	No Data	30.19	29.65	31.30	28.45	28.45	29.80
SEP	29.96	29.78	29.09	29.08	30.93	29.65	29.00	29.62	29.75	No Data	30.05	30.00	31.60	28.39	29.62	29.76
OCT	28.71	28.47	30.03	28.42	31.22	No Data	29.57	28.95	29.69	30.09	30.12	30.32	31.33	27.10	30.43	29.64
NOV	27.32	27.48	30.19	28.64	29.88	29.57	29.15	27.00	29.39	30.41	29.94	28.79	30.16	27.35	28.45	28.96
DEC	27.68	26.59	28.28	28.94	28.49	28.00	27.96	26.54	29.22	27.24	27.35	28.56	30.10	29.44	28.44	28.23
All	28.51	28.74	27.62	28.17	29.63	29.57	28.01	29.31	27.71	30.01	29.67	28.31	29.80	27.99	29.30	28.87

[a]1976 to 1990 Period.

From Able, K. W., R. Hoden, D. Witting, and J. B. Durand. 1992. Physical Parameters of the Mullica River-Great Bay Estuary (With a List of Research Publications). Technical Report, Contribution No. 92-06, Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, New Jersey. 38 p.

Appendix 7. Mean low tide (height in meters above mean low water) recorded at the Rutgers University Marine Field Station on Great Bay, New Jersey.[a]

	Year															
MONTH	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	ALL
JAN	No Data	2.75	2.05	2.42	2.35	1.53	1.80	2.26	2.23	2.17	1.56	2.39	1.85	2.10	1.84	2.05
FEB	No Data	2.29	2.59	2.25	2.29	1.66	2.06	2.57	2.28	2.06	2.49	2.20	2.26	2.02	2.10	2.21
MAR	No Data	2.08	2.28	2.27	2.16	2.01	1.95	2.68	2.59	2.00	1.71	2.77	2.11	2.39	1.96	2.22
APR	No Data	2.46	2.76	2.50	2.67	1.69	1.87	2.60	2.95	2.12	2.88	2.91	2.78	2.16	2.11	2.46
MAY	No Data	2.26	2.75	2.53	2.54	2.23	2.43	2.38	2.32	2.44	2.63	2.55	2.52	2.40	2.52	2.47
JUN	2.20	2.75	2.55	2.56	2.23	2.22	2.80	2.49	2.50	2.52	2.44	2.58	2.51	2.44	2.40	2.48
JUL	No Data	2.60	2.70	2.63	2.05	2.38	2.33	2.65	2.35	2.36	2.69	2.73	2.30	2.55	2.56	2.48
AUG	No Data	2.62	2.91	2.62	2.30	2.40	2.34	2.64	2.69	2.56	2.88	2.90	2.37	2.73	2.84	2.63
SEP	2.82	2.98	3.12	2.58	2.23	2.57	2.64	2.70	2.68	2.67	2.57	2.82	2.46	2.86	2.69	2.68
OCT	3.11	2.87	2.70	2.40	2.08	2.25	2.75	2.97	2.88	2.66	2.81	2.58	2.54	2.90	2.53	2.64
NOV	2.31	3.01	2.88	2.33	1.93	2.42	2.10	2.54	2.53	2.92	2.49	2.57	2.17	2.17	2.40	2.43
DEC	1.92	3.01	2.19	2.01	1.68	2.05	2.23	2.13	2.18	2.32	2.45	2.48	2.14	1.91	2.09	2.18
All	2.59	2.65	2.66	2.43	2.20	2.12	2.28	2.55	2.52	2.40	2.47	2.62	2.33	2.35	2.34	2.41

[a]1976 to 1990 Period.

From Able, K. W., R. Hoden, D. Witting, and J. B. Durand. 1992. Physical Parameters of the Mullica River-Great Bay Estuary (With a List of Research Publications). Technical Report, Contribution No. 92-06, Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, New Jersey. 38 p.

Appendix 8. Mean high tide (height in meters above mean low water) recorded at the Rutgers University Marine Field Station on Great Bay, New Jersey.[a]

	Year															
MONTH	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	ALL
JAN	No Data	4.85	5.34	5.89	5.70	4.98	5.19	5.67	5.76	5.35	5.15	5.79	5.21	5.32	5.28	5.43
FEB	No Data	5.56	6.08	5.65	5.73	5.07	5.38	5.93	5.53	5.32	5.70	5.27	5.41	5.39	5.32	5.51
MAR	No Data	5.36	5.78	5.68	5.60	5.42	5.33	6.07	5.79	5.15	5.23	5.92	5.25	5.49	5.30	5.53
APR	No Data	5.57	6.22	5.85	5.96	5.15	5.20	5.86	6.18	5.37	6.11	5.98	5.97	5.41	5.38	5.72
MAY	No Data	5.37	6.16	5.86	5.94	5.70	5.79	5.62	5.66	5.74	5.76	5.69	5.81	5.73	5.82	5.78
JUN	5.66	5.81	6.00	5.95	5.73	5.65	6.08	5.80	5.80	5.52	5.59	5.71	5.86	5.84	5.72	5.79
JUL	No Data	5.74	6.06	6.04	5.51	5.91	5.68	5.82	5.74	5.70	5.76	5.89	5.59	5.87	5.83	5.80
AUG	No Data	5.93	6.22	5.99	5.77	5.87	5.69	5.98	6.06	5.84	5.79	6.01	5.72	5.95	6.03	5.92
SEP	6.36	6.33	6.49	5.99	5.60	5.93	5.95	5.96	5.97	5.89	5.75	5.91	5.73	6.10	5.90	5.96
OCT	6.51	6.19	6.05	5.88	5.56	5.58	6.05	6.09	6.03	5.81	5.96	5.77	5.70	6.05	5.83	5.91
NOV	5.80	6.31	6.15	5.81	5.43	5.76	5.46	5.98	5.69	6.19	5.78	5.71	5.39	5.53	5.71	5.76
DEC	5.10	6.57	5.68	5.50	5.13	5.45	5.66	5.63	5.40	5.50	5.67	5.55	5.25	5.23	5.40	5.51
All	6.04	5.90	6.05	5.84	5.63	5.54	5.62	5.87	5.80	5.62	5.69	5.77	5.57	5.63	5.63	5.72

[a]1976 to 1990 Period.

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Appendix 9. Mean monthly water turbidity (NTU)[a] at the Rutgers University Marine Field Station on Great Bay, New Jersey.[b]

	Year			
MONTH	1988	1989	1990	All
JAN	No Data	13.58	12.91	13.24
FEB	No Data	17.00	12.34	14.48
MAR	No Data	16.81	8.11	12.36
APR	No Data	15.48	9.86	12.53
MAY	No Data	16.75	11.68	14.27
JUN	10.49	11.33	4.87	8.95
JUL	14.00	18.00	7.10	10.56
AUG	15.02	15.40	11.11	13.22
SEP	10.56	No Data	7.36	9.05
OCT	10.78	No Data	12.52	11.65
NOV	17.92	No Data	11.53	14.64
DEC	10.74	No Date	13.45	12.02
All	12.81	15.16	10.26	12.18

[a]Nephelometric Turbidity Units

[b]1988 to 1990 Period.

From Able, K. W., R. Hoden, D. Witting, and J. B. Durand. 1992. Physical Parameters of the Mullica River-Great Bay Estuary (With a List of Research Publications). Technical Report, Contribution No. 92-06, Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, New Jersey. 38 p.

Appendix 10. Summary statistics for environmental parameters monitored at three SWMP sites (i.e., Buoy 126, Chestnut Neck, and Lower Bank) in the JCNERR for data years 1999 and 2000 (covering the period from December 1998 to November 2000)(Kennish and O'Donnell, 2002).

Table 1. Lower Bank 1999 (Temperature and Salinity).

Yearly Temperature (°C)		Winter Temperature (°C)		Spring Temperature (°C)		Summer Temperature (°C)		Fall Temperature (°C)	
Mean	15.06	Mean	5.10	Mean	12.13	Mean	25.99	Mean	15.74
Std. Error	0.07	Std. Error	0.05	Std. Error	0.08	Std. Error	0.04	Std. Error	0.08
Median	14.03	Median	5.06	Median	12.34	Median	26.40	Median	15.13
Mode	27.00	Mode	4.73	Mode	15.70	Mode	27.00	Mode	9.77
Std. Deviation	8.59	Std. Deviation	3.14	Std. Deviation	5.13	Std. Deviation	2.38	Std. Deviation	5.18
Variance	73.74	Variance	9.86	Variance	26.33	Variance	5.66	Variance	26.82
Range	32.07	Range	13.38	Range	22.85	Range	12.10	Range	21.35
Minimum	-0.57	Minimum	-0.57	Minimum	2.05	Minimum	19.40	Minimum	5.59
Maximum	31.50	Maximum	12.81	Maximum	24.90	Maximum	31.50	Maximum	26.94
Count	16540.00	Count	3857.00	Count	4007.00	Count	4311.00	Count	4365.00

Yearly Salinity (ppt)		Winter Salinity (ppt)		Spring Salinity (ppt)		Summer Salinity (ppt)		Fall Salinity (ppt)	
Mean	3.15	Mean	3.30	Mean	0.98	Mean	6.49	Mean	1.69
Std. Error	0.03	Std. Error	0.06	Std. Error	0.02	Std. Error	0.06	Std. Error	0.03
Median	1.64	Median	1.57	Median	0.45	Median	5.90	Median	1.15
Mode	0.04	Mode	0.05	Mode	0.04	Mode	2.60	Mode	0.05
Std. Deviation	3.68	Std. Deviation	3.73	Std. Deviation	1.22	Std. Deviation	4.18	Std. Deviation	1.67
Variance	13.52	Variance	13.91	Variance	1.49	Variance	17.45	Variance	2.79
Range	18.50	Range	14.60	Range	7.30	Range	18.40	Range	9.39
Minimum	0.00	Minimum	0.04	Minimum	0.00	Minimum	0.10	Minimum	0.03
Maximum	18.50	Maximum	14.64	Maximum	7.30	Maximum	18.50	Maximum	9.42
Count	16514.00	Count	3852.00	Count	3999.00	Count	4311.00	Count	4352.00

Table 1. Lower Bank 1999 (Dissolved Oxygen).

Yearly DO (mg/L)		Winter DO (mg/L)		Spring DO (mg/L)		Summer DO (mg/L)		Fall DO (mg/L)	
Mean	8.98	Mean	11.49	Mean	9.67	Mean	6.32	Mean	8.28
Std. Error	0.02	Std. Error	0.01	Std. Error	0.02	Std. Error	0.01	Std. Error	0.03
Median	9.10	Median	11.41	Median	9.95	Median	6.40	Median	8.07
Mode	6.50	Mode	11.11	Mode	9.50	Mode	6.50	Mode	8.34
Std. Deviation	2.20	Std. Deviation	0.77	Std. Deviation	0.93	Std. Deviation	0.66	Std. Deviation	1.70
Variance	4.85	Variance	0.59	Variance	0.87	Variance	0.44	Variance	2.89
Range	9.93	Range	4.25	Range	4.85	Range	4.90	Range	7.55
Minimum	3.50	Minimum	9.18	Minimum	6.40	Minimum	3.50	Minimum	4.91
Maximum	13.43	Maximum	13.43	Maximum	11.25	Maximum	8.40	Maximum	12.46
Count	12309.00	Count	3316.00	Count	2516.00	Count	2793.00	Count	3684.00

Yearly DO (% saturation)		Winter DO (% saturation)		Spring DO (% saturation)		Summer DO (% saturation)		Fall DO (% saturation)	
Mean	87.69	Mean	92.48	Mean	94.35	Mean	80.81	Mean	84.06
Std. Error	0.08	Std. Error	0.08	Std. Error	0.09	Std. Error	0.14	Std. Error	0.15
Median	89.00	Median	91.90	Median	94.50	Median	80.90	Median	83.50
Mode	89.10	Mode	90.20	Mode	96.70	Mode	81.00	Mode	80.60
Std. Deviation	8.74	Std. Deviation	4.50	Std. Deviation	4.53	Std. Deviation	7.52	Std. Deviation	8.97
Variance	76.41	Variance	20.22	Variance	20.49	Variance	56.49	Variance	80.38
Range	60.00	Range	21.10	Range	27.50	Range	60.00	Range	45.60
Minimum	47.60	Minimum	83.70	Minimum	77.50	Minimum	47.60	Minimum	59.10
Maximum	107.60	Maximum	104.80	Maximum	105.00	Maximum	107.60	Maximum	104.70
Count	12309.00	Count	3316.00	Count	2516.00	Count	2793.00	Count	3684.00

Table 1. Lower Bank 1999 (Depth and pH).

Yearly Depth (m)	
Mean	1.74
Std. Error	0.00
Median	1.77
Mode	2.10
Std. Deviation	0.35
Variance	0.13
Range	1.93
Minimum	0.68
Maximum	2.61
Count	16537.00

Winter Depth (m)	
Mean	1.72
Std. Error	0.01
Median	1.73
Mode	2.17
Std. Deviation	0.36
Variance	0.13
Range	1.82
Minimum	0.78
Maximum	2.60
Count	3857.00

Spring Depth (m)	
Mean	1.77
Std. Error	0.01
Median	1.79
Mode	2.07
Std. Deviation	0.35
Variance	0.12
Range	1.86
Minimum	0.75
Maximum	2.61
Count	4007.00

Summer Depth (m)	
Mean	1.75
Std. Error	0.01
Median	1.78
Mode	2.10
Std. Deviation	0.34
Variance	0.11
Range	1.59
Minimum	0.96
Maximum	2.55
Count	4311.00

Fall Depth (m)	
Mean	1.73
Std. Error	0.01
Median	1.75
Mode	1.66
Std. Deviation	0.37
Variance	0.13
Range	1.85
Minimum	0.68
Maximum	2.54
Count	4362.00

Yearly pH	
Mean	6.14
Std. Error	0.01
Median	6.40
Mode	6.70
Std. Deviation	0.85
Variance	0.72
Range	4.00
Minimum	3.71
Maximum	7.71
Count	14489.00

Winter pH	
Mean	5.82
Std. Error	0.03
Median	5.64
Mode	7.48
Std. Deviation	1.29
Variance	1.66
Range	4.00
Minimum	3.71
Maximum	7.71
Count	2643.00

Spring pH	
Mean	5.74
Std. Error	0.01
Median	5.90
Mode	6.50
Std. Deviation	0.69
Variance	0.48
Range	2.74
Minimum	4.43
Maximum	7.17
Count	3199.00

Summer pH	
Mean	6.62
Std. Error	0.01
Median	6.70
Mode	6.80
Std. Deviation	0.37
Variance	0.13
Range	2.70
Minimum	4.50
Maximum	7.20
Count	4311.00

Fall pH	
Mean	6.14
Std. Error	0.01
Median	6.30
Mode	6.73
Std. Deviation	0.70
Variance	0.49
Range	3.05
Minimum	4.27
Maximum	7.32
Count	4336.00

Table 1. Lower Bank 1999 (Turbidity).

