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# Trend in Foredune Crestline Displacement, Fire Island National Seashore, New York, USA, 1976-2005

**N. P. Psuty† and T. M. Silveira†**
†Marine and Coastal Sciences, Rutgers University
74 Magruder Road, Unit 3
Highlands, NJ 07732, USA
psuty@marine.rutgers.edu
mendes@marine.rutgers.edu

**ABSTRACT**

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The foredune crestline is a geomorphological feature that shifts in response to sediment budget. Its position in the beach-dune profile is much more conservative than the variation in shoreline position or any other element in the response signature. A comparison of foredune crestline position covering a span of 29 years reveals spatial variation in response, tied to the alongshore transport mechanisms as well as evolutionary development of foredune features. The mean response of the entire Fire Island foredune is a displacement of -13.1 m. However, discounting the area affected by the large jetties at the updrift end, the mean displacement is -17.2 m. The 17 developed communities on the island had displacements ranging from -9.3 m to -21.7 m, whereas the natural areas had a mean displacement of -18.8 m. The spatial distribution of the displacements is related to the alongshore sediment supply and the effects of human alterations of the topography. Major deviations from the mean occur near Moriches Inlet (+49 m), at Cherry Grove, (+26 m), and a few other places. A land-use control mechanism, known as the Dune Management District, an area extending inland 12.2 m from the mapped 1976 crestline, is compromised severely in most of the communities. In both the natural and developed portions of the island, dune forming processes are maintaining the foredune characteristics and dimensions while shifting inland.

**ADITIONAL INDEX WORDS:** *Coastal dunes, Coastal change*

## INTRODUCTION

The concern with shoreline position monitoring is well documented (BYRNES, *et al*., 2003) and it has generated a wide range of evaluations that weigh the accuracy of the sources (GRAHAM, *et al*., 2003) as well as the variation in the temporal representation (MORTON, *et al*., 1995). The issues of temporal position exist independent of whether the shoreline interpretation is datum-based (e.g., mean sea level), or feature-based (e.g., wet/dry line on the beach face).

However, an alternative feature in the beach profile may provide an avenue for use of aerial photographs and other topographical data sources; it is the coastal foredune crestline. The coastal foredune is a relatively stable feature in the coastal landscape. Whereas the beach narrows and widens with modest changes in wave energies and sediment availability, the foredune characteristics and position are altered primarily under extreme events when waves reach above the beach or remove the beach to approach the seaward margin of the foredune (PSUTY, 2004). Under either of these conditions, some portion of the seaward margin of the foredune may be eroded. The foredune crestline is a bit more stable than the seaward margin because it will respond to conditions that erode a substantial portion of the dune, or transport great quantities of sand to the position of the crest or inland of the crestline. The foredune crestline is, therefore, a very conservative feature in the beach-dune system, altering its position only with those low-frequency events that directly affect the crestline. Although these events often result in erosion and displacement of the foredune crestline, there are conditions that cause accumulation of sand to the seaward margin of the crestline and produce a seaward displacement of the foredune crestline. Identification of the foredune crestline position interpreted from a sequence of aerial photographs will document the changing positions and describe the directions and dimensions of displacement. The approach should produce a more general portrayal of the shoreline vector because the position of the foredune crestline is less dependent on minor events or wet/dry boundaries that occur in the beach.

The issue of foredune mobility became important in a special case in the Fire Island National Seashore, a unit within the U.S. National Park Service, because the foredune crestline was the basis for jurisdictional authority between the National Seashore and the communities on the barrier island. The island is the site of Smith Point County Park (SPCP), Fire Island National Seashore (FINS), Robert Moses State Park, and 17 independent communities (Figure 1). Beyond the county and state park holdings, the national park manages the beaches, the communities manage their inland holdings, and a zone 12.2 m wide, Dune Management District, extending inland from the mapped foredune crestline (1976) is an area of co-jurisdiction (NORDSTROM and PSUTY, 1980).

Whereas the foredune was acknowledged to be dynamic and shift spatially, there were no measurements of the rates of foredune displacement. There was very little knowledge of the effects of foredune displacement on foredune form and function.

