Coastal Foredune Displacement and Recovery, Barrett Beach-Talisman, Fire Island, New York, USA

by

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with 9 figures and 1 table

Summary. Coastal foredune mobility has been tracked at Fire Island National Seashore since 1976 with annual field surveys and analysis of frequent aerial photography. Sequential mapping of the foredune crestline depicts nearly islandwide displacement during major storm events, such as in 1992, and localized displacement during alongshore passage of inshore circulation cells during other years. An instance of localized landward erosion and curvilinear displacement along approximately 400 m of foredune occurred in 1994, followed by recovery over the next nine years. Data from annual surveys and partially supported by four LIDAR flights establish that volume recovery rates in the foredune ranged from about 1.0 m^3/m/yr to nearly 12.0 m^3/m/yr. Analysis of the foredune morphology and location shows nearly complete recovery of foredune shape and dimension during this interval and it also demonstrates that there has been inland displacement of the foredune crestline of up to 40 m. Total volume recovery within the localized foredune erosion site was greatest, between 34 m^3/m to 47 m^3/m, in areas of greatest displacement and eventually contributed to creation of a foredune of similar dimension along the entire eroded zone. This process of erosion and recovery describes a mechanism for foredune dimension retention during episodic erosion and displacement and may be a model for foredune persistence accompanying barrier island migration.

Résumé. Un suivi de la mobilité de la dune bordière de Fire Island National Seashore, une île-barrière dans l'Etat de New York, a été effectué depuis 1976 en utilisant des données topographiques de terrain et des séquences de photographies aériennes. Une cartographie séquentielle de la ligne de crête de cette dune bordière montre un déplacement sur quasiment toute la largeur de l'île Durant des épisodes de tempêtes majeurs, comme en 1992, et un déplacement localize dendant le passage, le long de la cête, de cellules de circulation littorale Durant d'autres années. Un exemple d'érosion localisée et de déplacement curvilinéaire sur environ 400 m de dune bordière eut lieu en 1994, suivi d'un rétablissement sur les neufs années suivantes. Des données issues de suivis topographiques annuels et partiellement complétées par quatre vols LIDAR montrent que les taux de rétablissement du volume de la dune bordiére ont varié d'environ 1,0 m^3/m/an à presque 12,0 m^3/m/an. Une analyse de la morphologie et de la localization de la dune bordiére montre un rétablissement quasi complet de lat morphologie pendant cet intervalle, mais un déplacement vers l'intérieur de sa ligne de crête quie attaint jusqu' à 40 m. Le rétablissement de volume dans le site d'érosion localisée de la dune bordière a atteint un maximum, entre 34 m^3/m et 47 m^3/m, dans les zones de déplacement maximal et a contribué à la création d'une dune bordière de taille similaire le long de toute la zone érodée. Le recul et le rétablissement qui s'en et suivi décrivent un mécanisme de maintien de la taille de la dune bordière durant des phases d'érosion et de déplacement épisodiques, et pourraient s'inscrire dans un modèle de maintien de la dune bordière lors de la migration d'une île-barrière.

Key Words: foredune morphology, foredune migration, Fire Island National Seashore

1 Background

The geomorphological evolution of barrier islands is often portrayed as a transgressive displacement of sediment driven by sea-level rise with a number of stages that evolve from initial formation, waxing to maximum dimension, and then reduction in extent (DAVIS 1994). Overwash and inlet sedimentation sequences are often identified in cores to demonstrate the history of cross-island inland sediment transfers at different steps in this development. As part of barrier island evolution, the coastal foredune also manifests elements of formation, modification, and displacement as the shoreline shifts under the influence of sediment budget variations and local morphodynamics. As described by SHERMAN & BAUER (1993), the macro-scale development of the coastal foredune may involve centurial or longer time periods associated with barrier island genesis whereas meso-scale variations of foredune response may incorporate the annual to decadal sequences of morphological attenuation and recovery. In addition to the specific evolution of the active foredune ridge, there is the general spatial dichotomy between the foredune features that are constantly interacting with the ambient beach process and those dunal features of the barrier that are separated from the active beach. That is, within the spatial dichotomy of primary and secondary dune ridges is a continuum of interaction/separation that may be episodic, thereby resulting in conditions leading to the isolation of the established foredune from the beach at times (becoming a secondary dune), succeeded by a renewed exchange of sediment and interaction (becoming the active primary dune) (PSUTY 2004). Therefore, the site and situation of a coastal foredune may pass through sequences of growth and seaward displacement interspersed with attenuation, and with inland displacement. The dimensional and directional vectors need not be constant but may have reversals and gradations that reflect the variable character of the barrier island system and the episodic inputs of sediment as well as the episodic presence of high energy storm events in classic meso-scale developmental sequences (MORTON et al. 1995). The concept of foredune-beach interaction and its spatial/temporal variations was elaborated upon in a suite of papers (e.g., PSUTY 1988, DAVIDSON-ARNOTT & LAW 1996).