Yearly Turbidity (NTU)	
Mean	25.04
Std. Error	0.15
Median	20.60
Mode	9.00
Std. Deviation	17.64
Variance	311.28
Range	176.10
Minimum	0.00
Maximum	176.00
Count	13958.00

Winter Turbidity (NTU)	
Mean	18.85
Std. Error	0.25
Median	15.60
Mode	7.30
Std. Deviation	13.38
Variance	179.12
Range	86.10
Minimum	1.90
Maximum	88.00
Count	2830.00

Spring Turbidity (NTU)	
Mean	31.30
Std. Error	0.33
Median	26.00
Mode	14.00
Std. Deviation	20.89
Variance	436.55
Range	159.80
Minimum	0.00
Maximum	159.70
Count	4004.00

Summer Turbidity (NTU)	
Mean	20.02
Std. Error	0.29
Median	15.00
Mode	9.00
Std. Deviation	15.07
Variance	227.14
Range	171.00
Minimum	5.00
Maximum	176.00
Count	2760.00

Fall Turbidity (NTU)	
Mean	26.49
Std. Error	0.24
Median	23.20
Mode	12.20
Std. Deviation	16.02
Variance	256.55
Range	157.00
Minimum	1.90
Maximum	158.90
Count	4364.00

Table 2. Lower Bank 2000 (Temperature and Salinity).

Yearly Temperature (°C)		Winter Temperature (°C)		Spring Temperature (°C)		Summer Temperature (°C)		Fall Temperature (°C)	
Mean	15.26	Mean	4.70	Mean	14.17	Mean	24.70	Mean	14.91
Std. Error	0.06	Std. Error	0.05	Std. Error	0.07	Std. Error	0.03	Std. Error	0.09
Median	14.80	Median	5.39	Median	12.80	Median	24.90	Median	15.20
Mode	26.00	Mode	0.00	Mode	12.00	Mode	26.00	Mode	10.70
Std. Deviation	8.07	Std. Deviation	2.88	Std. Deviation	4.52	Std. Deviation	2.11	Std. Deviation	6.18
Variance	65.05	Variance	8.29	Variance	20.41	Variance	4.45	Variance	38.20
Range	30.30	Range	12.10	Range	19.60	Range	11.90	Range	25.30
Minimum	-0.70	Minimum	-0.70	Minimum	6.10	Minimum	17.70	Minimum	1.80
Maximum	29.60	Maximum	11.40	Maximum	25.70	Maximum	29.60	Maximum	27.10
Count	16531.00	Count	3343.00	Count	4415.00	Count	4406.00	Count	4367.00

Yearly Salinity (ppt)		Winter Salinity (ppt)		Spring Salinity (ppt)		Summer Salinity (ppt)		Fall Salinity (ppt)	
Mean	2.08	Mean	1.29	Mean	1.39	Mean	2.73	Mean	2.73
Std. Error	0.02	Std. Error	0.03	Std. Error	0.02	Std. Error	0.03	Std. Error	0.04
Median	1.30	Median	0.43	Median	0.70	Median	2.20	Median	2.10
Mode	0.10	Mode	0.00	Mode	0.10	Mode	0.40	Mode	0.10
Std. Deviation	2.16	Std. Deviation	1.79	Std. Deviation	1.63	Std. Deviation	2.09	Std. Deviation	2.51
Variance	4.66	Variance	3.22	Variance	2.66	Variance	4.35	Variance	6.29
Range	11.20	Range	10.61	Range	9.30	Range	9.70	Range	11.20
Minimum	0.00	Minimum	0.00	Minimum	0.00	Minimum	0.00	Minimum	0.00
Maximum	11.20	Maximum	10.61	Maximum	9.30	Maximum	9.70	Maximum	11.20
Count	16517.00	Count	3329.00	Count	4415.00	Count	4406.00	Count	4367.00

Table 2. Lower Bank 2000 (Dissolved Oxygen).

Yearly DO (mg/L)		Winter DO (mg/L)		Spring DO (mg/L)		Summer DO (mg/L)		Fall DO (mg/L)	
Mean	9.18	Mean	12.19	Mean	9.44	Mean	6.27	Mean	9.14
Std. Error	0.02	Std. Error	0.02	Std. Error	0.02	Std. Error	0.01	Std. Error	0.04
Median	9.40	Median	11.92	Median	9.60	Median	6.10	Median	8.10
Mode	6.00	Mode	12.10	Mode	9.60	Mode	6.00	Mode	7.60
Std. Deviation	2.50	Std. Deviation	1.03	Std. Deviation	1.21	Std. Deviation	0.76	Std. Deviation	2.36
Variance	6.27	Variance	1.06	Variance	1.47	Variance	0.58	Variance	5.57
Range	11.80	Range	4.31	Range	6.20	Range	5.70	Range	10.00
Minimum	3.10	Minimum	10.59	Minimum	5.60	Minimum	3.10	Minimum	4.50
Maximum	14.90	Maximum	14.90	Maximum	11.80	Maximum	8.80	Maximum	14.50
Count	14926.00	Count	3343.00	Count	4413.00	Count	3788.00	Count	3382.00

Yearly DO (% saturation)		Winter DO (% saturation)		Spring DO (% saturation)		Summer DO (% saturation)		Fall DO (% saturation)	
Mean	88.04	Mean	95.08	Mean	91.66	Mean	76.49	Mean	89.30
Std. Error	0.08	Std. Error	0.06	Std. Error	0.07	Std. Error	0.14	Std. Error	0.18
Median	91.00	Median	94.90	Median	92.70	Median	75.25	Median	87.90
Mode	93.80	Mode	97.60	Mode	93.80	Mode	74.80	Mode	83.20
Std. Deviation	10.14	Std. Deviation	3.51	Std. Deviation	4.86	Std. Deviation	8.33	Std. Deviation	10.75
Variance	102.77	Variance	12.35	Variance	23.57	Variance	69.42	Variance	115.64
Range	71.20	Range	22.50	Range	36.70	Range	65.90	Range	57.00
Minimum	39.30	Minimum	87.50	Minimum	67.10	Minimum	39.30	Minimum	53.50
Maximum	110.50	Maximum	110.00	Maximum	103.80	Maximum	105.20	Maximum	110.50
Count	14914.00	Count	3331.00	Count	4413.00	Count	3788.00	Count	3382.00

Table 2. Lower Bank 2000 (Depth and pH).

Yearly Depth (m)	
Mean	1.73
Std. Error	0.00
Median	1.75
Mode	2.03
Std. Deviation	0.37
Variance	0.14
Range	1.95
Minimum	0.63
Maximum	2.58
Count	16531.00

Winter Depth (m)	
Mean	1.60
Std. Error	0.01
Median	1.60
Mode	1.27
Std. Deviation	0.39
Variance	0.15
Range	1.83
Minimum	0.63
Maximum	2.46
Count	3343.00

Spring Depth (m)	
Mean	1.76
Std. Error	0.01
Median	1.79
Mode	2.03
Std. Deviation	0.37
Variance	0.14
Range	1.82
Minimum	0.76
Maximum	2.58
Count	4415.00

Summer Depth (m)	
Mean	1.80
Std. Error	0.01
Median	1.83
Mode	2.15
Std. Deviation	0.34
Variance	0.12
Range	1.51
Minimum	1.00
Maximum	2.51
Count	4406.00

Fall Depth (m)	
Mean	1.74
Std. Error	0.01
Median	1.76
Mode	2.05
Std. Deviation	0.37
Variance	0.14
Range	1.84
Minimum	0.74
Maximum	2.58
Count	4367.00

Yearly pH	
Mean	6.24
Std. Error	0.00
Median	6.40
Mode	6.60
Std. Deviation	0.64
Variance	0.41
Range	3.20
Minimum	4.50
Maximum	7.70
Count	16531.00

Winter pH	
Mean	5.75
Std. Error	0.01
Median	5.80
Mode	4.90
Std. Deviation	0.68
Variance	0.47
Range	2.88
Minimum	4.58
Maximum	7.46
Count	3343.00

Spring pH	
Mean	6.08
Std. Error	0.01
Median	6.20
Mode	6.60
Std. Deviation	0.68
Variance	0.46
Range	2.90
Minimum	4.50
Maximum	7.40
Count	4415.00

Summer pH	
Mean	6.44
Std. Error	0.00
Median	6.50
Mode	6.50
Std. Deviation	0.29
Variance	0.08
Range	1.50
Minimum	5.60
Maximum	7.10
Count	4406.00

Fall pH	
Mean	6.57
Std. Error	0.01
Median	6.70
Mode	6.90
Std. Deviation	0.53
Variance	0.28
Range	2.90
Minimum	4.80
Maximum	7.70
Count	4367.00

Table 2. Lower Bank 2000 (Turbidity).

	Yearly Turbidity (NTU)	Winter Turbidity (NTU)	Spring Turbidity (NTU)	Summer Turbidity (NTU)	Fall Turbidity (NTU)
Mean	24.27	27.96	32.39	22.67	16.13
Std. Error	0.15	0.38	0.37	0.20	0.21
Median	20.00	23.00	27.00	21.00	13.00
Mode	10.00	8.00	13.00	11.00	1.00
Std. Deviation	18.87	22.19	22.26	12.98	13.70
Variance	356.00	492.60	495.57	168.42	187.82
Range	335.40	334.20	140.00	119.00	130.00
Minimum	0.00	0.20	3.00	3.00	0.00
Maximum	334.40	334.40	143.00	122.00	129.00
Count	15682.00	3343.00	3646.00	4392.00	4301.00

Table 3. Chestnut Neck 1999 (Temperature and Salinity).

	Yearly Temperature (^oC)	Winter Temperature (^oC)	Spring Temperature (^oC)	Summer Temperature (^oC)	Fall Temperature (^oC)
Mean	12.91	4.88	10.52	24.52	16.25
Std. Error	0.07	0.05	0.07	0.05	0.08
Median	11.98	4.70	11.60	24.40	16.24
Mode	4.10	4.10	11.66	23.90	24.30
Std. Deviation	7.78	3.18	4.44	2.12	5.03
Variance	60.55	10.10	19.70	4.49	25.30
Range	29.96	12.89	18.00	9.23	18.82
Minimum	-0.57	-0.57	2.34	20.16	6.98
Maximum	29.39	12.32	20.34	29.39	25.80
Count	13823.00	3834.00	3657.00	2213.00	4119.00

	Yearly Salinity (ppt)	Winter Salinity (ppt)	Spring Salinity (ppt)	Summer Salinity (ppt)	Fall Salinity (ppt)
Mean	15.18	15.66	12.73	18.77	14.99
Std. Error	0.04	0.08	0.06	0.07	0.06
Median	15.30	16.29	12.75	18.86	15.22
Mode	15.50	13.50	11.78	18.40	14.40
Std. Deviation	4.43	4.93	3.55	3.24	3.75
Variance	19.66	24.27	12.57	10.51	14.10
Range	23.91	22.69	18.65	18.70	20.30
Minimum	2.89	2.89	4.31	8.10	3.50
Maximum	26.80	25.58	22.96	26.80	23.80
Count	13823.00	3834.00	3657.00	2213.00	4119.00

Table 3. Chestnut Neck 1999 (Dissolved Oxygen).

Yearly DO (mg/L)		Winter DO (mg/L)		Spring DO (mg/L)		Summer DO (mg/L)		Fall DO (mg/L)	
Mean	9.04	Mean	10.98	Mean	9.75	Mean	5.98	Mean	8.02
Std. Error	0.02	Std. Error	0.02	Std. Error	0.02	Std. Error	0.02	Std. Error	0.03
Median	9.21	Median	11.26	Median	9.37	Median	5.90	Median	7.78
Mode	12.20	Mode	12.20	Mode	9.15	Mode	5.40	Mode	6.70
Std. Deviation	2.12	Std. Deviation	0.98	Std. Deviation	1.35	Std. Deviation	0.85	Std. Deviation	1.40
Variance	4.50	Variance	0.97	Variance	1.84	Variance	0.72	Variance	1.97
Range	8.90	Range	3.71	Range	5.51	Range	4.85	Range	5.24
Minimum	3.60	Minimum	8.79	Minimum	6.96	Minimum	3.60	Minimum	5.10
Maximum	12.50	Maximum	12.50	Maximum	12.47	Maximum	8.45	Maximum	10.34
Count	11493.00	Count	3205.00	Count	3649.00	Count	2001.00	Count	2638.00

Yearly DO (% saturation)		Winter DO (% saturation)		Spring DO (% saturation)		Summer DO (% saturation)		Fall DO (% saturation)	
Mean	89.84	Mean	95.45	Mean	93.61	Mean	79.37	Mean	85.74
Std. Error	0.09	Std. Error	0.08	Std. Error	0.07	Std. Error	0.23	Std. Error	0.17
Median	92.20	Median	95.40	Median	94.10	Median	78.70	Median	87.60
Mode	93.40	Mode	93.90	Mode	96.00	Mode	77.00	Mode	92.60
Std. Deviation	9.13	Std. Deviation	4.77	Std. Deviation	4.01	Std. Deviation	10.38	Std. Deviation	8.59
Variance	83.38	Variance	22.71	Variance	16.04	Variance	107.78	Variance	73.78
Range	62.80	Range	23.20	Range	24.80	Range	62.80	Range	40.70
Minimum	48.50	Minimum	85.20	Minimum	77.10	Minimum	48.50	Minimum	61.50
Maximum	111.30	Maximum	108.40	Maximum	101.90	Maximum	111.30	Maximum	102.20
Count	11493.00	Count	3205.00	Count	3649.00	Count	2001.00	Count	2638.00

Table 3. Chestnut Neck 1999 (Depth and pH).

Yearly Depth (m)	
Mean	1.68
Std. Error	0.00
Median	1.72
Mode	1.60
Std. Deviation	0.47
Variance	0.22
Range	2.68
Minimum	0.11
Maximum	2.80
Count	13823.00

Winter Depth (m)	
Mean	1.86
Std. Error	0.01
Median	1.86
Mode	1.60
Std. Deviation	0.36
Variance	0.13
Range	1.86
Minimum	0.94
Maximum	2.80
Count	3834.00

Spring Depth (m)	
Mean	1.40
Std. Error	0.01
Median	1.34
Mode	1.26
Std. Deviation	0.62
Variance	0.39
Range	2.68
Minimum	0.11
Maximum	2.79
Count	3657.00

Summer Depth (m)	
Mean	1.75
Std. Error	0.01
Median	1.77
Mode	1.97
Std. Deviation	0.33
Variance	0.11
Range	1.61
Minimum	1.01
Maximum	2.62
Count	2213.00

Fall Depth (m)	
Mean	1.72
Std. Error	0.01
Median	1.74
Mode	2.11
Std. Deviation	0.33
Variance	0.11
Range	1.61
Minimum	0.84
Maximum	2.45
Count	4119.00

Yearly pH	
Mean	7.20
Std. Error	0.00
Median	7.20
Mode	7.20
Std. Deviation	0.22
Variance	0.05
Range	1.54
Minimum	6.34
Maximum	7.88
Count	13206.00

Winter pH	
Mean	7.15
Std. Error	0.00
Median	7.20
Mode	7.10
Std. Deviation	0.26
Variance	0.07
Range	1.46
Minimum	6.34
Maximum	7.80
Count	3834.00

Spring pH	
Mean	7.18
Std. Error	0.00
Median	7.19
Mode	7.23
Std. Deviation	0.21
Variance	0.04
Range	1.21
Minimum	6.48
Maximum	7.69
Count	3656.00

Summer pH	
Mean	7.26
Std. Error	0.00
Median	7.21
Mode	7.20
Std. Deviation	0.17
Variance	0.03
Range	1.08
Minimum	6.80
Maximum	7.88
Count	1597.00

Fall pH	
Mean	7.23
Std. Error	0.00
Median	7.23
Mode	7.20
Std. Deviation	0.19
Variance	0.04
Range	1.22
Minimum	6.50
Maximum	7.72
Count	4119.00

Table 3. Chestnut Neck 1999 (Turbidity).

