National Park Service
U.S. Department of the Interior

Northeast Region
Boston, Massachusetts

Human Interaction with the Coastal Geomorphology of Fire Island
(Fire Island National Seashore Science Synthesis Paper)

Technical Report NPS/NER/NRTR—2008/132

ON THE COVER

Foredune enhancement at Fire Island National Seashore. Photograph courtesy of the authors.

Human Interaction with the Coastal Geomorphology of Fire Island
(Fire Island National Seashore Science Synthesis Paper)

Technical Report NPS/NER/NRTR—2008/132

Norbert P. Psuty and Tanya M. Silveira

Institute of Marine and Coastal Sciences
Rutgers, The State University of New Jersey
74 Magruder Road
Sandy Hook, NJ 07732

September 2008

U.S. Department of the Interior
National Park Service
Northeast Region
Boston, Massachusetts

The Northeast Region of the National Park Service (NPS) comprises national parks and related areas in 13 New England and Mid-Atlantic states. The diversity of parks and their resources are reflected in their designations as national parks, seashores, historic sites, recreation areas, military parks, memorials, and rivers and trails. Biological, physical, and social science research results, natural resource inventory and monitoring data, scientific literature reviews, bibliographies, and proceedings of technical workshops and conferences related to these park units are disseminated through the NPS/NER Technical Report (NRTR) and Natural Resources Report (NRR) series. The reports are a continuation of series with previous acronyms of NPS/PHSO, NPS/MAR, NPS/BSO-RNR and NPS/NERBOST. Individual parks may also disseminate information through their own report series.

Natural Resources Reports are the designated medium for information on technologies and resource management methods; "how to" resource management papers; proceedings of resource management workshops or conferences; and natural resource program descriptions and resource action plans.

Technical Reports are the designated medium for initially disseminating data and results of biological, physical, and social science research that addresses natural resource management issues; natural resource inventories and monitoring activities; scientific literature reviews; bibliographies; and peer-reviewed proceedings of technical workshops, conferences, or symposia.

This report was accomplished under Cooperative Agreement 1443CA4520-99-007, task agreement J4506050670, with assistance from the NPS. The statements, findings, conclusions, recommendations, and data in this report are solely those of the author(s), and do not necessarily reflect the views of the U.S. Department of the Interior, National Park Service.

Print copies of reports in these series, produced in limited quantity and only available as long as the supply lasts, or preferably, file copies on CD, may be obtained by sending a request to the address on the back cover. Print copies also may be requested from the NPS Technical Information Center (TIC), Denver Service Center, PO Box 25287, Denver, CO 80225-0287. A copy charge may be involved. To order from TIC, refer to document D-137.

This report may also be available as a downloadable portable document format file from the Internet at http://www.nps.gov/nero/science/.

Please cite this publication as:

Psuty, N.P. and T.M. Silveira. September 2008. Human Interaction with the Coastal Geomorphology of Fire Island. (Fire Island National Seashore Science Synthesis Paper). Technical Report NPS/NER/NRTR—2008/132. National Park Service. Boston, MA.

NPS D-137 September 2008

Preface

A part of the preparation for a new General Management Plan (GMP) to guide the Fire Island National Seashore is to identify and address significant issues and changes facing the park. This paper has been prepared to provide the GMP planning team with relevant natural resource information in a professionally-synthesized format addressing the current "state-of-knowledge" on several selected geomorphological issues. It is intended that this paper be scientifically-supported and peer-reviewed, but written in a manner that is understandable by those that may not have technical or scientific backgrounds. Using the background paper *The Coastal Geomorphology of Fire Island: A Portrait of Continuity and Change* (Psuty, et al., 2005) as its foundation, this product focuses on the response of Fire Island's oceanside beaches and dunes to human activities. For a discussion of conditions and characteristics of Fire Island's bayshore, see the Science Synthesis Paper by Nordstrom and Jackson (2005).

The scientific literature addressing human impacts on the geomorphological processes of beaches and dunes is very uneven, and in most cases there are few publications pertaining specifically to Fire Island. Therefore, information from other sites will be used to provide perspective and to assist in the assessment of beach and dune response to types of human activity practiced on Fire Island. This is not to be a history of human manipulations, and will not exhaustively cover ecological or social impacts, but rather it will focus on several of the actions conducted by humans on Fire Island and describe the activity with regard to its interaction with the ambient coastal geomorphology. Importantly, the interaction is a complex activity occurring at a variety of spatial and temporal scales that require a broad perspective to be appreciated and managed. This report will focus on the human activities affecting the coastal foredune. The foredune is a primary locus of human interface with the natural system and it is the site of the greatest opportunity to influence the degree of intervention of processes and to maintain the integrity of the barrier island system.

TABLE OF CONTENTS

GEOMORPHOLOGICAL SETTING OF FIRE ISLAND

Fire Island is one of a series of barrier islands that occur along the eastern coast of the United States. These islands were formed during the last phases of the global sea-level rise that spanned the past 20,000 years. As great quantities of sediment were inundated during this rise, they were re-worked and distributed by the ambient waves and currents to create the barrier island system, a portion of which lines the southern margin of most of Long Island. The features of the modern day Fire Island were created in the past several thousand years as sea-level rise slowed and a series of barrier islands extended westward from the promontories of eastern Long Island. The present Fire Island extends alongshore for about 31 miles (50 km) and has widths that vary from about 0.2 to 0.6 miles (0.3 - 1.0 km). Although a single geomorphological unit, Fire Island has a number of political and administrative jurisdictions, including 17 communities, Robert Moses State Park, Smith Point County Park, and the Fire Island National Seashore (Fig. 1).

The coastal system is highly dynamic. The dimensional characteristics of the beaches are changing in response to short-term variations in wave energy and sediment availability, whereas dunes change less frequently in response to those storm events that cause water to reach the dunes and other weather events that cause winds and waves to propel sand into and across the coastal dunes. There is an acknowledgement that the quantity of sediment within the barrier island system is diminishing and that a slow inland displacement of the shoreline is occurring (Allen, et al., 2002; USACE, 2002). Further, the most recent evidence relating to sea-level rise, produced by the Intergovernmental Panel on Climatic Change (Bindoff, et al., 2007), shows an accelerating rate of inundation of the coastal zone. They conclude that during the past several centuries, sea level is now rising faster than has happened in the past several thousand years and there is a geomorphological response to that stress that is displacing the shoreline position inland. In addition to the natural processes that drive the evolution of beaches, dunes, and inlet features of Fire Island, humans are modifying the natural processes and the resulting landforms.

HUMAN IMPACTS ON PROCESSES AND LANDFORMS

If Fire Island may be thought of as a landform produced by the natural transfers and accumulations of sediment, human actions may be considered as altering the quantities of sand being moved, as redistributing the sand within the dune and beach system, as constructing barriers to the natural transfers of sand, and as selectively modifying the erosion, transport, and/or deposition of sediment driven by the natural system.

Human activity applied to the creation of geomorphological features on Fire Island is not a process in the same sense as the processes of wind and waves that shape the barrier island. Human activity is a modification of the natural processes, or an alteration of topography created by natural processes. It is an interaction with the processes and/or the products of the processes to produce their imprint on the coastal landscape. Although the human effects have been recognized by geomorphologists for over a century (Marsh, 1865), recent publications by Carter (1988), Walker (1990), and Nordstrom (2000) have focused attention on the myriad of features in the coastal zone that are products of the natural and cultural interplay. Walker (1990) and Nordstrom (2000) have directed special attention toward the role of humans in affecting the