In recent decades, a coastal monitoring program on Fire Island has tracked the spatial and morphological changes in the barrier island foredune that bears on the meso-scale issues of foredune evolution and displacement accompanying major erosion during high energy events, modest changes associated with localized events, and subsequent recovery (PSUTY & ALLEN 1993). Information derived from these historical sequences of meso-scale observations provide insight to a pattern of foredune sediment flux and it may also relate to the morphological dynamics of foredune retention and evolution during stages of barrier island attenuation.

2 Fire Island

Fire Island is a barrier island that extends currently for about 50 km along the southern margin of Long Island, NY (Fig. 1). It incorporates a variety of developed community landscapes interspersed among undeveloped park holdings in different stages of conservation and use. The island is exposed to storm and swell waves that produce a dominant east to west net alongshore transport of about 200,000 – 300,000 m^3/yr (ALLEN et al. 2002, ROSATI et al. 1999) and a mean inland shoreline displacement of 0.4 m/yr for the period 1870-1979 (ALLEN et al. 2002). However, as pointed out by ALLEN & LABASH (1997) and many others, mean rates and net rates of change conceal a great amount of variation within the spatial and temporal scales. Further, attempts at inlet stabilization at the western end of the barrier have resulted in a substantial seaward shoreline displacement updrift of the Fire Island Inlet jetty, whereas breaches associated with Moriches Inlet at the eastern terminus of the barrier have created landward shoreline displacements (TANEY 1961, LEATHERMAN & ALLEN 1985, SMITH et al. 1999, ALLEN et al. 2002). Also, several episodes of beach nourishment in some of the private communities in the past two decades have further altered the coastal sediment budget and general shoreline trends.

An additional complication in comparing shoreline position through time at Fire Island is the presence of progressive circulation cells that produce a sinuosity in the shoreline planform and contribute to short-term variation virtually independent of the long-term displacement of the barrier island (Fig. 2). At times, the curvilinear indentation may extend through the width of the beach. This characteristic is well described as the modal intermediate stage of beach morphodynamic conditions proposed by WRIGHT & SHORT (1984) that incorporates nearshore circulation cells and rhythmic topography of the beach and its adjacent longshore bar. The inherent variation in shoreline position caused by the progressive nature of these circulation cells was responsible for a National Park Service project that tracked changes along the seaward margin of the barrier by monitoring the position of the coastal foredune through time (PSUTY & ALLEN 1986). The rationale for selecting the foredune was that it was less likely to be affected by the short-term passage of the circulation cells and thus changes in the foredune position would be more representative of the longer-term trend of displacement.

Monitoring of the position and dimensions of the foredune consisted of very large scale rectified and registered aerial photography (1:1200) taken at 5-year intervals during 1976-1991, aerial photography at scales of 1:12,000 and 1:20,000 taken at 2-3 year intervals from 1992 through 2002, four LIDAR flights, and annual ground surveys. The combination of sources was used to identify displacements of the dune crestline and was also the basis for measures of foredune sinuosity (Fig. 3).