	Yearly Turbidity (NTU)	Winter Turbidity (NTU)	Spring Turbidity (NTU)	Summer Turbidity (NTU)	Fall Turbidity (NTU)
Mean	9.69	12.85	13.25	7.46	5.54
Std. Error	0.08	0.23	0.16	0.09	0.06
Median	7.10	11.00	10.80	7.00	4.60
Mode	4.00	1.90	6.10	3.00	4.00
Std. Deviation	8.88	12.08	9.46	4.03	4.06
Variance	78.88	145.95	89.48	16.27	16.49
Range	111.70	111.70	79.70	26.80	61.00
Minimum	0.00	0.00	1.90	1.00	0.00
Maximum	111.60	111.60	81.60	27.80	61.00
Count	12514.00	2876.00	3494.00	2031.00	4113.00

Table 4. Chestnut Neck 2000 (Temperature and Salinity).

Yearly Temperature (^oC)	
Mean	14.81
Std. Error	0.07
Median	15.30
Mode	24.60
Std. Deviation	7.99
Variance	63.79
Range	29.00
Minimum	-1.30
Maximum	27.70
Count	14673.00

Winter Temperature (^oC)	
Mean	4.21
Std. Error	0.05
Median	5.00
Mode	-0.90
Std. Deviation	2.95
Variance	8.68
Range	10.70
Minimum	-1.30
Maximum	9.40
Count	3052.00

Spring Temperature (^oC)	
Mean	13.41
Std. Error	0.07
Median	12.10
Mode	11.80
Std. Deviation	4.21
Variance	17.75
Range	15.90
Minimum	6.50
Maximum	22.40
Count	4142.00

Summer Temperature (^oC)	
Mean	24.29
Std. Error	0.03
Median	24.70
Mode	24.60
Std. Deviation	2.09
Variance	4.37
Range	10.80
Minimum	16.90
Maximum	27.70
Count	3869.00

Fall Temperature (^oC)	
Mean	15.24
Std. Error	0.10
Median	15.80
Mode	15.80
Std. Deviation	5.75
Variance	33.05
Range	21.50
Minimum	3.20
Maximum	24.70
Count	3610.00

Yearly Salinity (ppt)	
Mean	14.95
Std. Error	0.03
Median	15.20
Mode	15.90
Std. Deviation	3.57
Variance	12.78
Range	22.80
Minimum	4.10
Maximum	26.90
Count	14670.00

Winter Salinity (ppt)	
Mean	14.46
Std. Error	0.07
Median	14.43
Mode	14.60
Std. Deviation	3.83
Variance	14.67
Range	21.20
Minimum	5.70
Maximum	26.90
Count	3049.00

Spring Salinity (ppt)	
Mean	13.78
Std. Error	0.06
Median	14.00
Mode	13.50
Std. Deviation	3.75
Variance	14.08
Range	18.40
Minimum	4.10
Maximum	22.50
Count	4142.00

Summer Salinity (ppt)	
Mean	15.84
Std. Error	0.05
Median	16.00
Mode	15.10
Std. Deviation	2.99
Variance	8.94
Range	16.90
Minimum	5.90
Maximum	22.80
Count	3869.00

Fall Salinity (ppt)	
Mean	15.77
Std. Error	0.05
Median	16.00
Mode	17.10
Std. Deviation	3.24
Variance	10.52
Range	18.70
Minimum	5.80
Maximum	24.50
Count	3610.00

Table 4. Chestnut Neck 2000 (Dissolved Oxygen).

Yearly DO (mg/L)		Winter DO (mg/L)		Spring DO (mg/L)		Summer DO (mg/L)		Fall DO (mg/L)	
Mean	8.64	Mean	11.64	Mean	8.73	Mean	5.87	Mean	8.01
Std. Error	0.02	Std. Error	0.02	Std. Error	0.03	Std. Error	0.01	Std. Error	0.03
Median	9.00	Median	11.80	Median	9.20	Median	5.90	Median	7.80
Mode	5.90	Mode	12.20	Mode	9.20	Mode	5.90	Mode	7.90
Std. Deviation	2.25	Std. Deviation	0.99	Std. Deviation	1.66	Std. Deviation	0.48	Std. Deviation	1.72
Variance	5.08	Variance	0.98	Variance	2.76	Variance	0.23	Variance	2.95
Range	9.10	Range	4.37	Range	6.30	Range	2.50	Range	6.90
Minimum	4.60	Minimum	9.33	Minimum	5.40	Minimum	4.60	Minimum	4.90
Maximum	13.70	Maximum	13.70	Maximum	11.70	Maximum	7.10	Maximum	11.80
Count	11692.00	Count	2228.00	Count	4141.00	Count	1731.00	Count	3592.00

Yearly DO (% saturation)		Winter DO (% saturation)		Spring DO (% saturation)		Summer DO (% saturation)		Fall DO (% saturation)	
Mean	88.07	Mean	98.27	Mean	89.53	Mean	75.64	Mean	86.06
Std. Error	0.10	Std. Error	0.07	Std. Error	0.16	Std. Error	0.12	Std. Error	0.14
Median	91.00	Median	98.70	Median	92.70	Median	75.20	Median	86.90
Mode	98.80	Mode	98.80	Mode	92.80	Mode	72.30	Mode	95.40
Std. Deviation	10.48	Std. Deviation	3.48	Std. Deviation	10.07	Std. Deviation	5.12	Std. Deviation	8.67
Variance	109.89	Variance	12.11	Variance	101.32	Variance	26.25	Variance	75.20
Range	54.00	Range	22.20	Range	51.40	Range	31.50	Range	40.60
Minimum	61.30	Minimum	89.10	Minimum	63.90	Minimum	61.80	Minimum	61.30
Maximum	115.30	Maximum	111.30	Maximum	115.30	Maximum	93.30	Maximum	101.90
Count	11691.00	Count	2228.00	Count	4140.00	Count	1731.00	Count	3592.00

Table 4. Chestnut Neck 2000 (Depth and pH).

Yearly Depth (m)		Winter Depth (m)		Spring Depth (m)		Summer Depth (m)		Fall Depth (m)	
Mean	1.73	Mean	1.59	Mean	1.71	Mean	1.84	Mean	1.74
Std. Error	0.00	Std. Error	0.01	Std. Error	0.01	Std. Error	0.01	Std. Error	0.01
Median	1.74	Median	1.59	Median	1.73	Median	1.86	Median	1.75
Mode	1.97	Mode	1.23	Mode	1.97	Mode	2.16	Mode	1.97
Std. Deviation	0.36	Std. Deviation	0.37	Std. Deviation	0.38	Std. Deviation	0.33	Std. Deviation	0.34
Variance	0.13	Variance	0.14	Variance	0.14	Variance	0.11	Variance	0.12
Range	2.36	Range	2.17	Range	2.02	Range	1.47	Range	1.74
Minimum	0.27	Minimum	0.27	Minimum	0.61	Minimum	1.10	Minimum	0.88
Maximum	2.63	Maximum	2.44	Maximum	2.63	Maximum	2.57	Maximum	2.62
Count	14673.00	Count	3052.00	Count	4142.00	Count	3869.00	Count	3610.00

Yearly pH		Winter pH		Spring pH		Summer pH		Fall pH	
Mean	7.37	Mean	7.28	Mean	7.47	Mean	7.21	Mean	7.51
Std. Error	0.00	Std. Error	0.00	Std. Error	0.00	Std. Error	0.00	Std. Error	0.00
Median	7.40	Median	7.30	Median	7.50	Median	7.20	Median	7.50
Mode	7.30	Mode	7.40	Mode	7.60	Mode	7.20	Mode	7.70
Std. Deviation	0.27	Std. Deviation	0.20	Std. Deviation	0.26	Std. Deviation	0.21	Std. Deviation	0.27
Variance	0.07	Variance	0.04	Variance	0.07	Variance	0.04	Variance	0.07
Range	1.50	Range	1.20	Range	1.50	Range	1.20	Range	1.20
Minimum	6.60	Minimum	6.60	Minimum	6.60	Minimum	6.60	Minimum	6.80
Maximum	8.10	Maximum	7.80	Maximum	8.10	Maximum	7.80	Maximum	8.00
Count	14673.00	Count	3052.00	Count	4142.00	Count	3869.00	Count	3610.00

Table 4. Chestnut Neck 2000 (Turbidity).

	Yearly Turbidity (NTU)	Winter Turbidity (NTU)	Spring Turbidity (NTU)	Summer Turbidity (NTU)	Fall Turbidity (NTU)
Mean	7.85	9.98	11.77	4.28	5.35
Std. Error	0.06	0.16	0.14	0.06	0.08
Median	5.80	7.20	10.00	4.00	4.00
Mode	4.00	6.00	6.00	3.00	4.00
Std. Deviation	7.62	9.01	8.79	3.52	4.90
Variance	58.11	81.15	77.30	12.42	24.02
Range	107.00	106.00	98.00	62.00	56.00
Minimum	0.00	1.00	0.00	0.00	0.00
Maximum	107.00	107.00	98.00	62.00	56.00
Count	14612.00	3052.00	4121.00	3834.00	3605.00

Table 5. Buoy 126 1999 (Temperature and Salinity).

Yearly Temperature (°C)		Winter Temperature (°C)		Spring Temperature (°C)		Summer Temperature (°C)		Fall Temperature (°C)	
Mean	13.90	Mean	3.96	Mean	9.57	Mean	21.93	Mean	16.80
Std. Error	0.06	Std. Error	0.04	Std. Error	0.06	Std. Error	0.04	Std. Error	0.08
Median	13.33	Median	4.13	Median	9.50	Median	22.00	Median	17.40
Mode	11.80	Mode	4.61	Mode	10.70	Mode	22.00	Mode	12.40
Std. Deviation	7.56	Std. Deviation	1.91	Std. Deviation	3.80	Std. Deviation	2.61	Std. Deviation	4.75
Variance	57.17	Variance	3.66	Variance	14.48	Variance	6.81	Variance	22.55
Range	29.00	Range	11.64	Range	21.60	Range	14.70	Range	20.00
Minimum	-1.10	Minimum	-1.10	Minimum	1.10	Minimum	13.20	Minimum	6.00
Maximum	27.90	Maximum	10.54	Maximum	22.70	Maximum	27.90	Maximum	26.00
Count	14338.00	Count	2874.00	Count	3505.00	Count	4025.00	Count	3934.00

Yearly Salinity (ppt)		Winter Salinity (ppt)		Spring Salinity (ppt)		Summer Salinity (ppt)		Fall Salinity (ppt)	
Mean	29.46	Mean	29.15	Mean	28.27	Mean	30.63	Mean	29.79
Std. Error	0.02	Std. Error	0.03	Std. Error	0.03	Std. Error	0.02	Std. Error	0.03
Median	30.03	Median	29.70	Median	28.80	Median	30.80	Median	30.42
Mode	31.40	Mode	30.26	Mode	29.50	Mode	31.40	Mode	31.00
Std. Deviation	1.89	Std. Deviation	1.72	Std. Deviation	1.95	Std. Deviation	1.01	Std. Deviation	1.83
Variance	3.57	Variance	2.95	Variance	3.82	Variance	1.01	Variance	3.36
Range	10.15	Range	8.36	Range	9.50	Range	6.50	Range	9.34
Minimum	22.20	Minimum	23.18	Minimum	22.20	Minimum	25.50	Minimum	23.01
Maximum	32.35	Maximum	31.54	Maximum	31.70	Maximum	32.00	Maximum	32.35
Count	13016.00	Count	2874.00	Count	3243.00	Count	2965.00	Count	3934.00

Table 5. Buoy 126 1999 (Dissolved Oxygen).

Yearly DO (mg/L)		Winter DO (mg/L)		Spring DO (mg/L)		Summer DO (mg/L)		Fall DO (mg/L)	
Mean	9.54	Mean	12.15	Mean	10.09	Mean	6.89	Mean	8.06
Std. Error	0.02	Std. Error	0.02	Std. Error	0.02	Std. Error	0.02	Std. Error	0.01
Median	9.20	Median	12.06	Median	10.10	Median	6.80	Median	8.00
Mode	9.20	Mode	12.71	Mode	9.20	Mode	6.70	Mode	8.60
Std. Deviation	2.19	Std. Deviation	0.91	Std. Deviation	1.27	Std. Deviation	1.00	Std. Deviation	0.67
Variance	4.80	Variance	0.82	Variance	1.63	Variance	0.99	Variance	0.45
Range	12.56	Range	5.89	Range	9.20	Range	8.10	Range	4.08
Minimum	2.80	Minimum	9.47	Minimum	4.40	Minimum	2.80	Minimum	5.52
Maximum	15.36	Maximum	15.36	Maximum	13.60	Maximum	10.90	Maximum	9.60
Count	10151.00	Count	2707.00	Count	3066.00	Count	1981.00	Count	2397.00

Yearly DO (% saturation)		Winter DO (% saturation)		Spring DO (% saturation)		Summer DO (% saturation)		Fall DO (% saturation)	
Mean	102.82	Mean	112.50	Mean	103.76	Mean	94.36	Mean	97.65
Std. Error	0.11	Std. Error	0.16	Std. Error	0.18	Std. Error	0.28	Std. Error	0.11
Median	101.70	Median	111.10	Median	102.20	Median	93.30	Median	97.30
Mode	95.10	Mode	105.90	Mode	100.90	Mode	95.00	Mode	97.10
Std. Deviation	11.47	Std. Deviation	8.09	Std. Deviation	10.14	Std. Deviation	12.42	Std. Deviation	5.61
Variance	131.59	Variance	65.51	Variance	102.90	Variance	154.21	Variance	31.44
Range	94.40	Range	37.00	Range	79.80	Range	92.00	Range	48.90
Minimum	40.10	Minimum	94.70	Minimum	54.70	Minimum	40.10	Minimum	70.90
Maximum	134.50	Maximum	131.70	Maximum	134.50	Maximum	132.10	Maximum	119.80
Count	10151.00	Count	2707.00	Count	3066.00	Count	1981.00	Count	2397.00

Table 5. Buoy 126 1999 (Depth and pH).

Yearly Depth (m)		Winter Depth (m)		Spring Depth (m)		Summer Depth (m)		Fall Depth (m)	
Mean	2.83	Mean	2.82	Mean	2.79	Mean	2.85	Mean	2.87
Std. Error	0.00	Std. Error	0.01	Std. Error	0.01	Std. Error	0.01	Std. Error	0.01
Median	2.82	Median	2.80	Median	2.78	Median	2.84	Median	2.86
Mode	2.94	Mode	2.77	Mode	2.56	Mode	2.96	Mode	2.94
Std. Deviation	0.36	Std. Deviation	0.37	Std. Deviation	0.36	Std. Deviation	0.35	Std. Deviation	0.35
Variance	0.13	Variance	0.14	Variance	0.13	Variance	0.12	Variance	0.12
Range	1.98	Range	1.85	Range	1.88	Range	1.67	Range	1.69
Minimum	1.83	Minimum	1.96	Minimum	1.83	Minimum	2.13	Minimum	2.07
Maximum	3.81	Maximum	3.81	Maximum	3.71	Maximum	3.80	Maximum	3.76
Count	13679.00	Count	2874.00	Count	3505.00	Count	3366.00	Count	3934.00

Yearly pH		Winter pH		Spring pH		Summer pH		Fall pH	
Mean	8.10	Mean	8.14	Mean	8.16	Mean	7.95	Mean	8.15
Std. Error	0.00	Std. Error	0.01	Std. Error	0.00	Std. Error	0.00	Std. Error	0.00
Median	8.10	Median	8.11	Median	8.10	Median	8.00	Median	8.16
Mode	8.10	Mode	7.92	Mode	8.10	Mode	8.00	Mode	8.40
Std. Deviation	0.22	Std. Deviation	0.24	Std. Deviation	0.17	Std. Deviation	0.19	Std. Deviation	0.20
Variance	0.05	Variance	0.06	Variance	0.03	Variance	0.04	Variance	0.04
Range	1.15	Range	1.08	Range	0.90	Range	1.00	Range	0.90
Minimum	7.40	Minimum	7.47	Minimum	7.60	Minimum	7.40	Minimum	7.60
Maximum	8.55	Maximum	8.55	Maximum	8.50	Maximum	8.40	Maximum	8.50
Count	10181.00	Count	1908.00	Count	2233.00	Count	2476.00	Count	3564.00

Table 5. Buoy 126 1999 (Turbidity).