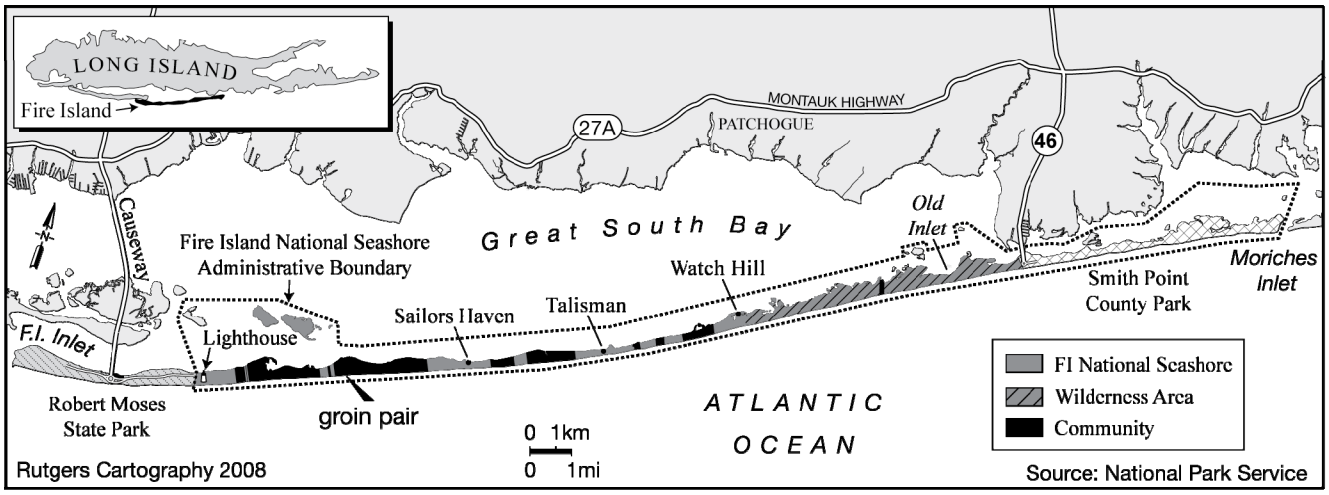


Figure 1. Location of Park lands and communities on Fire Island. Moriches Inlet is bordered by undeveloped land in a county park Fire Island Inlet is bordered by undeveloped land in a state park. Each of the inlets is the site of a jettied navigational channel. The Wilderness Area is a natural region within the National Seashore.

PSUTY (1990) provided an early report on the topographical response of the Fire Island foredune as it was displaced and established some measures of rates of displacement. ALLEN *et al.* (2002) reported on the long-term interpretations of Fire Island shoreline change from the old historical maps and charts, as well as aerial photographs, and they suggested that the foredune shifts were at a similar scale as the long-term shoreline changes, but with a very large error factor assigned to the historical sources.

In a very fortunate move, the Fire Island National Seashore contracted for very large scale aerial photos (1:2400) to be flown over the coastal area of the barrier island at 5-6 year intervals, beginning in 1976 and extending to 1992. Subsequently, aerial photos at about 1:9600 scale were flown by other agencies in 2000 and 2005. These photos are now the source for the identification of the foredune at the time and subsequent determination of the spatial and temporal displacement of the foredune crestline.

## METHODS

The objective of this project is to identify the position of the foredune crestline along Fire Island in 1976 and in 2005 and the vectors of displacement during this interval. Aerial photography from 1976 and aerial photos and LIDAR data sets taken in April and May of 2005 provide the temporal snapshot of the conditions at that time. Interpretation of the foredune topography was undertaken by examination of the aerial photographs and the LIDAR data to establish the seaward foredune crest and to delineate this crestline from Moriches Inlet at the eastern terminus for the length of Fire Island to the boundary at Robert Moses State Park. The State Park was exempted from the calculations because the foredune was highly manipulated and the western portion of the island was strongly influenced by the presence of a jettied inlet that did not permit migration of the natural foredune. On the other hand, the downdrift effects of the jetty at Moriches Inlet were applied to a naturally-responding foredune-beach system. Thus, the foredune shifted and represented the alteration created by changes in sediment supply and incident wave approach over the ebb-tide delta.

Digital, stereo aerial photos at the scale of 1:1200 were registered to a 2001 orthophoto base map and the foredune crestline was interpreted and mapped.