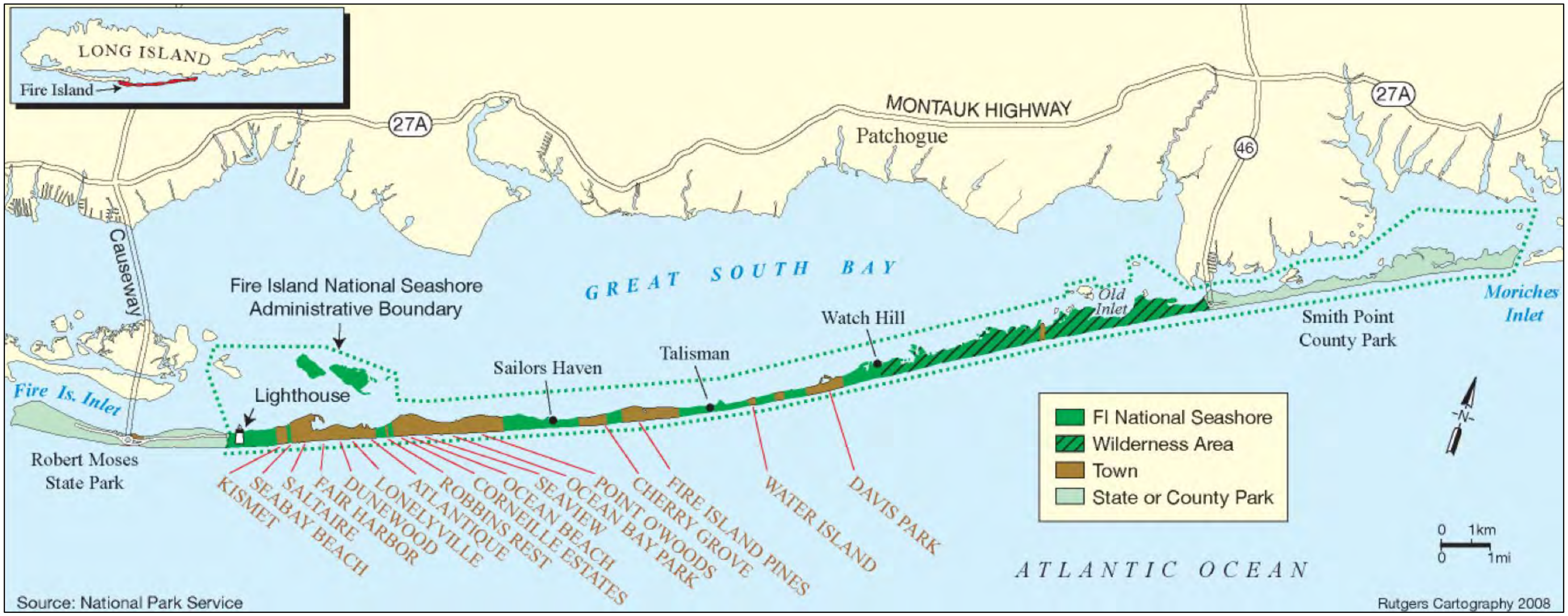

Figure 1. Parks and communities on Fire Island.

dimensions of the processes as well as modifying the topographical features produced by the coastal processes.

It is important to incorporate the role of people in the recent evolution of the coastal system. In most instances, the human presence may be considered as an impact to the coastal system and to the resources of the coastal system. Some impacts are minor and produce modest adjustments, whereas others may be major and devastating to the integrity of the coastal system. Within the National Parks and in those areas managed by the National Parks, there is concern regarding the impacts and the level of impacts. There is a need to understand and to gather information on the impacts and to evaluate them in relationship to the goals of park management incorporated in the published *Management Policies, 2006* (NPS, 2007); and General Management Plan (NPS, 1977) and to the functioning of the natural and cultural system (see NPS Inventory & Monitoring Program: http://science.nature.nps.gov/im/). Ongoing studies in the coastal parks include on-site assessment, behavior observation, remote sensing, and a variety of perception studies that are intended to better understand and direct the human interaction and to preserve the essence of the natural system (Ingle, et al., 2003).

Within the Fire Island setting, the coastal geomorphological features are the products of the ambient processes of waves, currents, and wind acting upon the supply of sediment arriving from updrift (from the east) and from offshore. Human interaction is very limited relative to the ambient processes, but it is primarily directed toward affecting the delivery of sediment in the alongshore transport system as well as manipulation of the sites and forms of the accumulated sediment, whether it be in foredune, the dry beach, or the wet beach face (Fig. 2).

In general, there are six types of cultural modifications to the oceanside geomorphological features. They include:

1) FOREDUNE BUILDING AND ENHANCEMENT - This action usually does not alter the quantity of sand in the system, but it does involve the movement of sand to create a ridge in the dune zone, or the accumulation of sand around emplaced fences; either action could occur with or without the planting of vegetation.

2) BEACH SCRAPING - This action does not alter the quantity of sand in the system, but it does physically shift the material from one part of the beach to another part of the profile, usually to enhance the foredune.

3) ORV TRAFFIC - Vehicles on the beach affect some aspects of sediment mobility/stability, but they do not alter the quantity of sand in the system.

4) HOUSES AND WALKWAYS IN THE FOREDUNE - Buildings and pathways constructed in the foredune cause alterations of the sediment transport rates and direction into and through the foredune system. There is no new sediment added.

5) HARD STRUCTURES - Jetties at inlets stabilize the locations of navigable channels. Groins are structures in the beach, constructed orthogonal to the shoreline. Neither jetties nor groins add sediment to the system, but they do alter the site-specific distribution of sediment by favoring accumulation on the updrift side and fostering a loss on the downdrift side of the structures.

6) BEACH NOURISHMENT - This action involves the introduction of new sand into the system to counter the natural losses. It causes a positive sediment supply for some time interval at selected sites. The goal is to add sand to the alongshore transport system that would otherwise be unavailable and to augment the sand supply to the local beach and dune topography.

Figure 2. An example of human impacts in the foredune topography with houses, and a few remnant fences and fence posts in the foredune. Impacts in the dry sand beach include pilings at the base of the foredune, a long line of sand fence, and many ORV tracks. The wet beach face is unaltered in this photograph, Davis Park, June 2, 2004.

THE COASTAL FOREDUNE: A CENTRAL COMPONENT OF THE BARRIER ISLAND SYSTEM

The creation of a natural coastal foredune is a product of an interaction between the wind and water processes that are shaping the very dynamic beach and the processes that transport some of the beach sands inland to accumulate at the location of vegetation. The foredune is the central element of the barrier island topography. It responds to the natural processes and the availability of sediment. The foredune is much more conservative in its mobility than the beach features, broadening slowly over a span of years, or being displaced inland only under extreme storm events. The foredune develops parallel to the shoreline and at the inner margin of the free sand beach; where the vegetation from inland extends into the harsh beach environment and catches sediment that is moving inland by wind processes. The vegetation type is referred to as pioneer vegetation because it extends from the zone of established plant growth in or near the foredune and advances to the inner boundary of the bare, hot, dry, saline, nutrient-limited beach (Fig. 3).

Figure 3. New growth of dune grass extending from the foredune into the upper beach. In turn, the vegetation is capturing some of the wind-transported sand and is adding mass to the foredune position. Atlantique Beach, June 2005.

Ehrenfeld (1990) reviewed the associations of these plants and their limiting variables and described the botanical characteristics that apply as plant roots and rhizomes colonize the bare sand. It is in this transition from bare sand beach to the zone of vegetation that sediment accumulates to form a sand ridge, or coastal foredune. An important aspect of the foredune is its position and dimension as a barrier to storm surge penetration. It is frequently the highest portion of the barrier island and it serves to limit the effects of storms to the seaward margin of the island. Thus, the fostering of foredune development is also enhancing the protective capacity of the sand ridge.

The understanding of dune-forming processes is based on the classic synthesis by Bagnold (1941) that relates wind and sediment types to the production of landforms. More recent geomorphological work focused on the interaction between the dune and the beach components at the shore (Psuty, 1988; Sherman and Bauer, 1993: Psuty, 2004) and the conditions of the exchanges of sediment that support the development of the foredune. As Sarre (1985) noted, the onshore winds that blow across the beach actually accelerate as they encounter the foredune because of the increase in elevation, thus increasing the transport potential. However, the presence of vegetation introduces a surface roughness that reduces the wind velocity at the sand surface. The higher and the more dense the vegetation, the more effective the reduction of sediment transport from the beach and its accumulation in the foredune. Thus, whereas a bare sand foredune would tend to speed the inland transfer of sediment, the presence of vegetation causes a localized accumulation to enhance the ridge form, and supports the continuity and increased dimensions of the natural foredune. Further, the foredune is a dynamic feature that increases and decreases in dimension, it shifts spatially in response to episodes of sediment loss or gain, and it shares in the general negative sediment budget of Fire Island by slowly shifting inland while retaining much of its characteristics and dimensions (Psuty, 1989; Psuty and Silveira, 2008). Therefore, the foredune is an excellent representative of the product of the natural processes operative on Fire Island, and the foredune features and dimensions will be supported by the continuity of the natural processes.

HUMAN MANIPULATION AND THE FOREDUNE

The coastal foredune is an essential element of the coastal system and it is positioned at the transition between the very dynamic bare sand beach and the human development of houses and other components of infrastructure. The foredune is the locus of primary human interaction with the natural system and it is the site of the greatest opportunity to influence the degree of intervention of processes and to maintain the integrity of the barrier island system. There are over 140 houses located in the natural coastal foredune (within the natural foredune crestline of 2005 (Psuty and Silveira, 2008)). Actions associated with the presence of these houses and their attendant characteristics offer the greatest challenges for resource management of the coastal system. Maintenance and restoration of the integrity of the coastal foredune processes and the evolving position of the natural foredune should be a management goal.

Human manipulation of the coastal dunes may be accomplished through the physical transfer of sediment to create a foredune ridge (as with beach scraping described below), with the planting of vegetation to encourage surface roughness and sediment deposition, with the placement of sand fences to cause localized deposition, or some combination of the three actions (Phillips and Willetts, 1978) (Fig. 4). Each of these actions is meant to enhance the integrity of the foredune and reduce its vulnerability to storm surge penetration and overwash.

There are also human manipulation activities, such as hard structures and beach nourishment, that do not directly affect the foredune because they primarily modify the intertidal area. However, they will inevitably influence the natural evolution of the foredune system by altering sediment availability and transport vectors.

