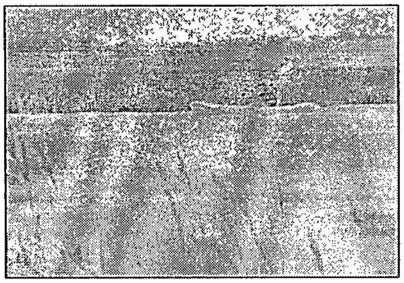
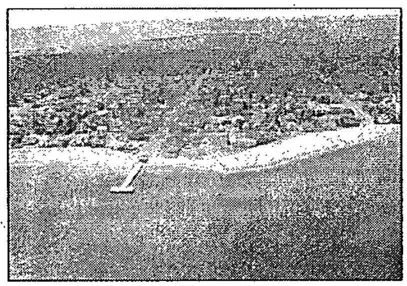
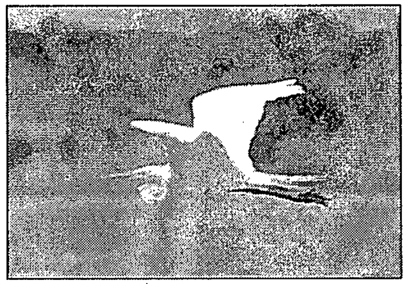
Barnegat Bay National Estuary Program

2005 State of the Bay Technical Report

August 2005

ACKNOWLEDGEMENTS

The creation of the 2005 State of the Bay Report was the collaborative work of many partnering organizations and committed individuals. The indicators adopted by the Barnegat Bay National Estuary Program, six of which are presented in this report, were selected by the BBNEP Science and Technical Advisory Committee. These indicators were incorporated in a Monitoring Program Plan, which was approved by the Environmental Protection Agency in 2003. Information on the status and trends for each indicator was provided by appropriate organizations and individual experts, as listed below. The technical adequacy of the report was reviewed by the BBNEP Science and Technical Advisory Committee. Numerous individuals contributed additional content and/or provided valuable feedback, and their contributions are gratefully acknowledged.

Coordination and Oversight

Robert Scro, Director
Shannon Shinnault, Public Outreach Coordinator
Barnegat Bay National Estuary Program Office, Ocean County College

Robert Dieterich, Barnegat Bay National Estuary Program Coordinator
U.S. Environmental Protection Agency, Region II

Robert Nicholson
U.S. Geological Survey, New Jersey Water Science Center

Submerged Aquatic Vegetation

Richard Lathrop
Rutgers University, Grant F. Walton Center for Remote Sensing and Spatial Analysis

Michael Kennish
Rutgers University, Institute of Marine and Coastal Sciences

Paul Bologna
Montclair State University

Shellfish Beds

Mike Curtis
New Jersey Department of Environmental Protection
Bureau of Marine Water Monitoring

Bathing Beaches

Robert Ingenito
Ocean County Health Department

Algal Blooms

Michael Kennish
Rutgers University, Institute of Marine and Coastal Sciences

Mary Downes Gastrich
New Jersey Department of Environmental Protection
Division of Science, Research, and Technology

Freshwater Inputs

Robert Nicholson
U.S. Geological Survey, New Jersey Water Science Center

Land Use/Land Cover

Richard Lathrop
Rutgers University
Grant F. Walton Center for Remote Sensing and Spatial Analysis

Disclaimer

This report is based solely on data provided by outside entities. The quality of the information provided by these entities has not been evaluated by the BBNEP.

EXECUTIVE SUMMARY

Update on Six Environmental Indicators

The Barnegat Bay-Little Egg Harbor estuary is a dynamic, complex system that greatly influences the region's economy, communities, quality of life, and environment. To gauge its relative health and the progress of efforts to protect and restore estuarine resources, the Barnegat Bay National Estuary Program has established plans to track key environmental indicators and evaluate their status and trends. This report communicates the status and trends of six of these indicators.

1. Submerged Aquatic Vegetation

Seagrasses are an important element of the bay ecosystem, because they harness energy and nutrients that are consumed by other organisms. The seagrass beds also provide a critical structural component in an otherwise barren sandy bottom, serving as essential habitat for a host of organisms, such as shellfish, finfish, and waterfowl. Seagrasses rank among the most sensitive indicators of long-term water quality and can be used as a barometer of coastal ecosystem health.

During the last 30 years, significant declines in SAV have occurred in New Jersey estuaries, resulting in the reduction of essential fish habitat and the potential loss of commercially and recreationally important species. SAV surveys showed evidence of a decline in the seagrass extent between the late 1970's and the mid-1990's, especially in the northern reaches of the bay.

Additional information is needed to address uncertainties in SAV mapping efforts, to determine the controls on SAV health, and to better understand the value of SAV species as habitat.

2. Shellfish Beds

Although shellfish harvests continue in Barnegat Bay, increasing pressure on the industry has resulted from the growing human population along its shores and throughout its watershed. As a result, commercial shellfishing has been severely curtailed. Along with the increase in development and human activity comes the potential for shellfish to be contaminated with pollutants. The New Jersey Department of Environmental Protection's Bureau of Marine Water Monitoring monitors shellfish growing waters to ensure that shellfish within these and other State waters are safe to consume. Shellfish growing water classifications are updated on a yearly basis to produce Shellfish Growing Waters Classification Charts for the State of New Jersey.

The status of shellfish growing waters classifications provides a good indicator of progress in improving estuarine water quality because it integrates results of water quality testing and pollution source surveys to establish the shellfish water classifications. A limitation of the indicator is that although it provides a measure of water quality in terms of public health and potential for disease transmission, it is not geared towards measuring the status of shellfish populations or the ecological health of the estuary.

Shellfish water classifications in New Jersey consist of four main types: *Approved, Seasonal, Special Restricted,* and *Prohibited.* In determining classifications, the potential impacts from possible sources of contamination are considered. Most of the waters within the Barnegat Bay and Little Egg Harbor estuary (80%) are of high water quality and are classified as *Approved* for shellfish harvesting. Of the changes in shellfish classifications for these waters during 2000 - 2004, 80% (336 acres) were upgraded, and 20% (84 acres) were downgraded.

3. Bathing Beaches

For the past twenty-five years, the Ocean County Health Department (OCHD) has obtained and analyzed water-quality samples from all public bathing beaches in the county on a weekly basis between Memorial Day and Labor Day. Results are used by the OCHD to determine whether beaches are to remain open for bathing or closed to bathing. Results of bathing beach monitoring provide an indication of the bacterial health of the waters that are utilized for recreational bathing. The number of brackish water beach closures in a particular year provides an indication of the extent to which the use of the bay for recreational bathing is impaired by these various sources. Closure statistics also provide a general indication of the non-point source loadings from these sources that have been shown to include contaminants other than bacteria.

The number of closures varies widely from year to year. From 1995 to 2004, the number of closures ranged from a low of 18 in 2001 to a high of 135 in 2004. This variability is attributable primarily to the number, duration, and intensity of rainfall events occurring immediately before and during the recreational bathing season. The highest number of annual closures occurred during three of the past four years.

It has been observed and documented that non-point source pollution delivered to the waters through stormwater discharges are the major contributing factor to beach closures. It is anticipated that implementation of the new stormwater regulations and other non-point source control efforts will favorably affect the current situation.

4. Algal Blooms

Recurring algal blooms have been documented in Barnegat Bay, which are symptomatic of eutrophication problems. The blooms have included serious brown tides and accelerated growth of drifting macroalgae. Rapid growth of other macroalgal species can also be detrimental. The spread of certain brown macroalgal species along the sediment surface of seagrass beds can hinder exchange of gases and promote the development of hypoxic/anoxic conditions that can be detrimental to the vascular plants. However, comprehensive studies of benthic macroalgae in the estuary are lacking, reflecting a significant information gap.

The presence of the brown tide-forming phytoplankton species (*A. anophagefferens*) was first reported in New Jersey coastal bays in 1988, with initial blooms documented in 1995, 1997 and 1999, 2000, 2001, and 2002. No significant bloom occurred in 2003.

More information is needed to understand the causes of brown tide and benthic algal blooms and how to control them. Monitoring and studies are needed to determine algal bloom occurrence, identify relevant environmental factors, assess shellfish stocks (which may be affected by algal blooms), and to evaluate effects on seagrass health and productivity.

5. Freshwater Inputs

The role of freshwater in estuarine health is pivotal. The mixing of freshwater with ocean water in the estuary results in the salinity regimes that support estuarine habitats. The rate of freshwater flow into the estuary also affects the rate at which the estuary is flushed, which in turn affects many water-quality and ecological processes. Freshwater inputs also dilute contaminants from a wide variety of sources. As a result of the potential for human alteration of freshwater inputs, tracking freshwater flows and maintaining an adequate rate of freshwater flow is critical to meeting estuarine water-quality and habitat goals.

Average freshwater inputs from streams and ground-water discharge are estimated by the U.S. Geological Survey to total about 590 million gallons per day. During typical drought conditions, the total freshwater inflow to the estuary is about one-third to one-half of the average inflow. Fluctuations in annual surface discharge of freshwater at a long-term monitoring station on the Toms River range from about 60 to 155 percent of the average discharge. Below-average annual discharges since the mid-1980s have been more frequent than above-average discharges. This recent trend is likely the result of both climatic variability and the effects of human activities.

Freshwater withdrawals from surface- and ground-water sources in Ocean County for various human uses have increased from about 56 million gallons per day in 1985 to about 71 million gallons per day in 2000. Most of the withdrawn water (70%) is for public supply. The amount of freshwater removed from the watershed through regional sewerage outfall to the ocean averages about 60 million gallons per day during high-demand summer months, equivalent to about one-third of the freshwater inflow to the estuary under extreme low-flow conditions.

Management efforts aimed at minimizing adverse effects of human activities on freshwater inputs are underway or under consideration. New stormwater regulations are being implemented that are intended to maintain natural rates of recharge in developing areas. Other approaches, including beneficial reuse of reclaimed wastewater; conjunctive use of surface water, unconfined aquifers, and confined aquifers; and aquifer storage and recovery, are being considered to help limit the effects of water demand on water resources.

6. Land Use/Land Cover

Land use by humans is a primary cause of ecological change at many scales. Several land use/change indicators have been identified as potentially valuable to the Barnegat Bay National Estuary Program. These indicators include changes in the extent of 1) altered vs. unaltered land, 2) interior forest land, 3) public open space, and 4) impervious surface cover.

Based on satellite imagery, The Rutgers University Center for Remote Sensing & Spatial Analysis (CRSSA) has mapped land cover at varying levels of detail for the Barnegat Bay watershed for the years of 1972, 1984, 1995 and more recently 2001. Data for 2001 show that development represents approximately 30% of the watershed area and that development within the Barnegat Bay watershed increased by 7,255 acres since 1995. The amount of altered land (total of developed, cultivated/grassland and bare land) in 2001 is estimated to be 131,311 acres or approximately 37% of the watershed. As of March 2004, there were approximately 122,500 acres of publicly owned land in the Barnegat Bay watershed (approximately 34% of the watershed). Development within the Barnegat Bay watershed has increased from 18% to 21% to 28% to 30% during the years 1972, 1984, 1995 and 2001 respectively.

Additional information is needed on recent changes in impervious surface cover within the bay watershed. The New Jersey Department of Environmental Protection Land Use Mapping Program was established to map land use and impervious surface statewide. When recent imagery has been interpreted, a closer examination of trends in altered vs. unaltered land use and impervious surface cover will be possible.

SUBMERGED AQUATIC VEGETATION

Central Question(s)

Are the distribution, abundance, and health of submerged aquatic vegetation changing over time in the Barnegat Bay-Little Egg Harbor Estuary?

Are trends evident in the existing databases?

Explanation of the Indicator

Submerged aquatic vegetation (SAV) is a key indicator of the environmental health of the Barnegat Bay-Little Egg Harbor Estuary. Seagrasses are an important element of the bay ecosystem because they harness energy and nutrients that are consumed by other organisms. The seagrass beds also provide a critical structural component in an otherwise barren sandy bottom, serving as essential habitat for a host of organisms such as shellfish, finfish, and waterfowl. However, in recent years seagrasses in the estuary have suffered due to declining water quality, dredging, brown tides, benthic algal infestation, boat scarring, and disease. To remain healthy, seagrasses are dependent on comparatively clear, transparent water. As bay waters become more turbid due to algal blooms and suspended sediment, the light levels needed to sustain photosynthesis and seagrass productivity decrease. Nutrient enrichment of the bay's waters, whether from runoff, atmospheric deposition or boat wastes, promotes algal blooms, as well as infestations of epiphytic algae that coat the seagrass blades and threaten the longevity of the seagrass beds. Thus, healthy and abundant seagrasses are indicators of good estuarine water quality.

Seagrasses rank among the most sensitive indicators of long-term water quality and can be used as a barometer of coastal ecosystem health (Dennison et al., 1993). Changes in the vitality and distribution of these vascular plants generally signal a decline in aquatic ecosystem health. During the last 30 years, significant declines in SAV have occurred in New Jersey estuaries (Lathrop and Bognar, 2001), resulting in the reduction of essential fish habitat and the potential loss of commercially and recreationally important species. Nutrient enrichment has caused blooms of phytoplankton (e.g., *Aureococcus anophagefferens*) and benthic macroalgae (e.g., *Ulva*, *Gracilaria*, and *Codium*). Dinoflagellate and brown-tide blooms can reduce light availability, adversely affect SAV (e.g., *Zostera marina*) (Dennison et al., 1989), and cause negative impacts on other living resources (Bricelj and Lonsdale, 1997). Brown-tide blooms are now a recurring phenomenon in the coastal bays of New Jersey, New York, and Maryland. In response to shading stress, it appears that *Z. marina* may also be susceptible to infection by "wasting disease"(*Labyrinthula zosterae*) (Bologna and Gastrich, unpublished data). This disease, which decimated *Z. marina* beds worldwide during the 1930's (den Hartog, 1987), may signal a significant decline in water quality. Aside from the impacts of "wasting disease" on *Z. marina*, large-scale losses of the SAV habitat might occur due to the additional physiological stress associated with harmful algal blooms (HABs).

Another factor that can affect the distribution of SAV is the availability of suitable substrate. A study was conducted to examine possible relations between SAV and bottom sediment in the estuary. The study, conducted by the Ocean County Soil Conservation District (OCSCD), in cooperation with the Natural Resources Conservation Service, concluded that the accumulation of fine particles and organic debris in bottom sediment can be detrimental to SAV growth, and that management of the watershed to lessen runoff containing fine particles and nutrients may help restore SAV in the estuary (OCSCD, 2005).

Status and Trends

CRSSA/JCNERR Mapping

Investigators at the Grant F. Walton Center for Remote Sensing and Spatial Analysis (CRSSA) at Rutgers University (Cook College) and the Jacques Cousteau National Estuarine Research Reserve (JCNERR) are monitoring SAV beds in the estuary. They conducted an extensive SAV mapping project during 2003 to better understand the present status of the seagrass habitats. This project, directed by Dr. Richard G. Lathrop of CRSSA, was conducted using advanced digital camera equipment flown in an airplane along the entire length of the estuary. Color imagery was flown in the spring (May 4 and 5, 2003) before bay waters became too turbid, thereby enabling the researchers to visualize the bay bottom and determine the location of the seagrass beds. The aerial overflight was complemented with boat-based surveys up and down the bay to determine species type (i.e., eelgrass, *Zostera marina*, or widgeon grass, *Ruppia maritima*), percent cover, blade height, and sediment type. Advanced computer-aided interpretation techniques were used to map the location, areal extent, and percent cover of the seagrass beds in much greater detail than ever before possible. Seagrass beds were mapped at three levels of density: (1) dense (80-100% coverage); (2) moderate (40-80% coverage); and (3) sparse (10-40% coverage) (Figures 1 and 2). Shallow sand/mud flats (< 10% seagrass) and benthic macroalgae (e.g., sea lettuce, *Ulva lactuca*) were also mapped. The resulting maps documented 5,184 ha (12,804 acres) of seagrass beds at the aforementioned levels of density (Table 1, Figure 1).

Assessment of the present overall condition of the indicator shows that the SAV distribution has remained reasonably stable over the past five years. There does not appear to be any wholesale loss of beds when compared with the maps of the 1990-2000 period. This stability is a positive outcome considering the continued development of the watershed, as well as the severe brown-tide blooms that occurred in the

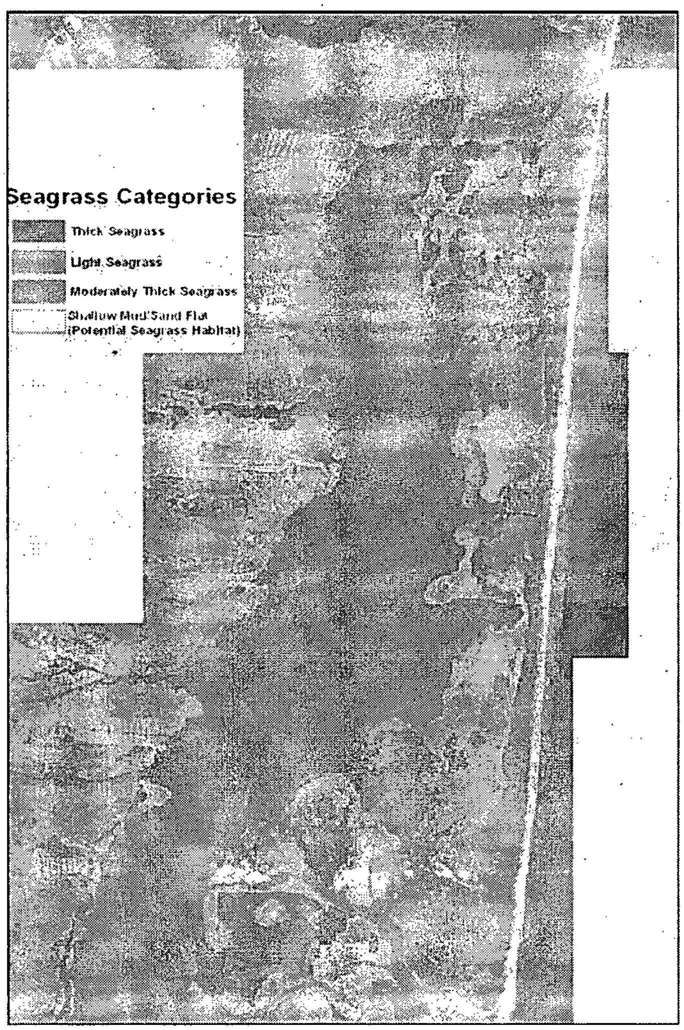


Figure 1. A 2003 SAV map overlaid on digital aerial imagery for central Barnegat Bay.

Submerged Aquatic Vegetation (cont.)

Bottom Type	Class Area (Ha.)	% of Seagrass
Sparse Seagrass (10-40%)	1,971	38
Moderate Seagrass (40-80%)	1,139	22
Dense Seagrass (80-100%)	2,074	40
Total Seagrass	5,184	
Shallow Sand/Mud Flat	**11,202**	
Macro Algae	**353**	
Deep Water	**19,125**	
Total Study Area	**35,864**	

Table 1. Bottom type classification results for the Barnegat Bay-Little Egg Harbor Estuary.

bay during 2001 and 2002. However, the condition of the indicator appears to have changed substantially in previous years. Since 1968, for example, mapping surveys conducted periodically to monitor the extent and status of seagrass beds in the Barnegat Bay-Little Egg Harbor Estuary indicated significant shifts in distribution. Of particular note, earlier surveys showed evidence of a decline in the seagrass extent between the late 1970's and the mid-1990's, especially in the northern reaches of the bay (Figure 3).