Integral to the project was the identification of the position of the natural foredune crestline rather than the crestline created through human manipulation of sediment to create a ridge of sand at the inland margin of the beach. The human-produced ridge may be at or near the position of the natural foredune, but it may also be at a considerable distance from the location of the natural foredune. Therefore, using the 2005 aerial photos and LIDAR data sets, all of the previous aerial photos, knowledge of the foredune morphology gained through decades of research on Fire Island foredune processes, and augmented by a recent field visit to the coastal dune along the length of the island, a delineation of the 2005 foredune crestline was conducted that extended through the natural as well as developed areas on Fire Island. In areas where the foredune was very modified by cultural practices, the trend of the natural foredune crestline was interpolated from the position of the feature in the adjacent areas. The adjacent areas were present in both natural and in developed portions of the island. Further, portions of the natural foredune crestline that continued to exist in the manipulated areas were aids in the identification.

After the two foredune crestlines were identified and registered to the base map, a U.S. Geological Survey shoreline change program, Digital Shoreline Analysis System (THEILER *et al*., 2005), was used to compare the two lines and to build the matrix of change for the length of the barrier island. Difference values were determined for every 10 m of dune crest length, extending from Moriches Inlet to the boundary with Robert Moses State Park. Subsequently, the matrix of differences between the two foredune crestlines was subjected to basic statistical analysis (mean, standard deviation) and grouped in geographical categories and land-holding units.

## RESULTS

A summary of the difference values for Fire Island (minus Robert Moses State Park) establishes several basic characteristics of the foredune displacement (Table 1). Perhaps, most importantly, the aerial photo interpretation records the presence of the foredune throughout the island as it is displaced by erosion or accretion. There were a few breaches of the foredune associated with storm events, but a comparison of foredune recovery evidenced on the intervening aerial photos documents the re

establishment of the foredune at the upper limit of the beach profile.

The mean change in foredune position over 29 years for the island is an inland displacement of 13.1 m with a standard deviation of 27.4 m, based on over 4000 points of comparison. Whereas the western portion of the barrier island was not part of the calculation because of the influence of the jetty, the eastern portion, Smith Point County Park and its associated jetty, was included in the initial comparison. Deleting that portion of SPCP that is influenced by the downdrift effects of the Moriches Inlet jetty, the mean displacement is -17.2 m, with a standard deviation of 18.7 m (Table 1). A comparison of foredune displacement amongst the several types of landholding indicates that the natural area has a greater net change than in the communities (-18.8 m versus -13.0 m) despite attempting to discount the efforts at human manipulation of the foredune in the communities. The one area of reduced inland displacement is updrift of the two groins in the western portion of Fire Island (Figure 1, Table 1). In this instance, the category of developed community east of the groin pair has a foredune crestline displacement approximately half that of the rest of the island. And, the area of developed community to the west of the groin pair has a foredune displacement that is similar to the natural area to the west of the groins. Both the developed community and the natural areas to the west of the groins have the lowest standard deviation in the matrix of measurements.

## DISCUSSION

The spatial distribution of foredune crestline displacement presents a pattern that is related to the alongshore sediment transport system and to additional variables that operate to affect the continuity of the coastal foredune (Figure 2). Whereas there is a general common displacement value of -15 to -20 m (mean of -17.2 m) present along the island, there is also a general oscillation about that value (standard deviation of 18.7 m).

For most of Fire Island, the foredune crestline is not a shore-parallel linear feature, but sinuous crestline that combines erosional scars from erosional events that scarped the dune unevenly and generated a sinuous crestline with alongshore oscillations from hundreds of meters to several kilometers (Figure 2). PSUTY and ALLEN (1993) and GRAVENS (1999) have called attention to nearshore circulation cells that progress alongshore at Fire Island and mobilize large sections of the beach and foredune in an episodic manner. PSUTY *et al.* (2005) reported on a specific circulation cell that scarped 400 m of dune crest in National Park lands at Talisman (near the mid-point on the island). Through one storm season, the circulation cell displaced the foredune as much as 25 m. Over the following eight years, the foredune recovered in place to attain similar topographical dimensions but located 25 m

Figure 2. Examples of variability and sinuosity in foredune crestline created by eolian processes in foreground and by wave and current processes with a nearshore circulation cell in the farground. Photo by James R. Allen.