FOREDUNE BUILDING AND ENHANCEMENT

In the short term, accumulation of sediment in the vicinity of the foredune location can occur with the placement of sand fences, and stabilization of the sand may be promoted with vegetation (Miller, et al., 2001), with the proviso that width of the upper beach berm seaward of the constructed foredune should be at least 100 ft (30 m) to provide a buffer from wave action (Hamer, et al., 1992; Psuty and Rohr, 2000). The constructed dune should occupy a site that is consistent with the location of the natural foredune at the site of the pioneer vegetation in the beach-dune system. Experimentation of fence design in a wind tunnel and subsequent field studies (Savage, 1963; Savage and Woodhouse, 1969; Hotta, et al., 1987) have identified wooden slat fences with a porosity of 50-60% as the most effective collectors of wind blown sand to their lee (Fig. 5).

Figure 4. Foredune enhancement by sediment placement at seaward margin of houses, planting of beach grass along the crest and seaward slope, and erection of sand fences at base of the constructed sand ridge, Dunewood, August 8, 2003.

Figure 5. Accumulation to lee of sand fence at base of foredune (to left on photo); sand fences on top of artificial sand ridge were part of design to control access as well as to stabilize newly-planted surface (to right on photo). Saltaire, Sept. 25, 2003.

Fences about 3.3 ft (1.0 m) high were normally used in the experiments. However, as sand accumulates and the fence is partially covered by the sand, the effectiveness tends to diminish, reducing to nothing when the fence is 75% buried. Savage and Woodhouse (1969) also tested woven and polyethylene fabric fences, and found that the wooden slat fences trapped greater volumes in the vicinity of the fence. A variety of slat widths and types of material were tested and slats about 1.5-2.0 inches (3.8-5.1 cm) were found to be most effective in total volume and keeping the accumulation near the placed fences. Woodhouse (1978) recommends a single row of dune fence immediately seaward of the dune crest position to enhance the foredune position and restore the topography. Multiple rows of fences could be used if winds and sediment transport were coming from several directions and trapping would essentially be creating several lee zones relative to a particular line of fences (Hotta, et al., 1991). But, multiple rows of fences related to transport from a single direction did not create significant increases in total volume accumulated, assuming all of the fences were of similar design. Fences should be sited parallel to the shoreline, but if the dominant wind arrives obliquely, porosity could be increased as compensation to improve the rate of accumulation (Hotta, et al., 1987). The wind tunnel experiments also demonstrated that sand fences were effective with wind speeds up to about 36 mph (about 16 m/s). Sand trapping dropped dramatically at winds speeds beyond this speed. Hotta, et al. (1987) indicate that no sand was caught by the fences at speeds greater than 36 mph.

The association of variables that describe sand accumulation at a fence is complex, but some of the fence variables are porosity, height, and inclination to wind direction. Wind conditions are important. Studies by Hotta, et al. (1987) demonstrate that the accumulated dune crest moves downwind with increase of speed, that fences trap more sand under lower wind speeds, that porosity greater than 50% results in lower rates of accumulation, and smaller openings are more effective than larger openings.

Miller, et al. (2001) conducted an evaluation of fences composed of biodegradable materials (Geojute) relative to fences of wooden slats, as well as orientation of fence lines, and compared the results with non-fenced control sites over a span of 31 months at a site where the foredune had been destroyed in a storm. Fences were placed in a location where secondary dunes would normally exist (330-400 ft inland (100-120 m)). Whereas the accumulation rates for the first six months were similar for Geojute and wooden fences, the subsequent period showed a reduction of accumulation in the Geojute fences compared to a consistent accumulation in the wooden fences. At the end of the study, Geojute accumulated 5.46 yds^3/yd (4.55 m^3/m) compared to 9.27 yds^3/yd (7.72 m^3/m) in the wooden fences, half of the accumulation was in the first six months, and at a decreasing rate thereafter. Over the similar period, the non-fenced control site accumulated 1.43 yds^3/yd (1.19 m^3/m). Likewise, the height and breadth of the accumulations associated with the wooden fences was greater. Orientation of the single fence lines did not affect the rates of accumulation. Further, planting did not increase accumulation in the first year of growth but did produce significantly greater rates in the second year compared to non-planted fenced areas.

Trapping efficiency is a combination of the rate of accumulation and the site of accumulation. Any fence will eventually trap a similar amount of sand, providing that a source is available. However, some fence designs tend to keep the accumulations close to the fence whereas other designs cause accumulation over a distance several times the height of the fence. Hotta, et al. (1987) suggest that all fences should be constructed of material that will break down after a few years.

In an effort to assist in sediment accumulation and to stabilize the accumulations, dune restoration should include planting of native grasses (Mendelssohn, et al., 1991), whether the sand is transported to the site by mechanical means (e.g., beach scraping) or collecting adjacent to fences. Ecological research on plant growth in new sand accumulations at the foredune location has contributed some insight into successful plant development and dune stabilization (Ehrenfeld, 1990). Maun (2004) suggests that enhanced plant vigor only occurs in the foredune with an input of new sand and associated nutrients. He has generated a multi-factor hypothesis that incorporates the incoming sand supply and its nutrient resources with the belowground presence of mycorrhizal fungi that together stimulate plant growth and dune cover. Koske and Gemma (1997) suggest that the successful colonization of coastal dunes is associated with mycorrhizal fungi in the root zones of the stabilizing plants. Koske, et al. (2004) add insights into the seasonal presence of mycorrhiza in the foredunes that are products of disturbance and parasites that will foster or inhibit plant development. They have carried on experiments with inoculations of planted dune grass to increase the survival of the plants and the growth rates. They suggest that inoculation be a standard practice in the Northeast when beach grass is planted to induce stabilization and in situations where sediment is introduced into the dune area from sites and sources outside of the foredune environment (Fig. 6).

Figure 6. Staining of the sediments in the foredune location is indicative of a source from outside of the beach environment, probably from an area outside of Fire Island. The absence of fungi in these imported sediments will slow the growth of the dune grasses and their stabilization of the sediments. Fences have accumulated sand at the base of the created foredune, but the sediments may be removed by wave action because the site is low and too near the active beach. Fair Harbor, August 8, 2003.

A number of guidelines are available regarding spacing, location, and fertilization appropriate to Fire Island. Most of the planting on Fire Island follows the recommendations of the Natural Resources Conservation Service and the Plant Materials Center of the US Department of Agriculture (Hamer, et al., 1992; Miller and Skaradek, 2001; Skaradek, et al., 2003). They provide a good source of guidance appropriate to this geographical area.

In those instances of foredune management, it is critical that the site of foredune enhancement and/or creation be located along the general trend of natural coastal foredune development. Foredunes are naturally positioned to occupy the inner margin of the bare sand beach and will function most effectively when in that location. Further, foredunes are dynamic and will migrate in keeping with the general sediment budget of the island. Foredune enhancement needs to recognize the scale of foredune migration and the conditions associated with the short-term and long-term spatial dynamics. Indeed, there is increasing recognition of the natural and cultural benefits that accrue with the conditions of dune mobility and habitat restoration rather than artificial stabilization of sand ridge in place (Martinez, et al., 2004).

BEACH SCRAPING

This action is a form of human manipulation of the coastal system that applies to the bare sand portion of the beach. As practiced in many locations, it consists of moving sand by mechanical means from the lower portion of the profile to the upper portion of the profile (Figs. 7 & 8). The goal is to increase the dimensions of the foredune and to improve its resistance to storm surge and its potential to penetrate inland into the communities. In concept, this action does not affect the total amount of sand in the system, but it does shape the beach profile and adds volume to the upper beach or dune segment of the profile. The existing NPS policy is to require a special use permit for the activity and to restrict it to areas that do not disturb nesting shorebirds. Present criteria for the Seashore require beach dimensions of at least 100 ft (30 m) width seaward of the foredune and elevations of at least 9 ft (2.7 m) above the National Geodetic Vertical Datum of 1929 (NGVD29)[1] at the foredune base and 7 ft (2.1 m) NGVD at a position 100 ft (30 m) seaward. The depth of sediment removal may not exceed 1 ft (0.3 m), and the total volume must not exceed 2.2 yds^3 per linear ft (5.42 m^3/m) of beach face.

Amongst the early studies of the efficacy of beach scraping, Kana and Svetlichny (1982) reported on a two-year program at Myrtle Beach, SC, that moved about 131,000 yds^3 (100,000 m^3) of sand from the low, intertidal portion of the profile to the inner margin of the dry sand beach (Fig. 9). In some instances, the inner margin was adjacent to a natural dune, in some cases it was at the base of a bulkhead or some constructed feature. Thus, the project was applied to a site that was characterized as varying from a near equilibrium condition with a natural foredune, to an area that was slowly eroding and having a variety of bulkheads and other hard structures at the upper beach. Further, the project goal was to remove sediment from the intertidal zone and place it at a position to widen the upper beach (to provide a recreational surface). Profile data were collected to track the performance of the new profile at the variety of locations along the island to determine aspects of recovery in the scraped portion and longevity of upper beach in the filled portions. Whereas the beach profile characteristics of the portion of the island that was near

[1] NGVD29 refers to a constant vertical reference plane established in 1929 and applied throughout the USA. It is presently about 1 ft (0.3 m) below mean sea level at Fire Island. Elevations are measured relative to this plane rather than to something that shifts through time, such as mean sea level.