2.1 Regional Change

The 1976-1986 aerial photos depicted a well-developed coherent foredune ridge that had a crestal elevation of about 6-10 m (NGVD29). Most of Fire Island had a foredune ridge that was broadly sinuous with some locations characterized by inland transfers of sand and landward displacement whereas other locations had incipient foredune development seaward of the well-defined crestline (PSUTY 1990). The central portion of Fire Island has had a history of landward displacement and narrowing. Major storm events caused extensive beach and dune erosion during 1991 and 1992. Severe loss of the protective beach in October 1991, in January1992, and the subsequent summer exposed the coastal foredune to a December 1992 storm that removed much of the seaward form and sediment of the foredune and altered the crestline from highly sinuous and irregular to a linear erosional remnant (Fig. 4). This latter displacement of the foredune crestline was associated with a severe 25-year recurrence interval storm (as measured at the nearby Sandy Hook tide gauge, PSUTY & OFIARA 2002: 128) and it represented a spatial shift of the sand ridge that could, if continued, be part of the general step-wise transgression of the Fire Island barrier as it evolves beyond its phase of maximum extent.

2.2 Localized/Episodic change

The sinuous character of the Fire Island shoreline has drawn attention previously because of its relationship to progressive inshore circulation cells, sinuous offshore topography, and wave energetics (ALLEN & PSUTY 1987) as well as its effect upon evaluating performance of beach nourishment projects (GRAVENS 1999). Further, these beach-face circulation cells frequently extend inland, completely eroding the berm in places and impinging upon the foredune. Their effect is to impose the sinuosity of the beach upon the foredune by intermittently scarping the foredune and creating an arcuate displacement for some alongshore distance (PSUTY et al. 1988).

Passage of a coastwise circulation cell in 1994 caused localized erosion and inland displacement of the foredune along a 400 m section at Talisman- Barrett Beach (see Fig. 1), a section of the barrier managed in a quasi-natural state by the National Park Service but with a small recreational inholding. This erosion caused an arcuate incursion into the foredune that had a maximum inland penetration of about 35-40 m and that tapered gradually to the margins (Fig. 4). The foredune ridge was completely removed for about 65 m and was severely scarped and partially removed for the remainder of the arcuate erosional embayment. Because this location was a very narrow portion of the barrier island and under the jurisdiction of the National Park Service, a monitoring program was created to track the subsequent changes in the area and to alert the Park Service if conditions appeared that might be related to potential breaching of the island at this location.

3 Data Collection

A systematic field topographic survey of the Talisman-Barrett Beach location was initiated in 1994 that concentrated on the foredune and was subsequently extended from the ocean shoreline inland to the bay shoreline. Fortunately, there were three Corps of Engineers' survey monuments in the area with x-y-z values for control. One was found to be altered and was not used as a reference. The two remaining monuments were in good agreement with independent GPS and ground surveys and were the benchmarks for succeeding topographic surveys and comparisons. Field surveys were run annually with a Sokkia total station over the area of foredune erosion to record the change in topographic form, volume in the foredune ridge, location of the foredune crest, and location of the foredune toe. The surveys were augmented by four LIDAR flights that generated topographic data for the area.

The topographical data sets were registered to a common base (UTM and NGVD29) and a digital terrain model was created for each of the survey periods. In order to track the recovery of the unevenly-eroded and morphologically-variable foredune, the alongshore ridge was segmented into 11 compartments on the basis of the altered topography recorded in 1994 (Fig. 4). Five of the compartments were identified as substantially altered by human manipulation of the pre-storm foredune topography (110 m alongshore length), three had some manipulation of form and sediment (65 m), and three were in a natural condition (120 m). An additional natural compartment extended to the west another 125 m, but was not consistently surveyed and is omitted from further discussion.

Measurement of the foredune change was established by creating a boundary at the seaward margin of the foredune that consisted of the intercept of the high tide beach surface and the face of the foredune. Utilization of a consistent high tide beach elevation permitted the recording of the accumulation of sediment above the beach form whether it was at the dune toe, on the seaward face, the crestal portion, or the landward portion of the foredune. In addition, it discriminated against any accumulations produced by migrations of the seaward and lower beach berms, and those high frequency changes in the active beach.

Changes in the foredune were generated as volume changes in each of the compartments compared to the base year of 1994. Further, as a means to compare the relative magnitude of compartment variation, the volumes were normalized as change per meter length of beach, thereby producing a data set that stressed successional changes of the severely altered topography, in designated compartments, per unit alongshore distance. As a result, the sequence is generally presented as annual change, except for the 1999 survey. The 1999 field survey did not record a sufficient number of points to create an adequate terrain model for volume determination. Further, the four LIDAR data sets were also dropped from the calculations because of inconsistent portrayal of the foredune dimensions apparently due to the effects of vegetation cover and the lack of coincident ground truthing. In some places with local reference monuments and existing ground controls, the LIDAR imagery was adequate in generating profiles of the bare sand beach that was comparable to the total station surveys. But, the larger digital terrain models that incorporated the foredune and its variable vegetation cover generated inconsistent topography, thus making the volumetric comparisons problematic were problematic. All of the LIDAR imagery was subsequently dropped from the analysis. Thus, there were eight successive calculations over a span of nine years, and up to thirteen profiles at selected transects over the same time span.