Table 1: Descriptive statistics of foredune crestline position change between 1976 and 2005, for Fire Island and its major components.

| Location: | Length (m) | Mean (m) | StDev (m) | Max (m) | Min (m) |
|---|---|---|---|---|---|
| Total | 40710 | -13.1 | 27.4 | 138.9 | -95.1 |
| Total (minus effects of Moriches Inlet) | 38210 | -17.2 | 18.7 | 36.9 | -95.1 |
| Smith Point County Park (total of natural and manipulated) | 10000 | -13.2 | 48.0 | 138.9 | -95.1 |
| Natural Área (FINS and SPCP) Total (no Inlet, no SPCP manipulated) | 26370 | -18.8 | 19.4 | 36.9 | -95.1 |
| Developed Communities Total (no Inlet, no SPCP manipulated) | 11380 | -13.0 | 16.5 | 36.9 | -41.3 |
| Natural Area West of Groin Pair | 660 | -21.9 | 3.2 | -15.1 | -28.6 |
| Natural Area East of Groin Pair (no Inlet, no SPCP manipulated) | 25710 | -18.7 | 19.6 | 36.9 | -95.1 |
| Developed Community West of Groin Pair | 3420 | -21.7 | 7.4 | -4.6 | -35.9 |
| Developed Community East of Groin Pair (no Inlet, no SPCP manipulated) | 7960 | -9.3 | 17.9 | 36.9 | -41.3 |

inland. If circulation cells of this dimension notched and displaced the foredune episodically along the entire barrier, the signature would be a sinuous crestline that was differentially shifting inland in any one point in time. And, in a comparison of two crestlines representing the sinuosity at two different points in time, part of the pattern would be related to temporal position in erosion and recovery.

The foredune displacement for this 29-year period incorporates a mix of natural responses to the environmental variables in addition to cultural modifications to the alongshore transport systems as well as modifications to the transverse transport in the locations of the developed communities. The largest single cultural modification is the jetty construction at Moriches Inlet (Figure 3). There are three effects of this jetty that extend for about 7 km west of the inlet. The first is an erosional displacement immediately adjacent to the jetty, followed by a zone, 1.8 km in length, of positive displacement where sediment bypassing and wave refraction are causing a local site of accumulation. This location has a series of low foredune ridges describing the site of accretion. However, the next 5 km is an area of erosion and the foredune was displaced inland about 90 m in the 29-year period. This is the site of the greatest inland displacement of the foredune along the entire barrier island. At about 7.5 km downdrift from the inlet, the general rate of -15 to -20 m inland displacement is encountered and it oscillates around that value until near the midpoint along the island. There are a few portions of the foredune that consist of an emplaced sand ridge, a manipulated foredune. It does not shift as readily as the natural foredune and is classified as 'manipulated' within SPCP.

The pattern of foredune displacement in the western half of Fire Island is complicated by the human manipulations of the foredune position in the communities (PSUTY and SILVEIRA, 2008). Sand fences in the beach as well as in the foredune interrupt the natural processes. Direct placement of sand by earth-moving equipment is another complication. However, two locations of large positive displacement at approximately 25 km and 31 km from Moriches Inlet are products of recovery following major erosion episodes. The 1976 aerial photos show the result of the passage of a large and deep circulation cell that eroded the beach and nearly all of the foredune at these two sites. The shoreline and the foredune displayed a large embayment that was subsequently filled by alongshore sediment transport. The 1976 foredune crestline marks the inland extent of the scarp, whereas the 2005 foredune crestline represents the location of the foredune in the recovered shoreline. This type of anomaly will occur in any comparison of two points in time. And, adjacent to the major positive displacements are values of inland displacements that are of similar magnitude to the mean negative values found throughout the remainder of the island.

There is a low displacement value near km 36.5. This is a site of a pair of groins in the beach that are retaining sediment on their eastern side. Locally, the groin pair had caused beach accretion and a foredune on the 1976 foredune crestline. In the post-1976 time until 2005, the shoreline was maintained in position by the groins and the foredune was stable in place. Farther to the west, downdrift of the groin pair, the foredune crestline returns to an inland displacement and the values of displacement in the natural area and the developed community are greater, -21.9 m and -21.7 m respectively, than in other portions of the barrier island.