Figure 7. Transfer of sand from the upper beach to the location of the created foredune ridge, Kismet, July 31, 2007 (photo by Erika Lentz).

Figure 8. Addition of scraped sand to the seaward margin of the foredune, Kismet, Oct 18, 2007.

equilibrium recovered quickly, the profile configuration in the eroding section lost much of the accumulation in a short time; in essence, indicating that the background rate of sediment transport was similar whether the sand was in the upper or lower portion of the profile.

In an early analysis of the applicability of beach scraping, Bruun (1983) approached the issue by indicating that beach scraping should only remove sediment from parts of the profile that were undergoing accumulation (Fig. 10). He described summer accumulation as occurring in and around the berm crest and winter accumulation as occurring on the berm surface. Depending on season, either of these sites, if they are gaining sediment, would be sources for removal. Placement of the sediment was to be located at the dune toe, seaward of the existing foredune. Bruun (1983) suggested that a removal to a depth of 1.0 ft (0.3 m) over a distance of 100 ft (30 m) was sufficient to provide adequate protection to the foredune, 11 yds^3/yd (9 m^3/m). Importantly, he restricted the transfers of sand to within the upper portion of the beach and to those areas of accumulation. He specifically suggested that scraping should be avoided in the intertidal zone where the beach is in continual flux.

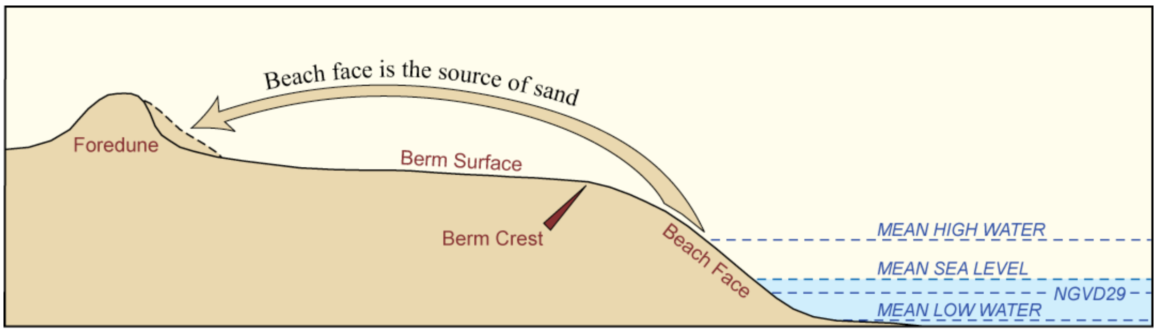

Figure 9. Scraping of sand from the beach face to foredune, the source location includes the entire area exposed during low water.

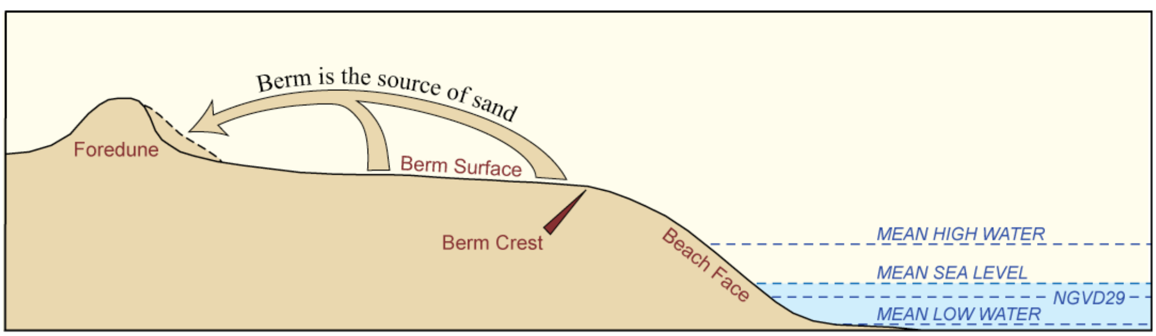

Figure 10. Scraping sand from the upper berm surface to the foredune applies to the dry sand beach that is not being actively molded by the contemporary waves and currents. It is affected by wind.

While acknowledging that scraping did not add new sediment to the beach, a study in Topsail Beach, NC attempted to determine if seasonal timing or technique of sediment transfer might affect the effectiveness of the manipulation (Wells and McNinch, 1991; McNinch and Wells, 1992). Profile data gathered over a period of one year and along 1.24 miles (2 km) of shoreline compared an updrift control section with a downdrift scraped section. The goal was to measure dune loss in the two sections. The comparison was made a bit more complex because two major storms struck the site during the surveys, a nor'easter in March 1989 and Hurricane Hugo in September 1989. Total loss of sediment was greater in the control area during the nor'easter, but greater in the scraped areas during the hurricane, perhaps indicating that scraping was more effective during smaller energy events. Because most of the sediment was taken from the active beach face, part of the comparison was related to the recovery period of the zone of sand harvest. It was determined that if the rates of scraping were similar to the rates of alongshore transport, the foreshore recovered quickly, within 48 hours, and there was no adverse impact to the profile. Therefore, scraping should occur at low rates of harvesting over an extended duration rather than major quantities over a short period.

Conaway and Wells (2005) determined that beach scraping contributed to an increased inland transport by wind to and across the foredune. Beach scraping transported sediments from the beach face to an area adjacent to the foredune location and provided a source for eolian transport. Although the amounts of subsequently sediment were small, they were a loss to the alongshore transport system. Quantities scraped varied from 19 to 35 yds^3/yd (16 to 29 m^3/m), with a control site nearby. Transport was highest immediately after scraping, and then decreased with time. However, the rates of inland eolian transport remained higher in the scraped areas than in the control areas. Although planted with American beach grass (*Ammophila brevilugulata*), the density of cover on the scraped dune was never as great as the control and thus higher transport rates ensued, about 50 times greater in the scraped site (0.035 $yd^3/yd/day$ vs. 0.0007 $yd^3/yd/day$ (712 $cm^3/m/day$ vs. 14.7 $cm^3/m/day$)). The sediments transported to the dune crest in the control site were slightly finer, whereas the site of scraped sediment disposal eventually had a concentration of shell debris and coarser sediments on the surface, a condition that was also reported at Bogue Banks by Peterson, et al. (2000).

In summary, beach scraping is practiced to enhance the height and breadth of the foredune as sand is transferred from a lower portion of the profile to the dune location. The several studies directed toward the impacts of beach scraping focus on impacts on the beach face regarding volumetric losses and slope adjustment. They show that in areas where the sediment supply is adequate, the beach profile tends to return to its original state in a short time. However, in areas of persistent erosion, the inland displacement of the beach continues and the emplaced sand ridge is removed in one season. Bruun (1983) considered whether there was a positive or negative effect of the translocation of the sediment on the profile; that is, was there an increase or decrease in the rate of sediment loss from the total profile. He indicates that if the scraping moves sediment that is in the zone of accumulation on the profile, it should not affect the sediment transport in the beach face. He suggests that the additional protection in the vicinity of the foredune has a greater benefit to the system than does the beach protection afforded by the sediment retained lower on the profile. He also stated that because the procedure only deals with "surplus" material accumulating on the beach profile, the downdrift effects should be minimal and should not increase the rate of erosion on adjacent areas. This view of beach scraping is in agreement with the current NPS and NYSDEC policy of only moving sediment that has accumulated high on the profile and when the upper portion of the profile has sufficient width (Fig. 4) (NPS, 2003). It is also consistent with placing the scraped sediment within 15 ft (4.6 m) of the position of the existing or determined foredune crestline (Fig. 5). Certainly, there is no amelioration of the erosional trend that is affected by the scraping of sand from one part of the profile and placing on another part. And, if the accumulation is too far seaward, it will be removed during periods of mobilization of the upper beach. There is some potential benefit associated with the enhancement of a foredune in its equilibrium location and the improvement of the general role it serves as a buffer to storm wave penetration, as well as to the possible embellishment of habitat in the dunal system. But, there is a conflict between putting the sand seaward of the equilibrium coastal foredune where it will be eroded more easily and putting the sand at the position of the equilibrium coastal foredune where it may damage the existing pioneer vegetation and associated habitat (see next section on ORV impacts). Placement of the sediment should be consistent with the guidelines for foredune enhancement that support the siting and stabilization of the repositioned beach sediment. There may be issues with the ecological effects of sediment removal as well as sediment placement, especially if the emplaced sand completely obliterates the pioneer vegetation on and emanating from the foredune. This particular impact is only partially addressed in the existing studies on beach scraping, but it is central to the integrity of the foredune form and habitat. The totality of the procedure and its features and impacts remains an area for further investigation.

