National Park Service
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Boston, Massachusetts

Bay Shoreline Physical Processes
(Fire Island National Seashore Science Synthesis Paper)

Technical Report NPS/NER/NRTR—2005/020

ON THE COVER
A section of the Great South Bay shore of Fire Island National Seashore. Photograph courtesy of the authors.

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Karl F. Nordstrom and Nancy L. Jackson

Institute of Marine and Coastal Sciences
Rutgers University
New Brunswick, NJ 08901

and

Department of Chemistry and Environmental Science
New Jersey Institute of Technology
Newark, NJ 07102

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U.S. Department of the Interior
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PREFACE

FIRE ISLAND NATIONAL SEASHORE
Science Synthesis Papers to Support Preparation of a General Management Plan

BACKGROUND AND PURPOSE

Fire Island National Seashore (FIIS) is scheduled to begin preparation of a new General Management Plan (GMP) in the near future. A GMP outlines how natural and cultural resources, public uses, and park operations should be managed over the next several decades. The GMP addresses significant issues or challenges that are facing the park, proposes management solutions, and establishes management priorities. The Fire Island GMP will be prepared by a team of planners, with input from the park, technical subject matter experts, and with substantial public involvement.

To insure that the GMP team has all relevant natural resource information available to them, a series of scientific synthesis papers has been prepared for a variety of natural resource topics that will be of special relevance to the Fire Island GMP. Based on a 2-day meeting with the FIIS Superintendent, FIIS Chief of Natural Resource Management, Northeast Region planners, and Northeast Region science staff, the following natural resource topic areas were identified;

- Geomorphology of beaches and dunes
- Physical processes of the bay shoreline
- Habitat ecology and water quality of Great South Bay
- Conservation of Living Marine Resources (habitats, finfish and shellfish)
- Vector-borne diseases
- White-tailed Deer ecology and management

For each of these topics, leading scientific experts were invited to prepare papers that synthesize our current state-of-knowledge. There is a wealth of published technical information on these topics. The purpose of these papers was to provide a scientifically credible summary of the available and relevant information and present this information in a succinct manner. The GMP team will receive papers that provide an objective, independent and expert synthesis of an extensive and often complex technical literature. Each paper was subject to the scientific peer review process.

Each synthesis paper is expected to accomplish the following;

- Synthesize and interpret the relevant literature and monitoring data to describe the fundamental processes controlling the natural resource, and describe historic and recent trends or rates of change for relevant processes, habitats, or species.
- Describe current and historic management, regulatory, and other activities that have been relevant to the particular natural resource.
- Identify gaps in our current understanding of the natural resource.

Because the synthesis papers are prepared prior to initiation of the GMP process, if information gaps are considered critical to decision-making for the GMP there may be adequate time to conduct the appropriate required studies or data analysis tasks. Moreover, the papers will serve to identify topics or issues that should be the focus of additional synthesis or review papers in support of the GMP information gathering and synthesis phase.

OVERVIEW OF THE PAPERS

These summaries are derived, with some editing, directly from the individual papers.

The Coastal Geomorphology of Fire Island: a Portrait of Continuity and Change
Technical Report NPS/NER/NRTR—2005/021
Authors: Norbert P. Psuty, Michele Grace, and Jeffrey P. Pace
Rutgers University

Summary: Fire Island has a well-developed beach on the ocean side and is dominated by a variety of dune features, reaching elevations of 11-13m. Much of the island is undeveloped and retains a wide array of coastal dune forms in near natural condition. However, there are a number of residential communities, primarily on the western portion of Fire Island, that have altered the landscape and geomorphological processes. The controlled inlets at either end of the island are a type of interactive feature that have particular roles in the passage of sand along the shore. Thus, the geomorphological characteristics and configuration of the island are products of a suite of natural processes, complemented by human actions. This paper describes the landforms (beaches, dunes, inlets, and barrier island gaps) and basic controls on these landforms, such as tides, wave climate, storm history, the availability and rate of supply of sediment, and sea level rise.

There is insufficient sediment coming to Fire Island from all of the potential sources to maintain the entire system. There is evidence of erosion on all parts of the island, except the artificially-created Democrat Point. The sediment deficits are greatest along the eastern portion of the island, but are buffered in the central and western area because of the contributions from an offshore source. The recent acceleration in sea-level rise, coupled with the general negative sediment budget, will result in continued beach erosion and dune displacement, with greater effects occurring in the eastern portion of the island.

During the peer review process, it was determined that a follow-up synthesis paper should be prepared that specifically focuses on the response of Fire Island beaches and dunes to human activities, including ORV traffic, structures, sand fencing, beach scraping, and other activities. This paper is presently being developed.

Bay Shoreline Physical Processes, Fire Island
Technical Report NPS/NER/NRTR—2005/020
Authors: Karl F. Nordstrom, Rutgers University
Nancy L. Jackson, New Jersey Institute of Technology

Summary: Wave and current energies on the bay side of Fire Island are low, but much of the bay shoreline is eroding. The greatest changes occur near inlets or next to marinas and bulkheads. Inlets, overwash and dune migration deliver sediment from the ocean to the bay where it forms substrate that evolves into tidal flats, marshes and beaches. These sediment inputs allow barrier islands to maintain themselves as they migrate landward under the influence of sea level rise. The creation and migration of inlets in the past extended their influence well beyond locations of present inlets.

About 17.0 km of the 49.5 km long bay shoreline of Fire Island is marsh; 24.5 km is beach; and 8.0 km is fronted by bulkheads, marina breakwaters and docks. The biggest constraints to allowing Fire Island to undergo natural dynamism are the desire to protect private properties on the island from erosion and overwash and the need to protect the mainland from flooding due to formation of new inlets. Bulkheads are common on the bay shore in developed communities. These structures replace natural formations landward of them and prevent sand from entering the littoral drift system, causing sediment starvation in unprotected areas downdrift. These adverse effects can be reduced by replacing lost sediment by beach nourishment. Use of beach fill on the low tide terrace covers benthic habitat. This problem could be avoided by placing fill above the mean high water mark, creating an eroding feeder upland.

Dune building projects on the oceanside and construction of bulkheads on the bayside restrict the delivery of sediment by inlets, wave overwash and aeolian transport. Temporary inlets would provide some sediment, but artificial closure by human efforts would limit these inputs to a much smaller area than in the past.

Future sea levels are expected to rise at a greater rate, causing increased frequency of overwash and creation of new inlets if not prevented by beach nourishment and dune-building projects on the oceanside. Elimination of the delivery of sediment to the bayside by these natural processes will result in continued retreat of the bay shoreline into the higher portions of the barrier island, resulting in loss of marsh habitat, increase in open water habitat, and truncation of cross-shore environmental gradients.

Water Quality and Ecology of Great South Bay
Technical Report NPS/NER/NRTR—2005/019
Author: Kenneth R. Hinga
University of Rhode Island

Summary: The overall objective of this paper is to present a short synopsis of information on the characteristics of water quality and ecology of the Great South Bay, with particular attention to the waters within the boundaries of Fire Island National Seashore (FIIS), where possible. This report serves as an update and addition to the report *Estuarine Resources of the Fire Island National Seashore and Vicinity* (Bokuniewicz et al., 1993). Great South Bay is approximately 45 km long, with a maximum width of about 11 km. The Bay is shallow, with an average depth at mean low water of just 1.3m.

Regarding water quality, a review of bacterial indicator monitoring data suggests that some bayside beaches and marinas of Fire Island have had fecal coliform concentrations that are at or approaching levels of concern, but in general the levels are quite acceptable. Nutrient enrichment is an issue for all shallow, enclosed, lagoon-type estuaries, like Great South Bay. There is an encouraging trend of decreasing dissolved inorganic nitrogen in Great South Bay over the past quarter century. Coincident with the decline in nitrogen, there appears to be a trend of decreasing primary production, as determined by measuring phytoplankton chlorophyll concentration, over the past 15 years. Historically, portions of Great South Bay (e.g., near and in Moriches Bay) experienced intense phytoplankton blooms, probably attributed to discharges from duck farms. Since 1985, a brown tide has occurred periodically to disruptive levels in the Bay. Brown tide blooms can cause significant mortalities of hard clams and can damage seagrass beds because the blooms prevent light sufficient to support growth of the seagrass species. The densest seagrass beds in the Bay are found along the shallow shoreline of the Seashore.

Conservation and Management of Living Marine Resources
Technical Report NPS/NER/NRTR—2005/023
Authors: David O. Conover, Robert Cerrato, and William Wise
Stony Brook University

Summary: The finfish species likely to be landed by commercial harvesters from Fire Island NS or nearby waters are bluefish, winter flounder, summer flounder, weakfish, Atlantic silversides, and menhaden. The recreational species landed within the Bay have not been described in detail since the 1960s, but total recreational landings for New York as a whole suggest that fluke, winter flounder, bluefish, weakfish, tautog, and black sea bass are the main species. Some of the fish species landed in the Seashore region are present only transiently as older juveniles and adults. Such species would include striped bass, menhaden, eels, and weakfish. These species do not use the Bay as a spawning and nursery area. Other species use Fire Island waters as both nursery grounds for young-of-the-year (YOY) stages as well as adults. The value of Seashore estuarine habitats for these species is great (bluefish, winter flounder, fluke, tautog, black sea bass). Ecologically important species, those that are an important forage species for piscivorous fishes, include Atlantic silversides, bay anchovy, sand lance, northern pipefish, and others. Killifishes are a major component of the fish fauna of salt marsh habitats. Shellfish of potential recreational or commercial value found within Seashore boundaries include surfclam, hard clam, blue mussel, soft clam, oyster, bay scallop, razor clam, conch, blue crab, Jonah crab, rock crab, lady crab, spider crab, and horseshoe crab (although not technically classified as shellfish). Generally, there has been a dramatic decline in the commercial harvest of shellfish species from the Bay. For example, since 1976 the harvest of hard clams has declined 100 fold. It is recommended that the Seashore take a leadership role in reaching out cooperatively to government and non-government agencies toward encouraging restoration of Great South Bay living marine resources and increasing public awareness of coastal zone management issues.

Vector-borne Diseases on Fire Island
Technical Report NPS/NER/NRTR—2005/018
Author: Howard S. Ginsberg
USGS-Patuxent Wildlife Research Center

Summary: This paper discusses eleven tick-borne and five mosquito-borne pathogens that are known to occur at FIIS, or could potentially occur. The potential for future occurrence, and ecological factors that influence occurrence, are assessed for each disease. Lyme disease is the most common vector-borne disease on Fire Island. The Lyme spirochete, *Borrelia burgdorferi*, is endemic in local tick and wildlife populations. Public education, personal precautions against tick bite, and prompt treatment of early-stage infections can help manage the risk of Lyme disease on Fire Island. The pathogens that cause Human Monocytic Ehrlichiosis and Tularemia have been isolated from ticks or wildlife on Fire Island, and conditions suggest that other tick-borne diseases (including Babesiosis, Rocky Mountain Spotted Fever, and Human Granulocytic Ehrlichiosis) might also occur, but these are far less common than Lyme disease, if present.