Yearly Turbidity (NTU)		Winter Turbidity (NTU)		Spring Turbidity (NTU)		Summer Turbidity (NTU)		Fall Turbidity (NTU)	
Mean	15.38	Mean	20.09	Mean	10.18	Mean	14.57	Mean	16.54
Std. Error	0.19	Std. Error	0.46	Std. Error	0.30	Std. Error	0.41	Std. Error	0.34
Median	9.10	Median	10.90	Median	5.00	Median	10.00	Median	10.90
Mode	2.00	Mode	5.90	Mode	2.00	Mode	8.00	Mode	7.00
Std. Deviation	20.44	Std. Deviation	24.74	Std. Deviation	16.70	Std. Deviation	16.50	Std. Deviation	20.19
Variance	417.77	Variance	611.87	Variance	278.97	Variance	272.12	Variance	407.58
Range	261.40	Range	259.80	Range	209.00	Range	249.00	Range	187.20
Minimum	0.00	Minimum	0.60	Minimum	0.00	Minimum	0.00	Minimum	1.00
Maximum	260.40	Maximum	260.40	Maximum	208.00	Maximum	249.00	Maximum	188.20
Count	11201.00	Count	2872.00	Count	3143.00	Count	1640.00	Count	3547.00

Table 6. Buoy 126 2000 (Temperature and Salinity).

Yearly Temperature (^oC)		Winter Temperature (^oC)		Spring Temperature (^oC)		Summer Temperature (^oC)		Fall Temperature (^oC)	
Mean	13.54	Mean	4.58	Mean	10.49	Mean	21.41	Mean	15.56
Std. Error	0.06	Std. Error	0.06	Std. Error	0.05	Std. Error	0.04	Std. Error	0.08
Median	13.20	Median	5.70	Median	9.80	Median	22.00	Median	16.05
Mode	22.60	Mode	-1.50	Mode	9.40	Mode	22.60	Mode	16.40
Std. Deviation	7.15	Std. Deviation	3.36	Std. Deviation	3.47	Std. Deviation	2.60	Std. Deviation	5.31
Variance	51.07	Variance	11.26	Variance	12.07	Variance	6.77	Variance	28.24
Range	28.80	Range	12.01	Range	15.10	Range	12.80	Range	24.30
Minimum	-1.70	Minimum	-1.70	Minimum	4.70	Minimum	14.30	Minimum	2.50
Maximum	27.10	Maximum	10.31	Maximum	19.80	Maximum	27.10	Maximum	26.80
Count	16556.00	Count	3357.00	Count	4415.00	Count	4414.00	Count	4366.00

Yearly Salinity (ppt)		Winter Salinity (ppt)		Spring Salinity (ppt)		Summer Salinity (ppt)		Fall Salinity (ppt)	
Mean	29.62	Mean	30.22	Mean	29.91	Mean	28.87	Mean	29.61
Std. Error	0.01	Std. Error	0.03	Std. Error	0.03	Std. Error	0.03	Std. Error	0.02
Median	30.00	Median	30.71	Median	30.20	Median	29.30	Median	30.10
Mode	31.30	Mode	32.20	Mode	30.40	Mode	30.50	Mode	31.30
Std. Deviation	1.88	Std. Deviation	1.88	Std. Deviation	1.94	Std. Deviation	1.81	Std. Deviation	1.65
Variance	3.55	Variance	3.54	Variance	3.75	Variance	3.27	Variance	2.71
Range	10.80	Range	9.12	Range	10.10	Range	9.20	Range	8.40
Minimum	22.50	Minimum	24.18	Minimum	23.20	Minimum	22.50	Minimum	23.70
Maximum	33.30	Maximum	33.30	Maximum	33.30	Maximum	31.70	Maximum	32.10
Count	16555.00	Count	3357.00	Count	4416.00	Count	4415.00	Count	4367.00

Table 6. Buoy 126 2000 (Dissolved Oxygen).

Statistic	Yearly DO (mg/L)	Winter DO (mg/L)	Spring DO (mg/L)	Summer DO (mg/L)	Fall DO (mg/L)
Mean	9.51	12.48	9.83	6.90	9.19
Std. Error	0.02	0.03	0.01	0.01	0.02
Median	9.50	12.20	9.90	6.80	9.00
Mode	10.40	11.90	10.60	6.20	8.80
Std. Deviation	2.19	1.42	0.95	0.89	1.21
Variance	4.82	2.02	0.90	0.78	1.46
Range	12.80	6.23	5.50	6.40	7.80
Minimum	3.20	9.77	6.40	3.20	4.90
Maximum	16.00	16.00	11.90	9.60	12.70
Count	14884.00	3124.00	4408.00	3631.00	3721.00

Statistic	Yearly DO (% saturation)	Winter DO (% saturation)	Spring DO (% saturation)	Summer DO (% saturation)	Fall DO (% saturation)
Mean	103.96	118.39	106.06	91.86	101.16
Std. Error	0.12	0.31	0.10	0.20	0.14
Median	102.50	109.20	105.30	90.90	100.10
Mode	103.20	103.20	103.90	91.10	99.90
Std. Deviation	14.54	17.11	6.86	12.18	8.29
Variance	211.40	292.64	47.07	148.34	68.79
Range	117.00	70.80	44.70	94.60	97.00
Minimum	42.80	89.00	82.40	42.80	58.80
Maximum	159.80	159.80	127.10	137.40	155.80
Count	14884.00	3124.00	4408.00	3631.00	3721.00

Table 6. Buoy 126 2000 (Depth and pH).

Yearly Depth (m)		Winter Depth (m)		Spring Depth (m)		Summer Depth (m)		Fall Depth (m)	
Mean	3.05	Mean	2.75	Mean	2.95	Mean	3.17	Mean	3.10
Std. Error	0.00	Std. Error	0.01	Std. Error	0.00	Std. Error	0.01	Std. Error	0.01
Median	3.04	Median	2.76	Median	2.95	Median	3.16	Median	3.09
Mode	2.85	Mode	2.94	Mode	2.98	Mode	2.90	Mode	2.76
Std. Deviation	0.41	Std. Deviation	0.41	Std. Deviation	0.44	Std. Deviation	0.37	Std. Deviation	0.36
Variance	0.17	Variance	0.17	Variance	0.19	Variance	0.14	Variance	0.13
Range	3.70	Range	3.38	Range	3.59	Range	1.92	Range	2.06
Minimum	0.59	Minimum	0.59	Minimum	0.59	Minimum	2.37	Minimum	2.11
Maximum	4.29	Maximum	3.97	Maximum	4.18	Maximum	4.29	Maximum	4.17
Count	16556.00	Count	3358.00	Count	7774.00	Count	4415.00	Count	4368.00

Yearly pH		Winter pH		Spring pH		Summer pH		Fall pH	
Mean	7.95	Mean	8.09	Mean	7.90	Mean	7.81	Mean	8.04
Std. Error	0.00	Std. Error	0.00	Std. Error	0.00	Std. Error	0.00	Std. Error	0.00
Median	8.00	Median	8.10	Median	7.90	Median	7.80	Median	8.00
Mode	8.10	Mode	8.10	Mode	8.10	Mode	7.90	Mode	8.10
Std. Deviation	0.20	Std. Deviation	0.10	Std. Deviation	0.22	Std. Deviation	0.19	Std. Deviation	0.13
Variance	0.04	Variance	0.01	Variance	0.05	Variance	0.04	Variance	0.02
Range	1.40	Range	0.90	Range	1.10	Range	1.40	Range	0.70
Minimum	7.00	Minimum	7.40	Minimum	7.30	Minimum	7.00	Minimum	7.60
Maximum	8.40	Maximum	8.30	Maximum	8.40	Maximum	8.40	Maximum	8.30
Count	15841.00	Count	3358.00	Count	3702.00	Count	4415.00	Count	4368.00

Table 6. Buoy 126 2000 (Turbidity).

Yearly Turbidity (NTU)		Winter Turbidity (NTU)		Spring Turbidity (NTU)		Summer Turbidity (NTU)		Fall Turbidity (NTU)	
Mean	11.18	Mean	20.64	Mean	8.43	Mean	6.69	Mean	10.33
Std. Error	0.11	Std. Error	0.34	Std. Error	0.17	Std. Error	0.12	Std. Error	0.16
Median	7.00	Median	15.00	Median	5.00	Median	5.00	Median	7.00
Mode	3.00	Mode	12.00	Mode	3.00	Mode	3.00	Mode	4.00
Std. Deviation	13.61	Std. Deviation	19.84	Std. Deviation	10.06	Std. Deviation	7.89	Std. Deviation	10.59
Variance	185.11	Variance	393.78	Variance	101.23	Variance	62.28	Variance	112.07
Range	196.00	Range	196.00	Range	88.00	Range	156.00	Range	115.00
Minimum	0.00	Minimum	0.00	Minimum	0.00	Minimum	0.00	Minimum	0.00
Maximum	196.00	Maximum	196.00	Maximum	88.00	Maximum	156.00	Maximum	115.00
Count	15285.00	Count	3355.00	Count	3684.00	Count	4034.00	Count	4212.00

Appendix 11. Results of ANOVAs comparing physical-chemical data across three JCNERR SWMP sites (Buoy 126, Chestnut Neck, and Lower Bank) in 1999.

Factor	Source	df	MS	F	P > F
Temperature	Site	2	66.65	1.08	0.3404
	Error	762	61.77		
Salinity	Site	2	44200.37	6620.21	<.0001
	Error	720	6.68		
Dissolved Oxygen (mg/l)	Site	2	13.33	3.45	0.0327
	Error	333	3.86		
pH	Site	2	177.46	957.16	<.0001
	Error	441	0.19		
Turbidity	Site	2	16271.96	114.22	<.0001
	Error	531	142.46		
Depth	Site	2	104.74	1726.05	<.0001
	Error	720	0.06		

From Kennish, M. J. and S. O'Donnell. 2002. Water quality monitoring in the Jacques Cousteau National Estuarine Research Reserve System. *Bulletin of the New Jersey Academy of Science* 47(2): 1-14.

Appendix 12. Results of ANOVAs comparing physical-chemical data across three JCNERR SWMP sites (Buoy 126, Chestnut Neck, and Lower Bank) in 2000.

Factor	Source	df	MS	F	P > F
Temperature	Site	2	269.39	4.77	0.0087
	Error	915	56.53		
Salinity	Site	2	57893.02	16571.69	<.0001
	Error	915	3.49		
Dissolved Oxygen (mg/l)	Site	2	59.23	13.47	<.0001
	Error	624	4.40		
pH	Site	2	215.18	1776.35	<.0001
	Error	873	0.12		
Turbidity	Site	2	21042.27	211.54	<.0001
	Error	825	99.47		
Depth	Site	2	177.90	4141.36	<.0001
	Error	915	0.04		

From Kennish, M. J. and S. O'Donnell. 2002. Water quality monitoring in the Jacques Cousteau National Estuarine Research Reserve System. *Bulletin of the New Jersey Academy of Science* 47(2): 1-14.

Appendix 13. Statistical tests comparing physical-chemical measurements between years (1999 and 2000) at each JCNERR SWMP site.

T-tests for Buoy 126

Variable	df	t Value	P > t
Temperature	290	-2.03	0.0432
Salinity	262	0.29	0.7755
Dissolved Oxygen (mg/l)	199	1.89	0.0608
pH	191	-5.73	<0.0001
Turbidity	213	3.07	0.0024
Depth	276	-15.77	<0.0001

T-tests for Chestnut Neck

Variable	df	t Value	P > t
Temperature	255	-0.12	0.9043
Salinity	255	-2.52	0.0122
Dissolved Oxygen (mg/l)	189	1.09	0.2773
pH	242	12.26	<0.0001
Turbidity	235	3.12	0.0020
Depth	255	-1.54	<0.1246

T-tests for Lower Bank

Variable	df	t Value	P > t
Temperature	334	-0.85	0.3947
Salinity	334	-6.60	<0.0001
Dissolved Oxygen (mg/l)	222	2.56	0.0111
pH	295	-1.83	0.0686
Turbidity	270	1.99	0.0471
Depth	334	0.42	0.6745

From Kennish, M. J. and S. O'Donnell. 2002. Water quality monitoring in the Jacques Cousteau National Estuarine Research Reserve System. *Bulletin of the New Jersey Academy of Science* 47(2): 1-14.

Appendix 14. Taxonomic list of plants identified along stream vegetation sites in the Mullica River Basin.