Boat-based surveys conducted between 1996 and 1999 mapped 6,083 ha (15,025 acres) of seagrass. When comparing the 2003 and the late 1990's maps, a decline of approximately 900 ha (2,220 acres) or 15% of seagrass beds appears to be evident. Rather than representing a significant decline in seagrass, the difference in area figures is most likely due to a change in mapping techniques and the timing of the aerial imagery acquisition. The 1990's boat-based survey

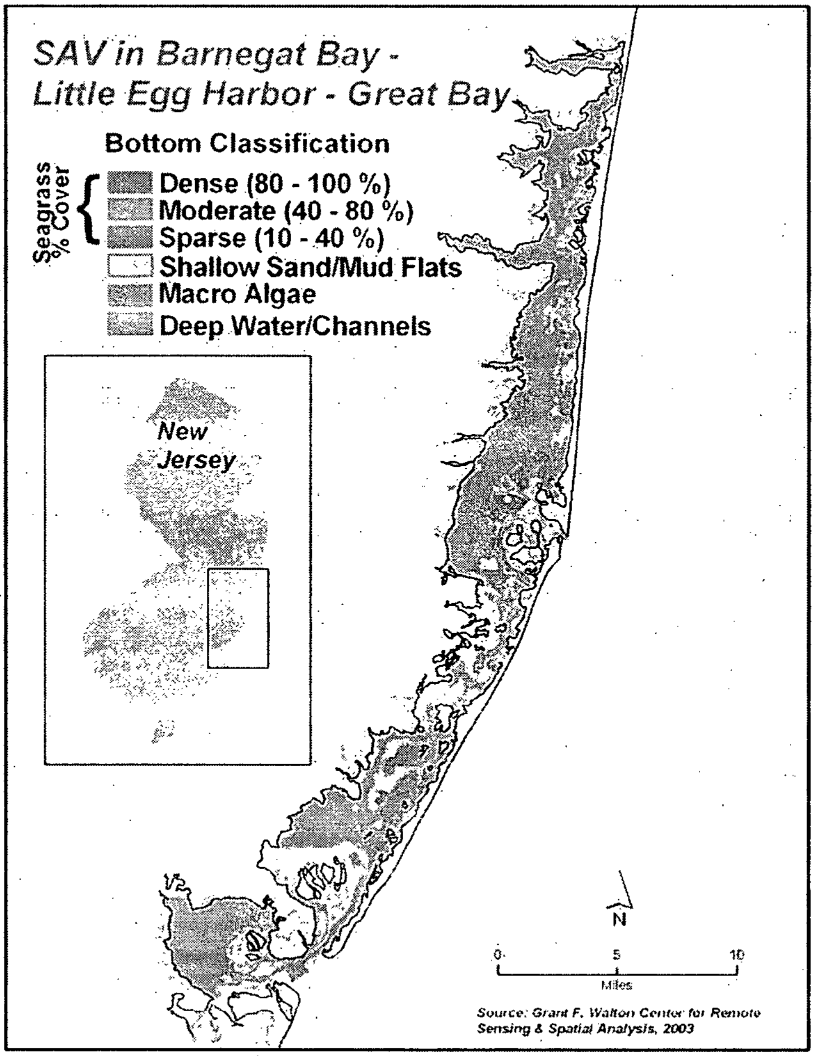


Figure 2. A 2003 SAV map for the Barnegat Bay-Little Egg Harbor study area.

Submerged Aquatic Vegetation (cont.)

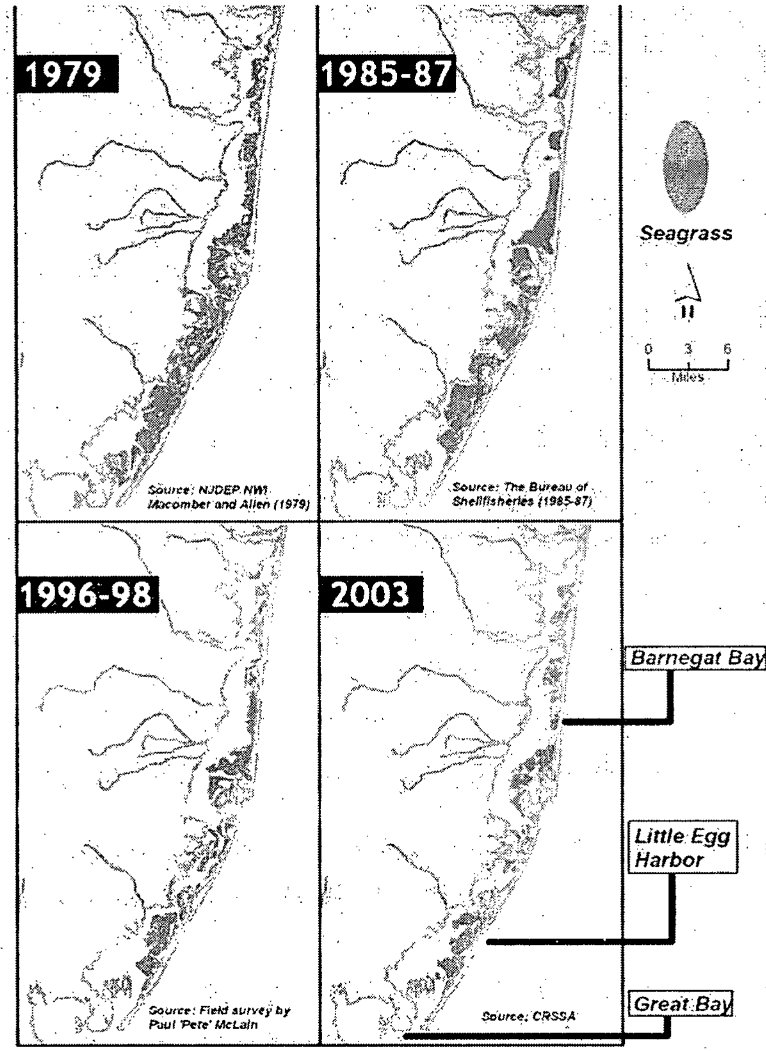


Figure 3. Time series of SAV maps for the Bay-Little Egg Harbor Estuary: 1979, 1985-1987, 1996-1998 and 2003.

mapped SAV by following the exterior perimeter of seagrass beds and recording waypoints using a GPS. This technique tends to homogenize characteristics within a bed, creating a continuous SAV coverage where it may actually be discontinuous. Aerial photographic imagery and the image segmentation/classification techniques adopted in the 2003 study permitted a much finer delineation of exterior boundaries and internal bed discontinuities. In addition, the early May 2003 aerial imagery may have underestimated the spatial extent and cover of widgeon grass beds, which generally do not reach their peak density until later in the summer growing season.

Detailed Investigations

There are major information gaps as to the relative importance of eutrophication and brown-tide blooms on diminished water clarity and potential impacts on seagrass health. The significance of epiphytic algae, benthic macroalgae, wasting disease, and other disturbance factors on seagrass health and abundance is also uncertain. Studies by researchers at Rutgers University and Montclair State University are underway to help fill some of these gaps. As part of ongoing work at the JCNERR, the remote sensing-based mapping is being complemented with in situ sampling to assess seagrass abundance and health and the impact of the aforementioned disturbance factors. Investigators at JCNERR established a series of permanent field plots in Little Egg Harbor, where intensive sampling of seagrass beds was undertaken over the growing season during 2004. This in situ effort will be expanded northward into Barnegat Bay proper during 2005. In addition, Dr. Paul Bologna of Montclair State University has been conducting detailed investigations (as well as restoration) of seagrass beds in the estuary since 1998. These investigations are described in more detail below.

Submerged Aquatic Vegetation (cont.)

Montclair State University Investigations

Dr. Bologna and his colleagues at Montclair State University are currently monitoring SAVs at five permanent sites in the Barnegat Bay-Little Egg Harbor Estuary, including Shelter Island, Marsh Elder, Ham Island, Barnegat Inlet, and Seaside Heights. Of these sites, the first four represent eelgrass (*Zostera marina*) dominated sites, whereas Seaside Heights is a widgeon grass (*Ruppia maritima*) habitat. At each of these sites, monthly core samples are being collected from May through September. The cores are separated into plant and animal portions and assessed in the laboratory. Seagrass shoot abundance is counted from cores, in addition to several demographic measurements (i.e., blade length, blade width, leaf biomass, root/rhizome biomass, and algal biomass), and eelgrass is visually inspected for the assessment of "wasting disease". Monitoring of some of these sites began as early as 1998, but all sites have been continuously monitored since 2001. Additionally, during the summer, bay-wide assessments of SAV are conducted to assess various community-level questions regarding the value of SAV as habitat for associated fauna.

While seagrass coverage has appeared to remain relatively stable over the last several years, greater fluctuations have occurred for seagrasses on a localized scale. For example, Bologna et al. (2001), investigating the relationship between *Zostera marina* and bay scallops (*Argopecten irradians*) in coastal New Jersey during 1998, found that a significant macroalgal bloom occurred. The initial high biomass of algae in June and subsequent algal-detrital fraction created a significant algal-detrital loading to the *Z. marina* bed, which continued throughout the summer and into the fall. Loading rates exceeded 397 g ash free dry weight m^{-2}. This massive accumulation of algae and detrital matter smothered *Z. marina* and led to the elimination of both aboveground and belowground biomass from several locations in the bay (Bologna et al., 2001). Since that event, numerous brown-tides have impeded the recovery of these beds to pre-impact levels. Currently, these beds continue to be monitored to assess how their recovery is progressing.

Appendix 1 (Tables 1-3) provide the results of sampling at the four *Zostera marina* sites in 2001 (Table 1), 2002 (Table 2), and 2003 (Table 3). One of the most important trends identified in these data is the relative relationship of brown-tide occurrence in the system and the development and spread of the "wasting disease" in the populations of *Z. marina*. It appears that during brown-tide events, added light stress allows the spread of the disease among the populations. It is not clear yet how this occurs, and whether it is an immediate response or a delayed reaction in the plants. The other important trend is the lack of site stability. SAV is inherently variable in shoot density and plant biomass. As such, there is significant inter-annual variation in these parameters at the monitoring sites. It will be necessary, therefore, to monitor these sites in the future to detect any larger temporal cycle in the plant demographics.

The primary limiting environmental factor for SAV in New Jersey is adequate light. It is well recognized that significant reduction of light transmission negatively impacts seagrass growth and production. Additionally, it has been demonstrated that various sources of light attenuation components exist and include phytoplankton, epiphytes, and macroalgae, as well as land runoff causing general turbidity. Coastal bays that undergo eutrophication frequently experience some degree of light attenuation from all of these sources (Hauxwell et al., 2003). These supplemental stresses, while impacting the growth, production, and health of expansive beds, may also greatly affect seedlings (Bintz and Nixon, 2001) and patchy or low shoot density beds (Tamaki et al., 2002). Consequently, light attenuation may significantly impair the natural recovery of SAV in regions that have undergone losses and may reduce the effectiveness and survival of expansive beds. It is this light attenuation that is the most critical control of SAV in Barnegat Bay.

JCNERR Investigations

In 2004, researchers at the Jacques Cousteau National Estuarine Research Reserve conducted detailed sampling of SAV in Little Egg Harbor to determine: (1) the demographic characteristics and spatial habitat change of SAV (*Zostera marina* and *Ruppia maritima*) in the system over an annual growing period; (2) the species composition, relative abundance, and potential impacts of benthic macroalgae on the SAV beds; and (3) the potential impacts of brown tide (*Aureococcus anophagefferans*) on the SAV. Two disjunct SAV beds in Little Egg Harbor, covering a total area of about 1700 ha, were sampled at ten equally spaced points along six, east-west trending transects in spring, summer, and fall of 2004 (Figures 4 and 5). Sampling was conducted during June, August, October, and November. More than 175 samples were collected at 60 transect sites during the sampling period. At each sampling site, the following demographic data were collected: percent cover per SAV species, aboveground and belowground biomass per SAV species, sheath and stem biomass per SAV species, leaf biomass per SAV species, average shoot height, average shoot width, number of shoots, as well as abun-

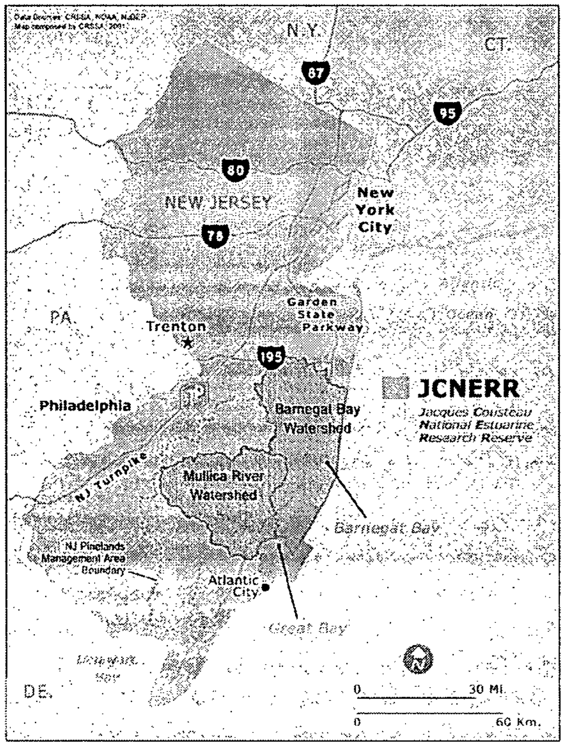


Figure 4. Map of the JCNERR and adjoining watersheds that drain into the Barnegat Bay-Little Egg Harbor Estuary.

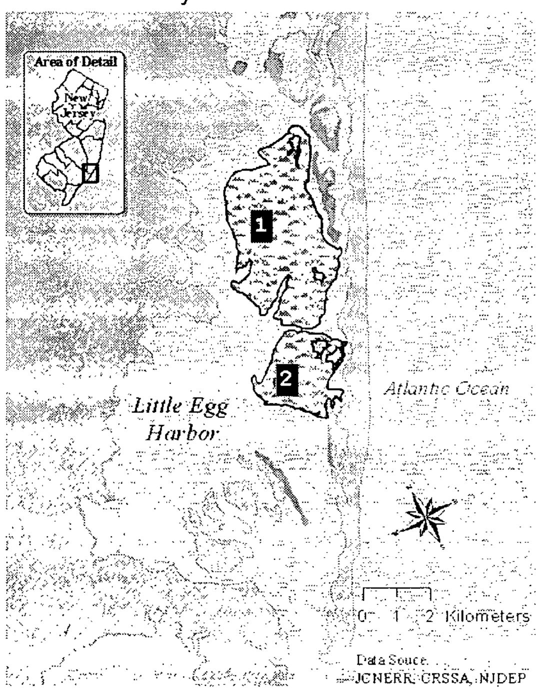


Figure 5. Map of Little Egg Harbor showing SAV bed 1 (~1260 ha) and SAV bed 2 (~430 ha).

dance and percent cover by macroalgae species. In addition, physico-chemical data (temperature, salinity, pH, dissolved oxygen, turbidity, and percent sand, silt, and clay) were collected at each sampling site. Nutrient data (ammonium, nitrate, nitrite, total organic nitrogen, and orthophosphate) were likewise collected along the sampling transects. These data are being analyzed through spring 2005, with a report of findings scheduled for summer 2005.

The major objective of this project is to determine the changes that occur in demographic characteristics of the SAV during an annual growing period in Little Egg Harbor. The ultimate goal is to develop a better understanding of the natural variability of the SAV beds and to assess potential anthropogenic impacts on them. Some of the questions that are being addressed by this investigation include the following:

- What quantitative changes take place in aboveground and belowground biomass, shoot or stem density, leaf and shoot width, and maximum canopy height of SAV beds over a growing season?

- How variable is the percent cover by each SAV species 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?

This project is in response to multiple coastal management needs. SAV is recognized as a critically important benthic habitat that receives special consideration in New Jersey. Because of the critical importance of SAV as habitat, the same type of study will be conducted in Barnegat Bay during spring, summer, and fall of 2005.

Information Gaps

Additional information is needed to address uncertainties in SAV mapping efforts and to determine the controls on SAV health. Additional study also is needed to better understand the value of SAV species as habitat. There is some indication of the loss of SAV beds in the estuary during the past few decades, although differences in mapping methods make it difficult to unequivocally establish the occurrence of a major dieback and loss of eelgrass area. Results of the GIS spatial comparison analysis of SAV surveys reported by Lathrop et al. (1999) and Lathrop and Bognar (2001) suggest that there has 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. Because of some uncertainty surrounding the conclusions of this analysis, however, periodic investigations of SAV beds in the estuary are recommended.

Submerged Aquatic Vegetation (cont.)

The major information gaps necessary to assess the health of the SAV resource include determining the relationships among brown-tide and macroalgal blooms and the health and biomass of SAV in Barnegat Bay. These two factors -- brown-tide and macroalgal blooms -- have been shown to negatively impact SAV and other living resources. To determine the future success of SAV in the bay, it will be necessary to understand how these variables impact seagrass beds. Perhaps the most critical data gap relates to the value of widgeon grass as a habitat. While studies have focused on eelgrass, there is little understanding of the role of widgeon grass in Barnegat Bay. It will be important to link the value of each seagrass species to the health of the bay.

References

Bintz, J. and S. W. Nixon. 2001. Responses of eelgrass *Zostera marina* seedlings to reduced light. *Marine Ecology Progress Series* 223: 133-141.

Bologna, P., A. Wilbur, and K. Able. 2001. Reproduction, population structure, and recruitment limitation in a bay scallop (*Argopecten irradians* Lamarck) population from New Jersey, USA. *Journal of Shellfish Research* 20: 89-96.

Bricelj, M. and D. Lonsdale. 1997. *Aureococcus anophagefferens*: causes and ecological consequences of brown tides in U.S. Mid-Atlantic coastal waters. *Limnology and Oceanography* 42:1023-1038.

den Hartog, C. 1987. Wasting disease and other dynamic phenomena in *Zostera* beds. *Aquatic Botany* 27: 3-14.

Dennison, W., G. Marshall, and C. Wigand. 1989. Effect of brown-tide shading on eelgrass (*Zostera marina* L.) distributions. In: E. Cosper, V. Bricelj, and E. Carpenter (eds.), *Novel Phytoplankton Blooms.* Springer-Verlag, New York, pp. 675-692.

Dennison, W. C., R. J. Orth, K. A. Moore, J. C. Stevenson, V. Carter, S. Kollar, P. Bergrsrom, and R. Batiuk. 1993. Assessing water quality with submersed aquatic vegetation: habitat requirements as barometers of Chesapeake Bay health. *BioScience* 43: 86-94.

Hauxwell, J., J. Cebrian, and I. Valiela. 2003. Eelgrass *Zostera marina* loss in temperate estuaries: relationships to land-derived nitrogen loads and effect of light limitation imposed by algae. *Marine Ecology Progress Series* 247: 59-73.

Lathrop, R. G., Jr., J. A. Bognar, A. C. Henrickson, and P. D. Bowers. 1999. Data synthesis effort for the Barnegat Bay Estuary Program: habitat loss and alteration in the Barnegat Bay region. Technical Report, Center for Remote Sensing and Spatial Analysis, Rutgers University, New Brunswick, New Jersey.

Lathrop, R. G., Jr. and J. A. Bognar. 2001. Habitat loss and alteration in the Barnegat Bay region. *Journal of Coastal Research* SI32: 212-228.

Ocean County Soil Conservation District, 2005, Sub-aqueous vegetation sediment classification system and mapping study for the Barnegat Bay (SCMS), Ocean County Soil Conservation District, in cooperation with the USDA - Natural Resources

Submerged Aquatic Vegetation (cont.)

Conservation Service, 31p. (report available online at http://www.bbep.org/dwnloads/sediment.pdf)

Tamaki, H., M. Tokuoka, W. Nishijima, T. Terawaki, and M. Okada. 2002. Deterioration of eelgrass, *Zostera marina* L., meadows by water pollution in Deto Inland Sea, Japan. Marine Pollution Bulletin 44: 1253-1258.

Example of submerged aquatic vegetation-*Zostera marina* (eelgrass)

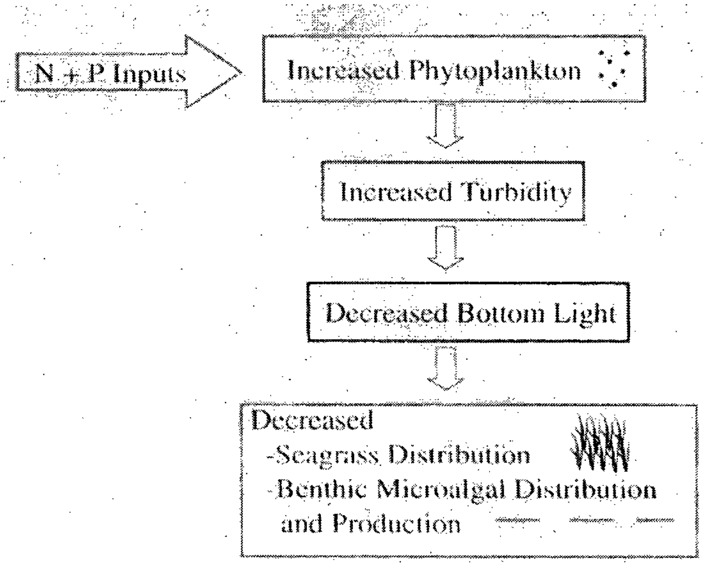
Photograph by Dr. Paul Bologna, Montclair State University

Links to Other Information Sources

Additional information about SAV mapping at the Rutgers University Grant F. Walton Center for Remote Sensing and Spatial Analysis (CRSSA) is available at
http://www.crssa.rutgers.edu/projects/runj/sav

Additional information about research activities at the Jacques Cousteau National Estuarine Research Reserve (JCNERR) is available at
http://marine.rutgers.edu/pt

Additional information about the Ocean County Soil Conservation District study of sub-aqueous vegetation sediment is available at
http://www.bbep.org/dwnloads/sediment.pdf



SHELLFISH BEDS

Central Question(s)

Is the acreage of shellfish beds open for harvest changing?