West Nile Virus (WNV) is the primary mosquito-borne human pathogen that is known to occur on Fire Island. Ecological conditions and recent epizootiological events suggest that WNV occurs in foci that can shift from year to year. Therefore, a surveillance program with appropriate responses to increasing epizootic activity can help manage the risk of WNV transmission on Fire Island.

White-tailed Deer Ecology and Management on Fire Island
Technical Report NPS/NER/NRTR—2005/022
Author: H. Brian Underwood
USGS-Patuxent Wildlife Research Center

Summary: Deer populations have grown dramatically on Fire Island National Seashore (FIIS) since 1983. Trend data reveal a dichotomy in deer dynamics. In the eastern half of the island, deer density appears to have stabilized between 25-35 deer/km^2. In the western half of the island, deer densities are 3-4 times as high in residential communities. Concomitant with that increase has been a general decline in physical stature of some animals, visible impacts on island vegetation, especially in the Sunken Forest, and a perceived increase in the frequency of human and deer interactions. Intensive research on FIIS has shown that deer occupy relatively predictable home ranges throughout the year, but can and do move up and down the island. Impacts of deer on vegetation are most dramatic in the Sunken Forest. Most obvious are the effects of browsing on the herb layer of the Sunken Forest. The least obvious, but perhaps more significant impact is the stark lack of regeneration of canopy tree species since about 1970, which coincides with the initiation of the deer population irruption. A number of herbs and shrubs have been greatly reduced in the understory, and their propagules from the soil.

Deer do not readily transmit the bacterium that causes Lyme disease to other organisms, but deer are important hosts for adult ticks which underscores their importance in the transmission pathway of the disease to humans. Deer on FIIS, while occasionally docile, are still wild animals and should be treated as such. Some animals are relatively unafraid of humans due to the absence of predation and a lack of harassment. This in turn has contributed to a long-standing tradition of feeding deer by many residents and visitors, particularly in western portions of the island. Feeding affects both the behavior and population dynamics of deer inhabiting Fire Island. Recent efforts to reduce deer feeding by visitors and residents have been very effective. Ongoing experiments with Porcine Zona Pellucida immunocontraception demonstrate some promise of this technology as a population management tool. Success appears to be linked directly to factors affecting access to deer, which vary considerably among treatment locations. Continued high National Park Service visibility among communities in the form of interpretive programs, extension and outreach activities, and continued support of research and monitoring of deer and their effects on island biota are keys to successful resolution of persistent issues.

Preface prepared by:
Charles T. Roman
National Park Service
North Atlantic Coast Cooperative Ecosystem Studies Unit

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SUMMARY

Wave and current energies on the bay side of Fire Island are low, but much of the bay shoreline is eroding. The greatest changes occur near inlets or next to marinas and bulkheads. Inlets, overwash and dune migration deliver sediment from the ocean to the bay where it forms substrate that evolves into tidal flats, marshes and beaches. These sediment inputs allow barrier islands to maintain themselves as they migrate landward under the influence of sea level rise. The creation and migration of inlets in the past extended their influence well beyond locations of present inlets.

About 17.0 km of the 49.5 km long bay shoreline of Fire Island is marsh; 24.5 km is beach; and 8.0 km is fronted by bulkheads, marina breakwaters and docks. The biggest constraints to allowing Fire Island to undergo natural dynamism are the desire to protect private properties on the island from erosion and overwash and the need to protect the mainland from flooding due to formation of new inlets. Shore-parallel walls, mostly bulkheads, are common on the bay shore in developed communities. These structures replace natural formations landward of them and prevent sand from entering the littoral drift system, causing sediment starvation in unprotected areas downdrift. These adverse effects can be reduced by replacing lost sediment by beach nourishment. Use of beach fill on the low tide terrace covers benthic habitat. This problem could be avoided by placing fill above the mean high water mark, creating an eroding feeder upland.

The natural resources on barrier islands are products of dynamic processes of erosion and deposition, making attempts to maintain a stable natural resource inventory difficult. Dune building projects on the oceanside and construction of bulkheads on the bayside restrict the delivery of sediment by inlets, wave overwash and aeolian transport. Temporary inlets would provide some sediment, but artificial closure by human efforts would limit these inputs to a much smaller area than in the past.

Future sea levels are expected to rise at a greater rate, causing increased frequency of overwash and creation of new inlets if not prevented by beach nourishment and dune-building projects on the oceanside. Elimination of the delivery of sediment to the bayside by these natural processes will result in continued retreat of the bay shoreline into the higher portions of the barrier island, resulting in loss of marsh habitat, increase in open water habitat, and truncation of cross-shore environmental gradients. New marshes could form if sediment is added artificially to the bayside to keep pace with sea level rise. The greater width of the barrier would allow for development of the cross-shore environmental gradient and help restrict formation of deep breaches during storms.

Suggestions for future research include 1) obtaining quantitative information within representative environments to evaluate changes through time; 2) identifying drift cells to determine the locations for establishing feeder beaches; 3) determining specific impacts of bayside bulkheads and other cultural features on adjacent unprotected land and options for overcoming detrimental effects; 4) evaluating the potential for using dredge spoil from navigation projects as fill for beaches and new marsh substrate; 5) estimating the effect on the bay shore of allowing new inlets to evolve or closing them; 6) evaluating the potential for

allowing for controlled overwash to periodically reinitiate landscape evolution without significantly increasing hazard potential.

INTRODUCTION

The ocean shore of Fire Island has received considerable attention in recent years, with studies focused on the sediment budget and its relationship to Moriches and Fire Island Inlets (Kana 1999; Smith et al. 1999), foredune mobility (Psuty 1990) and changes to the beach and foredune in relation to wave effects as influenced by offshore bars (Gravens 1999; Morang et al. 1999). In contrast, little has been written about the bay shore of Fire Island. The only detailed study is a single experiment on depths of sediment activation and longshore sediment transport at Sailors Haven (Jackson et al. 1993; Sherman et al. 1994; Nordstrom et al. 1996; Nordstrom et al. 2003). This white paper addresses this information need by identifying and synthesizing existing information on processes and landforms (beaches and marshes) on the bay shore of Fire Island and relevant literature on management of estuarine shores to assist the National Park Service in developing a new General Management Plan for the park. The effects of past human actions are evaluated, as are alternatives for future shore protection, including projects designed to address oceanside erosion that will affect bay resources.

Procedure

Insight into current issues and priorities were gained by review of the Fire Island Management Plan, the Strategic Plan for fiscal years 2001-2005, and the Geoindicator Scoping Report (Geologic Resources Division 2002) The literature on estuarine processes, landforms and management strategies, existing studies of physical and biological resources on Fire Island and Great South Bay, and analysis of aerial photographs from 1930 (from the Suffolk County Planning Department) and 2003 (from the New York District Engineer) were evaluated and used to identify the significance of the following:

1) the bay shore processes responsible for shoreline change on estuarine beaches;
2) shoreline characteristics associated with bay processes;
3) longshore drift compartments and sources and sinks for littoral sediments;
4) historic and recent trends in shoreline change at Fire Island;
5) resource values of estuarine beaches;
6) natural and cultural resources now threatened by erosion;
7) potential effects of accelerated sea level rise;
8) shore protection options;
9) effects of bayside protection structures and future protection projects on the oceanside on the unprotected bay shore;
10) research needs related to bayside processes and management strategies.

BAY SHORE PROCESSES

Waves

The primary agents of erosion on estuarine beaches are waves generated within the bays by local winds, although tidal currents, ocean waves that enter the bays through inlets, and boat wakes are important processes on some sites (Nordstrom 1992; Jackson 1995). In general, the longer the fetch (width of bay across which waves can be generated), the larger the wave. Fetch distances at Fire Island (Figure 1) are narrow, usually less than 15 km in the direction of northeasterly storm winds and the more frequent and stronger northwesterly winds, so the generation of waves is restricted. Shallow water depths also limit growth of waves and dissipate the energy of existing waves before they break onshore. Water depths bayward of the Fire Island shoreline are often less than 2 m at distances of 2 km and less than 1.0 m within 1 km. Wave heights and periods (interval between successive crests) are less than in many other estuaries because of the short fetch distances and shallow depths. Field data from Nordstrom et al. (1996) taken at Sailors Haven 17 km east of Fire Island Inlet indicate that significant wave heights are less than 0.14 m and periods are less than 2.6 s during onshore winds >10.0 m s^{-1}. The velocities of wave-generated longshore currents can be low due to the low wave energies. The greatest longshore current velocities monitored by Nordstrom et al. (1996) were 0.24 m s^{-1} although average wind speed was 11.7 m s^{-1} and winds blew at an angle of 71 degrees from shore normal. The steep foreshore (common on estuarine beaches) and low wave energies result in a narrow surf/swash zone. The width of this zone on Fire Island can be as little as 3.0 m during onshore winds of nearly 13 m s^{-1} (Nordstrom et al. 1996).

Ship and boat wakes are more conspicuous on estuarine sites than on oceanside sites because vessels can pass close to beaches, and the wakes account for a greater proportion of the total energy because incident estuarine waves are low (Nordstrom 1992). Boat wakes are conspicuous, especially when winds are relatively calm, giving the impression that they are more significant than they are. The average energy of boat wakes is usually only a small percentage of the average energy of wind waves in estuarine basins of any size, and detectable increases in shore erosion due to recreational boating only occur where beaches are close to navigation channels (Zabawa and Ostrom 1981). Boat wakes can play a significant role in erosion in narrow creeks and basins (Byrne et al. 1981; Levin and FitzGerald 1981), where they can be the principal cause of erosion (US Army Corps of Engineers 1981; Downing 1983), but their effect is probably minor on Fire Island, except perhaps in localized areas where boat activity is intense and close to the shore (e.g., vicinity of marinas and the inlets).

Tidal and Wind-Induced Water Levels

Tidal range varies significantly over short distances in estuaries. Tidal range usually decreases with distance from an inlet in shallow environments in long narrow bays behind barrier islands. Tidal range affects the strength of tidal currents and the vertical distribution of wave energy over the profile, determining the width of the beach and the duration that breaking waves will occur at any elevation. Tidal range is low within Great South Bay, except near Fire Island Inlet. Tidal currents can be strong near the inlets on both ends of the island, but they are subdued on the rest of the bay shore, where flows are dominated by longshore currents, due to acute angle of wave breaking or wind drift, due to winds blowing along the shore.