Group	Common Name	Scientific Name
Herbaceous Plants		
	Ticklegrass	*Agrostis hyemalis*
	Ticklegrass	*Agrostis hyemalis var. scabra*
	Upland bent-grass	*Agrostis perennans*
	Upland bent-grass	*Agrostis perennans var. elata*
	Small water plantain	*Alisma subcordatum*
	Garlic	*Allium* sp.
	Pursh's millet-grass	*Amphicarpum purshii*
	Bushy beard-grass	*Andropogon virginicus var. abbreviatus*
	Broomsedge	*Andropogon virginicus var. virginicus*
	Groundnut	*Apios americana*
	Wild sarsaparilla	*Aralia nudicaulis*
	Arethusa	*Arethusa bulbosa*
	Swamp milkweed	*Asclepias incarnata*
	Bushy aster	*Aster dumosus*
	Bog aster	*Aster nemoralis*
	New York aster	*Aster novi-belgii*
	Heath aster	*Aster pilosus var pringlei*
	Small white aster	*Aster racemosus*
	Twining bartonia	*Bartonia paniculata*
	Yellow bartonia	*Bartonia virginica*

Purple-stemmed beggar ticks	*Bidens connata*
Northern tickseed-sunflower	*Bidens coronata*
Small beggar ticks	*Bidens discoidea*
Beggar ticks	*Bidens frondosa*
False nettle	*Boehmeria cylindrica*
Blue-joint grass	*Calamagrostis canadensis*
Nuttall's reed-grass	*Calamagrostis cinnoides*
Larger water starwort	*Callitriche heterophylla*
Pennsylvania bitter-cress	*Cardamine pensylvanica*
Greenish-white sedge	*Carex albolutescens*
Atlantic sedge	*Carex atlantica*
Howe's sedge	*Carex atlantica var. capillacea*
Button sedge	*Carex bullata*
Silvery sedge	*Carex canescens*
Collins' sedge	*Carex collinsii*
Fringed sedge	*Carex crinita*
Coast sedge	*Carex exilis*
Long sedge	*Carex folliculata*
Bladder sedge	*Carex intumescens*
Livid sedge	*Carex livida*
Long's sedge	*Carex longii*
Sallow sedge	*Carex lurida*
Pennsylvania sedge	*Carex pensylvanica*
Pointed broom sedge	*Carex scoparia*
Awl-fruited sedge	*Carex stipata*
Walter's sedge	*Carex striata*

Tussock sedge	*Carex stricta*
Blunt broom sedge	*Carex tribuloides*
Three-fruited sedge	*Carex trisperma*
Dark green sedge	*Carex venusta*
Prickly hornwort	*Ceratophyllum echinatum*
Slender spike-grass	*Chasmanthium laxum*
Wood-reed	*Cinna arundinacea*
Twig-rush	*Cladium mariscoides*
Dodder	*Cuscuta* sp.
Toothed cyperus	*Cyperus dentatus*
Red-rooted cyperus	*Cyperus erythrorhizos*
Coarse cyperus	*Cyperus odoratus*
Pine Barrens cyperus	*Cyperus retrorsus*
Straw-colored cyperus	*Cyperus strigosus*
Silky wild oat-grass	*Danthonia sericea var. epilis*
Swamp loosestrife	*Decodon verticillatus*
Common wild yam	*Dioscorea villosa*
Thread-leaved sundew	*Drosera filiformis*
Spatulate-leaved sundew	*Drosera intermedia*
Round-leaved sundew	*Drosera rotundifolia*
Spinulose wood fern	*Dryopsteris carthusiana*
Dulichium	*Dulichium arundinaceum*
American barnyard grass	*Echinochloa muricata*
Needle spike-rush	*Eleocharis acicularis*
Green spike-rush	*Eleocharis flavescens var. olivacea*

Small-fruited spike-rush	*Eleocharis microcarpa*
Blunt spike-rush	*Eleocharis ovata*
Robbin's spike rush	*Eleocharis robbinsii*
Slender spike-rush	*Eleocharis tenuis*
Tubercled spike-grass	*Eleocharis tuberculosa*
Nuttall's water-weed	*Elodea nuttallii*
Purple-leaved willow-herb	*Epilobium coloratum*
Pilewort	*Erechtites hieracifolia*
Plume-grass	*Erianthus giganteus*
Seven-angled pipewort	*Eriocaulon aquaticum*
Flattened pipewort	*Eriocaulon compressum*
Ten-angled pipewort	*Eriocaulon decangulare*
Tawny cotton-grass	*Eriophorum virginicum*
Eastern joe-pye weed	*Eupatorium dubium*
Boneset	*Eupatorium perfoliatum*
Rough boneset	*Eupatorium pilosum*
Pine Barrens boneset	*Eupatorium resinosum*
Late-flowering boneset	*Eupatorium serotinum*
Ipecac spurge	*Euphorbia ipecacuanhae*
Slender-leaved goldenrod	*Euthamia tenuifolia*
Stiff marsh bedstraw	*Galium tinctorium*
Gill-over-the-ground	*Glechoma hederacea*
Rattlesnake grass	*Glyceria canadensis*
Blunt manna-grass	*Glyceria obtusa*
Fowl manna-grass	*Glycera striata*
Northern manna-grass	*Glyceria x laxa*

Green wood orchid	*Habenaria clavellata*
Ragged fringed orchid	*Habenaria lacera*
Swamp rose mallow	*Hibiscus moscheutos*
Canada Saint John's wort	*Hypericum canadense*
Coppery Saint John's wort	*Hypericum denticulatum*
Dwarf Saint John's-wort	*Hypericum mutilum*
Saint Andrew's cross	*Hypericum stragulum*
Spotted touch-me-not	*Impatiens capensis*
Slender blue flag	*Iris prismatica*
Larger blue flag	*Iris versicolor*
Spiny-spored quillwort	*Isoetes echinospora*
Sharp-fruited rush	*Juncus acuminatus*
Two-flowered rush	*Juncus biflorus*
New Jersey rush	*Juncus caesariensis*
Canada rush	*Juncus canadensis*
Common rush	*Juncus effusus*
Bayonet rush	*Juncus militaris*
Brown-fruited rush	*Juncus pelocarpus*
Redroot	*Lachnanthes caroliniana*
Rice cut-grass	*Leersia oryzoides*
Duckweed	*Lemna* sp.
Turk's-cap lily	*Lilium superbum*
Short-stalked false pimpernel	*Lindernia dubia*
Canby's lobelia	*Lobelia canbyi*
Cardinal flower	*Lobelia cardinalis*
Nuttall's lobelia	*Lobelia nuttalli*i

Golden-crest	*Lophiola aurea*
Seedbox	*Ludwigia alternifolia*
Water purslane	*Ludwigia palustris*
Foxtail-clubmoss	*Lycopodium alopecuroides*
Southern bog clubmoss	*Lycopodium appressum*
Tree clubmoss	*Lycoopodium obscurum*
Northern bugleweed	*Lycopus uniflorus*
Virginia bugleweed	*Lycopus virginicus*
Swamp loosestrife	*Lysimachia terrestris*
Purple loosestrife	*Lythrum salicaria*
Eulalia	*Microstegium vimineum*
Climbing hempweed	*Mikania scandens*
Square-stemmed monkey-flower	*Mimulus ringens*
Partridge berry	*Mitchella repens*
Indian pipe	*Monotropa uniflora*
Torrey's dropseed	*Muhlenbergia torreyana*
Late-flowering dropseed	*Muhlenbergia uniflora*
Bullhead lily	*Nuphar variegata*
White water lily	*Nymphaea odorata*
Sensitive fern	*Onoclea sensibilis*
Golden club	*Orontium aquaticum*
Cinnamon fern	*Osmunda cinnamomea*
Royal fern	*Osmunda regalis*
Upright yellow wood-sorrel	*Oxalis stricta*
Cowbane	*Oxypolis rigidior*
Deertongue grass	*Panicum clandestinum*

Forked panic-grass	*Panicum dichotomum*
Small-leaved panic-grass	*Panicum ensifolium*
Panic-grass	*Panicum lanuginosum*
Long-leaved panic-grass	*Panicum longifolium*
Long-leaved panic-grass	*Panicum rigidulum*
Sheathed panic-grass	*Panicum scabriusculum*
Eaton's panic-grass	*Panicum spretum*
Warty panic-grass	*Panicum verrucosum*
Switchgrass	*Panicum virgatum*
Arrow arum	*Peltandra virginica*
Reed canary grass	*Phalaris arundinacea*
Reed	*Pragmites australis*
Pokeweed	*Phytolacca americana*
Clearweed	*Pilea pumila*
Fowl bluegrass	*Poa palustris*
Kentucky bluegrass	*Poa pratensis*
Rose pogonia	*Pogonia ophioglossoides*
Short-leaved milkwort	*Polygala brevifolia*
Cross-leaved milkwort	*Polygala cruciata*
Halberd-leaved tearthumb	*Polygonum arifolium*
Cespitose knotweed	*Polygonum crespitosum*
Mild water pepper	*Polygonum hydropiperoides*
Dotted smartweed	*Polygonum punctatum*
Arrow-leaved tearthumb	*Polygonum sagittatum*
Pickerel-weed	*Ponderia cordata*
Algal-like pondweed	*Potamogeton confervoides*

Half-like pondweed	*Potamogeton diversifolius*
Nuttall's pondweed	*Potamogeton epihydrus*
Oakes' pondweed	*Potamogeton oakesianus*
Small pondweed	*Potamogeton pusillus*
Cut-leaved mermaid-weed	*Proserpinaca pectinata*
Bracken	*Pteridium aquilinum*
Maryland meadow beauty	*Rhexia mariana*
Virginia meadow beauty	*Rhexia virginica*
White-beaked-rush	*Rhynchospora alba*
Small-headed beaked-rush	*Rhynchospora capitellata*
Loose-headed beaked-rush	*Rhynchospora chalarocephala*
Marsh yellow cress	*Rorippa palustris*
Lance-leaved sabatia	*Sabatia difformis*
Engelmann's arrowhead	*Sagittaria engelmanniana*
Pitcher plant	*Sarracenia purpurea*
Little bluestem	*Schizachyrium scoparium*
Curly-grass fern	*Schizaea pusilla*
Wool-grass	*Scirpus cyperinus*
Three-square bulrush	*Scirpus pungens*
Water club-rush	*Scirpus subterminalis*
Reticulated nut-rush	*Scleria reticularis*
Sclerolepis	*Sclerolepis uniflora*
Mad-dog skullcap	*Scutellaria lateriflora*
Carrion flower	*Smilax herbacea*
Halberd-leaved greenbrier	*Smilax pseudochina*
Black nightshade	*Solanum nigrum*

Canada goldenrod	*Solidago canadensis*
Rough-stemmed goldenrod	*Solidago rugosa*
Slender-bur-reed	*Sparganium americanum*
Nodding ladies'-tresses	*Spiranthes cernua*
Common stitchwort	*Stellaria graminea*
Common chickweed	*Stellaria media*
Dandelion	*Taraxacum officinale*
Marsh fern	*Thelypteris palustris*
Bog fern	*Thelypteris simulata*
Marsh Saint John's-wort	*Triadenum virginicum*
Starflower	*Trientalis borealis*
Broad-leaved cattail	*Typha latifolia*
Stinging nettle	*Urtica dioica*
Horned bladderwort	*Utricularia cornuta*
Fibrous bladderwort	*Utricularia fibrosa*
Hidden-fruited bladderwort	*Utricularia geminiscapa*
Floating bladderwort	*Utricularia inflata*
Purple bladderwort	*Utricularia purpurea*
Zig-zag bladderwort	*Utricularia subulata*
Greater bladderwort	*Utricularia vulgaris*
Blue vervain	*Verbena hastata*
New York ironweed	*Vernonia noveboracensis*
Lance-leaved violet	*Viola lanceolata*
Primrose-leaved violet	*Viola primulifolia*
Woolly blue violet	*Viola sororia*
Netted chain fern	*Woodwardia areolata*

Virginia chain fern	*Woodwardia virginica*
Turkey-beard	*Xerophyllum asphodeloides*
Yellow-eyed grass	*Xyris difformis*
Small's yellow-eyed grass	*Xyris smalliana*
Wild rice	*Zizania aquatica*

Woody Plants

Red maple	*Acer rubrum*
Ailanthus	*Ailanthus altissima*
Smooth alder	*Alnus serrulata*
Oblongleaf juneberry	*Amelanchier canadensis*
Coastal juneberry	*Amelanchier obovalis*
Red chokeberry	*Aronia arbutifolia*
Japanese barberry	*Berberis thunbergii*
Black birch	*Betula lenta*
Gray birch	*Betula populifolia*
Common catalpa	*Catalpa bignonioides*
Buttonbush	*Cephalanthus occidentalis*
Atlantic white cedar	*Chamaecyparis thyoides*
Leatherleaf	*Chamaedaphne calyculata*
Yam-leaved clematis	*Clematis terniflora*
Sweet pepperbush	*Clethra alnifolia*
Persimmon	*Diospyros virginiana*
Fetterbush	*Eubotrys racemosa*
Wintergreen	*Gaultheria procumbens*
Black huckleberry	*Gaylussacia baccata*
Dwarf huckleberry	*Gaylussacia dumosa*

Dangleberry	*Gaylussacia frondosa*
Golden heather	*Hudsonia ericoides*
Bushy Saint-John's-wort	*Hypericum densiflorum*
Inkberry	*Ilex glabra*
Smooth winterberry	*Ilex laevigata*
American holly	*Ilex opaca*
Winterberry	*Ilex verticillata*
Virginia willow	*Itea virginica*
Red cedar	*Juniperus virginiana*
Sheep laurel	*Kalmia angustifolia*
Mountain laurel	*Kalmia latifolia*
Sand myrtle	*Leiophyllum buxifolium*
Sweet gum	*Liquidambar styraciflua*
Japanese honeysuckle	*Lonicera japonica*
Maleberry	*Lyonia ligustrina*
Staggerbush	*Lyonia mariana*
Sweet bay	*Magnolia virginiana*
Bayberry	*Myrica pensylvanica*
Black gum	*Nyssa sylvatica*
Virginia creeper	*Parthenocissus quinquefolia*
Shortleaf pine	*Pinus echinata*
Pitch pine	*Pinus rigida*
White pine	*Pinus strobus*
Sycamore	*Platanus occidentalus*
Black cherry	*Prunus serotina*
White oak	*Quercus alba*

Scrub oak	*Quercus ilicifolia*
Black-jack oak	*Quercus marilandica*
Black oak	*Quercus velutina*
Post oak	*Quercus stellata*
Swamp azalea	*Rhododendron viscosum*
Swamp rose	*Rosa palustris*
Swamp dewberry	*Rubus hispidus*
Blackberry	*Rubus* sp.
Black willow	*Salix nigra*
Common elder	*Sambuscus canadensis*
Sassafras	*Sassafras albidum*
Glaucous greenbrier	*Smilax glauca*
Laurel-leaved greenbrier	*Smilax laurifolia*
Common greenbrier	*Smilax rotundifolia*
Red-berried greenbrier	*Smilax walteri*
Narrow-leaved meadowsweet	*Spiraea alba var. latifolia*
Steeplebush	*Spiraea tomentosa*
Basswood	*Tilia americana*
Poison ivy	*Toxicodendron radicans*
Poison sumac	*Toxicodendron vernix*
American elm	*Ulmus americana*
Highbush blueberry	*Vaccinium corymbosum*
Large cranberry	*Vaccinum macrocarpon*
Early low blueberry	*Vaccinum pallidum*
Southern arrowwood	*Viburnum dentatum*
Naked withe-rod	*Viburnum nudum var. nudum*

Fox grape *Vitis labrusca*

From Zampella, R. A., J. F. Bunnell, K. J. Laidig, and C. L. Dow. 2001. The Mullica River Basin. Technical Report, New Jersey Pinelands Commission, New Lisbon, New Jersey.

Appendix 15. Taxonomic list of algae found in the New Jersey Pine Barrens.

Division Chlorophyta (Green Algae)

Order VOLVOCALES

Chlamydomonas spp.

Gonium sociale (Duj.)

Order TETRASPORALES

Gloeocystis sp.

Asterococcus limneticus

Tetraspora spp.

Order ULOTRICHACEAE

Ulothrix zonata (Weber and Mohr) Kutz.

Ulothrix spp.

Microspora loefgrenii (Nordst.) Lag.

M. quadrata Hazen

M. tumidula Hazen

M. willeana Lag.

Microspora spp.

Cylindrocapsa sp.

Stigeoclonium spp.

Microthamnion strictissimus Rab.

Microthamnion sp.

Aphanochaete repens A. Br.

Coleochaete irregularis Pringsh.

C. pulvinata A. Br.

Order OEDOGONIALES

Oedogonium polymorphus Wittr. and Lund.

O. ciliatum (Hass.) Pringsh.

O. undulatum A. Br.

Oedogonium spp.

Bulbochaete brebissonii Kütz.

Bulbochaete spp.

Order CLADOPHORALES

Cladophora spp.

Order CHLOROCOCCALES

Dictyosphaerium ehrenbergianum Näg.

Pediastrum integrum Näg.

Coelastrum cambricum Arch.

Coelastrum sp.

Ankistrodesmus sp.