## CONCLUSION

The coastal foredune crestline is another feature-based characteristic that can be monitored to track coastal change. It is easily discerned on aerial photographs and on LIDAR images and is relatively conservative in its response to the ambient processes of shoreline erosion or accretion. Therefore, it tends to represent the net effects of major episodic events that reach the foredune and mobilize its seaward margin. It does not respond to the shorter-term tidal range variations. The mean value of inland displacement of 18.8 m over 29 years, 0.65 m/yr, is a reasonable value and is similar to shoreline change estimates generated for the island. However, on Fire Island the foredune crestline is altered by the passage of alongshore circulation cells that intermittently scarp the seaward margin and generate inland

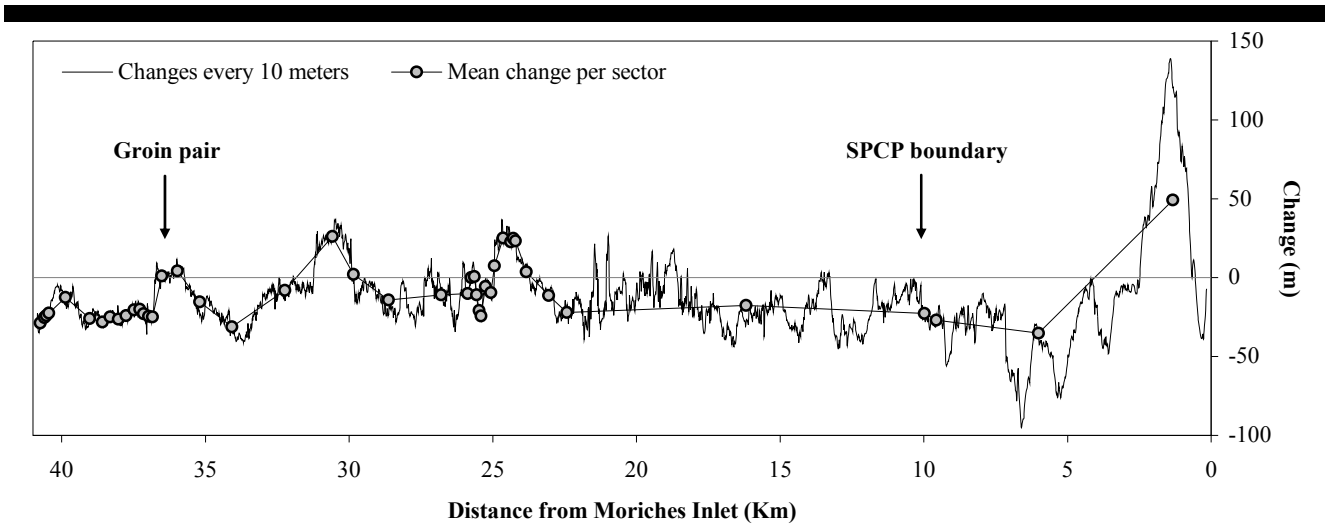


Figure 3. Displacement of the foredune crestline from 1976 to 2005 extending from Moriches Inlet to the border with Robert Moses State Park on the west. The border between Smith Point County Park (SPCP) and the Wilderness Area within Fire Island National Seashore is identified, as is the location of the pair of groins in the western portion of the island. The mean displacement of the crestline for each of the 17 communities as well as the segments of Park lands (sectors) is calculated and incorporated as a trend line for the island. SPCP is divided into four sectors based on the downdrift impacts of the jetties at Moriches Inlet and the level of manipulation of the foredune.

displacement of the feature. The comparison of foredune crestline position over the span of 29 years reveals the multi-faceted character of foredune dynamics and its spatial distinctions. The foredune is not a single linear sand ridge at the inland margin of the beach. It responds to variations in sediment supply and maintains a sediment budget in conjunction with the beach portion of the profile, but the foredune budget is at least partially-independent of the beach. Inland transfers of sediment and morphology are generated by eolian processes at the local scale, but the transfers are also products of nearshore wave and current systems that create displacements at the alongshore scale of hundreds of meters, up to several kilometers. At temporal scales of decades, the sinuosity of the foredune crestline will have alongshore wave-length dimensions similar to the dimensions of the circulation cells in the ambient system. However, comparison of foredune crestlines at different times will reveal not only the dimensions of the cells but also the sequence of scarping and recovery of the foredune. Through temporal dimensions of centuries, and longer, the episodic scarping, displacement, and recovery may be the vehicle for foredune migration and barrier island transgression under the influence of a decreasing sediment budget.

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