Explanation of the Indicator

Shellfish harvesting has been a part of the life of the Barnegat Bay-Little Egg Harbor Estuary for as long as humans have occupied its shores. However, the demise of the bay scallop (*Argopecten irradians*) fishery during the 1950s and 1960s, ongoing limited abundance of the soft clam (*Mya arenaria*), and rapidly declining stocks of hard clams since the mid-1980s have severely curtailed commercial shellfishing in this system. Both the soft clam and hard clam (*Mercenaria mercenaria*) remain only recreationally important in the estuary. As a result, most baymen working shellfish beds in the estuary during past years have shifted their activity to Great Bay or elsewhere or they have found other means of livelihood. The decline of shellfish harvesting in the Barnegat Bay-Little Egg Harbor Estuary may be attributed to various factors, including the effects of the growing human population along its shores and in upland areas of the watershed. Historically, two molluscan species have been of greatest commercial importance in New Jersey's back bay waters. These are the hard clam and the soft clam, although the hard clam population is more prevalent today. There have been some signs of the possibility of the bay scallop's return to Barnegat Bay, but hard clam abundance in Little Egg Harbor was assessed in 2001 showing a significant decline in standing stock. More study is needed to determine the overall status of the shellfish resource for the entire estuary. Shellfisheries of New Jersey's coastal waters are managed by the New Jersey Department of Environmental Protection's Bureau of Shellfisheries.

Although shellfish harvests continue in Barnegat Bay, increasing pressure on the industry has been created from growing human population along its shores and throughout its watershed. With this growth comes the potential for shellfish to be contaminated with pollutants from human activities (Figures 1, 2). Shellfish-borne infectious diseases generally

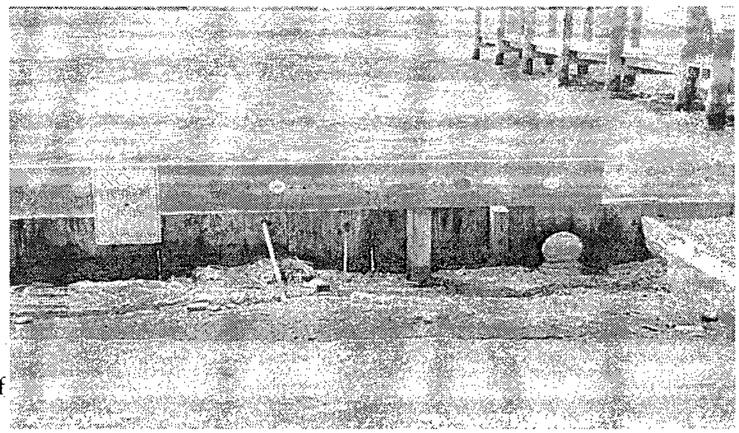


Figure 1. Stormwater drainage into New Jersey's back bay areas is a source of contamination for the shellfish residing in these waters.

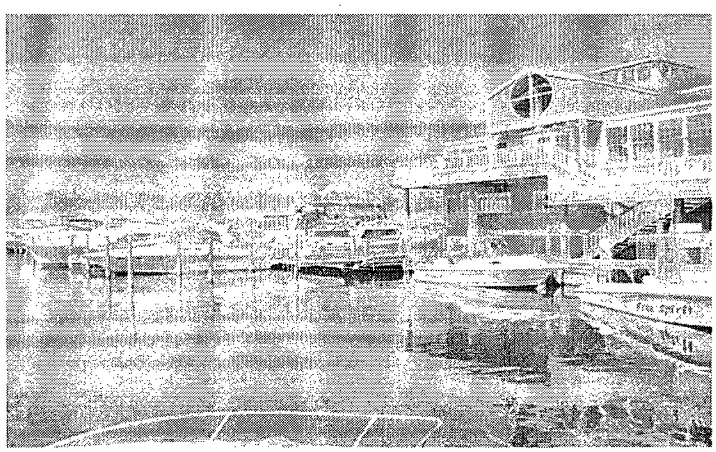


Figure 2. Boating and related activities associated with marinas can add pollutants to back bay waters

begin with fecal contamination of the shellfish growing waters by direct sources (pollutants from plants such as wastewater treatment facilities) or indirect sources (such as stormwater runoff from urban or agricultural areas). Shellfish ingest these contaminants, and if they in turn are ingested by humans, this could lead to illness or death. It is imperative that a system is in place to reduce the human health risk of consuming shellfish from areas of contamination.

The New Jersey Department of Environmental Protection's Bureau of Marine Water Monitoring monitors the shellfish growing waters contained within the Barnegat Bay National Estuary Program (BBNEP) to ensure that shellfish within these and other State waters are safe to consume. Back bay and ocean waters are analyzed for coliform bacteria, which are used to indicate the presence of human waste. From sample collection, monitoring, and analysis, back bay and ocean water classifications are updated on a yearly basis to produce Shellfish Growing Waters Classification Charts for the State of New Jersey. These charts are provided to anyone who purchases a license for shellfish harvest in New Jersey.

The status of shellfish growing waters classifications provides a good indicator of progress in improving estuarine water quality because it integrates results of water quality testing and pollution source surveys to establish the shellfish water classifications. A limitation of the indicator is that although it provides a measure of water quality in terms of public health and potential for disease transmission, it is not geared towards measuring the status of shellfish populations or the ecological health of the estuary.

Shellfish water classifications in New Jersey consist of four main types:

- *Approved* waters are the highest water quality. In *Approved* waters, shellfish can be harvested for consumption without any restrictions.
- *Seasonal* waters, as the name implies, are open to harvest for a portion (season) of each year when water quality meets the same criteria as *Approved* waters.
- *Special Restricted* areas are moderately polluted waters that are condemned for the harvest of oysters, clams, and mussels EXCEPT harvesting for further processing and purification prior to consumption. Further processing involves placing the shellfish in high quality water for a period of time sufficient to purge the shellfish of pollutants.
- *Prohibited* waters exist where the harvest of oysters, clams, and mussels cannot occur under any circumstances.

Status and trends: Barnegat Bay -Little Egg Harbor Classifications for 2000-2004

The overwhelming majority of waters within the Barnegat Bay and Little Egg Harbor estuary are of high water quality and are classified as *Approved*. Of the changes in shellfish classifications for these waters from 2000 - 2004, 80% (336 acres) were upgraded, and 20% (84 acres) were downgraded. Figure 3 shows the actual breakdown of the various classifications. Maps of the overall classifications for this region can be seen in Figures 4 and 5. All upgrades or downgrades were primarily based on water quality (as reflected in levels of total coliform bacteria), with the exception of a three-acre downgrade which was made to reduce potential impacts from an adjacent marina, as well as to create a protective buffer. Table 1 provides a more detailed summary of the upgrades and downgrades during this time period.

Controls

As with most back bay waters in New Jersey, the waters of the Barnegat Bay-Little Egg Harbor estuary have great variation in water quality that is reflected in the broad range of shellfish harvest classifications assigned to this area -- from Approved to Prohibited. In determining classifications, the potential impacts from possible sources of contamination are considered. Permit and discharge data from the Oyster Creek Nuclear Generating Station are routinely monitored. Additionally, there are instances where seasonal use by humans, tidal action, or rainfall and subsequent stormwater inputs can create higher coliform counts within specific areas of Barnegat Bay and Little Egg Harbor. This often occurs in areas such as lagoons, marinas, streams, and rivers. Again, these and any waters where there is a potential human health risk through consumption of shellfish are appropriately classified to preclude harvest.

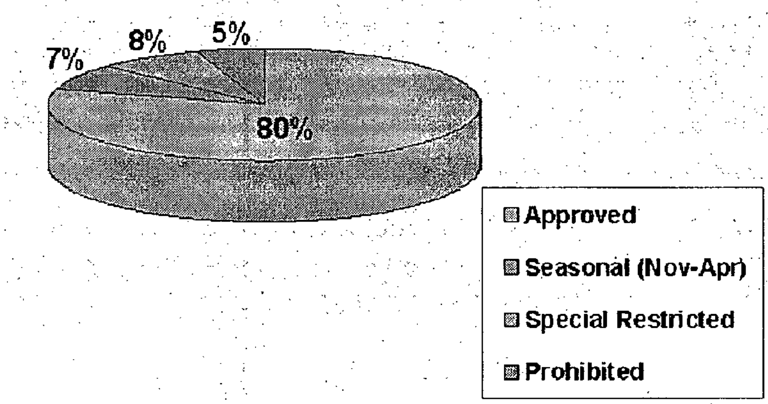


Figure 3. Shellfish Growing Water Classifications for Barnegat Bay – Little Egg Harbor. 2000-2004

Information gaps

The comprehensive program of sampling, analysis, and reporting of the NJDEP Bureau of Marine Water Monitoring provides a continuously updated indicator, and therefore, there are no information gaps for this particular indicator.

Links to Other Information Sources

Additional information on the water quality or shellfish classifications in Barnegat Bay and Little Egg Harbor may be obtained from the Bureau of Marine Water Monitoring's webpage at www.state.nj.us/dep/wmm/bmw.

Shellfish Beds (cont.)

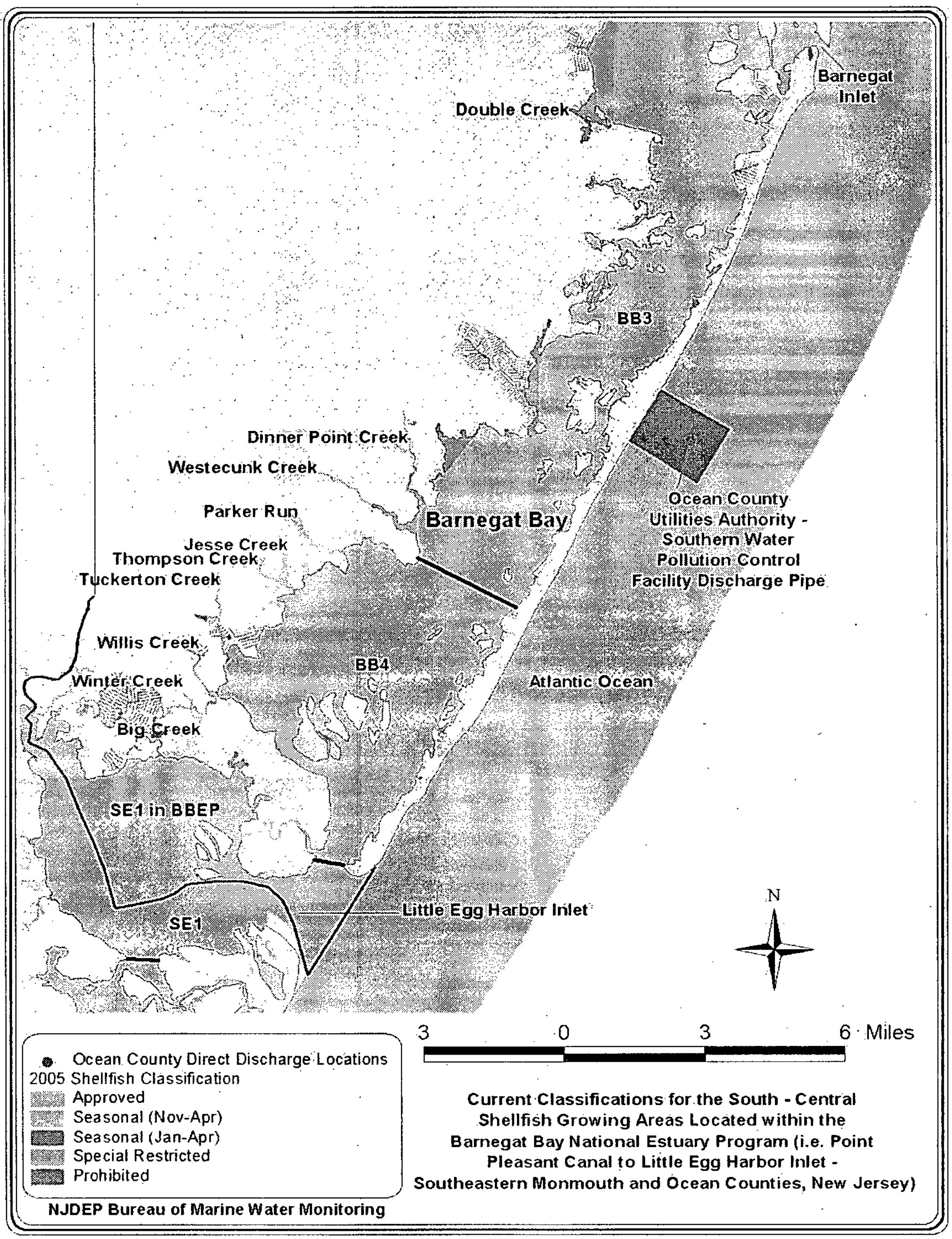


Figure 4: Current Classifications for the South - Central Shellfish Growing Areas of the Barnegat Bay National Estuary Program

Shellfish Beds (cont.)

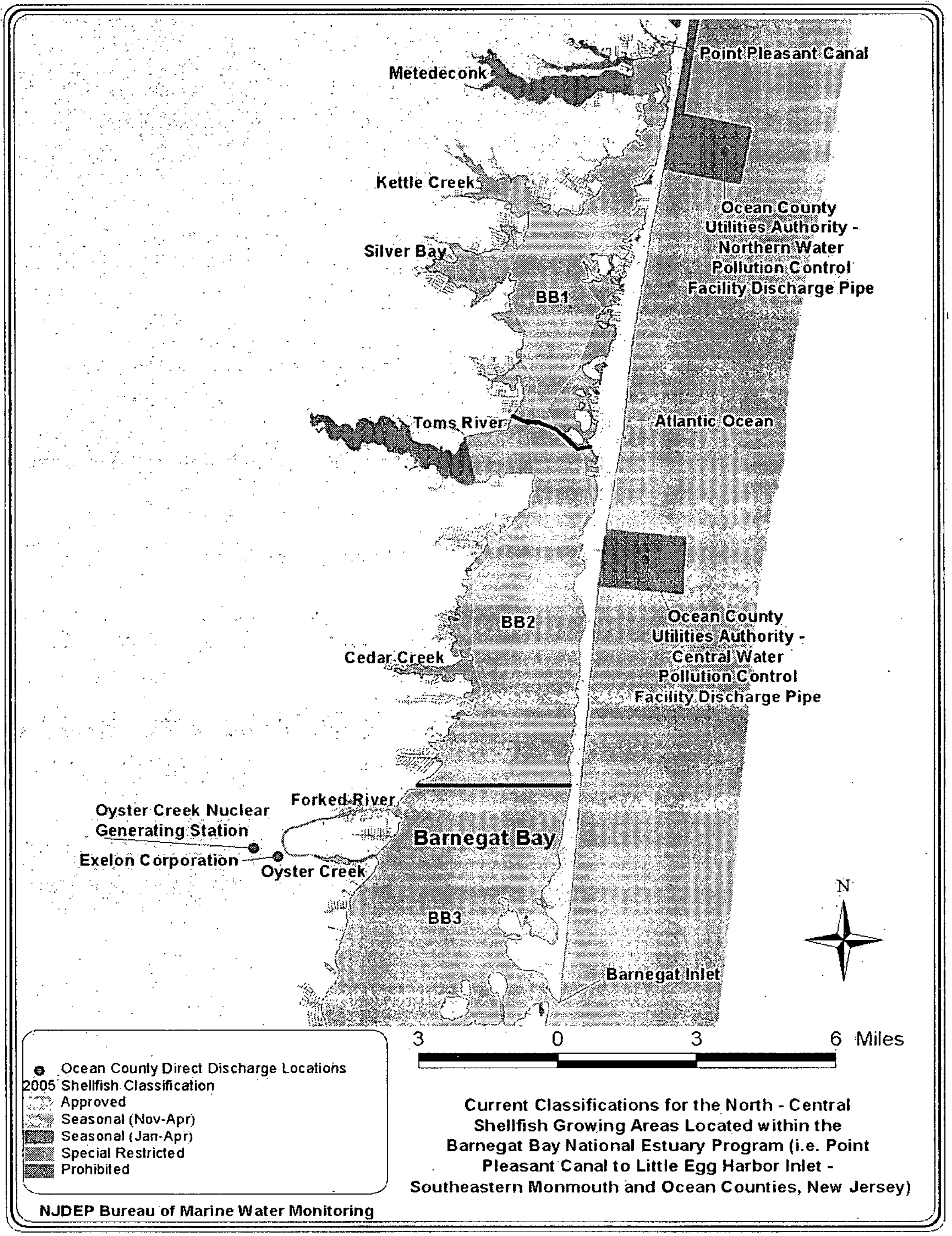


Figure 5: Current Classifications for the North - Central Shellfish Growing Areas of the Barnegat Bay National Estuary Program

Shellfish Beds (cont.)

Location	Classification Change
Tuckerton Cove	Upgrade of 44 acres from Seasonal (January - April) to Seasonal (November - April)
Beach Haven West	Upgrade of 132 acres from Seasonal (January - April) to Seasonal (November - April)
High Bar Harbor	Upgrade of 160 acres from Special Restricted to Approved
Vicinity of Wheelhouse Marina	Administrative downgrade of 3 acres from Approved to Seasonal
Havens Cove	Downgrade of 81 acres from Approved to Seasonal (November - April)

Table 1. Summary of upgraded and downgraded shellfish growing waters within the Barnegat Bay National Estuary Program area 2000-2004.

BATHING BEACHES

Central Question(s)

Is the number of bathing beach closures changing?

Explanation of the Indicator

For the past twenty-five years, the Ocean County Health Department (OCHD) has obtained and analyzed water-quality samples from all public bathing beaches in the county on a weekly basis between Memorial Day and Labor Day. Results are used by the OCHD to determine whether beaches are to remain open for bathing or closed to bathing. Figures 1-3 show the locations of bathing beach sites where samples are collected. Results of bathing beach monitoring provide an indication of the bacterial health of the waters that are utilized for recreational bathing. Closure statistics for beaches on the bay, freshwater lakes and rivers provide an indication of the amount of bacteria from various sources that is being flushed from the watershed into the waterways that eventually flow into the bay. The number of brackish water beach closures in a particular year provides an indication of the extent to which the use of the bay for recreational bathing is impaired by these various sources. Closure statistics also provide a general indication of the non-point source loadings from these sources that include contaminants other than bacteria. Stormwater typically contains suspended solids, nutrients, organic carbon, petroleum hydrocarbons, heavy metals, and pesticides, in addition to bacteria (NJDEP, 2004)

The status and trends on beach closures are characterized in this report by examining statistics for the years 1995 through 2004. For the years 1995 through 2003, the indicator organism utilized by the OCHD, at the direction of the NJDEP, is fecal coliform bacterium. This organism is present in the digestive tract of warm-blooded animals. The NJDEP beach closure standard for this organism is 200 colonies per 100 milliliter of water. The standard must be exceeded in two consecutive samples for the beach to be closed. One re-sample meeting the standard is sufficient to open the beach to bathing.

In 2004, the NJDEP, at the suggestion of the USEPA, changed the required indicator organisms. The organism now utilized for brackish and salt water beaches is enterococcus, also a bacterium found in the digestive tracts of warm-blooded animals. Enterococcus is considered to persist longer in the environment. The NJDEP beach closure standard for this organism is 104 colonies per 100 ml of water. The standard must be exceeded in two consecutive samples for the beach to be closed. One resample meeting the standard is sufficient to open the beach to bathing. Fresh water samples continue to be analyzed for fecal coliform.

Samples are obtained in a sterile 120ml bottle. The sampler attempts to proceed to chest depth (approximately four feet) and the sample is obtained using NJDEP methods. All samples are cooled and transported to a certified laboratory. Chain of custody forms are always used to transfer the samples. If the OCHD is notified of a sample result that exceeds the state standard, then a re-sample is immediately obtained. While obtaining the re-sample the sampler will also obtain two other samples at the site, on either side of the original sample. This procedure is followed to determine if a pollutant source may be indicated.

Northern Ocean County CCMP Sites

Figure 1. Map showing locations of Northern Ocean County sites samples as part of the Cooperative Coastal Monitoring Program.