Eremosphaera viridis De Bary

Order ZYGNEMATALES

Family ZYGNEMATACEAE

Mougeotia spp.

Debarya sp.

Zygnema spp.

Zygogonium ericetorum Kütz.

Pleurodiscus purpureus (Wolle) Lag.

Spirogyra buchetii Kütz.

S. parvispora Wood

S. punctata Cleve

Spirogyra spp.

Sirogonium sp.

Family MESOTAENIACEAE (Saccoderm desmids)

Mesotaenium endlicherianum Näg.

M. mirificum Arch.

Gonatozygon brebissonii De Bary

G. monotaenium De Bary

Cylindrocystis brebissonii Men.

Cylindrocystis spp.

Netrium digitus (Ehr.) Itz. and Rothe

N. interruptum (Bréb.) Lütk.

N. oblongum (De Bary) Lütk. var. cylindricum West and West

Netrium spp.

Spirotaenia condensata Bréb.

S. obscura Ralfs

Family DESMIDIACEAE (Placoderm desmids)

Closterium acutum (Lyngb.) Bréb

C. angustatum Kütz.

C. angustatum var. clavatum Hast.

C. baillyanum Bréb.

C. braunii Reinsch

C. costatum Corda

C. costatum var. *angustum* Graff.

C. cynthia De Not.

C. decorum Bréb.

C. dianae Ehr.

C. dianae var. *arcuatum* (Bréb.) Rab.

C. didymotocum (Corda) Ralfs

C. ehrenbergii Men.

C. gracile Bréb.

C. gracile var. *elongatum* West and West

C. idiosporum West and West

C. intermedium Ralfs

C. juncidum Ralfs

C. libellula Focke

C. libellula var. *intermedium* (Roy and Biss.) G. S. West

C. libellula var. *interruptum* (West and West) Donat

C. lineatum Ehr.

C. lunula Ehr.

C. macilentum Bréb.

C. moniliferum (Bory) Ehr.

C. moniliferum var. *concavum* Klebs

C. navicula (Bréb.) Lütk.

C. pritchardianum Arch.

C. pseudodianae Roy

C. ralfsii Bréb.

C. ralfsii var. *hybridum* Rab.

C. regulare Bréb.

C. rostratum Ehr.

C. setaceum Ehr.

C. striolatum Ehr

C. turgidum Ehr.

C. ulna Focke

C. venus Kütz.

Closterium spp.

Penium clevei Lund.

P. cylindrus (Ehr.) Bréb.

P. spirostriolatum Bark.

Penium spp.

Pleurotaenium constrictum (Bail.) Wood

P. ehrenbergii (Bréb.) De Bary

P. minutum (Ralfs) Delp.

P. minutum var. *latum* Kais.

P. nodosum (Bail.) Lund. Var. latum Irénée-Marie

P.trabecula (Ehr.) Näg.

P. truncatum (Bréb.) Näg.

Pleurotaenium sp.

Docidium dilatatum Cleve

D. spinulosum Wolle

D. tridentulum Wolle

D. undulatum Bail.

Triploceras gracile Bail.

T. verticillatum Bail.

Tetmemorus brebissonii (Men.) Ralfs

T. brebissonii var. *minor* De Bary

T. laevis (Kütz.) Ralfs –

T. laevis var. *borgei* Först.

T. granulatus (Bréb.) Ralfs

Tetmemorus spp.

Euastrum affine Ralfs

E. allenii Cushm.

E. bidentatum Näg.

E. binale (Turp.) Ehr. and vars.

E. crassum (Bréb.) Kütz.

E. crassum var. *scrobiculatum* Lund.

E. cuspidatum Wolle

E. denticulatum (Kirchn.) Gay

E. didelta (Turp.) Ralfs

E. formosum Wolle

E. giganteum (Wood) Nordst.

E. humerosum Ralfs

E. inerme Lund. var. *depressum* Wolle

E. insigne Hass.

E. insulare (Wittr.) Roy

E. intermedium Cleve

E. lapponicum Schmid.

E. magnificum Wolle

E. montanum West and West

E. purum Wolle

E. validum West and West

E. ventricosum Lund.

E. wollei Lag. var. *pearlingtonense* Presc. and Scott

Euastrum spp.

Actinotaenium cucurbita (Bréb.) Teil.

A. cucurbitinum (Biss.) Teil. var. *majellanicum* (Borge) Teil.

A. diplosporum (Lund.) Teil. var. *americanum* (West and West) Teil

Cosmarium abruptum Lund.

C. amoenum Bréb. var. *mediolaeve* Nordst.

C. angulosum Bréb

C. impressulum Elfv.

C. incertum Schmid. forma *consociatum* Croasd. (?)

C. isthmium West

C. kitchellii Wolle

C. margaritatum (Lund.) Roy and Biss.

C. moniliforme (Turp.) Ralfs

C. norimbergense Reinsch forma *depressa* West and West

C. novae-terrae Taylor

C. ornatum Ralfs

C. orthostichum Lund.

C ovale Ralfs

C. portianum Arch.

C. pseudoconnatum Nordst.

C. pseudoprotuberans Kirchn.

C. pseudopyramidatum Lund.

C. pseudotoxichondron Nordst.

C. punctulatum Bréb.

C. pyramidatum Bréb. and var. *convexum* Krieg. and Gerl.,

C. rectangulare Grun.

C. reniforme (Ralfs) Arch.

C. sejunctum Wolle

C. subcucumis Schmid.

C. subdepressum West and West

C. subtumidum Nordst.

C. tinctum Ralfs

C. trilobulatum Reinsch

Cosmarium spp.

Micrasterias americana (Ehr.) Ralfs

M. denticulata Bréb.

M. depauperata Nordst. var. *kitchelii* (Wolle) West and West

M. dichotoma Wolle

M. expansa Bail.

M. fimbriata Ralfs var. *apiculata* Men.

M. fimbriata var. *spinosa* Biss.

M. foliacea Bail.

M. jenneri Ralfs

M. laticeps Nordst.

M. mahabuleshwarensis Hobs. var. *ringens* (Bail.) Krieg.

M. muricata (Bail.) Ralfs

M. oscitans Ralfs

M. papillifera Bréb.

M. papillifera var. *glabra* Nordst.

M. papillifera var. *speciosa* Krieg.

M. pinnatifida (Kütz.) Ralfs var. *pseudoscitans* Grönbl.

M. piquata Salisb. var. *lata* Presc. and Scott

M. radiosa Ralfs

M. rotata (Grev.) Ralfs

M. triangularis Wolle

M. truncata (Corda) Bréb.

Micrasterias spp.

Xanthidium antilopaeum Kütz.

X. antilopaeum var. *minneapoliense* Wolle

X. armatum (Bréb.) Rab.

X. columbianum Wolle

Xanthidium spp.

Staurastrum alternans Bréb.

S. ankyroides Wolle

S. aspinosum Wolle

S. bienneanum Rab. var. *ellipticum* Wolle

S. brebissonii Arch.

S. botrophilum Wolle

S. calyxoides Wolle

S. cerastes Lund.

S. coronatum Wolle

S. cyrtocerum Bréb.

S. dilatatum Ehr.

S. divaricatum Wolle

S. elongatum Bark. var. *tetragonum* Wolle

S. forficatulatum Lund.

S. gracile Ralfs

S. hystrix Ralfs

S. inconspicuum Nordst.

S. leptacanthum Nordst. var. *tetrocterum* Wolle

S. muricatum Bréb.

S. ophiura Lund. forma

S. orbiculare Ralfs

S. pilosum (Näg.) Arch.

S. polytrichm (Perty) Rab.

S. pulchrum Wolle

S. punctulatum Bréb.

S. quaternum Wolle

S. rugulosum Bréb.

S. rugulosum var. *angulare* Grönbl.

S. simonyi Heim.

S. teliferum Ralfs

S. turgescens De Not.

S. vestitum Ralfs

Staurastrum spp.

Arthrodesmus crassus West and West

A. fragilis Wolle

A. incus (Bréb.) Hass.

A. rauii Wolle

A. subulatus Kütz. var. *subaequalis* West and West

A. triangularis Lag. var. *subtriangularis* (Borge) West and West

Hyalotheca dissiliens (Smith) Bréb.

H. mucosa (Mert.) Ehr.

Phymatodocis nordstedtiana Wolle

Desmidium aptogonum Bréb.

D. baileyi (Ralfs) Nordst.

D. elongatum Wolle

D. grevillii (Kütz.) De Bary

D. quadratum Nordst.

D. swartzii Ag.

Bambusina brebissonii Kütz (*Gymnozygon*)

B. delicatissima Wolle

Division Euglenophyta (Euglenoids)

Order EUGLENALES

Euglena acus Ehr.

E. elongata Schewiakoff

E. gracilis Klebs

E. mutabilis Schmitz

E. spirogyra Ehr.

Euglena spp.

Phacus crenulata Presc.

P. longicauda (Ehr.) Duj.

P. pleuronectes (O.F. Müll.) Duj.

P. pyrum (Ehr.) Stein

Phacus spp.

Trachelomonas armata (Ehr.) Stein

T. horrida Palm

T. lacustris Drezepolski

T. superba (Swir.) Defl

T. volvocina Ehr.

Trachelomonas spp.

Entosiphon sulcatum (Duj.) Stein

Peranema trichophorum (Ehr.) Stein

Division Chrysophyta (Yellow-green Algae)

Class XANTHOPHYCEAE

Order HETEROCOCCALES

Characiopsis sp.

Harpochytrium sp.

Ophiocytium capitatum Wolle

O. parvulum (Perty) A. Br.

Ophiocytium sp.

Botryococcus braunii Kütz.

Class CHRYSOPHYCEAE

Order CHRYSOMONADALES

Chrysococcus sp.

Derepyxis amphora Stokes

Derepyxis sp.

Synura ulvella Ehr.)

Uroglena volvox Ehr.

Cyclonexis annularis Stokes

Dinobryon sertularia Ehr.

D. stipitatum Stein

Epipyxis sp.

Order RHIZOCHRYSIDALES

Chrysopyxis bipes Stein

Lagynion scherffelii Pasch.

L. triangulare (Stokes) Pasch.

Class BACILLARIOPHYCEAE (Diatoms)

Order CENTRALES

Melosira sp.

Order PENNALES

Tabellaria fenestrata (Lyngb.) Kütz.

T. flocculosa (Roth) Kütz.

Fragilaria crotonensis Kitt.

F. virescens Ralf

F. virescens var. *capitata* Østr.

Fragilaria spp.

Synedra spp.

Asterionella formosa Hass.

Semiorbis hemicyclus (Ehr.) Patr.

Eunotia bactriana Ehr.

E. bidentula Wm. Sm.

E. curvata (Kütz) Lagerst.

E. flexuosa Bréb. ex Kütz.

E. incisa W. Sm. ex Greg. var. *incisa* Patr.

E. pectinalis (O.F. Müll) Rab. var. minor (Kütz.) Rab.

E. pectinalis var. *undulata* (Ralfs) Rab.

E. pectinalis var. *ventralis* (Ehr.) Hust.

E. serra Ehr. var. *serra* Patr.

E. soleirolii (Kütz.) Rab.

E. sudetica O. Müll. EggR;

E. tenella (Grun.) Hust. in Pascher

Eunotia spp.

Actinella punctata Lewis

Navicula oblongata Kütz.

Navicula spp.

Pinnularia gibba Ehr.

P. legumen Ehr.

P. maior (Kütz.) Rab. var. pulchella Boyer

P. nobilis (Ehr.) Ehr.

P. parvula (Ralfs) Cl. Eul. var. parvula Patr.

Pinnularia spp.

Anomoeoneis serians (Bréb.) Cl.

Stauroneis anceps Ehr.

S. phoenicenteron (Nitzsch) Ehr.

Stauroneis spp.

Frustulia rhomboides (Ehr.) DeT.

Frustulia spp.

Cymbella gracilis (Rab.) Cl.

Cymbella spp.

Nitzschia sigmatella Greg.

Nitzschia spp.

Surirella anceps Lewis

S. arctissima A. S.

S. linearis W. Sm.

Surirella spp. Helm

Stenopterobia intermedia Lewis

Division PYRROPHYTA (Dinoflagellates)

Order GYMNODINIALES

Gymnodinium spp.

Order PERIDINIALES

Peridinium sp.

Order DINOCOCCALES

Cystodinium bataviense Klebs

Division CYANOPHYTA (Blue-green Algae)

Order CHROOCOCCALES

Chroococcus turgida (Kütz.) Näg. [Anacystis dimidiata (Kütz.) Dr. and Dailey]

Aphanocapsa sp.

Eucapsis alpina Clem. And Shantz

Merismopedia punctata Meyen

Order OSCILLATORIALES

Oscillatoria princeps Vauch.

O. tenuis Ag.

Oscillatoria spp.

Symploca muralis Kütz.

Anabaena spp.

Cylindrospermum sp. – Helm; pond, squez

Scytonema tolypothrichoides Borr. and Flah.

Stigonema turfaceum (Bréb.) Cooke

Hapalosiphon sp.

Rivularia sp.

Calathrix sp.

Division RHODOPHYTA (Red Algae)

Order NEMALIONALE

Batrachospermum brugiense Sirod.

B. coerulescens Sirod.

Batrachospermum spp.

Audouinella violacea (Kütz.) Hamel

Groups of UNCERTAIN POSITION

Order CHLOROMONADALES

Gonyostomum semen (Ehr.) Diesing

Order CRYPTOMONADALES

Cryptomonas spp.)

From Moul, E. T. and H. T. Buell. 1998. Algae of the Pine Barrens. In:
R. T. T. Forman (ed.), *Pine Barrens: Ecosystems and Landscape*.
Rutgers University Press, New Brunswick, New Jersey, pp. 425-440.

Appendix 16. Taxonomic list of avifauna identified along Great Bay Boulevard and adjacent open waters of the Jacques Cousteau National Estuarine Research Reserve.