Because of the low tidal range, local water depths on much of the island are often a function of wind direction and wind speed that affect surge levels. Water depths at Sailors Haven during the kinds of wind events that occur in a single winter month can range from 0 m to 0.75 m above the height of the low tide terrace that forms the bay bottom at the break in slope at the base of the beach foreshore (Nordstrom et al. 1996). This range in water level is greater than the 0.21 m mean and 0.24 m spring range at that site. The high water levels and wind-generated waves accompanying them create the small bay overwash platforms that occur landward of the beach in low areas along the bay shore.

Water levels are not always correlated with wind direction on the bay shore because surge levels are a function of the regional shoreline orientation, basin configuration, and ocean surge that passes through the inlets into the bay, and there is a time lag between changes in wind and changes in water level. High water levels on the bay shore of Fire Island can be associated with both onshore winds (when bay water is blown against the shore and has not had time to exit the inlets) and offshore winds (when ocean water enters the bay from the oceanside when surge levels are high on ocean beaches).

Inlets

Inlets have a pronounced influence on the bay shore due to their effect on tidal range and storm surge and the amount and form of sediment delivered to the bay from the ocean beaches. Tidal deltas form substrate that subsequently evolves into tidal flats and marshes. Spits at the ends of inlets extend into the bay and become eroding uplands that supply sediment to form beaches bayward and downdrift of them, and dunes that form on these spits may eventually be exposed on the bay shore where they form the highest land there. The frequent breaching of the island in the past and the rapid rate of migration of these inlets (especially Fire Island Inlet) extended the zone of inlet influence well beyond the locations of the present inlets. Fire Island Inlet is believed to have opened as far to the east as East and West Fire Islands (Figure 1) that may be flood tide deltas of the early inlet (Leatherman and Joneja 1980). Since 1825, this inlet migrated about 7.5 km to the west at an average rate of 65 m yr^{-1}, until migration was halted in 1941 by construction of the eastern jetty. The approximately 16-km-long portion of Fire Island between East and West Fire Islands and Davis Park does not appear to have been affected by inlets in the historic past, but the orientation of the surface topography just west of Sailors Haven mimics the spits that characterize the barrier island updrift of migrating inlets. The next former inlet to the east appears to be Bayberry Dunes Inlet that opened in the vicinity of Davis Park some time between 1770 and 1827; at least 5 inlets have opened and closed in historic time between this inlet and Moriches Inlet (Leatherman and Joneja 1980). The wide, irregular bay shore of this portion of Fire Island appears to be the result of sedimentary deposits delivered through these inlets. The persistence of the irregular shore is due in part to the recent nature of the deposits, the lower energy in the bay waves in this fetch-restricted zone, and the presence of marsh deposits on the shore that are more resistant to wave erosion than the sandy sediments on the higher overwash platforms.

Numerous inlets into Moriches Bay existed over the past several centuries, although no inlets appear to have existed between 1839 and 1931, when the present inlet opened (Smith et al. 1999). Breaches have occurred in the vicinity of Moriches Inlet since that time but have been closed artificially; the inlet migrated just over 1 km in 21 years prior to jetty construction in 1952-53 (Smith et al. 1999).

The impacts of a new inlet can be positive, negative, neutral or unknown, depending on the resource being evaluated or the specific management objective or management mandate (Tanski et al. 2001). The National Park Service may allow inlets to remain open or allow them to be closed artificially, depending on the degree of threat to human populations or facilities (York 2004). The enabling legislation for the wilderness area on Fire Island specifies that the park not preclude closing of breaches that form if loss of life, flooding or other severe economic or physical damage occurs to the Great South Bay region (Geological Resources Division 2002). It is likely that public sentiment and the attitudes of decision makers in most other management agencies would support closure of any new inlet through Fire Island. The investment society has made in the existing inlets and the magnitude and nature of environmental changes associated with formation of new inlets have led to recommendations to prevent new inlets from forming and closing inlets that do form (Long Island Regional Planning Board 1989).

Ocean Overwash

High waves during storms and raised water levels can wash over the backbeach, through gaps in dunes and over low dunes and deliver ocean water and sediment to landward portions of barrier islands. The delivery of these sediments is one of the ways barrier islands maintain their widths as they are translated landward under the influence of sea level rise. Overwash deposits are most likely to reach the bay when barrier islands are low and narrow, as occurs on the updrift side of migrating inlets where longshore accretion is too rapid to create large flood tide deltas, spits or dune fields or away from inlets in locations where erosion occurs on the seaward side, landward side, or both sides.

Sediment delivered to the bay bottom creates higher substrate that can be colonized by marsh, and sediments delivered to the marsh creates higher substrate that can be colonized by upland species. The higher overwash lobes that outcrop on the bay shore stand as upland. The lower overwash lobes have been reworked by bay waves, forming beach ridges of bay origin. Some of the ridges provide sufficient protection from wave attack to allow marsh to form to the lee. Overwash deposits are the substrate on which new dunes form on the oceanside and migrate bayward.

Leatherman and Allen (1985) report that substantial volumes of overwash occurred from 1938 to 1954. However, little of this sediment reached the bay shoreline. The lack of recent ocean overwash and delivery of sediment through inlets have contributed to bay shore erosion. Prevention of ocean overwash and inlet formation by maintaining high oceanside dunes on

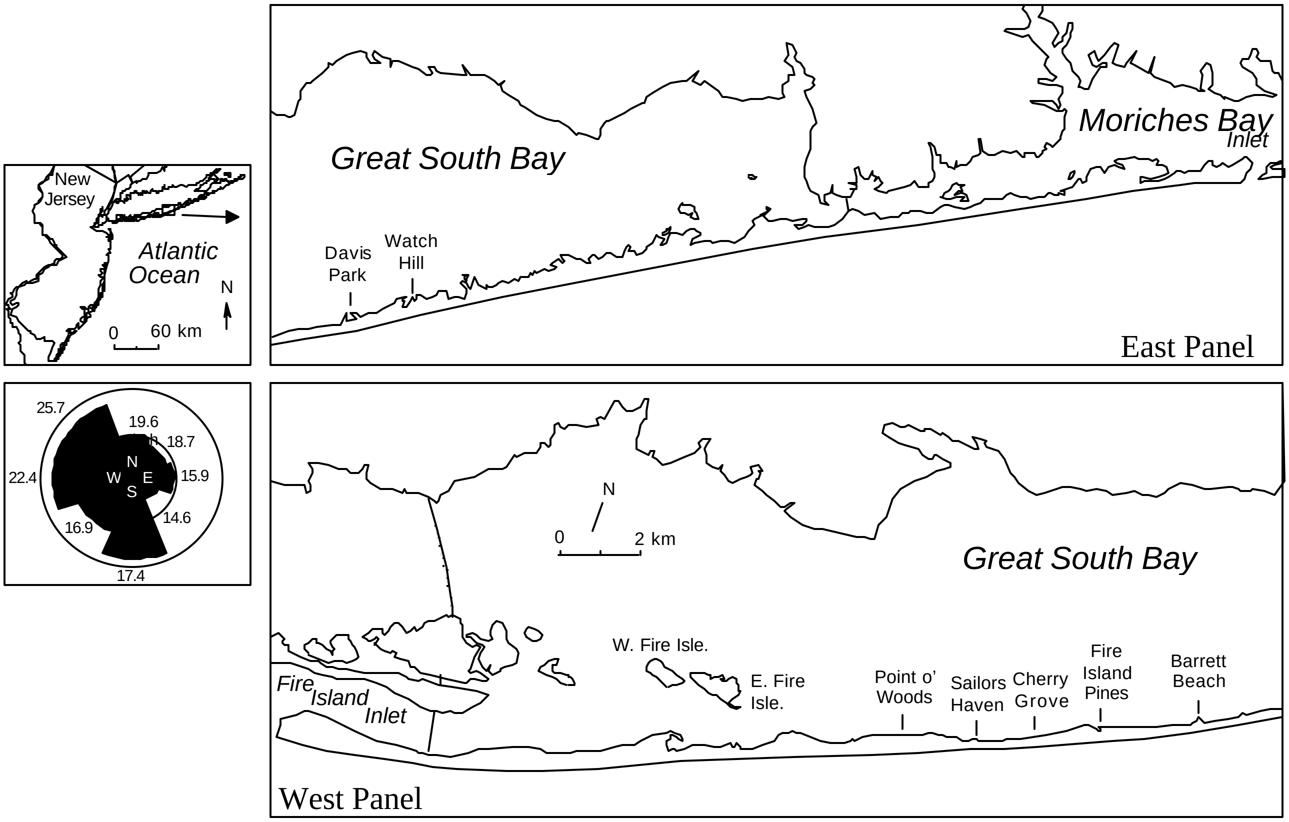

Figure 1. Fire Island and Great South Bay. Wind rose data are from Kennedy Airport for 1975—1979. Kennedy Airport is located 40 km to the west of Fire Island Inlet.

narrow portions of the barrier keeps the bay shore in a sand-starved state. Many bulkheads have been built on the high ground that would normally erode and provide sediment to nearby beaches, so even the former overwash deposits are unavailable in places.

Aeolian Transport

The width of unvegetated beach has a pronounced effect on the potential rate of transport of sand by wind (Davidson-Arnott and Law 1990). Estuarine beaches are narrow, even at low tide, so substantial source widths for aeolian transport occur only over a portion of each tide cycle and only when the wind blows at an oblique angle to beach orientation (Nordstrom and Jackson 1994). Jackson et al. (1993) found that no aeolian transport occurred on a narrow beach with a mean grain size 0.40 mm at Sailors Haven under a mean wind speed of 11.5 to 13.2 m s^{-1}, even where the acute wind angle resulted in a beach width of just over 10.0 m. In contrast, a rate of transport of 1.16 kg m^{-1} h^{-1} occurred on a nearby beach that was wider and had a more acute orientation to wind resulting in a 20.1 m wide source width.

Relatively low salinities and low amounts of salt spray on estuarine beaches enable growth of dense vegetation on the dunes and backbeach, further reducing the source width and reducing the likelihood that sand will be mobilized by winds. Vegetation litter can provide a nearly complete cover early in the fall and early winter, before it is broken down, removed or displaced higher on the beach. The displacement of wrack higher on the beach exposes more of the sand source below it, but the small amount of wind blown sand is usually insufficient to bury the wrack and allow sediment to pass into the dune. Subsequent wave action during small storms removes the wrack and the wind-blown sediment within it (Nordstrom and Jackson 1994). As a result, estuarine dunes usually are smaller than their ocean counterparts and comprise a smaller percentage of shoreline length. The few dune forms landward of bay beaches at Fire Island are little more than a thin aeolian cap on wave-formed beach ridges. Isolated relict dunes, resulting from aeolian transport from the oceanside, occur in some locations. These dunes form the highest land on the bay shore.