Central Ocean County CCMP Sites

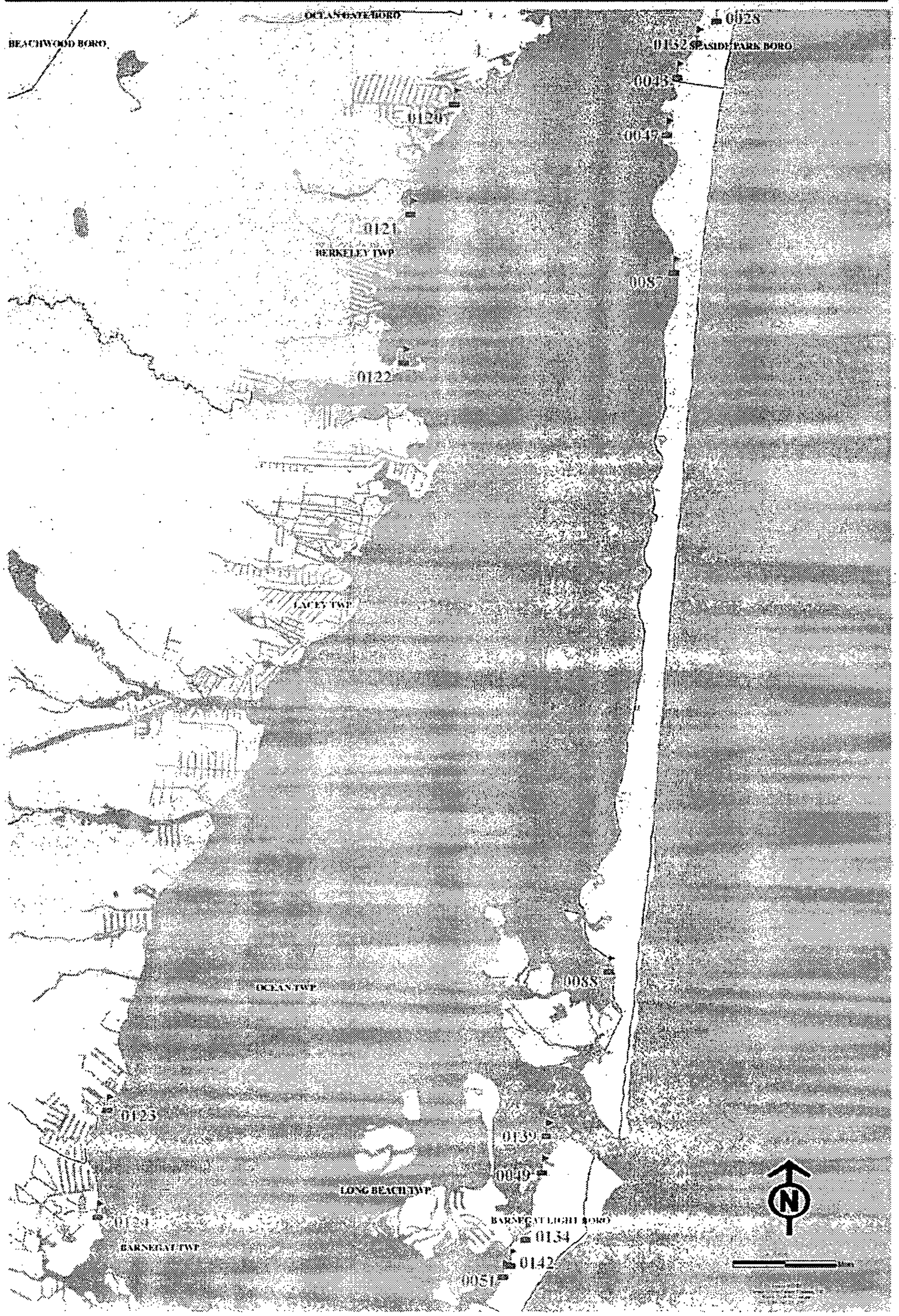


Figure 2. Map showing locations of Central Ocean County sites samples as part of the Cooperative Coastal Monitoring Program.

Southern Ocean County CCMP Sites

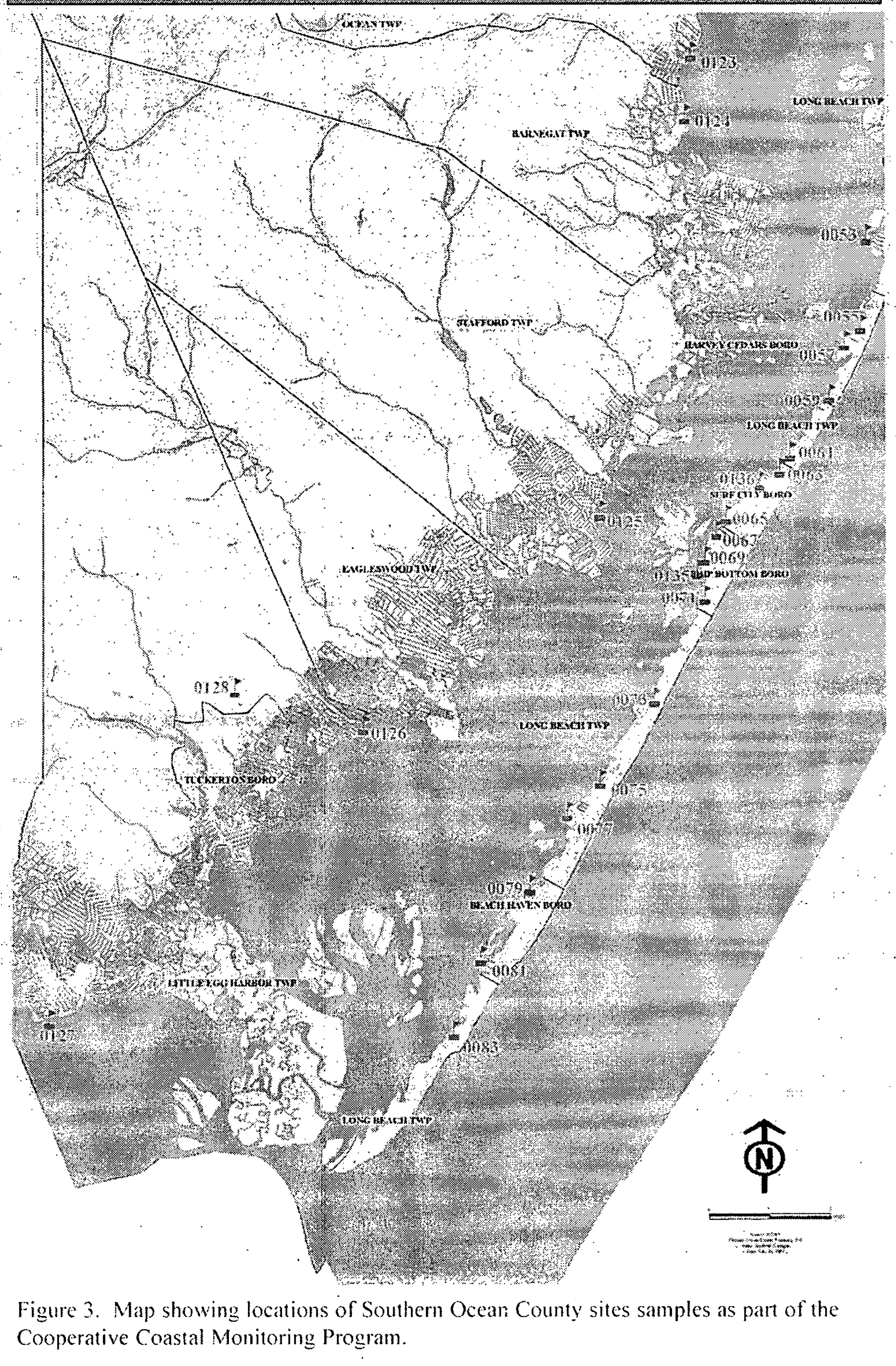


Figure 3. Map showing locations of Southern Ocean County sites samples as part of the Cooperative Coastal Monitoring Program.

Status

Lakes

The bathing areas at the lakes usually make up 50% of the total number of exceedences during the bathing season. Two factors, stormwater runoff and waterfowl, influence the occurrence of elevated bacterial counts in lakes of the Barnegat Bay-Little Egg Harbor watershed:

- Stormwater runoff--The amount of indicator organisms found in a lake after a rainfall event is directly influenced by the amount of stormwater that is channeled into the lake. Lakes that receive little or no stormwater can be expected to show much lower bacteria counts than lakes that receive a greater inflow of stormwater. Without outside influence of waterfowl, the numbers of bacteria can be expected to recede within 24 hours after the rain event.

- Waterfowl--Several of the inland lakes in the watershed are home to great numbers of gulls, geese and ducks (Figure 4). The fecal material from these birds are considered to be the cause of 75 of the 86 lake closures in 2004. Park visitors often ignore the signs that implore people not to feed the waterfowl at lakes such as those in county parks and Pine Lake in Manchester.

Without external factors such as waterfowl, the lakes appear to recover within approximately 24 to 36 hours after a rainfall event. With an abundance of waterfowl, the lake may take several days to recover. The severity of the initial influx of bacteria is proportional to the density of development in the area serviced by the storm drain system that empties into the lake. Lakes such as Harry Wright Lake in Manchester (MCH-5 and MCH-6) which are surrounded with a lower density of housing, recover fairly quickly in comparison to Lake Barnegat in Lacey Twp (LAC-3), which receives stormwater from a relatively higher density area.

Creeks

Cedar Creek is the only freshwater creek in Ocean County that contains public bathing areas. The creek is sampled at two locations; in Berkeley Twp. at William Dudley Park, and in Lacey Twp. at Forest Ave.

Cedar Creek is an indicator of how bacteria-free a water body can be without the influence of storm drains. Cedar Creek could almost be considered a control regarding stormwater influence and non-point source pollution. The stream is not encumbered with storm drains, and as a result, it seldom has an elevated bacteria count.

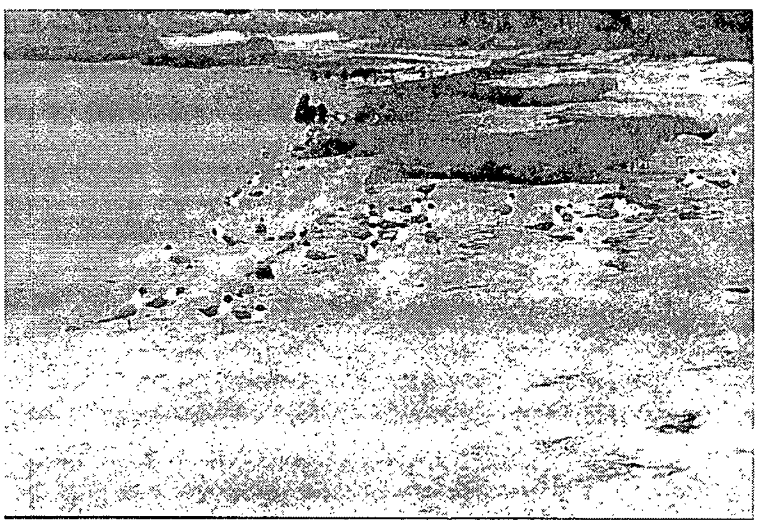


Figure 4. Waterfowl, such as gulls, geese, and ducks are a significant source of fecal coliform bacteria and are considered a major cause of closures of many bathing beaches on lakes. Feeding waterfowl at these locations contributes to this problem by encouraging waterfowl to congregate near recreational lakes. Park visitors are urged not to feed the waterfowl.

The site at William Dudley Park is totally free of discharges from storm drains, while the site at Forest Ave. is under the influence of one storm drain that drains an area of Route #9 that is not influenced by human activities other than traffic and road maintenance. During the past five years the Berkeley site was closed once while the Lacey site was closed three times. Usually the bacteria counts at both of these sites are measured at less than 10 colonies per 100ml. of water, which is extremely clean.

Rivers

Brackish rivers in the watershed with public recreational bathing areas are the Manasquan River, the Metedeconk River, and the Toms River. One site on the Toms River that is not a bathing beach, Central Ave. in Island Heights (site #0113) is an environmental site which was previously designated a beach but is no longer utilized as such.

It has been observed that water quality at the river beach sites is affected by stormwater and geographic factors. Immediately following a rain event that causes the storm drains to flow, most if not all of these sites will exhibit elevated bacteria counts. Figure 5 illustrates the relation between precipitation and elevated bacteria counts. The duration of an elevated bacteria level depends upon the flow of water through the site. While there is a considerably larger rate of water circulation in the rivers than in the lakes, if the sampling point (beach) is located in a cove where the water circulation is poor, the duration of the event may be extended by several days. Sampling points such as the two Beachwood beaches, Money Island beach in Dover and Windward Beach in Brick fall into the poor circulation category.

Non-point source pollution delivered via stormwater is the primary source of contamination at these beaches. The OCHD has performed several analytical surveys of marinas, beaches, and storm drain outfalls. Results of these surveys indicate that the primary bacteria source is the outfalls. Other surveys conducted by the OCHD have observed that septic system malfunctions are not a contributor to the overall bacteria load. Sanitary sewer networks service most if not all structures in the vicinity of the beaches.

Until the change of indicator organism that occurred in the spring of 2004, it could be assumed that these beaches would receive and retain bacteria counts exceeding state standards for between 24 and 36 hours. With the change

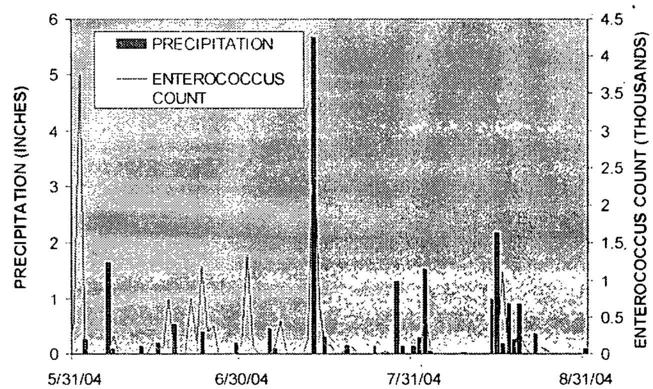


Figure 5. Enterococcus bacteria counts at the East Beach in Beachwood and relation to daily precipitation amounts measured at Toms River, May 31 – August 31, 2004. Rainfall events that produce non-point source runoff are typically followed by elevated bacteria counts at beaches on waterbodies receiving the runoff.

of indicator to enterrococcus, several subtle changes have been observed. While most of the river beaches have shown the same patterns of bacterial influx after a rain event, the beaches at Windward Beach in Brick Twp (0103); two beaches in Pine Beach Borough (0117 & 0118); and Maxon and River Ave beaches in Point Pleasant (0109 & 0110) have shown substantially lower bacteria counts after a rainfall. At the present time this phenomenon cannot be explained, and further research is needed in these areas.

The drought year of 2002 yielded only nine (9) beach closures of river beaches while the heavy rainfalls of 2004 resulted in fifty-eight (58) closures. This further implicates non-point source via storm drainage as the major contributor to bacterial pollution.

Bays

The OCHD samples nineteen bay beaches through the recreational bathing season. There are five bay sites that are not beaches that are sampled as environmental sites: Amherst Dr. in Berkeley Twp., three sites on the Bay side of Island Beach State Park, and L St. in Seaside Park.

The sources of bacterial contamination at bay beach sites are essentially the same as those of the river beaches. However, the water circulation at the bay sites is generally higher than at the river sites. Consequently, the bay beaches also show an increase in bacteria counts after a rainfall, but the rate at which they recover is generally faster than that of the rivers.

The water quality at these beaches is influenced by nearby storm drain outlets and tidal circulation. Because of the greater volume of circulating water in the bay, heavy concentrations of bacteria at these sites tend to be quickly diluted. The exception to this pattern is the bay beach at Hancock Avenue in Seaside Heights, where tidal action and circulation are low. Because this beach is isolated between the Tunney Bridge, Middlesedge Island, a Jet Ski rental establishment, and also because approximately 13 storm drain outlets are located in the vicinity of this beach, it is slow to recover after a storm event.

Trends

Figure 6 shows the number of closures for freshwater lake and creek beaches and for brackish water beaches in Ocean County during 1995-2004. The number of closures varies widely from year to year, and this variability is attributable primarily to the number, duration, and intensity of rainfall events occurring imme-

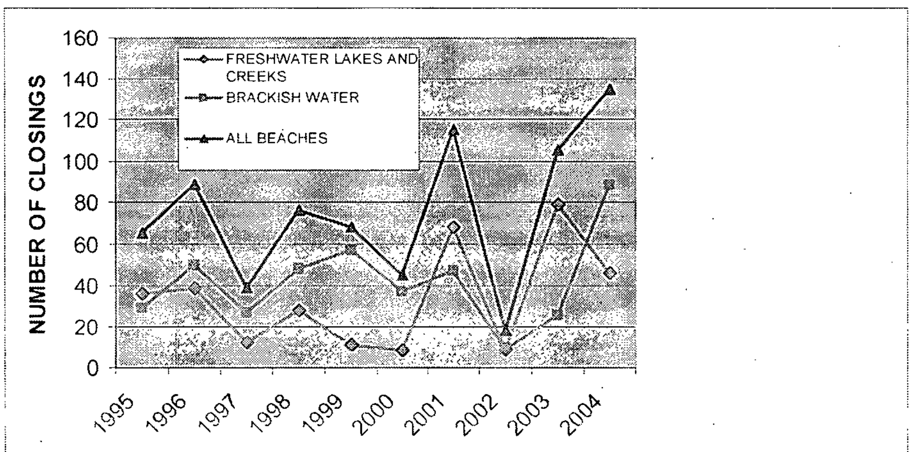


Figure 6. Annual bathing beach closures in Ocean County, 1995-2004.

diately before and during the recreational bathing season. The highest number of annual closures occurred during three of the past four years.

It has been observed and documented that non-point source pollution delivered to the waters through stormwater discharges are the major contributing factor to beach closures. It is anticipated that implementation of the new Stormwater Regulations and other non-point source control efforts will favorably affect the current situation.

Reference

New Jersey Department of Environmental Protection, 2004, New Jersey Stormwater Best Management Practices Manual, New Jersey Department of Environmental Protection, Division of Watershed Management, Trenton, NJ, 9 chapters (separately paginated), 4 appendices.

Links to Other Information Sources

Water quality updates during the recreational bathing season are available on-line at Ocean County Health Department Beach Report web site at
http://www.ochd.org/beach
or by calling the Ocean County Health Department Bathing Beach Hotline.
The Hotline is available 24 hours per day and can be reached at 732-341-9700 ext. 7776 in northern Ocean County and at 800-342-9738 in southern Ocean County.

The New Jersey Stormwater Management Rules and Regulations and the New Jersey Stormwater Best Management Practices Manual are available on-line at
http://www.state.nj.us/dep/stormwater

ALGAL BLOOMS

Central Question(s)

Are the frequency and spatial extent of algal blooms in the Barnegat Bay-Little Egg Harbor Estuary increasing over time?

Explanation of the Indicator

Nutrient enrichment of estuarine waters is closely linked to a series of cascading environmental problems, notably increased growth of phytoplankton and benthic macroalgae (including both harmful and nuisance forms), loss of submerged aquatic vegetation (SAV), and reduced dissolved oxygen levels. These problems can then lead to a deterioration of sediment and water quality, loss of biodiversity, and disruption of ecosystem health and function. Human uses of estuarine resources can also be seriously impaired.

Nutrient loading, particularly nitrogen, is generally correlated with the occurrence of both nuisance and toxic algal blooms. Severe toxic and noxious phytoplankton blooms are on the rise worldwide due to accelerated coastal development and associated nutrient inputs to receiving waters. These blooms are typically characterized by the explosive growth of a single phytoplankton species, which is responsible for an array of negative impacts. Excessive growth of some phytoplankton species generates harmful algal blooms (HABs), which variously encompass brown tides, yellow tides, red tides, and other types. The toxic forms are particularly dangerous to numerous organisms such as macroalgae, shellfish, finfish, as well as humans. Secondary impacts include shading effects, altered grazing patterns, and changes in trophic dynamics that are detrimental to estuarine function. A number of HAB-forming species have been recorded in the Barnegat Bay-Little Egg Harbor Estuary, including *Dinophysis* spp., *Gymnodinium* (*Karlodonium*) spp., *Heterosigma* sp., and *Prorocentrum* spp.) (Olsen and Mahoney, 2001).

More recently, emphasis has been placed on macroalgal blooms in shallow eutrophic estuaries. Green-tide forming taxa (e.g., *Enteromorpha* and *Ulva*) may be particularly problematic. When exposed to elevated nutrient levels, these plants can grow very rapidly to form sheet-like masses that drift along the estuarine floor. Such high biomasses of macroalgae often degrade benthic habitats and communities.

HABs, however, comprise the most serious algal blooms in estuaries, with blue-green algae, diatoms, dinoflagellates, pyrmnesiophytes, and raphidophytes well represented. They exist in three general forms (Hallegreaff et al., 1995; Livingston, 2000):

1. Nontoxic bloom populations reaching concentrations that eventually affect important environmental factors such as dissolved oxygen, with resulting hypoxia/anoxia ending in debilitation and/or extirpation of other populations.

2. Toxic bloom species that introduce toxic agents into associated food webs to the extent that upper trophic levels (including humans) are adversely affected.

3. Toxic bloom species that produce and release substances having direct and/or indirect effects on associated populations. These species are usually not harmful to humans, but are known to adversely affect other aquatic plant and animal species.

Algal Blooms (cont.)

Although there is general correlation of HABs with elevated nutrient levels, the blooms cannot always be coupled to nutrient overenrichment. It is also unclear if dissolved organic or dissolved inorganic nitrogen forms play a more significant role in their generation.