ORV Impacts

There is no interior paved road that traverses the length of the island. A narrow route, primarily on sand, wends through much of the western and central portions of Fire Island as far as Watch Hill. Nearly all of the current vehicle driving involves some transit of the beach and through breaches in the dunes. There are 213 permits for private vehicles and another 110 permits issued to contractors and public utilities. Other vehicles include school buses, police, and Park security. The traffic is part of the Fire Island scene and it is slowly decreasing as some permits reach the end of their cycle and are not being renewed. There is concern that off-road vehicles are affecting the quality of the habitats on Fire Island and that they may be contributing factors in sediment loss in the beaches and dunes (Fig. 11). Vehicles have been shown to reduce the plant cover on barrier islands and lower species diversity as well as alter the community composition (Stephenson, 1999). Godfrey, Leatherman, and Buckley (1978) and Godfrey and Godfrey (1980) indicate that ORV traffic inhibited plant growth, crushed faunal populations, and resulted in a compaction of subsurface layers in sandy sediments in the Cape Cod National Seashore.

Hosier and Eaton (1980) compared sections of a barrier island in North Carolina with and without ORV traffic and found that dune vegetation was less dense in the ORV areas, and there were more blowouts in the dunes (the lower density of vegetation cover presumably caused the area to be more susceptible to eolian action). They also found higher compaction values in the sediments with ORV traffic. On Padre Island National Seashore, McAtee and Drawe (1980) attributed the intensity and type of traffic to decreased root production, percent cover, and diversity of vegetation in the dune areas as well as a modified species composition in the beach and dune areas. Further, they indicated that in the heavily-trafficked areas, the vegetation cover represented the earlier successional stages compared to the comparatively undisturbed areas. They also noted that the foredune was lower and less continuous in the heavily-trafficked areas. Anders and Leatherman (1987) conducted a two-year controlled experiment on Fire Island in the Wilderness Area that applied vehicle impacts to sets of side-by-side parcels (impacted and control) with 8 vehicle passes per week and over the same geomorphological feature (dune toe and immediate area to seaward). They reported vehicle impacts to the upper beach and dune zone with as few as one pass per week, with a significant loss of vegetation on the foredune and an alteration of the natural foredune profile through blowouts and sand mobilization compared to the adjacent area with no ORV traffic. And, in a comparison of impacts at the dune cut to the west of Kismet, there was visual evidence of greater vegetation loss and dune toe erosion eastward of the break in the dunes, in the direction that all the vehicles turned when accessing the beach (Anders and Leatherman, 1987). Thus, even light ORV traffic damaged the seaward colonizing plants at the base of the dunes (American beach grass and dusty miller) and prevented the expansion of the pioneer vegetation (Fig. 12).

Figure 11. A multitude of ORV tracks in the beach. These tracks are in the seaward half of the beach profile, near the top of the beach face and on the seaward portion of the berm surface, Davis Park, June 1, 2005.

At Cape Cod National Seashore, studies indicated that ORVs broke underground rhizomes extending seaward from the face of the dune to the depth of 8 inches (20 cm) (Niedoroda, 1979). The ORV traffic tore the roots and rhizomes apart and also crushed the seedlings of young annual and perennial plants (Zaremba, et al., 1978). Atkinson and Clark (2003) report that only a few passes of an ORV is sufficient to destroy the seedlings, rhizomes, and regenerating plants both on and below the sand surface. This is especially true for the new growth that emanates from the drift line found near the base of the foredune (Fig. 12). As a result, it is often recommended that ORV use be directed to the intertidal zone where the natural dynamics cause continuing change and adjustment (Atkinson and Clark, 2003). The zone of pioneer vegetation that extends seaward from the foredune is very vulnerable to the tearing action of ORV traffic and it is the basis for a ban of ORV traffic within 20 ft (6.1 m) of the base of the foredune at Fire Island, known as the “rhizome rule”.

A study by Steinback (1999) on Fire Island compared the invertebrate fauna found in the wrack zone to either side of the vehicle cut and seaward of the foredune at the western margin of

Sailors Haven. The area to the east of the vehicle cut was in a location that banned ORVs whereas the area to the west had all of the traffic that was destined for the vehicle access path. One focus of the research was on the constituents of the wrack, its persistence and character with and without ORV traffic, and the invertebrate community present in the wrack zones to either side of the vehicle cut. Although there was natural variation between the two sites and at different times of the year, statistical analysis indicated that the wrack was more prone to desiccation because of vehicle traffic dispersing it and mixing it into the berm surface. It was a less favorable site for the invertebrate population and this characteristic led to a lower diversity in community structure in the ORV side. Further, the impacts of ORV traffic were seen to be greater on the higher, well-developed berm surfaces than on narrow beaches and berms because they were a more stable component of the beach profile and less likely to be modified by storm events.

Figure 12. ORV tracks in upper beach, breaking any roots or rhizomes that may have extended from the erosional face in the foredune. Further, tracks may have damaged seeds and plants emanating from the swash line deposits, Talisman, June 3, 2005.

Possible ORV impacts to the ecology of the wet beach have received a modicum of attention. Wolcott and Wolcott (1984) studied ORV effects on beach macro invertebrates in North Carolina and found that the organisms in the sand tended not to be affected by ORV traffic whereas any organisms on the surface that emerged from their burrows to feed were crushed. Steiner and Leatherman (1981) report that fewer ghost crabs were found on ORV-used beaches in Assateague Island National Seashore than where ORVs were prohibited. And, it did not matter if the use were high or low intensity. A similar finding related to ghost crabs was reported from South Africa (van der Merwe, 1988: van der Merwe and van der Merwe, 1991).

In a study to determine geomorphological effects, Smith and Guatella (2002) found that whereas ORV traffic obviously displaces beach sand, it is difficult to determine if the traffic impacts result in increased sediment loss from the beach to the dune zone or increased alongshore transport. ORV traffic obviously displaces sand along the ruts, but there is a question whether the roughened surface accelerates or reduces the flows of wave runup and backwash to change the capacity of alongshore sand transport.

As identified in Celliers, et al. (2004) in an assessment of ORV regulations in recreational areas in South Africa, the intertidal zone and adjacent portions of the beach are continually being modified by waves and are very resilient to a variety of vehicular activity. However, the upper portion of the beach, and the base of the foredune, are much more susceptible to damage by vehicle impacts because of the destruction of vegetation rhizomes and roots at the foot of the dunes, and the damage to drift lines where seeds and new plants accumulate. Driving should not be permitted in the upper backshore area, particularly in those areas of drift line accumulations. A similar recommendation is made by Atkinson and Clark (2003) who suggest that ORV traffic be restricted to below the drift line, no driving on the upper backshore (near the dunes). In essence, this field of research identifies the upper beach seaward of the dunes as an important location for pioneer vegetation and its accompanying habitat. And, as referred in the "foredune building and enhancement" section, it is in this transition from bare sand beach to the zone of vegetation that sediment accumulates to form a sand ridge, or coastal foredune. The research supports the existing Park policy on the 'rhizome rule' for posting to identify approved routes, closures of the beach during periods of high water, and enforcement to prevent any vehicle use within an area where pioneer vegetation or roots and rhizomes are present. It is also consistent with the general policy to support the natural development of the coastal foredune in the zone of pioneer vegetation growth and sediment stabilization as a measure to promote foredune growth.

Houses and Walkways in the Foredune

The presence of people and their activity on the foredune is generally associated with traffic and with buildings. Bonner (1988) analyzed pedestrian pathways through the dunes on Fire Island and related them to impacts on the foredune. She found that footpaths on grade through the dunes broadened through time and were sites of inland eolian transport, leading to a degradation of the dunal form and its accompanying habitats. However, wooden walkways that crossed the dunes had lower impacts that did not increase with time. If the walkways were elevated sufficiently, the adjacent dune topography functioned in much the same way and at the same rates as the dunes located some distance from the walkway.

In an attempt to understand the effects of houses on inland sediment transport at the foredune crest, Nordstrom and McCluskey (1985) monitored the wind flows and sediment budgets in and around several houses on Fire Island. They were able to compare conditions while a house was on-site relative to after it was removed. They only monitored houses that were on pilings inland of the foredune. Their findings indicated that with elevation, the houses had very little effect on the wind flows and on sediment transport. They suggested that houses built at grade would have greater effect in increasing transport to their margins but might be a barrier to direct transport (Fig. 9). An outcome of their work was to suggest that as the foredune migrated inland, and the space below the houses decreased, there would be greater effects on sediment transport on the inland side of the foredune and greater effects on the integrity of the foredune (Fig. 8).

In a comparison of foredune configuration in undeveloped areas adjacent to developed areas, Gares (1983) determined that the dunes in the developed areas lost volume through time because they did not migrate inland in the same manner as in the adjacent natural areas. Instead they became narrower and steeper. There was some compensation for foredune sand accumulation in the developed areas produced by sand fences at the foredune base. His conclusion was that the enhanced sand accumulation associated with sand fences is necessary to maintain dune mass in the developed areas. Otherwise, narrowing of the dune profile and lowering of the foredune crest will ensue as it shifts. Conway and Nordstrom (2003) suggest that the barriers to inland transport be removed or minimized to allow coastal dune migration or they will be unstable on the beach profile. There is evidence that the natural foredune migrated inland through zones of houses in Point O'Woods at the same rate it migrated in adjacent natural areas (Psuty and Piccola, 1994).