SHORELINE CHARACTERISTICS

Shoreline Orientation

Bay shorelines are often composed of isolated reaches with different orientations resulting from variations in subsurface stratigraphy, irregular topography inherited from drainage systems, differential erosion of vegetation on the surface of the beach and in peat outcrops on the foreshore, and varying amounts of sediment in eroding formations (Drew and Kraft 1980; Rosen 1980; Phillips 1985). The irregular orientation of the bay side of Fire Island is largely due to periodic additions of sediment delivered from the oceanside through overwash, dune migration, and through inlets as flood tide deltas. Small depositional cuspate forelands occur in places, but these forelands comprise a small percentage of the shoreline.

Differential erosion may account for subsequent differences in orientation, for example, where resistant marsh substrate is adjacent to readily erodible unconsolidated sandy strata. Human activities also have contributed to shoreline irregularity where marinas have been built and where dredge sediment has been placed in the water or on the marsh or where deeper channels have been dredged into the barrier island. Segments of shore have been smoothed or made more irregular by installation of bulkheads, depending on whether the installation was done in one large project or piecemeal. Bay filling has occurred in association with construction of some bulkheads and marinas.

Low tidal ranges tend to favor transverse bar and rip morphology (Wright et al, 1986; Short 1991), and observations of estuarine beaches in microtidal environments reveal this kind of topography on the low tide terraces (Nordstrom 1992). The relatively large size of these bars and their attachment to the beach foreshore implies that they affect change on the upper beach and that sediment may be exchanged between them (Bruner and Smosna 1989). Tracer experiments conducted at Sailors Haven indicate that there is transfer of sediment from the foreshore to the bars, but the quantities are appreciable only near the attachment of the bars to the upper foreshore (Nordstrom et al. 1996). Inspection of 1930 aerial photos indicates that these transverse bars were common along the bay shore, but they are no longer conspicuous in locations that are now protected by bulkheads.

Types of Shoreline Environments

An inventory of shoreline features taken from the 2003 vertical air photos and 1:24,000 scale topographic sheets indicates that approximately 17.0 km of the 49.5 km long shoreline of Fire Island is saltmarsh. The total length of marsh shoreline is actually greater than this linear distance because of the crenulate shape of the areas of overwash and flood shoals on which the marsh has formed. Bokuniewicz et al. (1993) estimated that 250 ha of saltmarsh existed within the seashore. Bulkheads, marina breakwaters and docks extend along about 8.0 km of shoreline. Beaches extend along 24.5 km of the shoreline. Many of these beach deposits have formed on platforms formed by former oceanic overwash. In some places, the eroding upland portion of the bay shore is a dune deposit, resulting from aeolian transport on the oceanside. The higher land on the bay shore of Fire Island has been subject to the most intensive human development in the past, and thus beaches are more threatened than marshes by human attempts to develop and protect homes and navigation structures. The threat to marshes is due to sea level rise that will be of greater importance in the future.

Saltmarshes are beds of intertidal vegetation that are alternately inundated and drained by the tides (Day et al. 1989). They are accretional environments, accumulating biogenic and terrigenous sediment in response to this inundation. Backbarrier marshes often begin their evolution as growth on sandy sediments delivered by ocean wave overwash or inlets to the bay bottom that raise the substrate into the intertidal frame. Subsequent deposition may be due to biogenic or terrigenous sedimentation. Future vertical growth is required to maintain elevation as sea level rises. Most of the saltmarsh on Fire Island is east of Davis Park where numerous inlets formed in the historic past. Enclaves of marsh exist west of Davis Park, but they are fronted by small barrier beaches that are a response to the more energetic wave regime there. The beaches provide protection to the marshes landward of them and allow them to reach a mature state. Marshes within the seashore are dominated by Spartina alterniflora and S. patens (Bokuniewicz et al. 1993).

Bay beaches on Fire Island are similar to estuarine beaches elsewhere, being characterized by relatively steep planar foreshores fronted by a broad, flat low tide terrace (Figure 2). The interaction between these two different components of the beach results in distinct differences in the characteristics of waves at different stages of the tide and different stages in storm passage (Nordstrom and Jackson 1992). The low tide terrace dissipates wave energies during strong onshore winds, when water levels are low. The surf zone may be wide at these times, but the energy is not concentrated. Waves usually break as plunging waves on the upper foreshore at higher water levels, concentrating energy over distances of only a few meters.

Two general profile responses associated with wind/wave interaction occur on bay beaches (Figure 3). The first response (Figure 3A) is when sediment is removed from the upper foreshore and deposited on the lower foreshore with a change to a concave upward profile. This response is favored by winds blowing more directly onshore. Erosion occurs on the upper foreshore at higher water levels associated with high tide or storm surge. The second response (Figure 3B) is the vertical landward displacement of the entire foreshore profile while the profile slope is maintained. This parallel slope retreat results from longshore sediment transport and can occur as a result of prolonged periods of unidirectional wave approach or during high energy events when little sediment enters the beach from updrift. Parallel retreat is typical of sand starved beaches downdrift of natural breaks in shoreline orientation or downdrift of shore protection structures. The implication is that protection structures can both starve the downdrift beach of sand and change the way the beach profile responds to a given wave condition.

LONGSHORE DRIFT COMPARTMENTS AND SOURCES AND SINKS FOR LITTORAL SEDIMENTS

The irregular orientation of bay shorelines isolates beach compartments, reducing or eliminating the exchange of sediments between them, creating numerous small drift cells, resulting in different types of environments with different erosion rates in adjacent shoreline segments (Phillips 1985). The low energy of the bay waves and currents is insufficient to smooth the shoreline orientation by concentrating energy on the small headlands. Even groups of trees and marsh outcrops may act as headlands defining drift compartments (Hardaway et al. 1989; Nordstrom 1992). Longshore drift cells are short, which simplifies efforts to manage local problem areas but complicates development of a single comprehensive strategy for the bayside.

Longshore transport rates on estuarine beaches can be an order of magnitude less than rates on ocean beaches (Kraft et al. 1979). Annual rates of 17,000 to 47,000 m^3 yr^{-1} have been determined on energetic beaches in Chesapeake Bay, Delaware Bay and San Francisco Bay (US Army Corps of Engineers 1981; Zabawa et al. 1981) but rates can be <10,000 m^3 yr^{-1} for more sheltered beaches (US Army Corps of Engineers 1981; Wallace 1988; Freire and Andrade 1999). No long-term rates of transport exist for bay beaches on Fire Island, but a short-term study at

Figure 2. Bayside beach west of Sailors Haven showing narrow, steep upper foreshore and broad, flat low tide terrace and bars. Peat outcrops on the lower foreshore and vegetation litter on the upper foreshore resist landward migration of the bay barrier but do not prevent it.

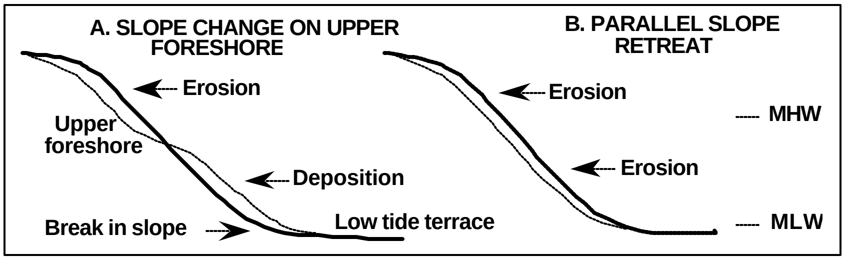

Figure 3. Beach profile responses to storm erosion. Source: Nordstrom and Jackson (1992).

Sailors Haven reveals a rate of transport of 0.97 m^3 hr^{-1} with a wind speed of 9.9 m s^{-1} blowing onshore at an angle of 49 degrees (Nordstrom et al. 2003). These rates may appear low, but they may cause high rates of erosion because the quantities of sediment in transport represent a sizeable fraction of the total unconsolidated sediment in the active beach prism on the small beaches (Nordstrom 1992). An annual loss of only about 7,000 m^3 yr^{-1} from a 1/2 km long bay beach at Sandy Hook, NJ resulted in a net landward displacement of the shoreline of 3.5 m yr^{-1} (Nordstrom 1989). An annual rate of transport of only 765 m^3 yr^{-1} can cause substantial accretion and erosion at shore perpendicular structures (Downing 1983), but change may be relatively inconspicuous in the absence of shore perpendicular barriers. Geomorphic changes monitored by Nordstrom et al. (1996) indicate that storms with onshore wind speeds <13 m s^{-1} are not effective erosional agents on beaches where there is no interference with longshore transport from updrift. The lack of significant change in foreshore position throughout their study indicates that there is little cross-shore sediment exchange during small storms and that gross rates of longshore transport may greatly exceed net rates. However, the form of the overwash deposits behind the active beach indicate that surges in this micro-tidal estuary can create water levels well above the elevation of the low tide terrace during larger storms and cause considerable geomorphic change.

HISTORIC AND RECENT TRENDS ON THE BAY SHORE OF FIRE ISLAND

Changes to the shoreline of Fire Island were evaluated using existing reports (Leatherman and Joneja 1980; Leatherman and Allen 1985; Bokuniewicz et al. 1993; Tanski et al. 2001), supplemented by data from aerial photographs for 1930 made available by the Suffolk County Planning Department and fall 2003 aerial photographs made available by the US Army Corps of Engineers.

Much of the bay shoreline at Fire Island is eroding, with an average rate of about 0.3 m yr^{-1} and maximum rates of over 1.0 m yr^{-1} (Leatherman and Allen 1985). Comparison of the 1930 and 2003 aerial photographs reveals that the greatest changes to the estuarine shoreline have occurred near inlets or where marinas or bulkheads have been built. The marinas have had the most profound effect because their construction is accompanied by dredging and disposal of spoil which make portions of the bay deeper and create shoals and uplands in disposal areas. Several marinas form salients extending into the bay, and the bulkheads built around these structures have divided the shore into smaller drift cells and created wave shadow zones that alter the rate of sand moving alongshore. The salients constructed at Sailors Haven and Barrett Beach have caused the most conspicuous change because these structures were built along portions of the shore that were linear and fronted by a continuous beach. The marina at Davis Park and other marina facilities built within bulkheaded segments are less problematic because there is little, if any, sediment moved alongshore to be altered by the structures.

The bulkheads that have been constructed in one long section have made the shoreline more linear, whereas bulkheads that have been built incrementally (e.g. west of Ocean Beach) have made the shoreline more irregular. The most conspicuous differential erosion has occurred east of the bulkhead at Point o' Woods, where a structure was already in place in 1930. Bulkheads constructed at Cherry Grove and Fire Island Pines are more recent, but landward offsets of the unprotected shores adjacent to these structures reveal differences in erosion rates. Beaches that were conspicuous in these unprotected areas in 1930 are inconspicuous in 2003, implying that the eroding shore adjacent to these structures is sand-starved.

Piers also may affect shoreline response. Cuspate forelands have formed at and near some of these structures, indicating that they provide traps or wave shadow zones. Cuspate forelands have also developed within a few hundred meters of some bulkheads and marinas (but not immediately adjacent to them). These features are not conspicuous in these locations in the 1930 photographs, so they are attributed to the structures, but it is difficult to specify a cause-effect mechanism for their formation.