Eutrophication, defined as a long-term increase in organic matter input to a water body as a result of nutrient enrichment, is responsible for insidious degradation of estuarine systems worldwide (Nixon, 1995; Boesch et al., 2001). Generally linked to nutrient loading from adjoining coastal watersheds and local airsheds, eutrophication has been deemed a priority problem of the Barnegat Bay-Little Egg Harbor Estuary (Kennish, 2001). Nutrient enrichment is problematic for the estuary because it can over-stimulate the growth of phytoplankton as well as benthic microphytes and macrophytes. The result is often recurring phytoplankton blooms and the excessive proliferation of epiphytic algae and benthic macroalgae. Negative impacts often arise, such as reduced dissolved oxygen, loss of SAV, and impacted benthic faunal communities. Tracking the occurrence of algal blooms provides an indication of the severity of eutrophication, as well as an indication of the likelihood that the related negative impacts of algal blooms may also be occurring.

Status

Symptoms of eutrophication problems have surfaced in the Barnegat Bay-Little Egg Harbor Estuary. Recurring phytoplankton blooms have been documented, including serious brown tides (*Aureococcus anophagefferans*) (Olsen and Mahoney, 2001; Gastrich et al, 2005). Accelerated growth of drifting macroalgae (e.g., *Ulva lactuca*) has produced extensive organic mats that pose a potential danger to seagrass beds and other phanerogams serving as benthic habitat (M. Kennish, personal observation, 2004). Rapid growth of other macroalgal species in the estuary, such as the rhodophytes *Agardhiella subulata*, *Ceramium* spp., and *Gracilaria tikvahiae*, can also be deterimental. In addition, the spread of certain brown macroalgal species along the sediment surface of seagrass beds can hinder exchange of gases and promote the development of hypoxic/anoxic conditions that can be detrimental to the vascular plants. However, comprehensive studies of benthic macroalgae in the estuary are lacking, reflecting a significant information gap.

Other significant biotic changes linked to nutrient enrichment of estuaries are shifts from large to small phytoplankton species and from diatoms to dinoflagellates that can adversely affect shellfish species. Additional impacts include a shift from filter-feeding to deposit-feeding benthos, and a progressive change from larger, long-lived benthos to smaller, rapidly growing but shorter-lived species. The net effect is the potential for a permanent alteration of biotic communities in the system.

Schramm (1999) and Rabalais (2002) described a predictable series of changes in autotrophic components of estuarine and shallow marine ecosystems in response to progressive eutrophication. For those systems that are uneutrophied, the predominant benthic macrophytes inhabiting soft bottoms typically include perennial seagrasses and other phanerogams, with long-lived seaweeds occupying hard substrates. As slight to medium eutrophic conditions develop, bloom-forming phytoplankton species and fast-growing, short-lived epiphytic macroalgae gradually replace the longer lived macrophytes; hence, perennial macroalgal communities decline. Under greater eutrophic conditions, dense phytoplankton blooms occur along with drifting macroalgal species (e.g., *Enteromorpha* and *Ulva*), ultimately eliminating the perennial and slow-growing benthic macrophytes, a situation that may be taking place in the Barnegat Bay-Little Egg Harbor Estuary. With hypereutrophic conditions, benthic macrophytes become locally extinct, and phytoplankton overwhelmingly dominate the autotrophic communities.

Howarth et al. (2000a, b) and Livingston (2002) not only correlated hypereutrophication with proliferation of nuisance and toxic algal blooms but also with increased algal biomass, diminished seagrass habitat, increased biochemical oxygen demand, hypoxia/anoxia, degraded sediment quality, and loss of fisheries. Excessive nutrification problems are on the rise in U.S. waters and abroad, and they are impacting secondary production through altered food web interactions (Livingston, 2002). These effects may be occurring today in the Barnegat Bay-Little Egg Harbor Estuary.

Frequent phytoplankton blooms can lead to shading effects and potentially dangerous oxygen depletion. Both may result in indirect impacts on seagrass beds and other vital habitat in the Barnegat Bay-Little Egg Harbor Estuary. Because excessive growth of benthic macroalgae may have greater direct impacts on seagrass beds, it is also critically important to assess the effects of this algal group on seagrasses (notably *Zostera marina*) in the estuary.

Trends

Brown-Tide Blooms

Brown-tide blooms, caused by the minute alga, *Aureococcus anophagefferens*, have continued to plague Barnegat Bay since 1995, the coastal bays in New York since the mid-1980's, and the Maryland coastal bays since 1998. These algal blooms can discolor the water brown and may cause negative impacts on shellfish, notably the ecologically and commercially important hard clam and scallop, as well as on seagrasses. During 2000-2002, the levels of brown-tide blooms in the Barnegat Bay-Little Egg Harbor Estuary were elevated as compared to levels in other estuaries that exhibited negative impacts on natural resources (Gastrich et al., 2004, 2005). Gastrich and Wazniak (2002) showed that elevated levels of brown tide may cause negative biotic impacts, such as a reduction in the growth of juvenile and adult shellfish (e.g., hard clams and mussels), reduced feeding rates in adult hard clams and other shellfish, recruitment failures, and even mortality of shellfish. The dense shading of these blooms may also contribute to the loss of seagrass beds, which serve as important habitat for fish and shellfish.

The Division of Science, Research and Technology of the New Jersey Department of Environmental Protection (NJDEP), in collaboration with several partnering institutions, established the Brown-Tide Assessment Project, which resulted in the systematic monitoring of brown-tide blooms from 2000-2004 at selected water-quality network stations in Barnegat Bay and Little Egg Harbor (Figure 1). Water samples were collected by the New Jersey Marine Science Consortium from April through September using boat and USEPA helicopter monitoring. The samples were enumerated for *A. anophagefferens* by the University of Southern California, and environmental data were analyzed by the Center for Remote Sensing and Spatial Analysis at Rutgers University and the NJDEP. The objectives were: (1) to assess the spatial and temporal extent of brown tide in several coastal bays; (2) to determine the rela-

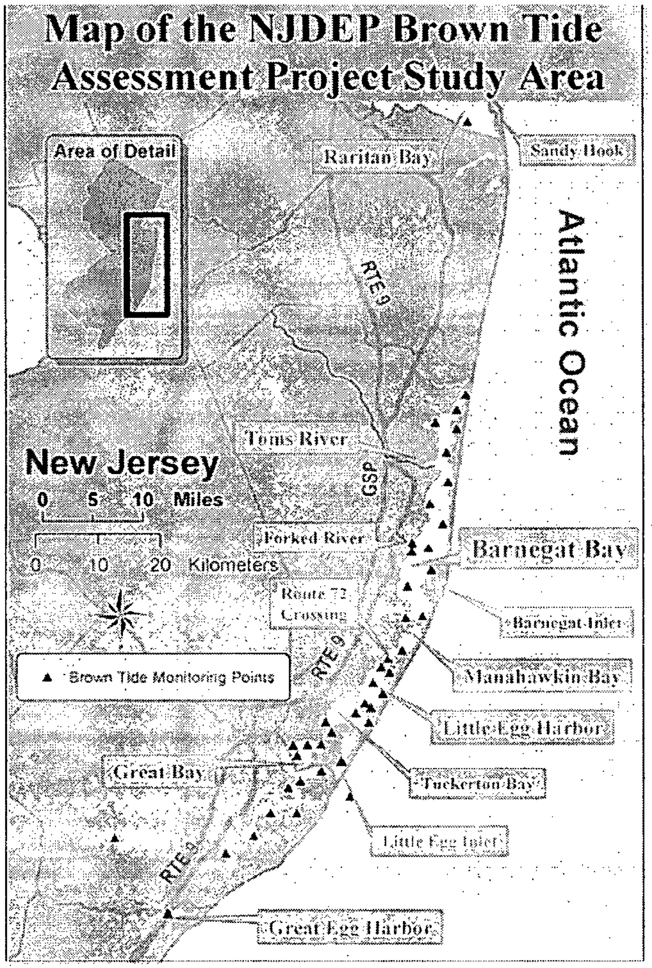


Figure 1. Map of the NJDEP brown-tide assessment project: 2000-2004.

tionship between the abundance of *A. anophagefferens* and environmental data; and (3) to analyze the risk of brown-tide blooms to SAV.

Abundances of *A. anophagefferens* were classified using the Brown Tide Bloom Index (Gastrich and Wazniak, 2002) (Figure 2) and mapped, along with salinity and temperature parameters, to their georeferenced location using the ArcView GIS.

The highest *A. anophagefferens* abundances (>106 cells/ml), Category 3 blooms (≥200,000 cells ml-1), and Category 2 blooms (≥35,000 to ≤200,000 cells ml-1), recurred during each of the three years of sampling and covered significant geographic areas of the estuary, especially in Little Egg Harbor (Figure 3). While Category 3 blooms were generally associated with warmer water temperatures (> 16°C) and higher salinities (> 25-26 ppt), these factors were not sufficient alone to explain the timing or distribution of *A. anophagefferens* blooms. There was no significant relationship between brown-tide abundances and dissolved organic nitrogen measured in 2002, which was consistent with results of other studies.

Extended drought conditions, with corresponding low freshwater inputs (Figure 4) and elevated bay salinity that occurred during the 2000-2004 period, were conducive to blooms. Abundances of *A. anophagefferens* were well above those reported to cause negative

CATEGORY 1: <35,000 *Aureococcus anophagefferens* cells ml^{-1} (No observed impacts)

CATEGORY 2: ≥35,000 to <200,000 cells ml^{-1}

- Reduction in growth of juvenile hard clams, *Mercenaria mercenaria*
- Reduced feeding rates in adult hard clams
- Growth reduction in mussels (*Mytilus edulis*) and bay scallops (*Argopecten irradians*)

CATEGORY 3: ≥200,000 cells ml^{-1}

- Water becomes discolored yellow-brown
- Feeding rates of mussels severely reduced
- Recruitment failures of bay scallops and high mortalities
- No significant growth of juvenile hard clams
- Negative impacts to eelgrass due to algal shading
- Copepod production reduced and negative impacts to protozoa.

Figure 2. Brown-tide bloom index. (from Gastrich and Wazniak, 2002).

Algal Blooms (cont.)

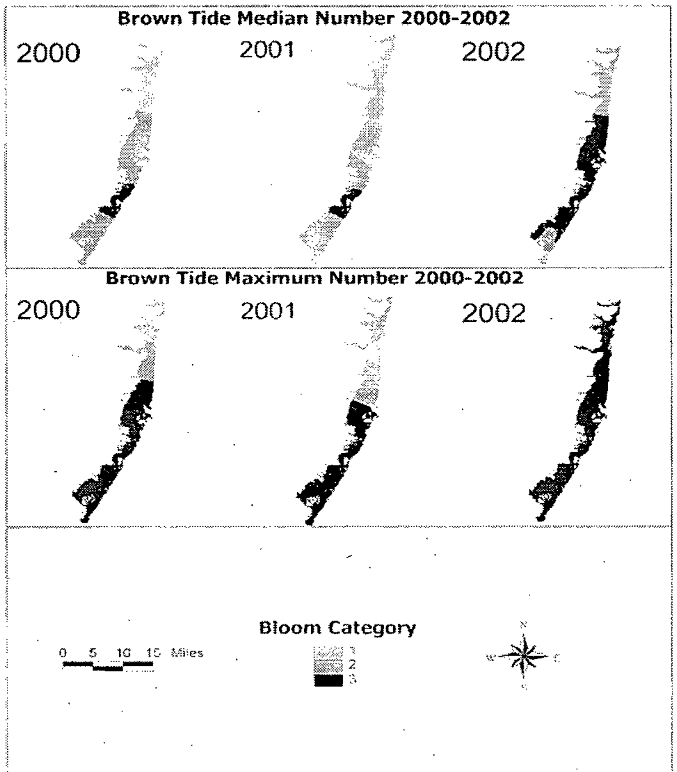


Figure 3. Occurrence of brown-tide blooms in the Barnegat Bay-Little Egg Harbor Estuary during the 2000-2002 period.

impacts on shellfish. Category 3 blooms generally occurred at water temperatures above 13-17 ^{o}C and within a salinity range between 25 and 31 ppt. There was a significant difference in temperature of occurrence between the three bloom categories (F-value = 5.6759 and p = 0.0037). Category 3 blooms were generally observed where salinity was above 25 ppt and below 31 ppt. However, while the highest abundances of *A. anophagefferens* were generally observed at > 25-26 ppt, this salinity range did not always result in a Category 3 bloom. In summary, these data support the view that Category 3 blooms are positively associated with warmer temperatures (> 16^{o}C). Category 3 brown-tide blooms suppress water transparency from a mean Secchi depth of 0.6 m.

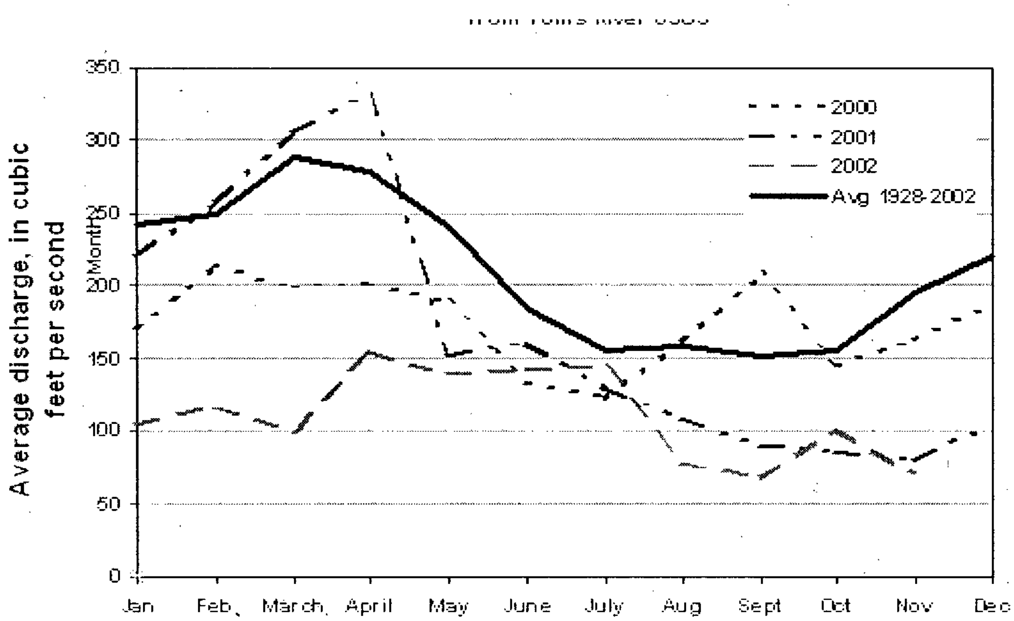


Figure 4. Average monthly stream discharge of the Toms River for the 2000-2002 survey period.

An assessment of the risk of SAV habitat to brown-tide bloom categories indicates that 35% of the SAV habitat located in Barnegat Bay-Little Egg Harbor Estuary had a high frequency of Category 2 or 3 blooms for all three years of study (Figure 5). This is important considering that over 70% of the New Jersey's eelgrass beds are located in this system (Lathrop et al., 2001), and brown tides may pose a risk to these seagrass resources.

Although the presence of *A. anophagefferens* was first reported in New Jersey coastal bays in 1988, with blooms documented in 1995, 1997 and 1999, there were insufficient data to develop trends. The current monitoring program of NJDEP has shown a trend in elevated abundances of brown tide from 2000-2002. Since there was no significant bloom in 2003, brown-tide blooms do not occur every year in the estuary. While our GIS analysis has shown that seagrass habitat areas are located in the High-Risk Category 3 bloom "hotspot" areas, no direct causal link has yet been established between brown-tide blooms and seagrass decline in the Barnegat Bay-Little Egg Harbor Estuary.

Controls

Managers would like to know more about the causes of brown-tide blooms and how to control them. The usual factors in algal removal are not effective for brown tides. While numerous studies have addressed some factors that may promote blooms (e.g., high salinity, warmer temperatures, organic nutrients), infection by viruses may aid in the demise of brown tide. For example, a virus specific to *A. anophagefferens* isolated during brown-tide blooms in New Jersey and New York coastal bays has the ability to lyse healthy brown-tide cells (Gastrich et al., 2002, 2004). The percent of brown-tide cells infected by the virus appears highest at the end of the blooms (Gastrich et al., 2004). These results support the hypothesis that viruses may be a major source of mortality for brown-tide blooms in regional coastal bays.

Major Information Gaps

Major information gaps on brown tide and benthic macroalgae include:

- Continuous and long-term monitoring data on their spatial and temporal occurrence in the coastal bays;
- Identification of environmental factors that promote, initiate, maintain, and terminate these blooms;
- More frequent shellfish stock assessments, along with studies that distinguish the potential negative impacts of brown-tide and benthic macroalgal blooms (as opposed to other causes of shellfish decline in these areas).
- Assessments that provide a greater understanding of the relative importance of maximum brown-

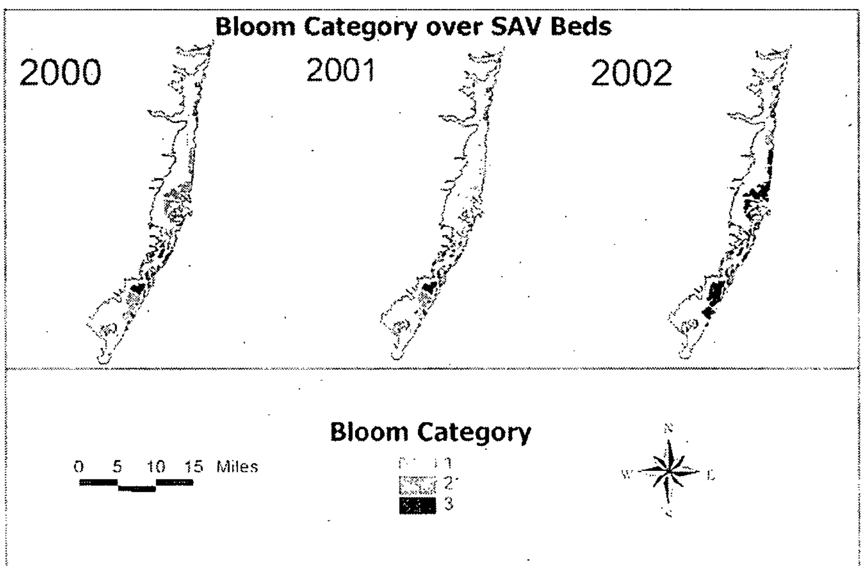


Figure 5. Brown-tide bloom categories recoded during the 2000-2002 survey period.

tide bloom abundance and bloom duration, and the effects of specific levels of blooms on seagrass health and productivity.

References

Boesch, D. F., R. H. Burroughs, J. E. Baker, R. P. Mason, C. L. Rowe, and R. L. Siefert: 2001. Marine Pollution in the United States. Technical Report, Prepared for the Pew Oceans Commission, Arlington, Virginia. 49 pp.

Gastrich, M. D. and C. E. Wazniak. 2002. A brown-tide bloom index based on the potential harmful effects of the brown-tide alga, *Aureococcus anophagefferens. Aquatic Ecosystems Health & Management* 33: 175-190.

Gastrich, M. D., O. R. Anderson, and E. M. Cosper. 2002. Viral-like particles (VLPs) in the alga, *Aureococcus anophagefferens* (Pelagophyceae), during 1999-2000 brown tide blooms in Little Egg Harbor, New Jersey. *Estuaries*. 25 (5): 938-943.

Gastrich, M. D., J. A. Leigh-Bell, C. J. Gobler, O. R. Anderson, S. W. Wilhelm, and M. Bryan. 2004. Viruses as potential regulators of regional brown-tide blooms caused by the alga, *Aureococcus anophagefferens. Estuaries* 27: 112-119.

Gastrich, M. D., R. Lathrop, S. Haag, M. P. Weinstein, M. Danko, D. A. Caron, and R. Schaffner. 2005. Assessment of brown-tide blooms, caused by *Aureococcus anophagefferens*, and contributing factors in New Jersey coastal bays: 2000-2002. Accepted for Harmful Algal Bloom Special Publication.

Hallegreaff, G. M. 1995. Harmful algal blooms: a global overview. In: Hallegreaff, G. M., D. M. Anderson, and A. D. Cembella (Eds.), *Manual on Harmful Marine Microalgae*. IOC Manual and Guides No. 33, UNESCO, pp. 1-22.

Howarth, R. W., D. Anderson, J. Cloern, C. Elfring, C. Hopkinson, B. Lapointe, T. Malone, N. Marcus, K. McGlathery, A. Sharpley, and D. Walker. 2000a. Nutrient Pollution of Coastal Rivers, Bays, and Seas. Ecological Society of America, Issues in Ecology. 15 pp.