Group	Common Name	Scienctific Name
Gulls and Terns		
	Common tern	*Sterna hirundo*
	Least tern	*Sterna antillarum*
	Caspian tern	*Sterna caspia*
	Forester's tern	*Sterna forsteri*
	Royal tern	*Sterna maxima*
	Gull-billed tern	*Sterna nilotica*
	Herring gull	*Larus argentatus*
	Laughing gull	*Larus atricilla*
	Ring-billed gull	*Larus delawarensis*
	Great black-backed gull	*Larus marinus*
	Black skimmer	*Rynchops niger*
Loons and Grebes		
	Common loon	*Gavia immer*
	Red-throated loon	*Gavia stellata*
	Horned grebe	*Podiceps auritus*
	Pied-billed grebe	*Podilymbus podiceps*

	Red-throated grebe	*Podiceps grisegena*
	Northern gannet	*Sula bassanus*
	Double-crested cormorant	*Phalacrocorax auritus*
	Brown pelican	*Pelecanus occidentalis*
Bitterns, Herons, and Ibises		
	American bittern	*Botaurus lentiginosus*
	Great blue heron	*Ardea herodias*
	Little blue heron	*Egretta caerulea*
	Tricolored heron	*Egretta tricolor*
	Green-backed heron	*Butorides striatus*
	Black-crowned night heron	*Nycticorax nycticorax*
	Yellow-crowned night heron	*Nycticorax violaceus*
	Great egret	*Casmerodius albus*
	Snowy egret	*Egretta thula*
	Cattle egret	*Bubulcus ibis*
	Glossy ibis	*Plegadis falcinellus*
	White-faced ibis	*Plegadis chihi*
Rails		
	Clapper rail	*Rallus longirostris*
	American coot	*Fulica americana*
Ducks, Geese, and Swans		
	American black duck	*Anas rubripes*

Mallard	*Anas platyrhynchos*
Ruddy duck	*Oxyura jamaicensis*
Atlantic brant	*Branta bernicla*
Blue-winged teal	*Anas discors*
Green-winged teal	*Anas crecca*
Gadwall	*Anas strepera*
American wigeon	*Anas americana*
Canvasback	*Aythya valisineria*
Greater scaup	*Aythya marila*
Lesser scaup	*Aythya affinis*
Oldsquaw	*Clangula hyemalis*
Black scoter	*Melanitta nigra*
Surf scoter	*Melanitta perspicillata*
White-winged scoter	*Melanitta fusca*
Common goldeneye	*Bucephala clangula*
Bufflehead	*Bucephala albeola*
Common merganser	*Mergus merganser*
Hooded merganser	*Lophodytes cucullatus*
Red-breasted merganser	*Mergus serrator*
Canada goose	*Branta canadensis*
Snow goose	*Chen caerulescens*
Mute swan	*Cygnus olor*

Eagles, Falcons, Hawks, and Owls

Bald eagle	*Haliaeetus leucocephalus*

Cooper's hawk	*Accipiter striatus*
Sharp-shinned hawk	*Accipiter striatus*
Osprey	*Pandion haliaetus*
Northern harrier	*Circus cyaneus*
American kestrel	*Falco peregrinus*
Merlin	*Falco columbarius*
Peregrine falcon	*Falco peregrinus*
Common barn owl	*Tyto alba*
Great horned owl	*Bubo virginianus*
Short-eared owl	*Asio flameus*
Turkey vulture	*Cathartes aura*

Plovers and Sandpipers

Piping plover	*Charadrius melodus*
Semipalmated plover	*Charadrius semipalmatus*
Black-bellied plover	*Pluvialis squatarola*
Semipalmated sandpiper	*Calidris pusilla*
Western sandpiper	*Calidris mauri*
Least sandpiper	*Calidris minutilla*
White-rumped sandpiper	*Calidris fuscicollis*
Pectoral sandpiper	*Calidris melanotos*
Purple sandpiper	*Calidris maritima*
Curlew sandpiper	*Calidris ferruginea*
Dunlin	*Calidris alpina*
Whimbrel	*Numenius phaeopus*

	Marbled godwit	*Limosa fedoa*
	Ruddy turnestone	*Arenaria interpres*
	Red knot	*Calidris canutus*
	Sanderling	*Calidris alba*
	Killdeer	*Charadrius vociferus*
	American oystercatcher	*Itaematopus palliatus*
	American avocet	*Recurvirostra americana*
	Greater yellowlegs	*Tringa melanoleuca*
	Lesser yellowlegs	*Tringa flavipes*
	Willet	*Catoptrphorus semipalmatu*
Doves and Swifts		
	Mourning dove	*Zenaida macroura*
	Rock dove	*Columba livia*
	Belted kingfisher	*Ceryle alcyon*
	Common nighthawk	*Chordeiles minor*
Flycatchers and Woodpeckers		
	Northern flicker	*Colaptes auratus*
	Eastern kingbird	*Tyrannus tyrannus*
	Eastern phoebe	*Sayornis phoebe*
	Red-headed woodpecker	*Melanerpes erythrocephalus*
Larks, Swallows, Jays, and Crows		
	Horned lark	*Eremophila alpestris*
	Purple martin	*Progne subris*

Tree swallow	*Iridoprocne bicolor*
Northern rough-winged swallow	*Stelgedopteryx serripennis*
Bank swallow	*Riparia riparia*
Barn swallow	*Hirundo rustica*
Blue jay	*Cyanocitta cristata*
Fish crow	*Corvus ossifragus*

Kinglets and Thrashers

Golden-crowned kinglet	*Regulus satrapa*
Ruby-crowned kinglet	*Regulus calendula*
American robin	*Turdus migratorius*
Hermit thrush	*Catherus guttatus*
Grey catbird	*Dumetella carolinensis*
Northern mockingbird	*Mimus polyglottos*
Brown thrasher	*Toxostoma rufum*
Cedar waxwing	*Bombycilla cedrorum*
European starling	Sturnus vulgaris

Blackbirds and Finches

Red-winged blackbird	*Agelaius phoeniceus*
Eastern meadowlark	*Sturnella magna*
Common grackle	*Quiscalus quiscalus*
Boat-tailed grackle	*Quiscalus major*
Brown-headed cowbird	*Molothrus ater*
American goldfinch	*Carduelis tristis*

House finch	*Carpodacus mexicanus*
Evening grosbeak	*Coccothraustes vespertinas*

Titmice, Nuthatch, and Wrens

Tufted titmouse	*Parus bicolor*
Carolina chickadee	*Parus carolinensis*
White-breasted nuthatch	*Sitta carolinensis*
Red-breasted nuthatch	*Sitta canadensis*
Brown creeper	*Certhia familiaris*
Carolina wren	*Thryothorus ludovicianus*
Marsh wren	*Cistothorus palustris*

Vireos and Warblers

Red-eyed vireo	*Vireo olivaceus*
Northern parula	*Parula americana*
Blue-winged warbler	*Vermivora pinus*
Yellow warbler	*Dendroica petechia*
Chestnut-sided warbler	*Dendroica pensylvanica*
Magnolia warbler	*Dendroica magnolia*
Cape May warbler	*Dendroica tigrina*
Black-throated blue warbler	*Dendroica caerulescens*
Yellow-rumped warbler	*Dendroica coronata*
Black-throated green warbler	*Dendroica virens*

Blackburnian warbler	*Dendroica fusca*
Blackpoll warbler	*Dendroica striata*
Black-and-white warbler	*Mniotilla varia*
Worm-eating yellowthroat	*Helmitheros vermivorus*
Common Yellowthroat	*Geothlypis trichas*
Yellow-breasted chat	*Icteria virens*

Sparrows and Tanagers

American tree sparrow	*Spizella arborea*
Sharp-tailed sparrow	*Ammospiza caudacuta*
Seaside sparrow	*Ammospiza maritima*
Fox sparrow	*Passerella iliaca*
Song sparrow	*Melospiza melodia*
Swamp sparrow	*Melospiza georgiana*
White-throated sparrow	*Zonotrichia albicollis*
White-crowned sparrow	*Zonotrichia leucophrys*
Scarlet tanager	*Piranga olivacea*
Northern cardinal	*Cardinalis cardinalis*
Rose-breasted grosbeak	*Pheucticus ludovicianus*
Indigo bunting	*Passerina cyanea*
Snow bunting	*Plectrophenax nivalis*
Rufous-sided towhee	*Pipilo erythrophthalmus*
Dark-eyed junco	*Junco hyemalis*

Appendix 17. List of research and monitoring publications on the Jacques Cousteau National Estuarine Research Reserve.

PUBLICATIONS

Able, K. W. 1990. Life history patterns of salt marsh killifishes in New Jersey. Bull. N.J. Acad. Sci. 35(2):23-30.

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Appendix 18. Phytoplankton nitrogen requirement relative to standing stocks of nitrogen in the Mullica River-Great Bay Estuary. At the river station, nitrogen available (A) is in excess of nitrogen required (C). At the mid-station, nitrogen available is sometimes in excess of and sometimes less than that required. At the bay station, nitrogen available is less than that required.

	River Station 7					Mid-Station 8					Bay Station 9				
Date	GP[a] mg C	A µg-at N	B µg-at N	C µg-at N	tide ± hr[b]	GP[a] mg C	A µg-at N	B µg-at N	C µg-at N	tide ± hr[b]	GP[a] mg C	A µg-at N	B µg-at N	C µg-at N	tide ± hr[b]
6/24/63	735	8.8			H-2-1/4	645	7.7			H-2-1/2	659	7.9			H-3
6/24			18.6	9.8	H-3/4			3.8	-3.9	H-1			2.5	-5.4	H-1-3/4
7/4	422	5.0			H+2-3/4	667	7.9			H+2-1/2	825	9.9			H+1-3/4
7/5			36.6	31.6	H+2-1/4			7.2	-0.7	H+2			1.1	-8.8	H+-1
7/12						577	6.9			L-2-3/4	482	5.7			L+1-1/4
7/11								4.1	-2.8	H+2-1/2			1.8	-3.9	H+1-3/4
7/18	686	8.2			L-2-1/2	419	5.0			H+3	784	9.4			H+2-1/2
7/18			10.6	2.4	L-2-1/2			12.4	7.4	H+3			3.4	-6.0	H+2-1/2
7/24	634	7.6			H-2	958	11.4			H-2					
7/25			31.2	23.6	H+1			12.4	1.0	H-1/2					
8/7	553	6.6			H-1	487	5.8			H-1	814	9.7			H-1-1/4
8/8			24.6	18.0	H-1			5.2	-0.6	H-1			4.5	-5.2	H-1-1/2
8/11	446	5.3			L-1-1/2	485	5.8			L-2					
8/15			18.0	12.7	L-2			27.2	21.4	L-2-1/4					
8/23	613	7.3			H-1-3/4	798	9.5			H-2-1/4	1362	16.2			H-2-3/4
8/22			49.3	42.0	H-1			11.0	1.5	H-1-1/4			5.1	-11.1	H-2
8/28	1081	12.9			L-3/4	525	6.3			L-1	577	6.9			L-1
8/29			24.6	11.7	L-1/2			21.0	14.7	L-1			4.9	-2.0	L-1

[a]Gross primary productivity as mg C m^{-2} d^{-1}. Nitrogen required (A) calculated as µg-at N m^{-2} d^{-1}. Nitrogen available (B) equals sum of ammonium-N and nitrate-N m^{-2} on day of sampling indicated. Excess [b]H, high tide; L, low tide.

From Durand, J. B. 1984. Nitrogen distribution in New Jersey coastal bays. In: M. J. Kennish and R. A. Lutz (eds.), *Ecology of Barnegat Bay, New Jersey*. Springer-Verlag, New York, pp. 29-51.

Appendix 19. Taxonomic list of benthic invertebrates collected by Petersen Dredge in the Mullica River-Great Bay estuarine system.

PHYLUM PORIFERA

Class Demospongiae

Cliona sp.

Microciona prolifera (Ellis & Solander)

PHYLUM COELENTERATA

Class Hydrozoa

Stylactis hooperi (Sigerfoos)

Class Anthozoa

Sagartia modesta (Verrill)

PHYLUM PLATYHELMINTHES

Class Turbellaria

Euplana gracilis (Girard)

PHYLUM NEMERTINEA

Class Anopla

Carinoma tremepheros (Thompson)

Cerebratulus lacteus (Leidy)

Zygeupolia rubens (Coe)

PHYLUM ANNELIDA

Class Polychaeta

Amphitrite affinis (Malmgren)

Amphitrite cirrata (O. F. Müller)

Amphitrite johnstoni (Malmgren)

Aricidea jeffreysii (McIntosh)

Brania clavata (Claparede)

Chone infundibuliformis (Kroyer)

Cirratulus grandis (Verrill)

Clymenella torquata (Leidy)

Diopatra cuprea (Bosc)

Dispio uncinata (Hartman)

Drilonereis longa (Webster)

Drilonereis magna (Webster and Benedict)

Eteone heteropoda (Hartman)

Eteone longa (Fabricius)

Eumida sanguinea (Cersted)

Exogone dispar (Webster)

Glycera americana (Leidy)

Glycera dibranchiata (Ehlers)

Glycinde solitaria (Webster)

Harmothoe imbricata (L.)

Hydroides dianthus (Verrill)

Hypaniola grayi (Pettibone)

Lumbrineris tenuis (Verrill)

Maldinopsis elongata (Verrill)

Nephtys bucera (Ehlers)

Nephtys incisa (Malmgren)

Nephtys picta (Ehlers)

Nereis arenaceodonta (Moore)

Nereis grayi (Pettibone)

Nereis succinea (Frey and Leuckart)

Nerinides agilis (Verrill)

Notomastus latereus (Sara)

Paranaitis speciosa (Webster)

Pectinaria gouldii (Verrill)

Phyllodoce arenae (Webster)

Pista palmata (Verrill)

Polycirrus eximius (Leidy)

Polydora ligni (Webster)

Pygospio elegans (Verrill)

Sabella microphthalma (Verrill)

Scolecolepides viridis (Verrill)

Scoloplos fragilis (Verrill)

Scoloplos robustus (Verrill)

Sphaerosyllis hystrix (Claparède)

Spio filicornis (O. F. Müller)

Streblospio benedicti (Webster)

Tharyx acutus (Webster and Benedict)

PHYLUM MOLLUSCA

Class Gastropoda

Acteocina canaliculata (Say)

Acteon punctostriatus (C. B. Adams)

Anachis avara (Say)

Bittium alternatum (Say)

Busycon canaliculatum (L.)

Crepidula convexa (Say)

Crepidula fornicata (L.)

Crepidula plana (Say)

Cylichna alba (Brown)

Epitonium lineatum (Say)

Eupleura caudata (Say)

Littorina littorea (L.)

Nitrella lunata (Say)

Nassarius obsoletus (Say)

*Nassarius vibex (*Say)

Odostomia impressa (Say)

Triphora nigrocincta (C. B. Adams)

Trophon truncatus (Say)

Turbonilla sp.

Urosalpinx cinera (Say)

Class Bivalvia

Arca pexata (Say)

Crassostrea virginica (Gmelin)

Ensis directus (Conrad)

Gemma gemma (Totten)

Lyonsia hyalina (Conrad)

Macoma tenta (Say)

Mercenaria mercenaria (L.)

Mulinia lateralis (Say)

Mya arenaria (L.)

Mytilus edulis (L.)

Nucula sp.

Spisula solidissima (Dillwyn)

Tagelus divisus (Spengler)

Tellina agilis (Stimpson)

PHYLUM ARTHROPODA

Class Crustacea

Aeginella longicornis (Kröyer)

Ampelisca abdita (Mills)

Ampelisca verrilli (Mills)

Amphithoe longimana (Smith)

Amphithoe rubricata (Montagu))

Anoplodactylus lentus (Wilson)

Batea secunda (Holmes)

Caprella geometrica (Say)

Carinogammarus mucronatus (Say)

Chiridotea almyra (Bowman)

Corophium cylindricum (Say)

Crangon septemspinosa (Say)

Cyathura polita (Stimpson)

Edotea triloba (Say)

Elasmopus laevis (Smith)

Erichsonella attenuata (Harger)

Ericthonius minax (Smith)

Eurypanopeus depressus (Smith)

Gammarus locusta (L.)

Grubia compta (Smith)

Haustorius arenarius (Slabber)

Heteromysis formosa (S. I. Smith)

Hippolyte zostericolor (Smith)

Idotea balthica (Pallas)

Labidocera aestiva (Wheeler)

Leucon americanus (Zimmer)

Lysianopsis alba (Holmes)

Melita nitida (Smith)

Microdeutopus gryllotalpa (Costa)

Monoculodes edwardsi (S. I. Smith)

Neomysis americana (S. I. Smith)

Neopanope texana (Smith)

Oxyurostylis smithi (Calman)

Pagurus longicarpus (Say)

Palaemonetes vulgaris (Say)

Paraphosux spinosus (Holmes)

Ptilocheirus pinquis (Stimpson)

Rithropanopeus harrisi (Gould)

Stenothoe cypris (Say)

Sympleustes glaber (Boeck)

Unciola irrorata (Say)

PHYLUM ECOTOPROCTA

Class Gymnolaemata

Electra crustulenta (Pallas)

Electra hastingsae (Marcus)

Membranipora sp.