Saltmarsh shorelines are a result of low wave energy, and the marsh, once formed, is even more resistant to erosion. As a result, some marsh shorelines reveal little change in position or orientation over many decades. The position of the marsh shoreline to the east of Davis Park changed little between 1930 and 2003, except at Bayberry Dunes, where a relatively large marina has been built into the marsh. Marshes that form landward of beach barriers in more open parts of the bay (Figure 2) are more vulnerable because the wave energies are sufficiently great to displace the bay barriers landward, burying the marsh and killing the vegetation. The resulting outcrops of marsh peat on the foreshore are not sufficiently resistant in this wave energy regime to prevent further erosion, although they may slow the process.

Marshes are also vulnerable to changes in water level. Bokuniewicz et al. (1993) speculate that the extent of tidal marshes was reduced during 1835 to 1931 due to inlet closures that reduced the tidal range and left portions of marsh above the tidal zone. The dependence of marshes on inlets is not confined to tidal range alone. Delivery of sediment from the oceanside is required to maintain substrate elevation to help keep pace with sea level rise.

RESOURCE VALUES OF ESTUARINE SHORES

Local variability of estuarine shores creates great variability of habitats, including beach, marsh and tidal flat. Upland (backbarrier) habitat may directly abut the bay, where wave erosion has eliminated the beaches. Human structures add still other kinds of habitats to these natural ones. Much of the Fire Island shoreline is comprised of sandy beaches because wave energies are sufficient to rework the sandy substrate and prevent marsh growth, but marshes outcrop on the shoreline where wave energies are typically low.

Saltmarshes provide habitat for many young and adult estuarine organisms and a source of food to the rest of the estuary and to ocean organisms; they also regulate important components of estuarine chemical cycles (Day et al. 1989). Saltmarshes are among the most productive natural environments in the world and often comprise a large proportion of the total area of estuaries (Day et al. 1989). They comprise a relatively small proportion of the Great South Bay and Moriches Bay estuaries, which increases the relative importance of the marshes in the seashore. Nearly half of the area of the subaerial barrier island east of Davis Park is saltmarsh.

The low tide terrace provides habitat for benthic fauna and substrate for seagrass beds. Several studies of the shellfish and benthic invertebrates of Great South Bay and Moriches Bay have been conducted (reviewed in Bokuniewicz et al. 1993), but these studies do not address the significance of shoreline position to benthic communities. Seagrasses on more stable, somewhat deeper portions of the low tide terrace bind sediments with their roots and rhizomes, baffle waves and currents with their leaf canopy, inhibit entrainment of sediment, trap waterborne particles and incorporate dissolved nutrients into plant biomass (Fonseca 1996). Despite their in-situ importance, the linkage between seagrass beds and the beaches and marshes that comprise the shoreline landward of them is not clear. Seagrass litter as well as macroalgae provide physical and chemical inputs to the intertidal environments, but the significance of changes to the shoreline to aquatic vegetation is obscure.

Under natural conditions, overwash and inlet creation provide sediment that inundates the low tide terrace landward of the barrier island, converting subaqueous habitat to intertidal and subaerial habitat. Under present conditions, with stable inlets and with little potential for new inlets to remain open, subaqueous habitat is slowly expanding at the expense of these other two environments.

Estuarine beaches have a different resource potential from ocean beaches because of differences in wave energy, nearshore water depth, temperature of water and land, water quality, and size, shape and surface characteristics of the landforms (Nordstrom 1992). The resources may not be immediately appealing or readily apparent because of their scale and isolation from locations favored by humans for recreation. The low perceived value of estuarine beaches often results in loss of beach habitat as the shoreline is modified to accommodate uses or shore protection methods, such as bulkheads that do not require a beach.

Sandy beaches in estuaries provide important habitat (Burger 1986; Botton and Loveland 1989; Nordstrom, 1992) but have not been, historically, a high priority area of concern (Jackson et al. 2002). Studies of the effects of protection structures on beach biota are rare, but existing studies indicate that structures adversely affect meiofaunal abundance and horseshoe crab spawning (Botton et al. 1988; Dove and Nyman 1995; Spalding and Jackson 2001).

Intertidal (and shallow subtidal) lands can be important feeding areas for young marine fish and spawning areas for mature marine fish because of productive substrate and offshore vegetation. The intertidal area provides habitat for clam species and numerous epifauna and infauna (Spalding and Jackson 2001). Fish and invertebrates in the regularly exposed intertidal zone are prey for foraging waterfowl and shorebirds. The dry upper foreshore and wrack line are also foraging areas for upland species, especially in early morning and evening (Nordstrom 1992). Vegetation species that could not tolerate the stress of wave erosion or salt spray in an ocean-dune environment are found close to the backbeach in an estuary. The proximity of upland species to the beach, combined with the large amount of vegetation litter on the foreshore enable frequent faunal interactions between terrestrial and aquatic species, in contrast to ocean shores where the wide beach and dune provide a wider buffer zone between terrestrial and aquatic species. Many of these habitats and interactions are prevented or truncated by bulkheads.

The estuarine beaches of Fire Island are the least studied marine habitat in the seashore, presumably due to the relative scarcity of flora and fauna in this subenvironment relative to the sandy bottom, submerged aquatic vegetation and salt marsh, and no information about the abundance of intertidal macrofauna is available on these beaches (Bokuniewicz et al. 1993). There is a growing interest in the status of beaches in other estuaries where biota are being threatened by beach loss (Jackson et al. 2002). The bay beaches on Fire Island may be spawning sites for *Menidia menidia* (Atlantic silversides) and *Fundulus heteroclitus* (mummichogs), but there is insufficient knowledge of this use to decide whether habitat availability limits the abundance of these species (Bokuniewicz et al. 1993). The beaches also provide spawning areas for *Limulus polyphemus* (horseshoe crabs) and nesting sites for diamondback terrapins.

POTENTIAL EFFECTS OF SEA LEVEL RISE

There is a general consensus that global sea levels will rise at an increased rate from those in the recent past (Barth and Titus 1984; Tooley and Shennan 1987; National Research Council 1987; Oerlemans 1989; Meier 1990). Changes in sea level have important implications for future evolution of coastal landforms and ecosystems, but the changes are difficult to predict. Many studies of past changes exist (e.g. Psuty 1986; Tooley 1990; Gayes et al. 1991; Carter 1992; Finkl 1995), and predictions of future changes on coastal landforms are increasing (van Huis 1989; Nicholls and Leatherman 1995), but most predictions are highly speculative, and they cannot reliably address future human responses.

The effects of climatic change and sea level rise may reduce or eliminate coastal habitats (Carter 1992; Nicholls and Branson 1998; Brown and McLachlan 2002) or result in abandonment of coastal settlements and a return to more natural coastal characteristics (Corre 1989). Landforms that are low in elevation or have low gradients will be highly susceptible to inundation (Gornitz 1991). Substantial reductions in wetland area and a corresponding increase in open water habitat may occur if rates of sea level rise increase substantially (Orson et al. 1985). Beaches that formerly fringed marshes may be eliminated, although new beaches may form the contact with high ground at the former landward margin of the marsh. Accelerated sea level rise is likely to cause erosion along the seaward margins of coastal wetlands, accelerate erosion of beaches that are now retreating and initiate erosion on beaches that are presently stable or accreting (Bird 1987). The likelihood of erosion will be increased where a sea level rise deepens nearshore waters and allows larger waves to break on the foreshore (Bird 1987). Estuarine beaches and marshes will be vulnerable because water depths on the low tide terraces will increase, resulting in decreased wave attenuation. The relative increase in wave energy on bay beaches is likely to be most pronounced on micro-tidal shorelines like Fire Island where water depths on the low tide terrace are shallow over most of the tidal cycle under present conditions. The increase in still water level may also have a greater effect on flooding of formations behind beaches on micro-tidal shorelines. Thus the low upland portion of Fire Island could be converted to marsh.

Increased frequency of oceanic overwash is likely to result in greater amounts of sediment delivered to the bay side of the barrier island if it is not prevented by implementation of beach nourishment and dune-building projects. The overwash could compensate for increased water depths in the bay and allow for new saltmarsh to form. Both beaches and marshes may be more ephemeral because of more frequent displacement of the backbarrier shoreline through overwash, complicating efforts to manage these environments as stable resources.

Many of the future rates of environmental change associated with accelerated sea level rise will fall within limits of some of the prehistoric periods of natural changes but will exceed the recent, relatively slow rates to which humans have become accustomed. Conspicuous accelerations in rates of change are likely to be considered negative and generate a response from coastal managers. The above scenarios identify changes that could take place in the absence of human modifications. On developed shores, where mitigation efforts are cost effective, it is likely that many natural changes may have less impact than human actions to modify sediment supply or protect property and maintain a stable or predictable resource base (Titus 1990, Jones 1993; Midun and Lee 1995; Nordstrom 2000). Increased development of shores susceptible to erosion does not automatically guarantee loss of beach space and beach habitat over the short term if large-scale beach nourishment projects are implemented.

SHORE PROTECTION OPTIONS

The principal means of addressing shoreline erosion are: 1) no action; 2) employing land use controls; 3) building static engineering structures; and 4) augmenting natural protective features using vegetation or artificial beach nourishment. Erosion control is a major issue in many estuaries in the USA. The largest of the estuarine systems and the ones that have received the most study are Delaware Bay, Chesapeake Bay, Puget Sound and their tributaries and connecting channels. Shore-parallel walls (bulkheads and rip-rap revetments) were common in most esturaries in the past, but there is great interest in offshore breakwaters and sills in Chesapeake Bay (Hardaway and Byrne 1999). Pronounced differences occur in management approaches on the New Jersey and Delaware sides of Delaware Bay, with structural protection being preferred in New Jersey and beach nourishment being preferred in Delaware. Many creative measures that are more compatible with natural processes than shore-parallel walls are being carried out in Puget Sound, where many projects are being designed by individual property owners, often using anchored logs as an alternative construction material (Zelo and Shipman 2000). Many shore protection options exist. The management problem is one of finding the unique method or combination of methods appropriate to each site-specific problem area.

No Action

The no-action alternative is more likely to be implemented on estuarine shores than on ocean shorelines by agencies responsible for erosion management because of the lower value of buildings and investment potential. Several feasibility studies conducted by the US Army Corps of Engineers to examine alternatives to address critical erosion problems in estuarine communities in the USA recommended that no funds be appropriated by the federal government because there were no concentrations of buildings or properties for which structural protection would be economically feasible (Nordstrom 1992). These studies assumed that the changes to the estuarine shore were confined to bayside processes. On sparsely developed barrier islands, where sediment delivered from ocean sources provide the substrate on which bayside environments form, plans for protecting the bay shore should be linked to comprehensive plans to protect the ocean shore.