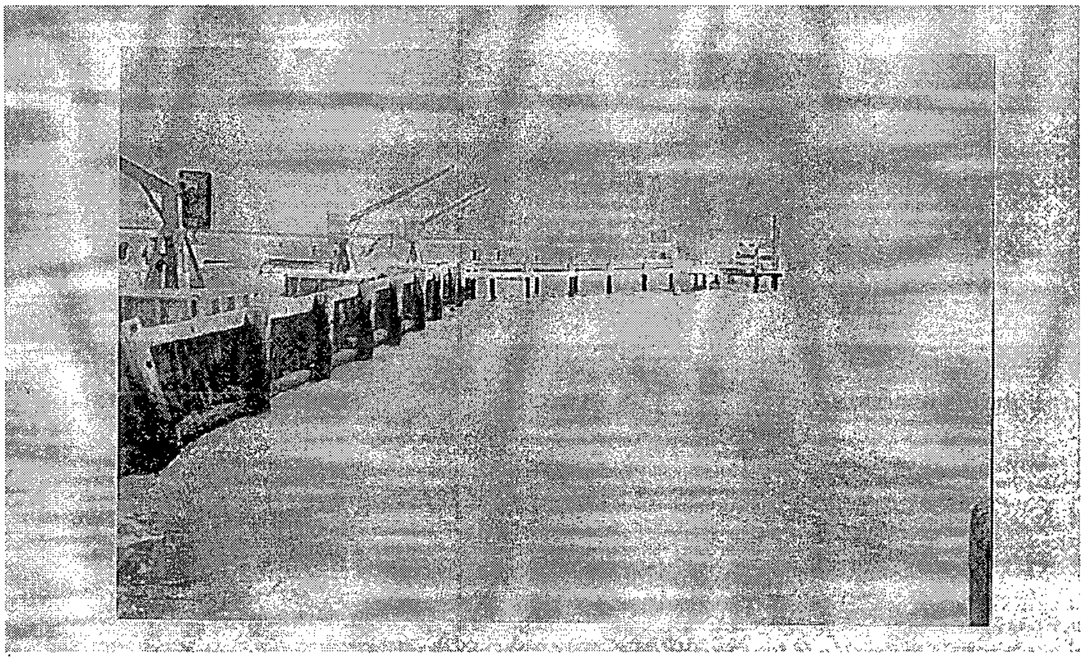
Howarth, R. W., D. M. Anderson, T. M. Church, H. Greening, C. S. Hopkinson, W. C. Huber, N. Marcus, R. J. Nainman, K. Segerson, A. N. Sharpley, and W. J. Wiseman. 2000b. Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution. Ocean Studies Board and Water Science and Technology Board, National Academy Press, Washington, D. C. 391 pp.

Kennish, M. J. (ed.). 2001. Barnegat Bay-Little Egg Harbor, New Jersey: Estuary and Watershed Assessment. *Journal of Coastal Research*, Special Issue 32, 280 pp.

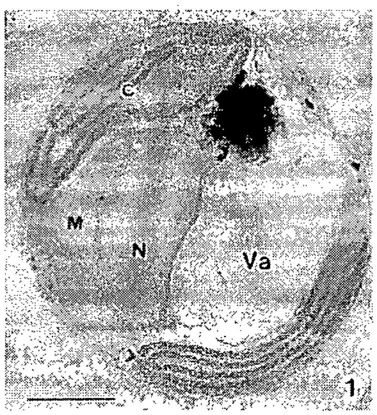
Lathrop, R., R. Styles, S. Seitzinger, and J. Bognar. 2001. Use of GIS mapping and modeling approaches to examine the spatial distribution of seagrasses in Barnegat Bay, New Jersey. *Estuaries* 24: 904-916.

Livingston, R. J. 2000. *Eutrophication Processes in Coastal Systems: Origin and Succession of Plankton Blooms and Secondary Production in Gulf Coast Estuaries*. Boca Raton, USA: CRC Press. 327 pp.

Algal Blooms (cont.)



Brown tide in Tuckerton Bay, NJ in 1999
(Photograph courtesy of Dr. Mary Downes Gastrich, NJDEP)



Brown tide alga, Aureococcus anophagefferens
(Courtesy of Dr. Mary Downes Gastrich, NJDEP)

Ulva Lactuca, or sea lettuce, is a drifting macroalgal species that has produced extensive organic mats and may threaten benthic habitats.

Photograph courtesy of M. Vis, Ohio University

Livingston, R. J. 2002. *Trophic Organization in Coastal Systems.* Boca Raton, USA: CRC Press. 388 pp.

Nixon, S. W. 1995. Coastal eutrophication: a definition, social causes, and future concerns. *Ophelia* 41: 199-220.

Olsen, P. S. and J. B. Mahoney. 2001. Phytoplankton in the Barnegat Bay-Little Egg Harbor estuarine system: species composition and picoplankton bloom development. In: Kennish, M. J. (Ed.), *Barnegat Bay-Little Egg Harbor, New Jersey: Estuary and Watershed Assessment. Journal of Coastal Research,* Special Issue 32, pp. 115-143.

Rabalais, N. N. 2002. Nitrogen in aquatic ecosystems. *Ambio* 21: 102-112.

Schramm, W. 1999. Factors influencing seaweed responses to eutrophication: some results from EU-project EUMAC. *Journal of Applied Phycology* 11: 69-78.

Links to Other Information Sources

New Jersey Brown-Tide Websites

Rutgers/CRSSA and NJDEP:
http://www.crssa.rutgers.edu/projects/btide/

NJDEP:
http://www.state.nj.us/dep/dsr/browntide

Maryland Brown-Tide Website:

http://www.dnr.state.md.us/coastalbays/bt_results.html

New York Brown-Tide Websites:

Suffolk County Department of Health Services:
http://www.co.suffolk.ny.us/webtemp3.cfm?dept=6&id=974

Brown-Tide Clearinghouse:
http://www.seagrant.sunysb.edu/browntide/default.htm

Harmful Algal Bloom Websites:

NY Sea Grant:
http://www.seagrant.sunysb.edu/btri

Woods Hole Oceanographic Institute:
http://www.whoi.edu/redtide/

Ecology and Oceanography of Harmful Algal Blooms:
http://www.redtide.whoi.edu/hab/nationplan/ECOHAB/ECOHABhtml.html

Bigelow Laboratory for Ocean Sciences (West Boothbay Harbor, ME):
http://www.bigelow.org/hab/

NOAA Harmful Algal Bloom Project:
http://www.csc.noaa.gov/crs/habf/

FRESHWATER INPUTS

Central Question(s)

Is the streamflow of tributaries to the Barnegat Bay-Little Egg Harbor estuary changing over time?

Is the amount of freshwater withdrawn from the watershed area for human use changing over time?

Explanation of the Indicator

The Barnegat Bay-Little Egg Harbor watershed provides freshwater from streams, lakes, and ground water for many human uses, including drinking water, recreation, irrigation, and various industrial and commercial activities, as well as for freshwater fish and wildlife habitats. Freshwater from the watershed also is needed as inflow to the estuary to maintain an ecosystem where freshwater and saltwater mix and create a vital nursery for life along the Atlantic coast.

Freshwater inputs from the watershed include the flow of rivers and streams that drain to the estuary, and the direct seepage of ground water into the estuary (Figure 1). Ground-water discharge from the unconfined Kirkwood-Cohansey aquifer system to major streams in the watershed accounts for a high percentage of surface-water flow and is the largest source of freshwater input to Barnegat Bay. The rate of direct ground-water discharge to the estuary and small streams as seepage is significant, but less than the rate of ground-water discharge to larger streams (Hunchack-Kariouk and Nicholson, 2001). Some of the freshwater flow originates in the protected Pinelands Area (Figure 1), and some originates in areas outside the Pinelands where population and development pressures on water resources are more intense. Demand for freshwater for human use is supplied primarily from ground-water wells but also from surface-water intakes. Supply wells in the watershed withdraw water from the unconfined Kirkwood-Cohansey aquifer system and deeper confined aquifers.

The role of freshwater in estuarine health is pivotal. The mixing of freshwater with ocean water in the estuary results in the salinity regimes that support estuarine habitats. The rate of freshwater flow into the estuary also affects the rate at which the estuary is flushed, which in turn affects many water-quality and ecological processes. Freshwater inputs also dilute contaminants from a wide variety of sources. The importance of freshwater inputs to estuarine health leads to a central question: Is the flow of freshwater from streams into the estuary changing over time? Tracking and maintaining an adequate rate of freshwater flow is critical to meeting estuarine water-quality and habitat goals.

Status

Flow measurements of rivers and streams that contribute to the estuary have been made at 14 stations, and these measured inputs account for about 79 percent of the surface-water discharge from the watershed (Figure 1). Additional freshwater enters the estuary as runoff from ungaged areas and as discharge of ground water from the Kirkwood-Cohansey aquifer system to the estuary and minor streams. On average, these inputs are estimated to total about 26 cubic meters per second, or about 590 million gallons per day (Hunchack-Kariouk and Nicholson, 2001). During typical drought conditions, the total freshwater inflow to the estuary is about one-third to one-half of the average inflow, and so considerably less fresh-

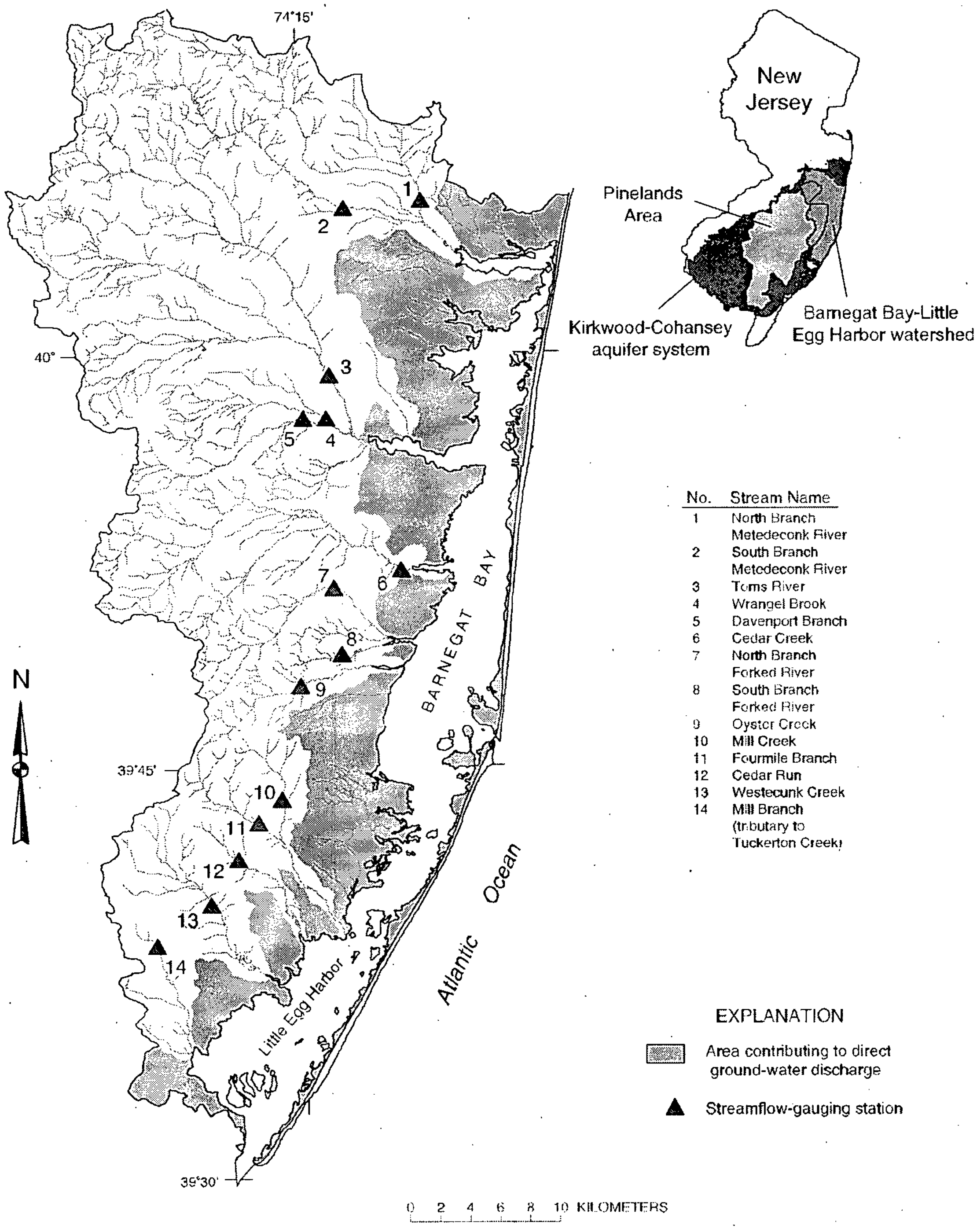


Figure 1. Location of the Barnegat Bay-Little Egg Harbor estuary and watershed, Kirkwood-Cohansey aquifer system, Pinelands Area, streamflow gauging stations and areas contributing to direct ground-water discharge to the estuary and minor streams.

water is available for mixing with ocean water and for diluting contaminant loads, and flushing times tend to be longer. Elevated salinity regimes that accompany drought conditions are known to have coincided with brown tide blooms (Cosper and others, 1997).

Maintaining adequate freshwater flow in streams and to coastal waters has become a concern with the increasing demands for water supply in the Barnegat Bay watershed. The New Jersey Statewide Water Supply Plan has identified the Barnegat Bay watershed as an area of substantial projected water-supply deficit by the year 2040, an indication that pressure for additional withdrawals from the watershed for water supply is expected to increase over coming decades (New Jersey Department of Environmental Protection, 1996). At the same time, the withdrawal of potable fresh water for this area is almost totally consumptive in regard to the watershed, as most of the water is discharged to the ocean as treated wastewater, bypassing the estuary. This water loss has resulted in reduced streamflows (Nicholson and Watt, 1997) and saltwater intrusion into confined and unconfined aquifer systems in coastal areas (Watt, 2000).

The amount of freshwater removed from the watershed through regional sewerage outfall to the ocean averages about 2.6 cubic meters per second (60 million gallons per day) during high-demand summer months, equivalent to about one-third of the freshwater inflow to the estuary under extreme low-flow conditions (Hunchack-Kariouk and Nicholson, 2001). Some of this sewered water is originally withdrawn from confined aquifers or imported from other sources, and therefore, this portion of the sewered flow does not represent a loss of freshwater input to the estuary. Much of the sewered flow, however, is originally withdrawn for water supply from surficial sources within the watershed; therefore, this remaining portion of the sewered flow represents a loss of freshwater input to the estuary. In addition to water lost through sewering, some water is lost through crop and lawn irrigation and evaporative industrial cooling. The question of how the water withdrawn from the watershed for human use is changing over time is critical to assessing the health of the estuary.

In addition to the effects of human use of freshwater for water supply, modifications to the landscape, such as the development of impervious surfaces, can change the natural hydrology of the watershed by changing recharge and runoff rates and altering the hydrologic patterns. Storm runoff from impervious areas may increase the rate of freshwater inputs during wet periods at the expense of reduced recharge and subsequently lower stream base flow during dry periods. A summary of the status and trends in land use and land cover (including impervious cover) is presented in another section of this report.

Monitoring surface-water discharge is a cost-effective means of tracking freshwater inputs. The U.S. Geological Survey (USGS) maintains a network of stream-gauging stations (Figure 2) that measure the rate of flow in some of the major streams and serves the data on a continuous basis. These streams include North Branch Metedeconk River, Toms River, Cedar Creek, and Westecunk Creek (Stations 1, 3, 6, and 13, Figure 1). These gauging stations transmit data via satellite telemetry, and the streamflow data are served online in near real time at http://nj.usgs.gov. The other stations shown in Figure 1 (Stations 2, 4, 5, 7-12, and 14) are either discontinued or are used to make measurements less frequently.

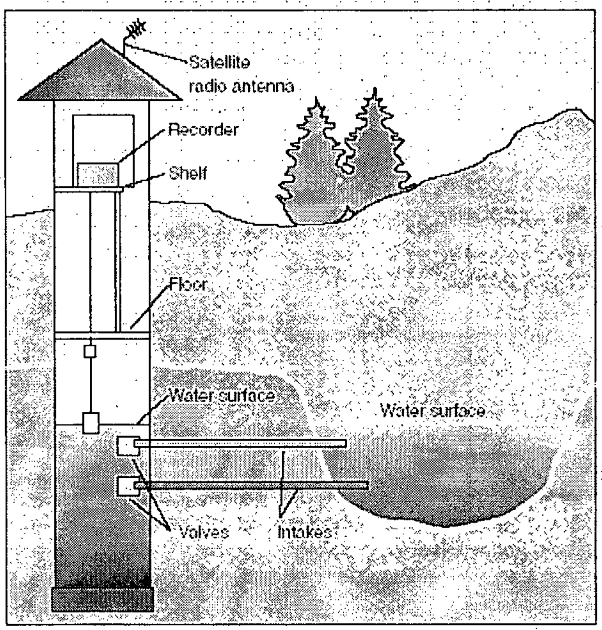


Figure 2. Typical U.S. Geological Survey streamflow-gauging station.

Trends

In order to understand changes that occur in streamflows, long-term monitoring is required. The streamflow-gauging station that measures the flow of the Toms River (station 3 in Figure 1) has been in continuous operation by the USGS since 1929 (Figure 3). The Toms River is the largest stream draining to the estuary. It drains 319 square kilometers upstream from this station, and the average flow passing this station, referred to as stream discharge, is 6.3 cubic meters per second (140 million gallons per day), or about 24 percent of the freshwater flowing into the estuary. The long period of record for this station provides a valuable resource for understanding long-term trends and fluctuations in freshwater inputs. Fluctuations in annual surface discharge of freshwater at this site range from about 60 to 155 percent of the average discharge (Figure 4). Below-average annual discharges since the mid-1980s have been more frequent than above-average discharges. This recent trend is likely the result of both climatic variability and the effects of human activities.

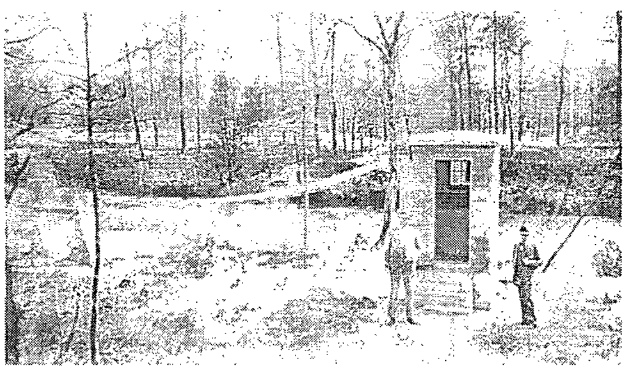


Figure 3. USGS streamflow-gauging station on the Toms River as it appeared in 1930. The Toms River is the largest stream flowing into Barnegat Bay. The station has been used to measure the flow of the river on a continuous basis for 75 years.

Freshwater withdrawals from surface- and ground-water sources in Ocean County for various human uses have increased from about 56 million gallons per day in 1985 to about 71 million gallons per day in 2000 (Figure 5). Most of these withdrawals (about 70 percent) are for public supply with additional withdrawals for other uses (Figure 6). Most of the increase in withdrawals during 1985-2000 is attributable to increases in withdrawals for public supply. Continued increases in demand for water are expected to result in increased stress on the supply of freshwater to the estuary.

Freshwater Management and Information Gaps

Although changing land use and increasing water demand can affect freshwater flow to the estuary, management efforts aimed at minimiz-

Freshwater Inputs (cont.)

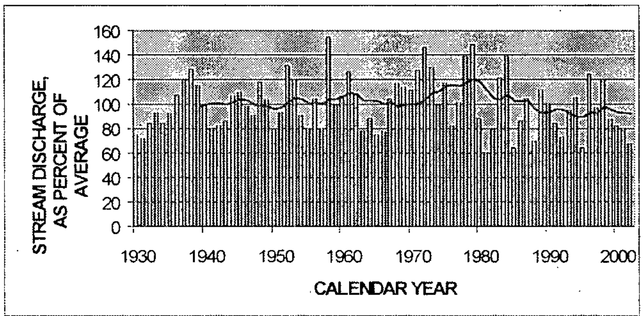


Figure 4. Annual stream discharge of the Toms River. Below average annual discharges since the late 1980s have been more frequent than above average discharges. Average annual stream discharge is 6.3 cubic meters per second.