Overall, the general effects of buildings are increased if they are in the zone of the foredune by altering the wind field and directing sediment transport to the lee of the foredune crest. Further, there is an alteration of form and dimension that is also associated with the presence of buildings in and near the foredune. Elevation of the buildings above the foredune crest, elevated walkways, and restriction on the number of access points across the foredune reduce the impact on foredune development and migration. However, buildings do interfere with vegetative stabilization of the foredune with the result that there may be an increased mobilization of sediment in the vicinity of buildings.

HARD STRUCTURES

Human alteration of the shoreline occurs when hard structures are placed to modify the alongshore transport of sediment. Two types of engineering structures have been built on Fire Island: jetties and groins. Both structures are discussed in Psuty, et al. (2005) regarding their history and the sequence of alteration to the alongshore sediment transport system. The structures do not change the amount of sand present, but they do affect the distribution of the zones of deposition and erosion.

There are jettied inlets at both ends of Fire Island; they are part of the maintenance program for the navigable inlets at these locations. Each site has had a measurable effect on the island. Sediment accumulation updrift of the jettied inlet creates a seaward displacement of the beach and dune system whereas the downdrift area has an initial zone of accretion followed by a lengthier alongshore stretch of erosion. Together, the effects of the jettied inlets alter the general trend of the natural foredune crestline by creating localized landward displacement to the updrift side and seaward displacement on the downdrift side. The alongshore distance and the amount of displacement is related to the volume of sand transport altered by the structures at the inlets. This alteration of sediment transport situation is similar at the location of the groins constructed near the western end of Ocean Beach. They are in the beach and interfere with alongshore transport of sediment, causing accumulation toward the east and accelerated erosion on the downdrift western side and affecting the trend of foredune crestline development at this location (Fig. 13). There is a finite zone of accretion on the updrift margin that is established by the seaward length of the structures. The downdrift erosion has no such limitation; it will continue to erode and displace the dune-beach system to the limits of the barrier island if there is a reduction of alongshore sediment transport.

Figure 13. Erosion of upper beach and foredune downdrift of the groins installed at Ocean Beach, seen at upper right of photo. Creation of foredune and emplaced sediment, fences, and plantings are unable to stabilize this beach at Corneille Estates, May 31, 2005.

Beach Nourishment

The application of beach nourishment is meant to add to the sediment supply and replace sand that has been eroded. This is the one human action that modifies the amount of sand present and directly affects the sediment supply transported through the alongshore system. With this human action, sand is usually derived from an offshore source and pumped to the beach via a pipeline (Fig. 14). The beach is widened and elevated, and the shoreline is displaced seaward (Fig. 15). As the new sediment is eroded by the ambient waves and currents and is entrained into the alongshore transport system, it is intended to buffer sediment loss in downdrift locations. In concept, beach nourishment works with the natural system of sediment transport and topographical development once the initial artificial emplacement has been adjusted by the ambient processes. Usually, the quantities of sediment emplaced are intended to provide sufficient volume to last about five years or so. That is, after about five years, the shoreline will return to its previous position. Thus, there is a recurring need to continue to apply beach nourishment if the goal is to stabilize the position of the shoreline. The history of beach nourishment on Fire Island is reported in Psuty, et al. (2005).

Figure 14. Sand is being discharged through a pipeline onto the beach. Bulldozer is spreading the sand and shaping the beach profile, Fair Harbor, Nov. 17, 2003. Photo courtesy of Coastal Planning Associates, Boca Raton, Florida.

Figure 15. Completed beach nourishment project with broad beach and ramp of sand to dune crest position. Fair Harbor, January 13, 2004. Photo courtesy of Coastal Planning Associates, Boca Raton, Florida.

In its application to Fire Island, a primary question related to beach nourishment is the location of the source of sediment and the impacts of that dredging on the beaches. Researchers have identified sites located 2-3 miles (3-5 km) offshore from Fire Island that serve as sources of sand that buffer the rates of shoreline erosion (Williams, 1976; Williams and Meisburger, 1987; Schwab, et al., 2000). Some of these areas have been identified as likely sources of sand for beach nourishment. There are questions related to the interference of the existing vectors of sand transport and if some of this offshore sand is presently moving onshore. Further, it is possible that dredging of these offshore sites may have long-term negative consequences if the modified offshore topography results in a different pattern of wave refraction, diffraction, and inshore wave-current interaction (Kelley, et al., 2004). If other sites of offshore sand are available, they should be higher priority sources.

Whereas the importation and placement of sediment to balance the sediment budget is a low impact approach, there are several concerns regarding the quality of the new material, its source, its timing of application, and some issues with quantity. The positive and negative issues related to beach nourishment have been adequately detailed by two extensive National Research Council reports (Wood, et al., 1990; Seymour, et al., 1995) and a host of reviews, including Nordstrom (2000), Finkl and Walker (2002), and Dean (2003). In an extensive review of impacts, Speybroeck, et al. (2006) offer the following considerations: 1) use a grain size that is similar to the target beach; 2) apply in a period that does not conflict with bird use or the life cycle of other organisms; 3) apply in several small quantities rather than one large amount.

Peterson, et al. (2000) conducted a comparison of macro-invertebrates in areas that had nourishment and areas of scraping with control areas and found very reduced abundance of bean clams (donax) and mole crabs (Emerita) after three months. In a situation where the quality of the fill was much coarser than the original beach (Peterson, et al., 2006), the beach face became much steeper and the zone of macro-invertebrates much more restricted. The condition persisted for more than one year and apparently influenced predator-prey relationships for this period. Overall, impacts tend to be greater when nourishment sediments have a high proportion of fine to very fine sand and are not matched with the existing beach sediments (Peterson, et al., 2000; Nelson, 1993).

An essential issue related to the foredune is the relationship of the emplaced material relative to the trend of the natural foredune crestline. Because beach nourishment is intended to be a short-term response to a general negative sediment budget situation, the foredune crestline will not be affected much by the increased beach width during this time span. Therefore, in keeping with the goals of maintaining the integrity of the natural foredune, it should be retained in place and with the minimum of disruption. If sand is placed in the vicinity of the foredune, it should be accomplished in accord with the guidelines identified in the previous section on foredune enhancement.

Whereas there has been a concentration of physical and biological responses to beach nourishment at the intertidal portion of the profile, further research should be directed toward the entire dune-beach profile and to the cumulative effects to the system. Further, inquiry also needs to be directed to the impacts at the sediment source area, both in short-term and long-term modifications (Newell, et al., 1998; Greene, 2002). There remain questions about the net transport direction of the large masses of sand in the offshore zone and whether they are currently supporting the sediment budget of Fire Island.

CONCLUSIONS

The scale and variety of natural processes and cultural modifications have created the existing features present on Fire Island. However, there is new information emerging (Bindoff, et al., 2007) that global climate change is occurring, and that the rate of worldwide sea-level rise is increasing. A likely outcome of this combination is that an increased magnitude of changes in the coastal system will ensue. Amongst the predicted changes are increased mobility of beaches and dunes, higher penetration of storm surges, displacements of shorelines, greater exposure of human occupation and infrastructure to storm effects, etc. All coasts will be exposed to these changing conditions, and all coasts will be adjusting to the changes.

A continuation of the human modification of the evolving coastal system may likewise follow as a means to adapt to aspects of global climate change. As the barrier island responds via an inland displacement of the shoreline and the foredune migrates, static features such as houses and other elements of infrastructure will be increasingly exposed to the ambient winds, waves, and currents. It is likely that human actions to enhance the foredune as it shifts position will have the greatest positive impact in retaining the geomorphological characteristics of the island that function as a barrier to storm surge penetration and to keeping sand in the seaward portion of the island. Therefore, human actions that support the retention of the foredune mass and dimensions, such as the restoration of dune-forming processes and the rhizome rule, provide the greatest opportunity to combine maintenance of the natural system dynamics with protection of the development inland of the foredune. Actions that lead to a reduction of the foredune will hasten the negative impacts that are predicted under the global climate change scenarios. Therefore, there is an advantage to taking steps to reduce the negative cultural impacts in the dynamic foredune system as a means to preserve the integrity and continuity of the feature and to ensure its function as a viable component of the barrier island.

Most of the adaptations described above are largely cosmetic with no additional sand in the system to strengthen or add mass to the coastal forms. Therefore, they are directed toward retention of the characteristics and dimensions of the foredune. However, beach nourishment does add new sand to the beach-foredune system if the sand is derived from a source that is not presently contributing to the sediment supply of the island. Its impact is conditioned by the quantity of sand emplaced as well as the location of the emplacement. Beach nourishment is a short-term response to the long-term issue of a negative sediment budget in the Fire Island coastal system. Under the challenges of global climate change, the quantities of sand needed to balance the sediment budget will increase and may eventually become too costly to continue. Therefore, even with the opportunity to apply beach nourishment as a short-term adjustment, the long-term function and the migrating position of the coastal foredune should be retained as a central component of a healthy barrier island system.