The result of implementing the no-action alternative by government agencies to address erosion of private properties is usually a fragmented approach to protection as individual property owners exercise independent solutions. Property owners are often quick to install a static protection structure at the first sign of erosion. Their methods may be ineffective and they may destroy the resource value of the shore as the shoreline erodes to the location of the structure. The no-action alternative may be a preferred strategy on public parklands because 1) there is ample space to relocate threatened structures; 2) ecological resources that are not threatened by erosion often have greater importance than threatened structures; or 3) there is a need to retain the greatest variety of natural resources or flexibility in their use. The no action strategy for adjacent developed shores or developed enclaves within park holdings can have minimal impact on park resources if property owners do nothing or considerable impact if property owners protect their land with static structures.

Land Use Controls

Land use controls (zoning, setback lines, health ordinances, performance standards) can make people aware of coastal hazards, reduce or relocate population and property, reduce costly expenditures for repair of damages, and preserve and restore natural resources, but developed communities are often reluctant to apply land use controls when a property owner needs to protect existing facilities. Zoning is an effective form of land use control in sparsely developed areas of the shoreline. Sensitive ecologic areas and shoreline reaches that are vulnerable to storm wave attack can be delineated, and development can be prohibited or restricted within these zones such that human health and safety are not threatened or important habitat is not destroyed. Setbacks for coastal construction can take the form of erosion control setback lines or setbacks designed to maintain a buffer zone to retain the viability of other aspects of the estuary, such as water quality. Many jurisdictions have setback requirements for oceanside developments and for wetlands (Houlahan 1989; Phillips 1996). The concept could be applied to estuarine environments.

Ordinances can be passed that set performance standards on construction near the shoreline to ensure that buildings and structures can withstand storm wave attack without the need for protection structures. Public health ordinances that regulate on-site waste disposal and the location and construction of on-site water supplies are crucial to protecting the quality of ground water and minimizing estuarine pollution and can be used to control density of development and proximity to bay waters. Activities that accelerate erosion may also be controlled, including foot traffic, grading, removing natural vegetation, and watering of exotic species. Controls designed to insure continued sediment delivery to the beaches fronting high ground include limitations on the construction of bulkheads, seawalls, and other static defense structures designed to prevent erosion. Several states (e.g. Maine, North Carolina) have instituted controls on static erosion control structures that can be used as a model.

The great ecological value of some estuarine shores relative to ocean shores may call for greater emphasis on land use controls for environmental protection than is required on ocean shores. Marshes are already well protected. Aquatic and benthic habitat are important resources on bay shorelines, so restrictions on vegetation removal, use of exotic vegetation or use of fill could extend to the lower beach and nearshore.

Static Structures

Groins

Groins are shore-perpendicular structures designed to trap sand moving in the longshore current. These structures are common on ocean beaches but are often of limited usefulness on estuarine shores because the natural rate of longshore transport and the supply of sand are low (Downing 1983; Ward et al. 1989). Beaches may form within groin fields, but they are often too small to be effective as shore protection (Wang et al 1982). Groins have greater value in locations where longshore transport is more fully developed, as on long stretches of beach unbroken by pronounced breaks in shoreline orientation and subject to relatively high wave energies, immediately downdrift of local sources of readily mobilized sediment (such as eroding cliffs composed of unconsolidated sediment), or near inlet entrances, where strong tidal currents and refracted ocean waves deliver sediments from ocean sources. Groins are also of considerable value to retain beach resources at locations that have been artificially nourished (US Army Corps of Engineers 1981a) or to protect adjacent natural areas, such as salt marshes from excessive sedimentation (Anderson 1987; Hardaway et al. 1989). Because of their obtrusive nature and interference with the natural process of longshore sediment transport, groins appear to be of little use at Fire Island. One exception could be at locations where future beach nourishment projects are employed in developed communities adjacent to marsh habitat, where excessive sedimentation through longshore transport would threaten marsh growth.

Seawalls, bulkheads and revetments

Shore-parallel walls are the most common erosion control measure in estuaries, and their lengths are increasing through time (Canning and Shipman, 1993; Shipman and Canning, 1993; Douglass and Pickel 1999). They are the most common erosion control structure found on the bay shore of Fire Island (Bokuniewicz 1993). The low wave energies and gentle offshore gradients make construction of fixed engineering works more practical than in the ocean. Shore-parallel walls include bulkheads (vertical walls designed primarily to hold land in place), revetments (sloping structures designed to allow wave runup to dissipate) and seawalls (larger structures that withstand direct attack of storm waves). These structures (here collectively termed bulkheads) are often preferred on bay sites because they do not have to be massive to withstand attack by bay waves; they take up minimal space; or they seem appropriate because there is no perceived need for a beach (Nordstrom 1992). The space constraint is often critical because state regulations (including New York) often severely restrict construction in the intertidal or subtidal zone on the bay side and there is often little undeveloped property available between buildings and the shore on the landward side.

Bulkheads replace natural formations landward of them and prevent upland sand sources from entering the littoral drift system, causing sediment starvation downdrift. Structures built of stone may create unique and stable habitat, but this habitat may support exotic species and lead to new patterns of predation. Construction of bulkheads is often incremental, creating a complex shoreline configuration, with beaches of different widths isolated from each other by artificial headlands formed by short lengths of protective walls (Figure 4). The closed drift segments help maintain sediment in these beach enclaves but the structures restrict longshore transport of sediments and biota. Local reversals of longshore transport within the confined beaches can increase foreshore mobility near the ends of the segments (Figure 4, Transect A), contributing to cycles of parallel beach change (Type B response, Figure 3). Progressive loss of sediment bayward of a bulkhead will cause the structure to intersect the beach at a lower elevation on the profile (Transects B and C, Figure 4). The interaction of waves with a structure increases wave reflection and turbulence, nearshore current velocities, and sediment activation and transport at the base of the structure (Kraus 1988; Kraus and McDougal 1996; Miles et al. 1997). Changes in infiltration and exfiltration of water through the beach near the structure can change moisture content of sediments (Plant and Griggs 1992). These conditions can lead to coarsening of beach foreshore sediments, increased scour and steepening of the foreshore, reducing its suitability as habitat (Thom et al. 1994). The sequence of changes seaward of a bulkhead progresses from truncation of the upper foreshore (Transect B, Figure 4) to elimination of the foreshore (Transect C, Figure 4) (Thom et al. 1994). A conclusion of studies of impacts of shore armoring is that the level of physical impacts increases as structures are placed successively seaward of high water (MacDonald et al. 1994). Sea level rise will place structures even lower in the intertidal frame, and structures built as backup protection landward of high water may eventually interact with waves and currents during non-storm periods.

Zonation models link cross-shore meiofaunal density in the foreshore to oxygen and moisture content of the beach, but these models are sensitive to local conditions (Field and Griffiths 1990; McLachlan and Turner 1994), and these conditions will be altered by bulkheads. Spalding and Jackson (2001) found significant differences in meiofaunal density fronting a bulkhead compared to an unaltered site. Increased energy at the base of the bulkhead resulted in transport of meiofauna with eroded sediments. Thom et al. (1994) suggests that habitat function fronting bulkheads may change and new species will dominate as sediment composition changes to coarser sizes.

There are few process-based studies of bulkheads, and many inferences are based on conceptual arguments. Data are often qualitative or anecdotal (Starkes 2001), making it difficult to quantitatively predict the effects of shoreline armoring on the ecology of beaches and the biological resources they support (Thom et al. 1994). Thom et al. (1994) recommend systematic studies of existing sites in estuaries and development of methods to assess cumulative impacts.

<u>Breakwaters</u>

Breakwaters reduce incident wave energy and reduce the capability of the waves to transport sand both offshore and alongshore. They may be placed close to shore so the accretion fillet landward of them is attached (headland breakwaters) or farther offshore (detached breakwaters). Breakwaters construction is facilitated on the low tide terraces of estuarine beaches because the water depths are shallow, and the costs of breakwaters on sheltered estuarine reaches are competitive with rock revetments and bulkheads per linear meter (Hardaway and Gunn 1991). Breakwaters have a high probability of surviving and retaining their structural integrity because the surface of the low tide terrace is not subject to much scour.

Breakwaters must have a sufficiently high top elevation to have a significant dampening effect on the short-period bay waves to prevent erosion during high water levels. Low structures do not appear to play a significant role in reducing wave attack on the upland formations during storm surges (Nordstrom 1992). Beach nourishment should be used with breakwaters in locations where little sediment is available or where subsequent shoreline reorientation will threaten endangered resources.

Breakwaters are more obtrusive than many shore-parallel structures because they are an unnatural element within the waterscape, but they do not prevent beach access as do bulkheads and revetments. Breakwaters interfere with the natural process of longshore sediment transport, and the potential for alteration of benthic habitat and the requirement for permits make construction of offshore breakwaters more difficult than bulkheads or revetments.

Sills and perched beaches

Sills (low, shore-parallel walls) are combined with beach nourishment operations to create perched beaches or protected marshes on the upper part of the intertidal profile. Sills, like offshore breakwaters, have greater potential for success on estuarine beaches than on ocean beaches because of their ease of implementation in a low-energy environment and because the structures will not be undermined if placed sufficiently low on the beach. Sills are usually smaller than breakwaters, built relatively close to shore, and usually continuous (Hardaway and, Byrne 1999). Sills backed by marsh plantings may be effective in restricted-fetch environments, but these plantings would still be vulnerable to erosion if placed on sandy substrate in open estuaries. There is no conclusive evidence of the success of perched beaches in open estuaries and their use is subject to debate (Douglass and Weggel 1987). The structure may be too low to provide protection due to storm surges (Ward et al. 1989); if structures are placed too high on the active portion of the upper foreshore, they would function as bulkheads. Sills placed below the high water mark would require special permits.