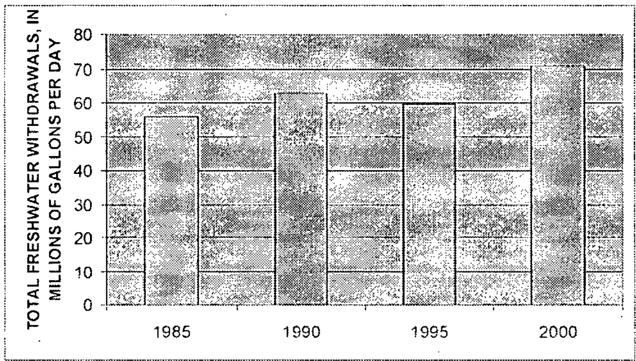


Figure 5. Freshwater withdrawals, Ocean County, New Jersey, 1985-2000. (Source: U.S. Geological Survey Aggregated Water-Use Data System)

ing adverse effects are underway or under consideration. New stormwater regulations are being implemented that are intended to maintain natural rates of recharge in developing areas (New Jersey Department of Environmental Protection, 2004a). Other approaches, including beneficial reuse of reclaimed wastewater; conjunctive use of surface water, unconfined aquifers, and confined aquifers; and aquifer storage and recovery, are being considered to help limit the effects of water demand on water resources (New Jersey Department of Environmental Protection, 2004b). These efforts also are intended to help protect aquifers from excessive drawdown and saltwater intrusion. The success of these efforts in helping to maintain the natural water balance and adequate freshwater flow to the Barnegat Bay-Little Egg Harbor estuary, as well as to maintain the viability of confined and unconfined aquifers, will depend on the effectiveness of the underlying resource-management principles and the extent to which they are implemented. In order to evaluate the success of these efforts, a broad hydrologic monitoring and evaluation program will be required

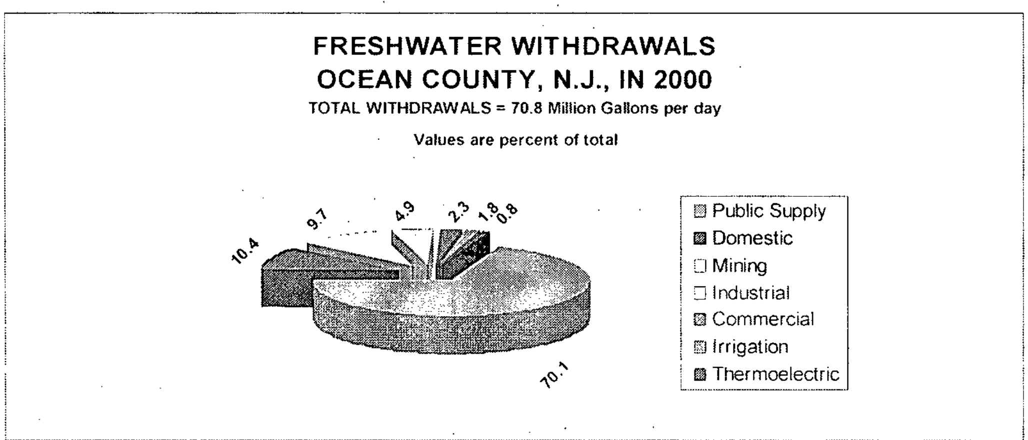


Figure 6. Distribution of 2000 freshwater withdrawals among different water-use categories, Ocean County, New Jersey. (Source: U.S. Geological Survey Aggregated Water-Use Data System)

in areas where development stresses are anticipated to track changes over time. This program will require additional continuous stream gauging stations for tracking surface discharges and monitoring wells to track water-level declines and saltwater intrusion.

References

Cosper, E.M., Gastrich, M.D., Anderson, O.R., and Benmayor, S.S., 1997. Viral infection and brown tide, In Flimlin, G.E., and Kennish, M.J. (eds.), Proceedings of the Barnegat Bay Ecosystem Workshop, November 14, 1996. Toms River, N.J., Cooperative Extension of Ocean County, p.233-242.

Hunchak-Kariouk, K., and Nicholson, R.S., 2001, Watershed contributions of nutrients and other nonpoint source contaminants to the Barnegat Bay-Little Egg Harbor estuary: Journal of Coastal Research, Special Issue 32, p. 28-82.

Gillespie, B.D., and Schopp, R.D., 1982, Low flow characteristics and flow duration of New Jersey streams: U.S. Geological Survey Open-File Report 81-1110, 164 p.

Gordon, A.D., 2004, Hydrology of the unconfined Kirkwood-Cohansey aquifer system, Forked River and Cedar, Oyster, Mill, Westecunk, and Tuckerton Creek basins and adjacent basins in the southern Ocean County area, New Jersey, 1998-1999: U.S. Geological Survey Water-Resources Investigations Report 03-4337, 5 pl.

New Jersey Department of Environmental Protection, 1996, The vital resource-New Jersey statewide water supply plan: Trenton, N.J., New Jersey Department of Environmental Protection, Policy and Planning, Office of Environmental Planning, August 1996, 173 p., 6 appendixes.

New Jersey Department of Environmental Protection, 2004a, Watershed Focus, New Jersey Department of Environmental Protection, Division of Watershed Management, Winter 2004, 16 p.

New Jersey Department of Environmental Protection, 2004b, Draft Water Supply Action Plan 2003-2004-New Jersey Statewide Water Supply Planning Process: Trenton, N.J., New Jersey Department of Environmental Protection, 17 p.

Nicholson, R.S., and Watt, M.K., 1997, Simulation of ground-water flow in the unconfined aquifer system of the Toms River, Metedeconk River, and Kettle Creek Basins, New Jersey: U.S. Geological Survey Water-Resources Investigations Report 97-4066, 100 p.

Watt, M.K., 2000, A hydrologic primer for New Jersey watershed management: U.S. Geological Survey Water-Resources Investigations Report 00-4140, 108 p.

Watt, M. K., Johnnson, M.L., and Lacombe, P.J., 1994. Hydrology of the unconfined aquifer system, Toms River, Metedeconk River, and Kettle Creek Basins, New Jersey, 1987-90: U.S. Geological Survey Water-Resources Investigations Report 93-4110, 5 pl.

Additional Information

The New Jersey District of the U.S. Geological Survey collects basic hydrologic data and conducts interpretive investigations of New Jersey's water resources. Information about USGS hydrologic monitoring networks, hydrologic data, research, fact sheets, and other publications are available at http://nj.usgs.gov.

Information about the New Jersey Department of Environmental Protection Water Supply programs, including water allocations policy, is available at http://www.state.nj.us/dep/watersupply.

New Jersey has a formal water-supply planning process. The New Jersey Statewide Water Supply Plan (NJSWSP) provides a framework to guide the management of potable, industrial, recreational, and ecological uses; initiate water conservation strategies; and develop the State's water-supply resources to ensure that a safe and adequate water supply will be available into the foreseeable future, including during times of drought. The current NJSWSP was completed in 1996 and is available at http://www.state.nj.us/dep/watershedmgt/publications.htm

While the NJSWSP is being updated, an Action Plan is being developed to identify those actions that cannot be delayed, including actions proposed for the Barnegat Bay-Little Egg Harbor watershed area. The draft New Jersey Water Supply Action Plan 2003-2004 is available at http://www.state.nj.us/dep/watershedmgt/DOCS/pdfs/WaterSupplyActionPlan03-04.pdf

The New Jersey Stormwater Best Management Practices Manual (BMP manual) has been developed to provide guidance to address the standards in the proposed Stormwater Management Rules. The New Jersey Stormwater Best Management Practices Manual is available at http://www.njstormwater.org/tier_A/bmp_manual.htm

LAND USE/LAND COVER

Central Question(s)

How is human development changing the land use/land cover of the Barnegat Bay watershed?

How much of the Barnegat Bay watershed has been preserved as publicly owned open space?

Explanation of the Indicator

Land use by humans is a primary cause of ecological change at many scales. The effects of some land use change on water quality and habitat quality may not be evident for decades. Poorly planned growth of urban areas throughout the nation has been responsible for fragmentation of landscapes and disruption of hydrologic and other natural cycles. Research has linked the degradation of estuarine habitat quality, as measured by the condition of benthic communities, sediment contamination and the frequency of hypoxia, to increased urbanization and loss of forested uplands within the nearby watershed. Examination of the extent and fragmentation of habitats as it relates to land cover and use is important to understand long-term change in estuarine systems. The amount of publicly owned open space lands provides some indication of those lands that will see a minimum of future development.

Several land use/change indicators have been identified as potentially being valuable to the Barnegat Bay National Estuary Program (BBNEP). These land use / change indicators include changes in the extent of 1) altered vs. unaltered land, 2) interior forest land, 3) public open space, and 4) impervious surface cover. Altered land would be defined as land that has been altered by humans, such as developed land or land used for agriculture or surface mining. Unaltered land refers to forests and wetlands. The interior forest indicator looks at the amount of both the upper watershed and wetland areas and subtracts out a 90m boundary around these areas adjacent to altered areas. The public open space indicator tracks that amount of publicly owned land, both land that is developed and undeveloped.

The Rutgers University Center for Remote Sensing & Spatial Analysis (CRSSA) has an ongoing land cover mapping and monitoring program for the Barnegat Bay watershed and adjacent Jacques Cousteau National Estuarine Research Reserve. Land cover represents the biophysical material or features covering the land surface and includes such categories as High Intensity developed, grassland, forestland, etc. Greater detail as to the vegetation community or habitat type is also mapped (e.g., Pitch pine lowland, high salt marsh). Based on satellite imagery, CRSSA has mapped land cover at varying levels of detail for the Barnegat Bay watershed for the years of 1972, 1984, 1995, and more recently, 2001.

GIS data for publicly owned open space and/or park lands were assembled from variety of sources, including: New Jersey Green Acres; the Ocean County Planning Office; the U.S. Fish & Wildlife Service; the New Jersey Conservation Foundation; and the Trust for Public Land. Data from 1999 was used to provide a pre-BBEP baseline, and March 2004 data were used for the update. This publicly owned land may not have necessarily been set aside for natural resources conservation purposes, but, due to its existing uses and conditions, it does serve that purpose. A prime example in the Barnegat Bay watershed is Lakehurst Naval Air Station, which includes extensive areas of valuable wildlife habitat. The impervious surface cover indicator indicates the extent of surfaces that are covered by impervious materials which would include such things as parking lots, roadways, and building structures.

Table 1. Year 2001 land cover in acres and as % of watershed study area for the Barnegat Bay Watershed.

Land Cover Code	Land cover description	Acres	% of Area
111	Developed: High intensity	23,924	5.6
112	Developed: Moderate intensity	48,493	11.3
113	Developed: low intensity (wooded)	24,727	5.8
114	Developed: low intensity (unwooded)	9,088	2.1
	Developed: total	*106,232*	*24.8*
120	Cultivated/Grassland	13,829	3.2
140	Upland Forest	125,641	29.4
160	Bare Land (quarries, transitional)	11,250	2.6
200	Unconsolidated Shore	5,734	1.3
210	Estuarine Emergent Wetland	24,551	5.7
240	Palustrine Wetland	71,186	16.6
250	Water	69,660	16.3
	Total	428,083	

Status

The developed/altered land cover indicator and the public open space indicators have been updated for this State of the Bay report.

The acreage estimates from the 2001 Land Cover Update are enumerated in Table 1. The 2001 data show that development within the Barnegat Bay watershed increased by 7,255 acres since 1995. Development represents approximately 30% of the watershed area (excluding the water area). Most of the new development has taken place on forested land. Also of note is the increase in the amount of Bare Land (i.e. extractive mining/quarries and transitional land cleared for development or some other land use). At 11,250 acres, this represents an increase of approximately 5,200 acres over that mapped in 1995. The amount of altered land (total of developed, cultivated/grassland and bare land) in 2001 is estimated to be 131,311 acres or approximately 37% of the watershed (excluding water).

As of March 2004, there were over 122,500 acres of publicly owned land in the Barnegat Bay watershed or approximately 34% of the watershed land area (Figure 2).

Trends

The changes in land cover mapped by CRSSA for 1972, 1984, 1995 and 2001, are displayed in Figure 1. Results show development within the Barnegat Bay watershed (excluding the water area) has increased from 63,542 ac to 75,395 ac to 98,977 ac to 106,232 ac during the years 1972, 1984, 1995 and 2001, respectively (Table 2). As a percentage of the watershed area (excluding water), development within the Barnegat Bay watershed has increased from 18% to 21% to 28% to 30% during the years 1972, 1984, 1995 and 2001, respectively (Table 2, Figure 3). The Altered land indicator also shows a steady increase from 23% to 30% to 34% to 37% of the watershed (excluding water) during the years 1972, 1984, 1995 and 2001, respectively (Table 2, Figure 3).

In 1999, there were approximately 103,100 acres

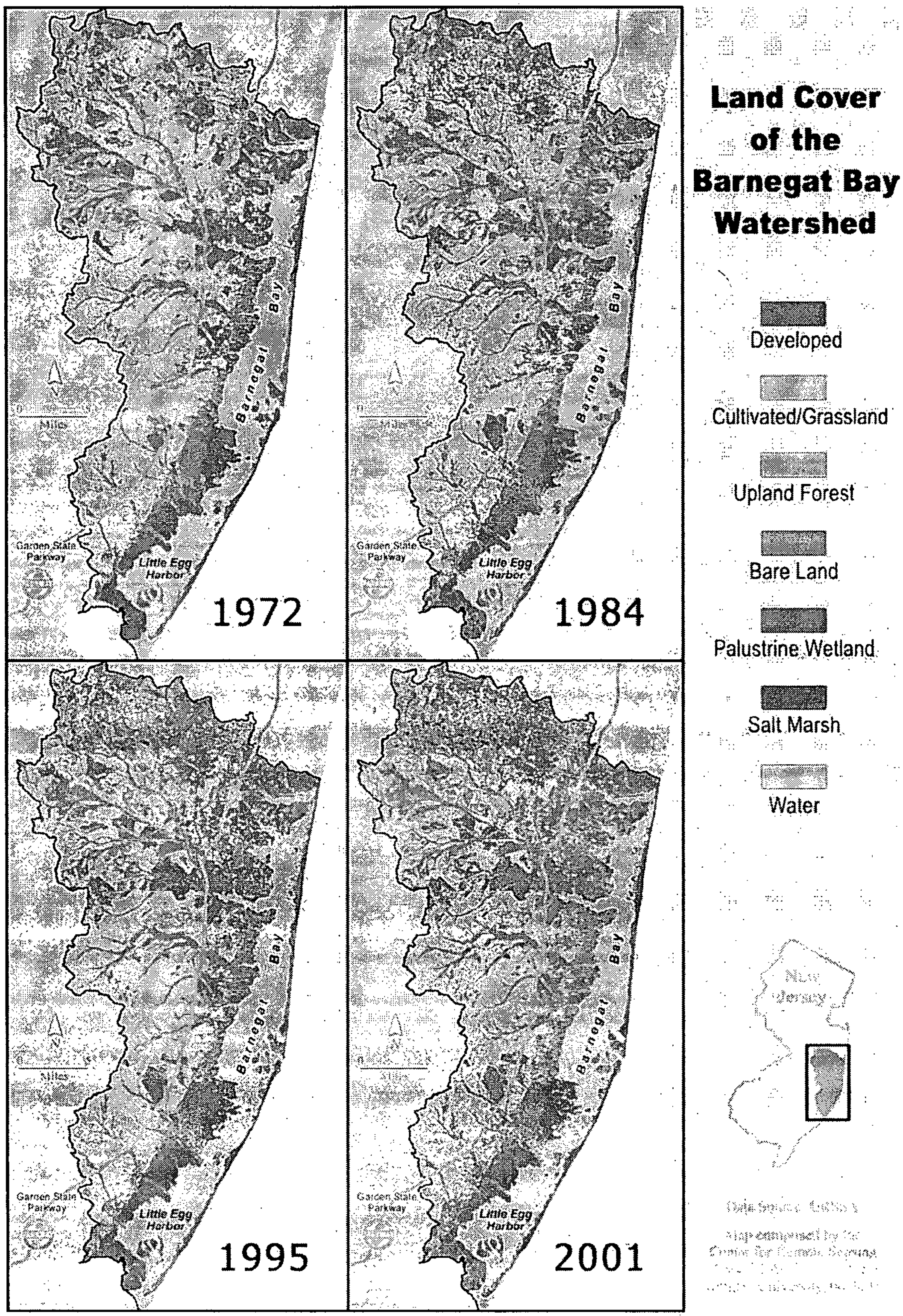


Figure 1. Land cover of Barnegat Bay watershed, 1972, 1984, 1995, and 2001.

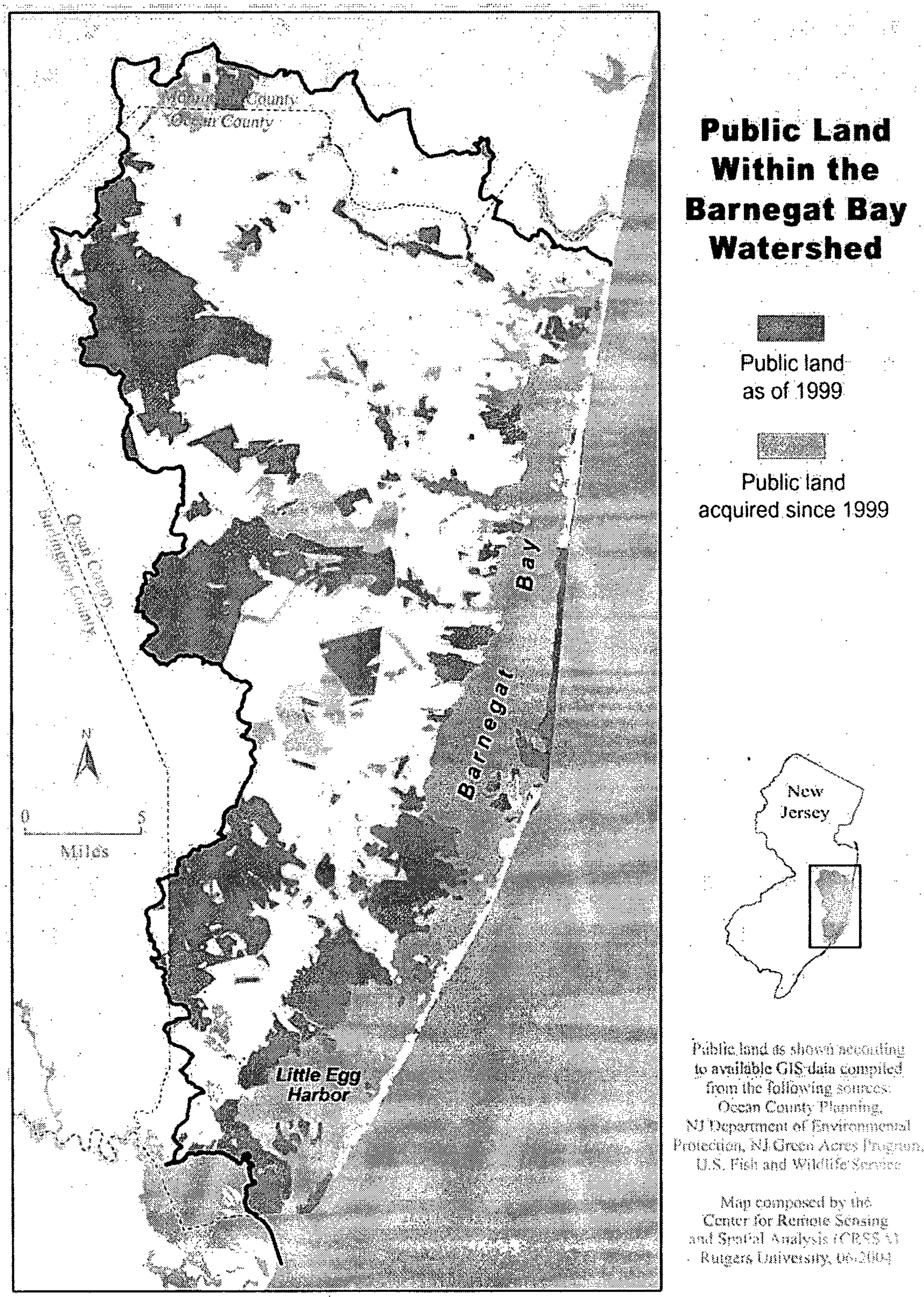


Figure 2. Publicly owned land in the Barnegat Bay watershed.

Table 2. Developed and altered land totals and percentage of watershed area (excluding water) by year for the Barnegat Bay watershed.

Category		1972	1984	1995	2001
Developed land	Area (acres)	63,542	75,395	98,977	106,232
	% of watershed	18%	21%	28%	30%
Altered land	Area (acres)	83,441	106,705	122,198	131,311
	% of watershed	23%	30%	34%	37%

of publicly owned land in the Barnegat Bay Watershed. As of March 2004, approximately 19,400 acres of additional publicly owned land were added in the intervening period (Figure 2). These new lands were primarily purchased as public open space by a variety of government and non-government organizations, including: Ocean County, New Jersey Department of Environmental Protection, The Nature Conservancy, the Trust for Public Land and individual municipalities. These additional acres included some major new purchases and/or easements in the Berkeley Triangle, Forked River Mountains, and Turkey Swamp area in the bay's upper watershed, as well as several key sites along the bayshore, including Good Luck Point and Kettle Creek.