ACKNOWLEDGEMENTS

The process of searching through the literature takes dedication and a critical eye to sift a wide range of sources. I was the recipient of two very helpful assistants in this venture, Dr. Jennifer Rahn, Assistant Professor at Samford University, and Andrea Spahn, a student at McDaniel College. In addition, Diane Abell, Patti Rafferty, and Mike Bilecki of the Fire Island National Seashore provided assistance in identifying resources and helping to move the process ahead. Michael Siegel, Director of the Cartography Lab, Rutgers University, produced the map and diagrams for the paper. Special thanks are extended to Steve Keehn of Coastal Planning Associates and to Erika Lentz of the University of Rhode Island for contributing photographs to this report. Dr. Charles T. Roman, Mike Bilecki, and Robin Lepore, Esq. of the National Park Service, as well as an anonymous reviewer, provided comments on drafts of this paper.

LITERATURE CITED

Allen, J.R., C. LaBash, P. August, and N.P. Psuty, 2002. Historical and Recent Shoreline Changes, Impacts of Moriches Inlet, and Relevance to Long Island Breaching at Fire Island National Seashore, NY, Technical Report NPS/BSO-RNR/NRTR/2002-7, Dept. of the Interior, National Park Service, 76 p.

Anders, F.J. and S. Leatherman, 1987. Effect of off-road vehicles on coastal foredunes at Fire Island, New York, NJ, USA. Environmental Management, 11: 45-52.

Atkinson, L. and B. Clark, 2003. Literature Review of Off-road Vehicle (ORV) Ecosystem Impacts and Management Protocols and Their Relevance to South Africa. Department of Environmental Affairs and Tourism, 33 p.

Bagnold, R.A., 1941. The Physics of Blown Sands and Desert Dunes. Methuen, London.

Bindoff, N.L., J. Willebrand, V. Artale, A. Cazenave, J. Gregory, S. Gulev, K. Hanawa, C. Le Quéré, S. Levitus, Y. Nojiri, C.K. Shum, L.D. Talley, and A. Unnikrishnan, 2007. Observations: Oceanic Climate Change and Sea Level. In: S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Avery, M. Tignor, and H.L. Miller, editors. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, NY, USA, pp. 387-432.

Bonner, A.E., 1988. Pedestrian walkover form and eolian sediment movement at Fire Island, New York. Shore and Beach, 56: 23-27.

Bruun, P., 1983. Beach Scraping – Is it damaging to beach stability? Coastal Engineering, 7: 167-173.

Carter, R.W.G., 1988. Coastal Environments. Academic Press, New York.

Celliers, L., T. Moffett, N.C. James, and B.Q. Mann, 2004. A strategic assessment of recreational use areas for off-road vehicles in the coastal zone of KwaZulu-Natal, South Africa. Ocean and Coastal Management, 47: 123-140.

Conaway, C. and J.T. Wells, 2005. Aeolian dynamics along scraped shorelines, Bogue Banks, North Carolina. Journal of Coastal Research, 21: 242-254.

Conway, T.M. and K.F. Nordstrom, 2003. Characteristics of topography and vegetation at boundaries between the beach and dune on residential shorefront lots in two municipalities in New Jersey, USA. Ocean & Coastal Management, 46: 635-648.

Dean, R.G., 2003. Beach Nourishment: Theory and Practice. World Scientific Publishing, Singapore.

Ehrenfeld, J.G., 1990. Dynamics and processes of barrier island vegetation. Reviews in Aquatic Sciences, 2: 437-480.

Finkl, C. and H.J. Walker, 2002. Beach nourishment. In: J.Y. Chen, D. Eisma, K. Hotta, and H.J. Walker, editors. Engineered Coasts. Springer, New York, pp. 1-22.

Gares, P.A., 1983. Beach/dune changes on natural and developed coasts. Proceedings, Coastal Zone '83. American Society of Coastal Engineers, New York, pp. 1178-1194.

Godfrey, P.J. and M.M. Godfrey, 1980. Ecological effects of off-road vehicles on Cape Cod. Oceanus, 23: 56-66.

Godfrey, P.J., S. Leatherman, and P.B. Buckley, 1978. Impact of offroad vehicles on coastal ecosystems. Proceedings, Symposium on Technical, Environmental, Socio-economic and

Regulatory Aspects of Coastal Zone Planning and Management, San Francisco, CA, pp. 581-600.
Greene, K., 2002. Beach Nourishment: A Review of the Biological and Physical Impacts. Atlantic States Marine Fisheries Commission Habitat Management Series no. 7, ASMFC, Washington, D.C.
Hamer, D., B. Cluster, and C. Miller, 1992. Restoration of Sand Dunes along the Mid-Atlantic Coast. Dept. of Agriculture, NRCS: Somerset, NJ.
Hosier, P.E. and T.E. Eaton, 1980. The impacts of vehicles on dune and grassland vegetation on a south-eastern North Carolina barrier beach. The Journal of Applied Ecology, 17: 173-182.
Hotta, S., N.C. Kraus, and K. Horikawa, 1987. Function of sand fences in controlling wind-blown sand. Proceedings, Coastal Sediments '87. American Society of Civil Engineers, p. 772-787.
Hotta, S., N.C. Kraus, and K. Horikawa, 1991. Functioning of multi-row sand fences in forming foredunes. Proceedings, Coastal Sediments '91. American Society of Civil Engineers, p. 261-275.
Ingle, C., Y.F. Leung, C. Monz, and H. Bauman, 2003. Monitoring visitor impacts in coastal national parks: A review of techniques. Proceedings, 12th George Wright Society Conference, p. 228-233.
Kana, T.W. and M. Svetlichny, 1982. Artificial manipulation of beach profiles. In: B. L. Edge, editor. Proceedings, Eighteenth Coastal Engineering Conference, American Society of Civil Engineers, p. 903-922.
Kelley, S.W., J.S. Ramsey, and M.R. Byrnes, 2004. Evaluating shoreline response to offshore sand mining for beach nourishment. Journal of Coastal Research, 20: 89-100.
Koske, R.E. and J.N. Gemma, 1997. Mycorrhizae and succession in plantings of beachgrass in sand dunes. American Journal of Botany 84: 118-130.
Koske, R.E., J.N. Gemma, L. Corkidi, C. Iguenza, and R. Rincon, 2004. Arbuscular mycorrhizas in coastal dunes. In: M. Martinez and N.P. Psuty, editors. Coastal Dunes: Ecology and Conservation, Springer-Verlag, Berlin, pp. 173-187.
Marsh, G.P., 1865. Man and Nature; Physical Geography as Modified by Human Action. Scribner, New York, 560 p.
Martinez, M.L., M.A. Maun, and N.P. Psuty, 2004. The fragility and conservation of the world's coastal dunes: geomorphological, ecological, and socioeconomic perspectives. In: M. Martinez, and N.P. Psuty, editors. Coastal Dunes: Ecology and Conservation. Springer-Verlag, Berlin, pp. 355-366.
Maun, M.A., 2004. Burial of plants as a selective force in sand dunes. In: M. Martinez, and N.P. Psuty, editors. Coastal Dunes: Ecology and Conservation. Springer-Verlag, Berlin, pp. 119-135.
McAtee, J.W. and D.L. Drawe, 1980. Human impacts on beach and foredune vegetation of North Padre Island, Texas. Environmental Management, 4: 527-538.
McNinch, J.E. and J.T. Wells, 1992. Effectiveness of beach scraping as a method of erosion control. Shore and Beach, 60: 13-20.
Mendelssohn, I.A., M.W. Hester, F.J. Montefemante, and F. Talbot, 1991. Experimental dune building and vegetative stabilization in a sand-deficient barrier island setting on the Louisiana coast, USA. Journal of Coastal Research, 7: 137-149.
Miller, C.F. and W. Skaradek, 2001. Standard for Creating Sand Dunes. USDA, NRCS - Cape May Plant Materials Center, 11 p.