Schizoporella unicornis (Johnston)

PHYLUM CHORDATA

Class Ascidiacea

Molgula manhattensis (De Kay)

From Kennish, M. J., S. M. Haag, G. P. Sakowicz, and J. B. Durand. 2004. Benthic macrofaunal community structure along a well-defined salinity gradient in the Mullica River-Great Bay Estuary. *Journal of Coastal Research*, SI 45: 209-226.

Appendix 20. Taxonomic list of fishes and selected decapods caught in Little Egg Harbor.

Species	Common Name	Gear Used
Fish		
Alosa aestivalis	Blueback herring	S, T, W
Alosa pseudoharengus	Alewife	S, T, W
Alosa sapidissima	American shad	S, T
Aluterus scriptus	Scrawled filefish	T
Ammodytes americanus	American sand lance	S
Anchoa mitchilli	Bay anchovy	S, T, W, SS, TT
Anchoa hepsetus	Striped anchovy	S, T, W
Anguilla rostrata	American eel	S, T, W, SS, TT
Apeltes quadracus	Four-spine stickleback	S, T, SS, TT
Astroscopus guttatus	Northern stargazer	S
Bairdiella chrysoura	Silver perch	S, T
Brevoortia tyrannus	Atlantic menhaden	S, T, W
Caranx hippos	Crevalle jack	S, T, W
Centropristis striata	Black sea bass	T, SS, TT
Chasmodes bosquianus	Striped blenny	S, T
Chilomycterus schoepfi	Striped burrfish	S, T
Clupea harengus	Atlantic herring	S, T, W
Conger oceanicus	Conger eel	S, T
Cynoscion regalis	Weakfish	S, T
Cynoscion nebulosus	Spotted seatrout	
Cyprinodon variegatus	Sheepshead minnow	S, T, W, TT
Dasyatis sp.	Stingray	S
Dorosoma cepedianum	Gizzard shad	S, T

Engraulis eurystole	Silver anchovy	S, T
Epinephelus gorio	Red grouper	S
Esox niger	Chain pickerel	S
Etropus microstomus	Smallmouth flounder	S, T, SS, TT
Fundulus diaphanus	Banded killifish	S, T
Fundulus heteroclitus	Mummichog	S, T, W, SS, TT
Fundulus luciae	Spotfin killifish	W
Fundulus majalis	Striped killifish	S, T, W, SS, TT
Gasterosteus aculeatus	Three-spined stickleback	S, T, W
Gobiosoma bosc	Naked goby	S, T, W, SS, TT
Gobiosoma ginsburgi	Starboard goby	SS, TT
Hippocampus erectus	Lined seahorse	S, T, SS, TT
Hyporhamphus unifasciatus	Halfbeak	S
Hypsoblennius hentzi	Feather blenny	S, T
Ictalurus punctatus	Channel catfish	
Lagodon rhomboides	Pinfish	S
Leiostomus xanthurus	Spot	S, T, W, TT
Lucania parva	Rainwater killifish	S, T, W, SS, TT
Lutjanus griseus	Grey snapper	S, SS, TT
Menidia beryllina	Inland silverside	S, W
Menidia menidia	Atlantic silveride	S, T, W, SS, TT
Menticirrhus saxatilis	Northern kingfish	S, T
Merluccius bilinearis	Silver hake	
Micropogonias undulatus	Atlantic croaker	T
Monacanthus hispidus	Planehead filefish	S
Morone americana	White perch	S, T
Morone saxatilis	Striped bass	S
Mugil cephalus	Striped mullet	S, T

Mugil curema	White mullet	S, T, W
Mustelus canis	Smooth dogfish	S, T, W
Myoxocephalus aenaeus	Grubby	S, T
Notemigonus crysoleucas	Golden shiner	S
Ophidion marginatum	Cusk-eel	T
Opsanus tau	Oyster toadfish	S, T, W, SS, TT
Paralichthys dentatus	Summer flounder	S, T, W, SS, TT
Peprilus triacanthus	Butterfish	S, T
Perca flavescens	Yellow perch	
Pogonias cromis	Black drum	S
Pollachius virens	Pollack	S, W, TT
Pomatomus saltatrix	Bluefish	S, T, W
Priacanthus arenatus	Bigeye	S
Prionotus carolinus	Northern searobin	S, T, TT
Prionotus evolans	Striped searobin	S, T
Pseudopleuonectes americanus	Winter flounder	S, T, W, SS, TT
Raja elanteria	Skate	
Rhinoptera bonansus	Cownose ray	
Sardinella aurita	Spanish sardine	S, W
Sciaenops ocellatus	Red drum	
Scomber scombrus	Atlantic mackerel	
Scophthalmus aquosus	Windowpane	S, T
Selene vomer	Lookdown	S, T
Sphoeroides maculatus	Northern puffer	S, T, TT
Sphyraena borealis	Northern sennet	S, T, W
Stenopus chrysops	Scup	T
Strongylura marina	Atlantic needlefish	S, T, W
Syngnathus fuscus	Pipefish	S, T, W, SS, TT

Synodus foetens	Lizardfish	T
Tautoga onitis	Tautog	S, T, W, SS, TT
Tautogolabrus adspersus	Cunner	S
Trachinotus falcatus	Permit	S, T
Trinectes maculatus	Hogchoker	S, T
Urophycis chuss	Red hake	T
Urophycis regia	Spotted hake	S, T, W
Urophycis tenuis	White hake	S
Vomer setapinnis	Atlantic moonfish	S
Selected Decapods		
Callinectes sapidus	Blue crab	W, TT
Callinectes similis	Lesser blue crab	TT
Cancer irroratus	Rock crab	TT
Libinia dubia	6-spined spider crab	TT
Libinia emarginata	Common spider crab	TT
Limulus polyphemus	Horseshoe crab	
Ovalipes ocellatus	Lady crab	TT
Portunus gibbesii	Swimming crab	

S = seine; T = trawl; W = weir; SS = suction sampling; TT = throw trap.
From Jivoff, P. and K. W. Able. 2001. Characterization of the fish and selected decapods in Little Egg Harbor. *Journal of Coastal Research*, SI 32: 178-196.

Appendix 21. A list of state- and federal-designated endangered and threatened species identified in the Mullica River-Great Bay Estuary and Watershed.

Common Name	Federal Status	Scientific Name	State Status
Plants			
American Chaffseed	Endangered	*Schwalbea americana*	Endangered
Awned meadow-beauty	Endangered	*Rhexia aristosa*	
Barton's Saint John's wort	Endangered	*Hypericum adpressum*	
Bog asphodel	Endangered	*Narthecium americanum*	
Boykin's lobelia	Endangered	*Lobelia boykinii*	
Bristling panic grass	Endangered	*Panicum aciculare*	
Broom crowberry	Endangered	*Corema conradii*	
Buttonbush dodder	Endangered	*Cuscuta cephalanthi*	
Clustered sedge	Endangered	*Carex cumulata*	
Coarse grass-like beak-rush	Endangered	*Rhynchospora globularis*	
Coast flat sedge	Endangered	*Cyperus polystachyos*	

Dwarf azalea	Endangered	*Rhododendron atlanticum*	
Dwarf white bladderwort	Endangered	*Utricularia olivacea*	
False asphodel	Endangered	*Tofieldia racemosa*	
False boneset	Endangered	*Kuhnia eupatorioides*	
Fringed yellow-eyed grass	Endangered	*Xyris fimbriata*	
Hirst brothers' panic grass	Endangered	*Panicum hirstii*	
Knieskern's beaked-rush	Threatened	*Rhynchospora knieskernii*	Endangered
Knotted spike rush	Endangered	*Eleocharis equisetoides*	
Koehn's toothcup	Endangered	*Ammannia latifolia*	
Lace-lip ladies'-tresses	Endangered	*Spiranthes laciniata*	
Lancaster flat-sedge	Endangered	*Cyperus lancastriensis*	
Long-awn smoke grass	Endangered	*Muhlenbergia capillaris*	
Long's bittercress	Endangered	*Cardamine longii*	
Long's woolgrass	Endangered	*Scirpus longii*	
Low rough aster	Endangered	*Aster radula*	

Minute duckweed	Endangered	*Lemna perpusilla*	
Narrow-leaf vervain	Endangered	*Verbena simplex*	
New Jersey rush	Endangered	*Juncus caesariensis*	
Pickering's morning-glory	Endangered	*Stylisma pickeringii va. pickeringii*	
Pickering's reed grass	Endangered	*Calamagrostis pickeringii*	
Pine Barren bellwort	Endangered	*Uvularia puberula var. nitida*	
Pine Barren boneset	Endangered	*Eupatorium resinosum*	
Red goosefoot	Endangered	*Chenopodium rubrum*	
Reversed bladderwort	Endangered	*Utricularia resupinata*	
Rough cotton grass	Endangered	*Eriophorum tenellum*	
Rough flat sedge	Endangered	*Cyperus retrofractus*	
Sand yellow-eyed grass	Endangered	*Xyris caroliniana*	
Sandplain flx	Endangered	*Linum intercursum*	
Seabeach amaranth	Threatened	*Amaranthus pumilus*	Endangered
Sea-beach evening primrose	Endangered	*Oenothera humifusa*	

Sea-beach knotweed	Endangered	*Polygonum glucum*	
Sea milkwort	Endangered	*Glaux maritima*	
Seaside buttercup	Endangered	*Ranunculus cymbalaria*	
Sensitive joint-vetch	Threatened	*Aeschynomene virginica*	Endangered
Sessile-leaf tick-trefoil	Endangered	*Desmodium sessilifolium*	
Slender arrowhead	Endangered	*Sagittaria teres*	
Slender water-milfoil	Endangered	*Myriophyllum tenellum*	
Small everlasting	Endangered	*Gnaphalium helleri*	
Small-head beaked-rush	Endangered	*Rhynchospora microcephala*	
Southern arrowhead	Endangered	*Sagittaria australis*	
Spreading pogonia	Endangered	*Cleistes divaricata*	
Twisted spikerush	Endangered	*Eleocharis tortilis*	
Two-flower bladderwort	Endangered	*Utricularia biflora*	
Virginia buchflower	Endangered	*Melanthium virginicum*	
Virginia false-gromwell	Endangered	*Onosmodium virginianum*	

Virginia thistle	Endangered	*Cirsium virginianum*	
Whorled nut-rush	Endangered	*Scleria verticillata*	
Whorled water-milfoil	Endangered	*Myriophyllum verticillatum*	
Wrinkled jointgrass	Endangered	*Coelorachis rugosa*	
Yellow fringeless orchid	Endangered	*Platanthera integra*	
Swamp pink	Threatened	*Helonias bullata*	

Animals

Insects

Silver-bordered fritillary	Threatened	*Boloria selene myrina*	
American burying beetle	Endangered	*Nicrophorus americanus*	Endangered
Arogos skipper	Endangered	*Atrytone arogos arogos*	
Northeast beach tiger beetle	Threatened	*Cincindela dorsalis dorsalis*	Threatened
Frosted elfin	Threatened	*Callophrys irus*	

Amphibians

Cope's gray treefrog	Endangered	*Hyla chrysoscelis*	
Eastern mud salamander	Threatened	*Pseudotriton montanus montanus*	

Eastern tiger salamander	Endangered	*Ambystoma tigrinum tigrinum*	
Long-tailed salamander	Threatened	*Eurycea longicauda*	
Pine Barrens treefrog	Endangered	*Hyla andersonii*	

Reptiles

Bog turtle	Threatened	*Clemmys muhlenbergii*	Endangered
Corn snake	Endangered	*Elaphe guttata guttata*	
Northern pine snake	Threatened	*Pituophis melanoleucas*	
Timber rattlesnake	Endangered	*Crotalus horridus horridus*	
Wood turtle	Threatened	*Clemmys insculpta*	

Mammals

Bobcat	Endangered	*Lynx rufus*	

Birds

American bittern	Endangered	*Botaurus lentiginosos*	
Bald eagle	Threatened	*Haliaeetus leucocephalus*	Endangered
Barred owl	Threatened	*Strix varia*	

Black-crowned night-heron	Threatened	*Nycticorax nycticorax*	
Black rail	Threatened	*Laterallus jamaicensis*	
Black skimmer	Endangered	*Rynchops niger*	
Grasshopper sparrow	Threatened	*Ammodramus savannarum*	
Cooper's hawk	Threatened	*Accipiter cooprii*	
Least tern	Endangered	*Sterna antillarum*	
Northern harrier	Endangered	*Circus cyaneus*	
Osprey	Threatened	*Pandion haliaetus*	
Peregrine falcon	Endangered	*Falco peregrinus*	
Piping plover	Threatened	*Charadrius melodus*	Endangered
Podilymbus podiceps	Endangered	*Podilymbus podiceps*	
Red knot	Threatened	*Calidris cantus*	
Red-shouldered hawk	Endangered	*Buteo lineatus*	Threatened
Red-headed woodpecker	Threatened	*Melanerpes erythrocephalus*	
Roseate tern	Endangered	*Sterna dougallii dougallii*	Endangered

Sedge wren	Endangered	*Cistothorus platensis*
Upland sandpiper	Endangered	*Bartramia longicauda*
Versper sparrow	Endangered	*Pooecetes gramineus*
Yellow-crowned night-heron	Threatened	*Nyctanassa violaceus*

From the New Jersey National Heritage Program, U.S. Fish and Wildlife Service, and New Jersey Division of Fish and Wildlife.

Appendix 22. Federal listing of threatened and endangered species for the State of New Jersey.

	COMMON NAME	SCIENTIFIC NAME
Plants		
	American chaffseed	*Schwalbea americana* (E)
	Knieskern's beaked-rush	*Rhynchospora knieskernii* (T)
	Seabeach amaranth	*Amaranthus pumilus* (T)
	Sensitive joint-vetch	*Aeschynomene virginica* (T)
	Small whorled pogonia	*Isotria medeoloides* (T)
	Swamp pink	*Helonias bullata* (T)
Animals		
	Indiana bat	*Myotis sodalis* (E)
	Bald eagle	*Haliaeetus leucocephalus* (T)
	Piping plover	*Charadrius melodus* (T)
	Eastern puma	*Puma* (=*Felis*) *concolor couguar* (E)
	Bog turtle	*Clemmys muhlenbergii* (T)
	Hawksbill sea turtle	*Eretmochelys imbricata* (E)
	Kemp's Ridley sea turtle	*Lepidochelys kempii* (E)
	Leatherback sea turtle	*Dermochelys coriacea* (E)
	Loggerhead sea turtle	*Caretta caretta* (T)

Green Turtle	*Chelonia mydas* (T)
Northeastern beach tiger beetle	*Cicindela dorsalis dorsalis* (T)
Dwarf wedge mussel	*Alasmidonta heterodon* (E)
Shortnose sturgeon	*Acipenser brevirostrum* (E)
Roseate tern	*Sterna dougallii dougallii* (E)
Finback whale	*Balaenoptera physalus* (E)
Humpback whale	*Megaptera novaeangliae* (E)
Right whale	*Balaena glacialis* (E)
Gray eastern wolf	*Canis lupus* (E)

E = Endangered
T = Threatened
Data from the U.S. Fish and Wildlife Service