Augmenting Natural Protective Features

Vegetation

Vegetation that is above the zone of normal wave reworking provides resistance to deflation and to entrainment of sediments by waves during storm surges; vegetation on the bay bottom

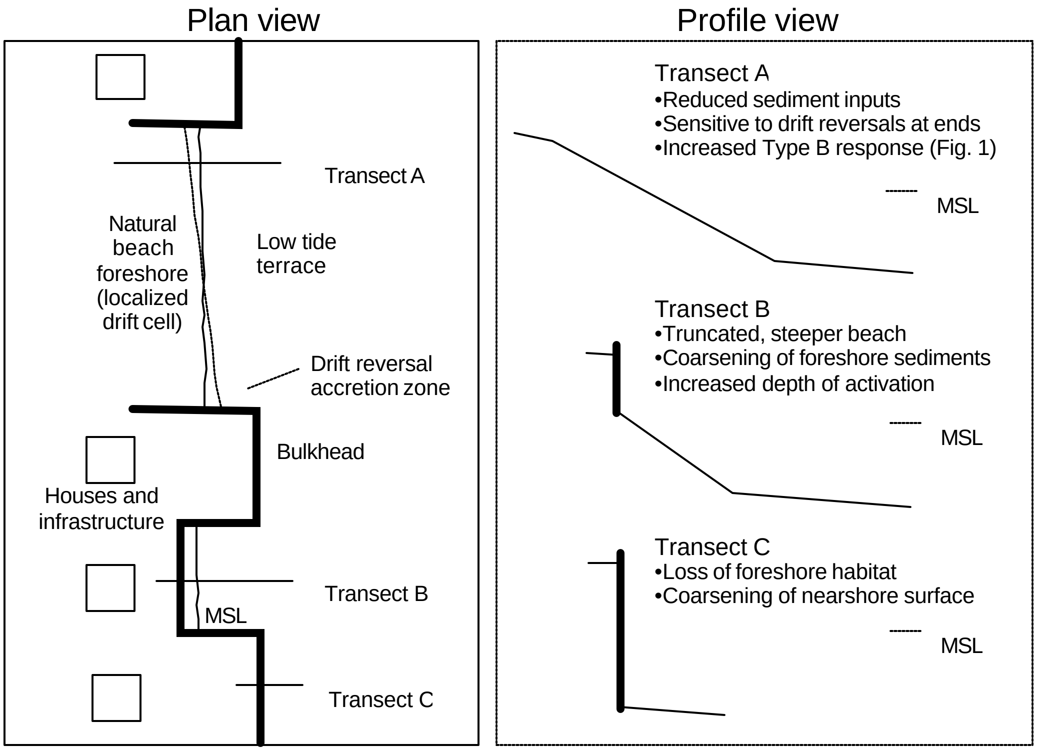

Figure 4. Effects of bulkheads on an estuarine shore. Source: Jackson et al. (2002).

below the zone of breaking waves provides a wave energy filter; and vegetation in the intertidal zone functions as both an energy filter and a trap for sediment moved by waves and currents (Nordstrom 1992). There has been much experimental work on use of vegetation for stabilizing banks of intertidal streams, and success rates are high in some areas (Garbisch et al. 1975 Woodhouse et al. 1976; Knutson 1978), but vegetation is only successful in areas where wave energy is low, where underlying substrate provides stability for plants and where weather is amenable to growth. Plantings are often ineffective on sandy substrate subject to direct wave attack, such as most of the bay shore of Fire Island. Although salt marsh plantings are ineffective on sandy substrate subject to direct wave effects (US Army Corps of Engineers 1981a), they may be effective on the same beach above mean high water (Garbisch et al. 1975). The energy of bay waves can be diminished to the point where salt marsh can grow successfully if a sill is built on the beach or nearshore. Sills combine some of the elements of rock revetments and offshore breakwaters; they generally have a free-standing trapezoidal cross section like breakwaters but are usually smaller and built relatively close to the shoreline and are usually continuous (Hardaway and Byrne 1999).

Detailed evaluations of vegetation plantings in a variety of settings are presented in US Army Corps of Engineers (1981) as part of the Erosion Control Demonstration Program. The types of vegetation that are most effective in stabilizing the bay shore of Fire Island would be Spartina alterniflora in the tidal zone and Spartina patens, and Ammophila breviligulata (above the normal tidal zone).

The existence of new marsh plants in locations that are now eroding has been taken as evidence that vegetation plantings may provide effective erosion control (US Army Corps of Engineers 1981), but small portions of active marsh may grow naturally on peat outcrops on the foreshores of estuarine beaches that have a relatively high wave energy regime. The occurrence of marsh growing on peat may give the false impression that: 1) either the wave energies are lower than they actually are; 2) there is no erosion problem; or 3) that vegetation is a viable alternative for protection of adjacent portions of the beach where the substrate is only sand. The existence of vegetation alone is not a good indicator of either erosional conditions or that vegetation is an appropriate management strategy. The peat layer forms an excellent substrate for the growth of marsh because it resists erosion, but the peat outcrop is an indicator that erosion has occurred (Nordstrom 1992).

Dead vegetation provides another option for shore protection. Woody debris adds both stability and habitat structure, and its great abundance in Puget Sound has made it a viable option for shore protection there (Zelo and Shipman 2000). Woody debris in Great South Bay does not occur in sufficient quantity to provide a viable natural alternative for widespread use, except in localized reaches where litter from marsh plants and submerged aquatic vegetation accumulate in fall and winter (Figure 2). Wave energies on the north side of Fire Island are sufficiently low that this litter can restrict wave action on the upper beach and greatly reduce beach change (Nordstrom et al. 1996). Litter could be made more resistant to erosion by finding ways to bundle and anchor stalks and convert individual plant parts into a more resistant structure.

Bayside dunes

Dunes that form landward of natural estuarine beaches are small relative to their ocean counterparts. Bayside dunes are lower and closer to the edge of the water than ocean dunes. Aeolian accretion, thus dune building, is slow due to the small size of the sand source on the beach. The winds that blow sand onshore to form dunes also create higher wave heights and storm surge that erode what little sediment is deposited by wind in the litter lines behind the active beach, so net losses of sediment are often observed on estuarine beaches despite initial aeolian accretion (Nordstrom and Jackson 1992). Where dunes survive, the discontinuous nature of bay beaches creates discontinuous dune lines, so raised water levels during storms can flood the backbarrier from low points alongshore. The source of sand on estuarine beaches at Fire Island is no narrow that the small deposits resulting from onshore winds are often indistinguishable from the wave-shaped deposits they cover. Accordingly, natural bayside dunes appear to have little value as distinctive subenvironments or in protecting human facilities within NPS boundaries or in the developed communities from overwash. Dunes originating on the oceanside and now exposed on the bay shore due to bayside erosion are conspicuous in places, but their presence is not an indication that sizeable dunes will form by bayside processes.

Bayside dune building processes can be enhanced by human efforts using sand fences to trap sand or earth moving equipment to emplace sediment directly. The resulting structure would function more like a dike and could form the bayward section of a ring levee around properties or resources to be protected from flooding and a source of sediment for adjacent undeveloped segments. The limited amounts of local sediment available for building such a large structure would require use of sand from external sources, and the landform would be unnatural in appearance and function.

Beach nourishment

Beach nourishment is the current preferred shore protection alternative on ocean beaches, and it is effective in maintaining beach widths on estuarine shores. Many nourishment operations have been employed on estuarine beaches, ranging in size from tens of cubic meters to millions of cubic meters (Nordstrom 1992). Like other shore protection alternatives, beach nourishment becomes most viable when it is implemented on a reach basis. This alternative is often beyond the capability or interest of individual residents because of the cost, commitment to ongoing maintenance, requirement for permits to place materials below mean high water, and creation of a recreation beach that may attract non-resident beach users to private property. An advantage of beach nourishment in developed communities is that costs may be spread among residents who are users of the beach resource but who may not own beach-front property. The greater willingness of regulators to approve permits for non-structural erosion control methods is an incentive in some states (Zelo and Shipman 2000).

Use of beach fill on the low tide terrace covers benthic habitat. This concern is frequently mentioned in reviews of potential fill operations by agencies charged with maintenance of ecosystems, and the perceived losses are often cited as the primary reason for lack of acceptability of nourishment projects (US Army Corps of Engineers Baltimore 1980; US Army Corps of Engineers Seattle 1986). The New York Department of Environmental Conservation has a strong policy against use of beach fill on the low tide terrace. One alternative is to place the fill above the mean high water mark, creating an eroding feeder upland, so benthic communities on the low tide terrace will not be buried in the initial operation, and any transport of fill material offshore will be gradual and allow organisms to adapt.

Beach fill could be placed landward of bulkheads, and bulkhead segments could be modified to make them controlled-erosion headlands that would supply sediments to eroding downdrift areas. The precedent for creating eroding headlands is found in Shuisky and Schwartz (1988), but, in their study area, the erosion process was designed to provide a natural mechanism to sort poorly sorted fill material. The precedent for creating nourished beaches landward of static protection structures is found in projects in the Puget Sound region (Zelo and Shipman 2000). Lack of space between bulkheads and buildings on Fire Island may render this option unfeasible in some areas, but there may be enough space for this option at Water Island and Point o'Woods. There is enough space at Saltaire, but sediment that would be delivered to the eastern end of that community would be lost to the bay. The lower portions of bulkheads could be left as remnants to provide sills to keep sediment from moving onto the low tide terrace. The precedent for leaving portions of bulkheads as sills is found in projects identified in Zelo and Shipman (2000) and the rationale for constructing new sills is found in Hardaway and Byrne (1999). Bulkheaded segments used as controlled-erosion areas would only remain effective if the segments are periodically nourished.

Large amounts of sand and gravel are available through dredging navigation channels at Fire Island and Moriches Inlets. Maintenance dredging of Fire Island Inlet has been performed almost annually since 1954, removing nearly 16 million m^3 from 1954 to 1994 (Smith et al. 1999). This sediment is needed to overcome local downdrift deficits caused by this dredging and by trapping at jetties. Inlet bypassing is a critical erosion management strategy that has high priority in hazard management plans (Long Island Regional Planning Board 1989), and it is likely that sites on the ocean and within the inlets would be given priority in use of these sediments. Navigation channels in backbays are a more likely source of fill for estuarine beaches because the quantities are too small to be of much value for use on ocean sites and the cost of moving the sediment to ocean beaches would be greater.

Suitable beach fill materials are available from dredging in Great South Bay and Moriches Bay and their tributaries. Vast quantities of sediment were dredged in Suffolk County in the past, with much of the material from Islip and Brookhaven placed on beaches (Suffolk County Planning Department 1985). Less material is now available because the activities within the county have changed from channel creation to channel maintenance (Suffolk County Planning Department 1985). Spoil materials dredged from channels in the bays are mostly sand and would make good beach material.

Fill materials brought in from outside the nourished area may differ in color or size from local sediments and may retain an exotic appearance for long periods because of limited mixing by low-energy waves (Hallegouet and Guilcher 1990). They also result in different growing conditions for vegetation and have different packing, porosity and permeability that affect burrowing of organisms and groundwater flow. Fine sediment will be removed from the beach and create sedimentation problems on the bay bottom. Pebbles will remain on the beach as lag deposits. Coarser sediments may have greater value for desired wildlife (Jackson et al. 2002), and they may provide added value where nourishment is primarily for shore protection, rather than recreation, but cobble or boulder sized rocks may create exotic habitat on a sandy barrier island. Improvement of habitat for certain species may be a major consideration in implementing projects in some areas. Space for horseshoe crab spawning is now restricted because of bulkheads, salt marsh and peat deposits (Botton et al. 1988). Replacing bulkheads with fill would increase the amount of beach available for spawning by horseshoe crabs (Limulus polyphemus) as well as for nesting by diamondback terrapins.