Major Information Gaps

Additional information is needed on the more recent changes in impervious surface cover within the bay watershed. The New Jersey Department of Environmental Protection Land Use Mapping Program was established to map land use and impervious surface statewide. The NJDEP has contracted to have color-infrared aerial photography acquired statewide. This aerial photography has then been further processed to produce digital orthophotography. Based on this aerial photographic data, the NJDEP has contracted out the detailed mapping of land use. The first land use mapping for the Barnegat Bay watershed is for 1986. In 1995, imagery was acquired, and in addition to land use type, estimates of impervious surface cover were mapped. This data set has been updated recently with 2002 photography. Once the 2002 imagery has been interpreted (expected to be completed in 2005), a closer examination of trends in altered vs. unaltered land use and impervious surface cover will be possible. Comprehensive, up-to-date information with accurate boundaries on the publicly owned land is still not readily available in a digital GIS format. There is no single repository of such data across all ownerships (e.g., federal, state, county, municipal and non-governmental organization).

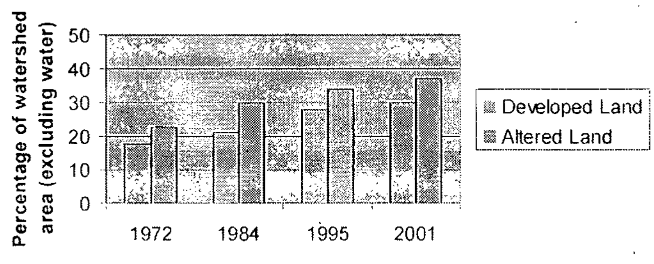
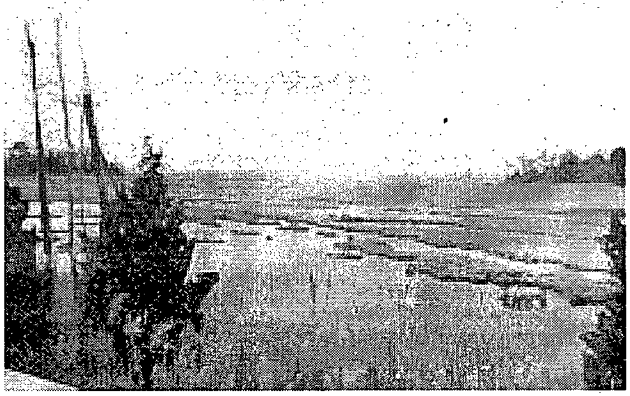


Figure 3. Developed and altered land, 1972-2001

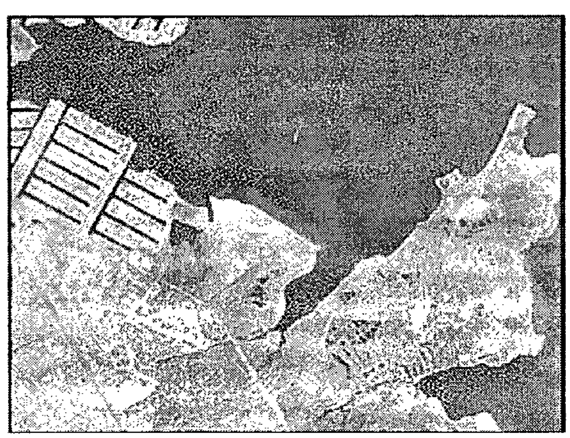
Additional Information

Rutgers Center for Remote Sensing & Spatial Analysis

Barnegat Bay Data Synthesis Project:
http://crssa.rutgers.edu/projects/runj/datasnth.html



Cattus Island County Park
Photograph by Bob Nicholson



Cattus Island and nearby development

APPENDIX

Appendix 1

Table 1
Plant Demographic Summary for Donor and Reference Sites 2001

Data presented in the table represent the average value of the parameter measured within the core with an error value of ± 1 standard deviation: Wasting Disease Infection (Presence presented as a decimal fraction), Shoot Density (# shoots/core), Leaf Biomass (grams ash free dry weight (g AFDW)/core), Below Ground Biomass (g AFDW/core), Algal Biomass (g AFDW/core), Blade Length (cm), Blade Width (mm).

Barnegat Inlet

Date	May 21	June 4	June 29	July 13	July 23	August 7	August 21	September 28
Wasting Disease Infection (% Presence)	0.22 ± 0.15	0.24 ± 0.24	0	0.0256 ± 0.0256	0	0	0	0
Shoot Density (#/core)	7.0 ± 2.08	7.33 ± 2.33	4.0 ± 1.52	16.33 ± 2.027	8.66 ± 2.6	9.66 ± 1.33	13.33 ± 3.71	22.0 ± 5.0
Leaf Biomass (g/core)	0.58 ± 0.14	2.10 ± 1.53	0.19 ± 0.02	0.84 ± 0.048	0.35 ± 0.11	0.26 ± 0.006	0.803 ± 0.27	2.14 ± 0.56
Below Ground Biomass (g/core)	0.32 ± 0.11	0.18 ± 0.027	0.42 ± 0.24	0.5 ± 0.12	0.67 ± 0.26	0.64 ± 0.021	0.13 ± 0.087	0.37 ± 0.12
Algal Biomass (g/core)	0.67 ± 0.187	0.53 ± 0.28	0.31 ± 0.14	0.19 ± 0.155	1.79 ± 1.52	0.038 ± 0.02	0.227 ± 0.13	0.17 ± 0.062
Blade Length (cm)	22.12 ± 3.77	16.16 ± 5.04	17.41 ± 1.63	17.69 ± 1.61	15.02 ± 1.32	14.44 ± 1.49	21.43 ± 2.59	29.4 ± 3.41
Blade Width (mm)	2.26 ± 0.082	2.156 ± 0.156	2.33 ± 0.166	2.36 ± 0.055	1.86 ± 0.13	1.63 ± 0.11	1.96 ± 0.36	1.84 ± 0.01

Date	May 21	June 4	June 29	July 13	July 23	August 7	August 21	September 28
Wasting Disease Infection (% Presence)		0	0	0.109 ± 0.093	0.06 ± 0.03	0.166 ± 0.059		0
Shoot Density (#/core)		4.3 ± 0.33	27.0 ± 1.53	18.33 ± 6.39	11.0 ± 1.53	20.33 ± 4.09		9.67 ± 3.84
Leaf Biomass (g/core)		0.089 ± 0.026	1.79 ± 0.21	0.72 ± 0.23	0.85 ± 0.11	0.78 ± 0.10		0.54 ± 0.25
Below Ground Biomass (g/core)		2.66 ± 2.56	1.67 ± 0.17	0.602 ± 0.23	0.36 ± 0.069	0.62 ± 0.12		0.204 ± .098
Algal Biomass (g/core)		0.033 ± 0.02	0.005 ± 0.003	0	0.031 ± 0.031	0.0003 ± 0.0003		0.107 ± 01.02
Blade Length (cm)		11.87 ± 0.59	26.4 ± 0.38	17.19 ± 1.77	22.55 ± 1.55	19.37 ± 2.03		24.48 ± 0.26
Blade Width (mm)		1.61 ± 0.18	2.28 ± 0.049	2.10 ± 1.00	2.55 ± 0.029	2.12 ± 0.15		1.88 ± 0.14

Ham Island

Table 1
Plant Demographic Summary for Donor and Reference Sites 2001

Data presented in the table represent the average value of the parameter measured within the core with an error value of ± 1 standard deviation: Wasting Disease Infection (% Presence), Shoot Density (# shoots/core), Leaf Biomass (grams ash free dry weight (g AFDW)/core), Below Ground Biomass (g AFDW/core), Algal Biomass (g AFDW/core), Blade Length (cm), Blade Width (mm).

Marsh Elder

Date	May 21	June 4	June 29	July 13	July 23	August 7	August 21	September 28
Wasting Disease Infection (% Presence)	0.37 ± 0.019	0.052±0.032	0	0.12±0.068	0.21±0.024	0.115 ± 0.038	0.059±0.059	0
Shoot Density (#/core)	19.33 ± 2.19	28.33 ± 5.17	16.5 ± 11.5	19.0 ± 1.53	6.5 ± 6.5	25.67 ± 4.70	14.0 ± 4.04	19.33 ± 2.19
Leaf Biomass (g/core)	0.91 ± 0.292	0.71 ± 0.18	0.84 ± 0.052	0.76 ± 0.029	0.846 ± 0.136	1.53 ± 0.33	1.90 ± 0.48	1.72 ± 0.33
Below Ground Biomass (g/core)	1.964 ± 0.205	2.14 ± 0.84	0.67 ± 0.30	1.59 ± 0.167	0.334 ± 0.305	1.47 ± 0.242	0.947 ± 0.288	1.32 ± 0.21
Algal Biomass (g/core)	0.64 ± 0.63	0.15 ± 0.027	0.003± 0.003	0.13 ± 0.13	14.41 ± 14.41	0.139 ± 0.035	0.207 ± 0.044	0.286 ± 0.096
Blade Length (cm)	12.68 ± 1.09	12.51 ± 1.50	23.0 ± 0.296	17.54 ± 1.13	12.08 ± 9.61	23.38 ± 2.16	33.81 ± 3.40	28.06 ± 0.56
Blade Width (mm)	2.03 ± 0.13	2.21 ± 0.13	1.96 ± 0.24	1.89 ± 0.13	2.59 ± 0.404	2.15 ± 0.11	2.75 ± 0.042	1.695 ± 0.106

Shelter Island

Date	May 21	June 4	June 29	July 13	July 23	August 7	August 21	September 28
Wasting Disease Infection (% Presence)	0.167 ± 0.104	0.155 ± 0.052	0.063 ± 0.06	0.148 ± 0.15	0.013 ± 0.013	0.047 ± 0.028	0	0
Shoot Density (#/core)	9.33 ± 2.33	9.67 ± 2.19	17.67 ± 3.18	10.33 ± 2.40	28.33 ± 12.47	24.67 ± 3.18	19.0 ± 6.24	37.33 ± 11.84
Leaf Biomass (g/core)	0.29 ± 0.054	0.177 ± 0.048	0.54 ± 018	0.408 ± 0.12	0.88 ± 0.38	3.155 ± 2.361	0.738 ± 0.259	1.34 ± 0.44
Below Ground Biomass (g/core)	0.173 ± 0.017	0.46 ± 0.178	0.46 ± 0.15	0.349 ± 0.12	0.57 ± 0.014	2.86 ± 2.21	0.456 ± 0.212	0.76 ± 0.24
Algal Biomass (g/core)	0.164 ± 0.053	0.36 ± 0.17	0.077 ± 0.07	0.65 ± 0.05	0.236 ± 0.095	0.0007±0.0007	0.005 ± 0.005	0
Blade Length (cm)	16.89 ± 1.013	14.507 ± 0.649	13.49 ± 1.28	14.86 ± 0.28	15.53 ± 2.84	17.82 ± 1.85	20.45 ± 0.67	18.29 ± 1.63
Blade Width (mm)	2.02 ± 0.172	1.61 ± 0.100	1.90 ± 0.013	2.19 ± 0.024	2.23 ± 0.053	1.94 ± 0.055	1.79 ± 0.13	1.739 ± 0.122

Table 2
Plant Demographic Summary for Donor and Reference Sites 2002

Data presented in the table represent the average value of the parameter measured within the core with an error value of ± 1 standard deviation: Wasting Disease Infection (% Presence), Shoot Density (# shoots/core), Leaf Biomass (grams ash free dry weight (g AFDW)/core), Below Ground Biomass (g AFDW/core), Algal Biomass (g AFDW/core), Blade Length (cm), Blade Width (mm).

Barnegat Inlet

Date	May 29	June 25	July 12	August 14	September 13	October 4
Wasting Disease Infection		0	0.0196 ± 0.019	0		0
Shoot Density		12.0 ± 1.73	13.33 ± 3.67	0		10.67 ± 2.33
Leaf Biomass		3.197 ± 1.469	1.66 ± 0.396	9.0 ± 4.51		4.22 ± 2.66
Below Ground Biomass		0.708 ± 0.165	0.316 ± 0.108	1.79 ± 0.41		2.72 ± 2.32
Algal Biomass		0.014 ± 0.009	0.097 ± 0.093	0.185 ± 0.044		0.61 ± 0.56
Blade Length		37.69 ± 6.76	25.9 ± 1.94	36.99 ± 4.77		37.22 ± 2.01
Blade Width		3.23 ± 0.266	1.93 ± 0.33	2.24 ± 0.24		3.11 ± 1.12

Ham Island

Date	May 29	June 25	July 12	August 14	September 13	October 4
Wasting Disease Infection	0.03 ± 0.03	0.11 ± 0.057		0	0.042 ± 0.042	
Shoot Density	20.67 ± 4.84	19.67 ± 6.98		9.33 ± 2.60	10.33 ± 2.96	
Leaf Biomass	1.4 ± 0.23	2.016 ± 0.418		1.30 ± 0.25	1.026 ± 0.114	
Below Ground Biomass	1.51 ± 0.58	1.42 ± 0.104		0.913 ± 0.249	3.79 ± 2.39	
Algal Biomass	0.077 ± 0.156	0.081 ± 0.0599		0	0.0017 ± 0.0017	
Blade Length	21.88 ± 1.09	34.09 ± 2.10		27.69 ± 2.19	19.08 ± 1.81	
Blade Width	2.37 ± 0.15	2.51 ± 0.176		1.67 ± 0.309	2.22 ± 0.11	

Table 2
Plant Demographic Summary for Donor and Reference Sites 2002

Data presented in the table represent the average value of the parameter measured within the core with an error value of ± 1 standard deviation: Wasting Disease Infection (% Presence), Shoot Density (# shoots/core), Leaf Biomass (grams ash free dry weight (g AFDW)/core), Below Ground Biomass (g AFDW/core), Algal Biomass (g AFDW/core), Blade Length (cm), Blade Width (mm).

Marsh Elder

Date	May 29	June 25	July 12	August 14	September 13	October 4
Wasting Disease Infection	0.064 ± 0.064	0.14 ± 0.079		0.078 ± 0.078	0	
Shoot Density	16.33 ± 6.49	16.00 ± 2.52		14.00 ± 2.08	7.67 ± 1.86	
Leaf Biomass	0.88±0.36	0.98 ± 0.19		1.68 ± 0.144	0.87 ± 0.23	
Below Ground Biomass	1.64 ± 0.17	2.01 ± 1.06		0.87 ± 0.17	0.73 ± 0.18	
Algal Biomass	0.24 ± 0.067	0.0053 ± 0.0039		0.104 ± 0.056	0.13 ± 0.04	
Blade Length	16.56 ± 0.94	21.43 ± 3.87		27.33 ± 2.27	19.88 ± 1.30	
Blade Width	1.91 ± 0.32	2.19 ± 0.15		2.41 ± 0.24	2.37 ± 0.096	

Shelter Island

Date	May 29	June 25	July 12	August 14	September 13	October 4
Wasting Disease Infection	0.133 ± 0.133	0		0	0	
Shoot Density	3.67 ± 0.88	9.67 ± 1.20		4.33 ± 0.33	6.00 ± 1.15	
Leaf Biomass	0.403 ± 0.132	0.85 ± 0.077		1.69 ± 0.45	1.79 ± 0.65	
Below Ground Biomass	0.169 ± 0.052	0.302 ± 0.043		0.14 ± 0.096	0.638 ± 0.196	
Algal Biomass	0.308 ± 0.222	0.103 ± 0.040		0.517 ± 0.162	16.42 ± 15.85	
Blade Length	27.42 ± 1.55	24.52 ± 2.21		36.20 ± 1.06	37.45 ± 4.39	
Blade Width	2.32 ± 0.16	1.88 ± 0.259		2.41 ± 0.48	2.89 ± 0.18	

Table 3
Plant Demographic Summary for Donor and Reference Sites 2003

Data presented in the table represent the average value of the parameter measured within the core with an error value of ± 1 standard deviation: Wasting Disease Infection (% Presence), Shoot Density (# shoots/core), Leaf Biomass (grams ash free dry weight (g AFDW)/core), Below Ground Biomass (g AFDW/core), Algal Biomass (g AFDW/core), Blade Length (cm), Blade Width (mm).

Barnegat Inlet

Date	5/29/2003	6/23/2003	7/25/2003	8/14/2003	9/17/2003
Wasting Disease Infection (% Presence)	0	0	0	0	0.11 ± 0.19
Shoot Density (#/core)	9.67 ± 4.04	18.0 ± 7.0	14.67 ± 11.24	6.0 ± 4.58	4.67 ± 1.53
Leaf Biomass (g/core)	0.99 ± 0.62	0.92 ± 0.27	0.79 ± 0.25	0.19 ± 0.09	0.33 ± 0.3
Below Ground Biomass (g/core)	3.44 ± 1.42	2.06 ± 0.64	2.31 ± 0.92	0.74 ± 0.83	0.49 ± 0.39
Algal Biomass (g/core)	0.51 ± 0.61	0.14 ± 0.14	0.15 ± 0.08	0.16 ± 0.20	0.11 ± 0.09
Blade Length (cm)	28.01 ± 19.68	15.20 ± 7.41	12.18 ± 3.9	13.55 ± 4.29	17.91 ± 2.56
Blade Width (mm)	2.58 ± 0.25	2.85 ± 0.2	1.88 ± 0.26	2.04 ± 0.04	1.98 ± 0.13

Ham Island

Date	5/22/03	6/12/03	7/25/03	8/13/03	9/17/03
Wasting Disease Infection (% Presence)	0	0.04 ± 0.07	0	0	0.39 ± 0.35
Shoot Density (#/core)	21.33 ± 15.57	6.0 ± 1.73	22.67 ± 3.79	31.0 ± 8.66	17.0 ± 6.0
Leaf Biomass (g/core)	1.19 ± 0.59	1.09 ± 0.44	0.94 ± 0.14	1.83 ± 0.43	0.95 ± 0.66
Below Ground Biomass (g/core)	2.73 ± 0.53	7.39 ± 6.81	2.99 ± 0.51	2.03 ± 0.76	2.01 ± 0.5
Algal Biomass (g/core)	0.27 ± 0.12	0.06 ± 0.05	0	0.01 ± 0.01	0.02 ± 0.01
Blade Length (cm)	25.34 ± 4.18	17.1 ± 2.8	14.74± 1.35	15.85 ± 3.97	17.78 ± 1.79
Blade Width (mm)	2.44 ± 0.24	2.47 ± 0.06	2.53 ± 0.11	2.72 ± 0.2	2.36 ± 0.44

Table 3
Plant Demographic Summary for Donor and Reference Sites 2003

Data presented in the table represent the average value of the parameter measured within the core with an error value of ± 1 standard deviation: Wasting Disease Infection (% Presence), Shoot Density (# shoots/core), Leaf Biomass (grams ash free dry weight (g AFDW)/core), Below Ground Biomass (g AFDW/core), Algal Biomass (g AFDW/core), Blade Length (cm), Blade Width (mm).

Marsh Elder

Date	5/22/03	6/12/03	7/25/03	8/13/03	9/17/03
Wasting Disease Infection (% Presence)	0	0	0	0	0
Shoot Density (#/core)	18.0 ± 4.36	10.0 ± 2.83	16.33 ± 5.51	13.0 ± 1.73	5.33± 2.52
Leaf Biomass (g/core)	0.32 ± 0.04	0.6 ± 0.15	0.83 ± 0.26	0.34 ± 0.04	0.22 ± 0.1
Below Ground Biomass (g/core)	2.13 ± 0.58	2.57 ± 0.39	1.41 ± 0.45	1.33 ± 0.19	1.81 ± 0.16
Algal Biomass (g/core)	0.04 ± 0.06	0.06 ± 0.02	0.01 ± 0.01	0.66 ± 0.7	0.05 ± 0.04
Blade Length (cm)	14.58 ± 0.56	15.58 ± 1.13	17.62 ± 10.21	14.68 ± 4.85	15.69 ± 4.37
Blade Width (mm)	2.09 ± 0.18	2.31 ± 0.44	2.25 ± 0.26	2.27 ± 0.31	2.28 ± 0.3

Shelter Island

Date	5/22/03	6/12/03	7/25/03	8/13/03	9/17/03
Wasting Disease Infection (% Presence)	0	0	0	0.03 ± 0.04	0.06 ± 0.06
Shoot Density (#/core)	27.33 ± 22.68	8.0 ± 7.55	10.67 ± 7.09	26.0 ± 5.2	20.0 ± 6.56
Leaf Biomass (g/core)	0.57 ± 0.2	0.25 ± 0.08	1.16 ± 0.85	1.35 ± 0.51	0.61 ± 0.23
Below Ground Biomass (g/core)	1.73 ± 0.59	0.95 ± 0.55	1.04 ± 0.22	1.55 ± 0.58	1.23 ± 0.1
Algal Biomass (g/core)		0.11 ± 0.09	0.18 ± 0.06	0.76 ± 0.09	0.3 ± 0.25
Blade Length (cm)	15.16 ± 3.64	8.52 ± 0.74	14.45 ± 1.24	16.26 ± 1.89	14.34 ± 1.66
Blade Width (mm)	1.8 ± 0.2	2.29 ± 0.25	2.93 ± 0.35	2.24 ± 0.31	2.11 ± 0.31