4 Compartments

The episodic erosion associated with the circulation cell in 1994 penetrated a portion of the coast that was largely under the jurisdiction of the National Park Service and had a limited amount of human manipulation of the topography. However, the central portion of the zone of penetration encountered the privately-operated Barrett Beach recreation area, which had been raised in elevation and broadened by fill to form a high terrace-like topography immediately inland of the foredune. This high surface was replete with a building to house summer personnel, a covered picnic area, a sidewalk, and a small basketball court. Immediately to the west of Barrett Beach was a small topographical depression created by human action. A dune ridge of variable dimension comprised the rest of the margin of the arcuate penetration.

Compartments 1 and 9-10, at the two margins of the surveyed curving penetration, were in a natural condition with no manipulation of the foredune and a high foredune crest (9-10 m). Compartment 11 was the site of an active road cut through an otherwise natural foredune. However, the impact of the traffic altered that topography so greatly that the compartment was subsequently dropped from consideration in the analysis. Compartments 2 and 3 were partially altered along the inland toe of the foredune to accommodate placement of a Park residence following the 1992 erosion and inland displacement episode. The seaward margin and the crestal portion of these two compartments were in a natural state but with a lower foredune crest (6-7 m) than the compartments to the west. Compartment 4 completely lost its foredune in 1994 (Fig. 5); its highest elevation was only about 1 m above the high beach surface. Compartment 5 was a narrow transition between 4 and 6. Compartments 6 and 7 had a minor foredune remnant, ca. 1 m, but were backed by a high accumulation of sand, about 5.5 m, created by human manipulation to form a broad terrace overlooking the beach. Compartment 8 was an artificial surface without any foredune. It was a broad terrace occupied by a recreational basketball court with an elevation of 6 m and extending inland horizontally approximately 20 m. Thus, the zone of episodic erosion by the circulation cell impinged upon an area, in its greatest displacement, that included locations that were relatively natural and locations that were considerably manipulated, all in close proximity.

5 Data

The data matrix has been narrowed to ten compartments to focus on the areas of greatest change and fullest data sets (Table 1). The data are presented as volume change relative to 1994. Therefore, the emphasis is on the change or recovery of the sediment volume above the dune/beach contact (3.3 m) subsequent to the passage of the circulation cell in 1994 and does not represent the absolute dimensions of the resultant foredune.

There are several patterns present in the data set of foredune volume. One of these is the large initial quantity of sediment collected in the upper portion of Compartments 4 and 5, with decreased quantities of accumulations both east and west. Eventually, Compartments 3, 6, and 7 attain similar volume gains, but not until a passage of eight years. Another pattern is the general slow accumulation in most of the eroded area for the first few years, followed by a rapid increase, a general plateauing of increase, and subsequently a renewed accumulation in the central portion. The annual mean change in the 10 compartments was 3.19 m^3/m. Compartment 4 had the greatest change during this period, 5.3 m^3/m/yr, whereas the two ends of the survey area each had rates of slightly less that 2.0 m^3/yr. Following the initial year of relative stability (average rate of 2.26 m^3/yr), the next two-year period (1995-1997) witnessed an increasing rate of accumulation, maximizing at 8.7 m^3/yr, with Compartment 4 gaining 11.0 and 11.7 m^3/yr during this time. Afterwards, the rates tended to range from about 1.5 to 3.0 m^3/yr, with slightly greater rates in the central portion of the curvature.

Over the 9-year monitoring period, the location of the foredune breach accumulated the greatest amount of sediment, 47.3 m^3/m, with adjacent areas also gaining high quantities of sand. The eastern area tended to have greater rates of recovery than the western area. All of the compartments accumulated sand relative to the volumes present in 1994.