Miller, C.F. and W. Skaradek, n.d. Improving Plant Diversity on Coastal Sand Dunes. USDA, NRCS – Cape May Plant Materials Center, 3 p.
Miller, D.L., M. Thetford, and L. Yager, 2001. Evaluation of sand fence and vegetation for dune building following overwash by Hurricane Opal on Santa Rosa Island, Florida. Journal of Coastal Research, 17: 936-948.
National Park Service, 1977. General Management Plan, Fire Island National Seashore. Dept. of the Interior, Washington, D.C.,
National Park Service, 2003. Beach Scraping. In: Fire Island National Seashore, Short-term Community Storm Surge Protection Plan, Environmental Assessment. Patchogue, pp. 32-37.
National Park Service, 2007. Management Policies, 2006: The Guide to Managing the National Park System. Dept of the Interior, Washington, D.C., 176 p.
Nelson, W.G., 1993. Beach restoration in the southeastern US: Environmental effect and biological monitoring. Ocean & Coastal Management, 19: 157-182.
Newell, R.C., L.J. Seiderer, D.R. Hitchcock, 1998. The impact of dredging works in coastal waters: A review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. Oceanography and Marine Biology: An Annual Review, 36: 127-178.
Niedoroda, A.W., 1979. The geomorphologic effects of off-road vehicles on coastal ecosystems of Cape Cod, Massachusetts. University of Massachusetts/National Park Service Cooperative Research Unit Report No. 17.
Nordstrom, K. F., 2000. Beaches and Dunes on Developed Coasts. Cambridge University Press, New York, 338 p.
Nordstrom, K.F. and J.M. McCluskey, 1985. The effects of houses and sand fences on the eolian sediment budget at Fire Island, New York. Journal of Coastal Research, 1: 39-46.
Nordstrom, K.F. and N.L. Jackson, 2005. Bay Shoreline Physical Processes (Fire Island National Seashore Science Synthesis Paper). Technical Report NPS/NER/NRTR—2005/020. National Park Service. Boston, MA. It is available at: http://www.nps.gov/nero/science/.
Peterson, C.H., D.H.M. Hickerson, and G.G. Johnson, 2000. Short-term consequences of nourishment and bulldozing on the dominant large invertebrates of the sandy beach. Journal of Coastal Research, 16: 368-378.
Peterson, C.H., M.J. Bishop, G.A. Johnson, L.M. Danna, and L.M. Manning, 2006. Exploiting beach filling as an unaffordable experiment: Benthic intertidal impacts propagating upwards to shorebirds. Journal of Experimental Marine Biology and Ecology, 338: 205-221.
Phillips, C.J. and B.B. Willetts, 1978. A review of selected literature on sand stabilization. Coastal Engineering, 2: 133-147.
Psuty, N.P. and E. Rohr, 2000. Coastal Dunes: A Primer for Dune Management with Models of Dune Response to Storm Frequencies. Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, 40 p.
Psuty, N.P. and T.A. Piccola, 1994. Foredune sediment budgets, Fire Island, New York, U.S.A., 1982-1991. In: A. Mioseec, editor. Défense des cotes ou protection de l'espace littoral, quelles perspectives? Proceedings, University of Nantes, France, pp. 186-196.
Psuty, N.P. editor, 1988. Beach-Dune Interaction. Journal of Coastal Research, Special Issue No. 3, 136 p.
Psuty, N.P., 1989. An application of science to the management of coastal dunes along the Atlantic Coast of the USA. In: Coastal Sand Dunes, Proceedings. Royal Society of

Edinburgh, Scotland, Section B(Biological Sciences), United Kingdom, C.H.Gimingham, W. Ritchie, B.B. Willetts and A.J. Willis, Editors, 96B:289-307.
Psuty, N.P., 2004. The coastal foredune: A morphological basis for regional coastal dune development. In: M.L. Martinez and N.P. Psuty, editors. Coastal Dunes: Ecology and Conservation, Springer-Verlag: Berlin, pp. 11-27.
Psuty, N.P., and T.M. Silveira, 2008. Trend in Foredune Crestline Displacement, Fire Island National Seashore, 1976-2005. Technical Report for the National Park Service. *In review.*
Psuty, N.P., M. Grace, and J.P. Pace, 2005. The Coastal Geomorphology of Fire Island: A Portrait of Continuity and Change (Fire Island National Seashore Science Synthesis Paper). Technical Report NPS/NER/NRTR—2005/021. National Park Service. Boston, MA. 70 p. It is available at: http://www.nps.gov/nero/science/.
Sarre, R.D., 1985. Sand movement over a vegetated dune ridge. In: F. El-Baz, I.A. El-Tayeb, and M.H.A. Hassan, editors. Sand Transport and Desertification n Arid Lands, Proceedings. World Scientific, London, pp. 419-437.
Savage, R.P. and W.W. Woodhouse, 1969. Creation and stabilization of coastal barrier dunes. Proceedings 11th Coastal Engineering Conference, American Society of Civil Engineers, New York, p. 671-700.
Savage, R.P., 1963. Experimental study of dune building with sand fences. Proceedings 8th Coastal Engineering Conference, American Society of Civil Engineers, New York.
Schwab, W.C., E.R. Thieler, J.R. Allen, D.S. Foster, B.A. Swift, and J.F. Denny, 2000. Influence of inner-continental shelf geologic framework on the evolution and behavior of the barrier-island system between Fire Inland Inlet and Shinnecock Inlet, Long Island, New York. Journal of Coastal Research, 16: 408-422.
Seymour, R.J., N.E. Bockstael, T.J. Campbell, R.G. Dean, P.D. Komar, O.H. Pilkey, A.P. Pratt, M.R. Snow, R.F. van Dolah, J.R. Weggel, and R.L. Wiegel, 1995. Beach Nourishment and Protection. National Research Council, National Academy Press, Washington, D.C., 334 p.
Sherman, D.J. and B.O. Bauer, 1993. Dynamics of beach-dune systems. Progress in Physical Geography, 17: 413-447.
Skaradek, W., C. Miller, and P. Hocker, 2003. Beachgrass Planting Guide for Municipalities and Volunteers. USDA Plant Materials Center: Cape May, NJ, 4 p.
Smith, A. and M.S.C. Guatella, 2002. Assessment of Geomorphological and Sedimentological Damage by 4x4s and Launch Site Activities on the Beaches and Dunes of the Greater St. Lucia Wetland Park. Report prepared for Acer (Africa) Environmental Management Consultants, 36 p.
Speybroeck, J., D. Bonte, W. Courtens, T. Gheskiere, P. Grootaert, J.P. Maelfait, M. Mathys, S. Provoost, K. Sabbe, E.W.M. Stienene, V. van Lanker, M. Mincx, and S. Degraer, 2006. Beach nourishment: An ecologically sound coastal defence alternative? A review. Aquatic Conservation: Marine and Freshwater Ecosystems, 16: 419-435.
Steinback, J.M.K., 1999. The Ocean Beach Invertebrates of Fire Island National Seashore, New York: Spatial and Temporal Trends and the Effects of Vehicular Disturbance. Technical Report NPS/BSO-RNR/NRTR/00-7. National Park Service: Boston, 264 p.
Steiner, A.J. and S. Leatheman, 1981. Recreational impacts on the distribution of ghost crabs, Ocyode quadrata, Fab. Biological Conservation, 20: 111-122.
Stephenson, G., 1999. Vehicle Impacts on the Biota of Sandy Beaches and Coastal Dunes: A Review from a New Zealand Perspective. Department of Conservation, Wellington, New Zealand, 48 p.

USACE (U.S. Army Corps of Engineers), 2002. Fire Island to Montauk Point Reformulation Study, Draft Interim Report. New York District, NY.

van der Merwe, D., 1988. The Effect of Off-Road Vehicles (ORVs) on Coastal Ecosystems – A Review. Institute for Coastal Research Report No. 17, University of Port Elizabeth, South Africa, 64 p.

van der Merwe, D., and D. van der Merwe, 1991. Effects of off-road vehicles on the macrofauna of a sandy beach. South African Journal of Science, 87: 210-213.

Walker, H.J. 1990. The coastal zone. In: B.L. Turner, B. L., editor. The Earth as Transformed by Human Action. Cambridge: Cambridge University Press, pp. 271-294.

Wells, J.T. and J.E. McNinch, 1991. Beach scraping in North Carolina with special reference to its effectiveness during Hurricane Hugo. Journal of Coastal Research, Special Issue 8: pp. 249-261.

Williams, S.J. and E.P. Meisburger, 1987. Sand sources for the transgressive barrier coast of Long Island, New York: Evidence for landward transport of shelf sediments. In: N.C. Kraus, editor. Proceedings, Coastal Sediments '87, American Society of Civil Engineers, New York, NY, pp. 1517-1532

Williams, S.J., 1976. Geomorphology, shallow subbottom structure, and sediments of the Atlantic inner continental shelf off the Long Island, New York. Technical Paper No. 76-2, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA.

Wolcott, T.G. and D.L. Wolcott, 1984. Impact of off-road vehicles on macroinvertebrates of a Mid-Atlantic beach. Biological Conservation, 29: 217-240.

Wood, W.L., R.G. Dean, M. Jannereth, J.T. Kildow, S.P. Leatherman, B. le Mehaute, D.W. Owens, R.H. Platt, and R.L. Wiegel, 1990. Managing Coastal Erosion. National Research Council, National Academy Press, Washington, D.C., 182 p.

Woodhouse, Jr., W.W., 1978. Dune Building and Stabilization with Vegetation. Special Report No. 3. Fort Belvoir, Virginia, U.S. Army Corps of Engineers, Coastal Engineering Research Center, 112 p.

Zaremba, R.E., P.J. Godfrey, and S. Leatherman, 1978. The Ecological Effects of Off-Road Vehicles on the Beach/Backshore (drift line) Zone in Cape Cod National Seashore, Massachusetts. University of Massachusetts/National Park Service Cooperative Research Unit Report No. 29, 67 p.

As the nation's primary conservation agency, the Department of the Interior has responsibility for most of our nationally owned public land and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

NPS D-137 September 2008

National Park Service
U.S. Department of the Interior

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

http://www.nps.gov/nero/science/