THE MANAGEMENT DILEMMA

Much of the problem of managing beaches and dunes in developed areas relates to the conflict between the human desire for a system that is stabilized to make it safe, maintain property rights or simplify management and the tendency for a healthy natural coastal system to be dynamic (Nordstrom 2003). The natural resources found on the shores of barrier islands are products of this dynamism, making attempts to maintain a stable natural resource inventory by restricting natural processes an impossible goal. The concepts of protection or maintenance of natural resources cannot be applied to existing inventories but to the processes whereby these resources evolve. The best solution for maintenance of natural systems is to allow natural processes to remain unrestricted, but this option cannot be realized because of the human need for stability. Thus, the goal becomes one of minimizing interference with wave and wind action and sediment budgets while providing an adequate level of protection to critical human facilities.

The biggest problems confounding efforts to allow Fire Island to undergo natural dynamism are the desire to protect properties on the island from erosion and overwash and the need to protect the mainland from flooding due to formation of a new inlet. Problems stemming from the need to accommodate human needs have not all emanated outside the park. Attempts to accommodate tourist access and use have resulted in establishment of fixed facilities within the park that have altered natural processes. The most conspicuous problem areas on the bay shore of the park are the navigation structures at Sailors Haven and Barrett Beach, which have altered the sediment budget of adjacent beaches. Issues related to maintaining fixed facilities are more difficult to resolve in the developed communities, where there is little tolerance for natural mobility and where the spatial extent of the problem is greater.

The most difficult challenge to park management is managing mixed land ownership (Geologic Resources Division 2002). Not all stakeholders have the same perception of the values of coastal resources, so compromise is required in satisfying conflicting human desires as well as conflicting natural and human characteristics. It is assumed that the natural interplay of sediments, landforms and biota does not have to be limitless to maintain key landforms and species. Dynamism and complexity of topographic relief are important natural characteristics favoring biodiversity, but we do not know how much dynamism and complexity are critical to maintain long-term viability. Cycles of erosion and deposition may be truncated in space or altered in periodicity or location by humans, thus changing the natural history and areal extent of landforms and biota, but this does not mean that the landforms and biota will be eliminated.

Restrictions to the natural interplay of sediments and biota within developed areas may not represent threats to park resources if human actions can overcome these restrictions at park boundaries. One way to help accomplish part of this goal is to ensure that the volume, type and rate of transport of sediment and flora and fauna passing into the park from developed areas approximates the transfers under natural conditions. The larger scale problems associated with protecting the mainland and Great South Bay from new inlets are more difficult to resolve.

MANAGING EFFECTS OF SHORE PROTECTION STRATEGIES ON THE BAY SHORE OF THE PARK

Many of the shore protection strategies identified above are limited by land use considerations reflected in county, state and federal policies, although current restrictions should not discourage development of creative but workable designs. Neither structures nor beach fill can be employed seaward of mean high water without a state permit, and structural alternatives are discouraged within the park. The need to reestablish exchanges of sediment rather than prevent them from occurring argues against the use of groins within both the developed communities and the park. Bulkheads should be considered a last resort option and perhaps then only used to protect built facilities, not the land around them. One way of limiting the use of new bulkheads is to introduce land use controls, beach fill (perhaps in the form of a sacrificial upland), or an erodible dune dike before erosion proceeds to the point where space becomes an issue. This option requires establishing proactive monitoring programs and land use controls.

Several of the problems associated with structures can be overcome by taking positive action to reduce the adverse effects on adjacent undeveloped land by reducing the length and height of structures, particularly near their longshore ends or by replacing lost sediment by beach nourishment. Design alternatives for addressing downdrift effects of structures are being tested in Chesapeake Bay and include 1) modifying crest heights, widths and orientation at their ends to create gradual transitions in longshore wave energy levels; and 2) reducing the lengths of structures, so increased downdrift erosion is confined within the boundaries of the property to be protected (Hardaway et al. 1993).

Modifying structures at their ends to allow sediment to pass into adjacent locations could displace the zone of sand starvation updrift and away from presently eroding areas, but this would be a temporary solution, and fill of these areas would be necessary to reestablish the sediment budget and prevent flanking of the area requiring structural protection. Converting the ends of structures into feeder beaches could allow most of the structures to remain intact bayward of threatened buildings yet alleviate sand starvation in adjacent areas. The natural interaction of the beach with the low tide terrace would not be restored in locations where the bulkhead remains in place, but the cost of modifying the bulkhead would be lower and the feeling of security provided by the bulkhead would remain.

Where it is feasible to modify the entire length of a bulkhead, the lower portion of the structure could be left in place to function as a sill to create a perched beach landward (Zelo and Shipman 2000) or create a sheltered environment allow for marsh growth (Hardaway and Byrne

1999). The use of the marsh alternative would not replicate the pre-development function of the shoreline at these locations because bulkheaded segments are located where high ground existed prior to development, and the result would be replacement of a formerly eroding barrier island upland with a marsh. It may not be possible to replicate site-specific topography and biota in this way, but the approximate proportion of pre-disturbance environments could be maintained, albeit in new locations.

Local beach nourishment and dune building projects on the oceanside and construction of bulkheads on the bayside in developed communities restrict the delivery of sediment landward of them by wave overwash and aeolian transport. Much of the character of the bay shoreline and the portion of the barrier island immediately landward of it is attributed to sediment inputs from the oceanside. Future projects designed to protect these communities, the bay, and the mainland from flooding would further restrict these transfers and help prevent a new inlet from forming. The prevention of overwash and inlet formation, seen as a benefit from the standpoint of safety or economics, would prevent the large-scale cycles of destruction and growth and long-term evolution of the island, seen as evidence of a healthy natural system. If an inlet did form but was closed by human efforts, some transfers from ocean to bay would occur in the time between inlet formation and closure, but the areal extent of these changes would be small relative to past changes that reflect inlet inputs over many kilometers of shoreline.

The most important coastal process issue relates to the opening of new inlets in the barrier island during storms, but the importance of inlets formation in maintaining the barrier system is manifested over time periods of hundreds to thousands of years (Bokuniewicz 1993). Significant inputs of sediment from the ocean to the bay in the past 1½ centuries occurred only at the migrating Fire Island Inlet before it was stabilized. This relative stability would not be expected in the future in the absence of human alterations because the increased rate of sea level rise would make the island more susceptible to overwash, breaching and inlet formation. Thus future human attempts to stabilize the island and protect landward areas from flooding would increase the rate of divergence in evolutionary trajectory even more than at present.

Attempts to maintain the existing resource inventory by reinstating sediment budgets at the locations where bulkheads interfere with longshore transport would resolve some highly localized erosion problems, but they would not address erosion of the shore within these segments farther downdrift of the present sand-starved zones or reinstate the larger scale process whereby the barrier island evolves. Elimination of the natural mechanisms for periodically increasing the width of the barrier island on the bayside and the elevation of the adjacent bay bottom will result in continued retreat of the bay shoreline into the higher portions of the barrier island. If beach restoration and dune building occurs only on the oceanside, the result will be a narrowing of the barrier, loss of marsh habitat, and truncation of cross-shore environmental gradients landward of the beach by erosion and inundation. Beaches are likely to form a greater proportion of the shoreline in the future because wave heights will be somewhat greater due to deeper water depths in the bays and because more sediment will be available from the higher interior portions of the barrier. Marshes appear to be the resource that will be most threatened. One way of increasing the potential for new marshes to form and reduce the likelihood of barrier island breaching is to add sediment to the bay shore to allow the surface to retain its elevation in the intertidal frame to keep pace with sea level rise. The greater width of the barrier would allow for complete development of the cross-shore environmental gradient and help restrict formation of deep breaches during storms.

RESEARCH NEEDS RELATED TO BAYSIDE PROCESSES AND MANAGEMENT STRATEGIES

Several data gaps and monitoring needs for estuarine resources were previously identified in Bokuniewicz et al. (1993). They note that previous studies do not contain sufficient detail to adequately address management issues related to coastal processes on the bay shore due to the many relatively small subenvironments subject to different physical processes over short distances. Several of their suggestions relative to water quality, turbidity, dredging impacts, clamming, algal blooms apply to the general bay environment as well as the shore and are not repeated here. The topics they mention that apply directly to the bay shoreline are included, along with relevant suggestions for future study from Geological Resources Division (2002). Some of the suggestions are somewhat non-traditional. The need to achieve compromise between the demands of competing interests and the need to address many different problem areas in small scale projects may require solutions that are more creative and expensive than have been practiced in the past.

Suggestions for Future Research

Conduct resource inventories

- Evaluate the shoreline history from aerial imagery and the coastal geomorphologic changes to provide background data on shoreline evolution.

- Obtain a baseline inventory of lengths, areas, and physical and biological characteristics of representative subenvironments (sand beach, beach with peat outcrops, upland, marsh margin, navigation channels, bulkheads) to provide quantitative information that can be used to monitor changes due to storm effects and human influences.

- Establish datum monuments and conduct periodic field surveys to determine rates of shoreline erosion and changes in biota at representative locations within these subenvironments.

Evaluate shore processes and their effect

- Identify sediment sources and sinks and longshore drift cells to determine the locations for establishing feeder beaches using beach fill.

- Estimate differences in the effect on the bay shore of new inlets that are closed artificially and new inlets that are not closed.

- Evaluate the potential for allowing new inlets to remain open for extended periods to increase the probability of delivery of sediment to the bay shore.

- Identify the extent to which overwash without inlet formation determines the character of the bay shore.

- Evaluate the potential for allowing for controlled overwash to periodically reinitiate landscape evolution in selected areas without significantly increasing hazard potential.

- Monitor boundaries between developed communities and natural areas to identify problems related to sediment deficits and invasion of exotic species.

<u>Evaluate management options</u>

- Conduct study of the impact of bayside bulkheads on adjacent unprotected land.

- Evaluate options for removal or modification of bulkheads to facilitate sand bypass to downdrift segments.

- Evaluate the effect of piers and docks on shoreline change.

- See if protected (bulkheaded) harbors are necessary, especially in day use areas where piers may suffice.

- Identify the practicality of nourishment operations of the small scale appropriate to estuarine sites.

- Identify the potential for using dredge spoil from navigation projects as fill for beaches and new marsh substrate.

    Determine volumes available.
    Evaluate grain size statistics.
    Determine the regulatory and environmental constraints in placing fill on the low tide terrace.
    Evaluate previous spoil sites, (East and West Fire Islands) to determine fate after placement.

- Evaluate the feasibility of establishing controlled-erosion feeder uplands or artificial headlands at upland contacts if beach fill placement below mean high water is not feasible.

- Identify headland and embayed features of the shoreline that could be enhanced or accentuated by headland breakwaters.

- Implement programs of adaptive management to address opportunities and problems resulting from implementation of non-traditional management strategies (such as controlled overwash) or temporary strategies that may have a longer or more widespread impact than anticipated.

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Northeast Region
Natural Resource Stewardship and Science
15 State Street
Boston, Massachusetts 02109

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