6 Discussion

Following the major erosional event in 1994, the foredune at Talisman-Barrett Beach recovered in several ways. In the area of the high foredune and other sites that retained their crestal elevations, as in Compartment 9, the initial features on the profile consisted of a low ramp at the toe of the foredune (Fig. 6A). The ramp was modest in the first year and then began to increase horizontally and seaward. During the years of maximum accumulation, the toe of the dune expanded seaward nearly 10 m and became elevated more than 2 m. The last stages of accumulation in these sites produced hummocky topography and a low incipient foredune with crestal elevations of 1.0 m above the beach berm and about 20-25 m seaward of the scarp face (Fig. 7). Small quantities of sand were also transported inland to heighten and broaden the foredune crest. Post 1998, nearly all of the accumulation was seaward of the dune toe as the upper beach gained volume and elevation.

Topographically, the accumulation of sediment in the area of complete foredune erosion occasioned several forms of recovery. In Compartment 4 (Fig. 6B), the initial phase of accumulation witnessed broad sand sheets transgressing inland across the very low breach and over any obstacle present. Later, sediment accumulated at the seaward margin and created an extensive sand sheet. By 1997, the breach was a site of sand sheet of about 25-30 m in cross-shore dimension and 2 m thick (Fig. 8). Later, the broad foredune ridge reached an elevation of about 3 m above the beach, with a crestal position about 30 m inland of the location of the former foredune position. Further, the foredune toe began to expand, similar to the topographical recovery of the other compartments. An incipient foredune also developed with similar dimensions as in the other compartments.

Thus, the end expression of the recovery sequence was a filling in of the scarped foredune and the foredune breach that produced a crestal position displaced inland as far as 35-40 m (Fig. 9). As the new foredune continued to amass volume at its seaward margin, most of it was an accumulation at the dune toe in the form of a ramp that elevated the upper beach. The foredune crest was elevated and broadened in the central compartments, but had very little change at the western and eastern margins. The scarped dune face essentially remained in its position with very little sediment accumulation throughout the surveyed area. Only the breach site in Compartment 4 displayed major foredune broadening and buildout on the landward side of the foredune position. Each of the compartments also recorded some accumulation above the general elevation of the beach berm surface, amounting to the majority of the post-episodic change; and each compartment also had an incipient foredune attaining about 1.5-2.5 m^3/m.

Some of the accumulation forms were partially associated with the placement of sand fences. Fences were sited at the base of the scarp shortly after the 1994 circulation cell event. They appeared to be at least somewhat successful because of accumulations at these locations on the profile. However, the fences were soon completely covered by the migrating sand supply. In some cases, the fence lines were re-established at the same location, or they were situated elsewhere on the profile, or not installed at all. Further, the sand fence installations were conducted annually and not in association with a successful history of accumulation. Thus, fence lines in areas of substantial eolian transport were often completely overwhelmed and their effectiveness was lost, allowing unrestrained inland transport. This was especially the case in the foredune breach where the topographical surveys show that broad zones of accumulation were the norm rather than well-defined lineations associated with fence positions. However, the fences were effective in creating some of the incipient foredune locations, or at least focusing the accumulations. In those compartments with fence lines, the incipient foredune was better defined. In the other compartments, the incipient foredune topography displayed a broader zone of hummocky features and a lack of a coherent linear ridge.

Geomorphologically, the foredune crestline may be considered to be the arcuate scarped ridge that is retained in the landscape. The crestline has been rebuilt in the one location where it had been breached. It now has an elevation of 5.5 m, about 2 m above the elevation of the high beach surface. It has amassed an accumulation of nearly 35 m^3/m of beach in Compartment 4 while being displaced inland approximately 35 m. It has attained a crestal elevation within about 1 m of the foredunes in Compartments 3 and 9, and a foredune cross-section greater than the natural or moderately-disturbed compartments within the erosional arc. As nearshore circulation cells continue to dominate the modal beach state on Fire Island, it is very likely that arcuate intrusions will continue to scarp the foredune and cause displacements similar to that at Talisman-Barrett Beach. The foredune will retain the scars of these erosional events as a broad sinuosity in its crestline, thereby adding episodes of wave sculpting to the processes of eolian transport and dunal topography. In the longer term, the dune scarping and recovery is part of the process of displacement and transgression of the Fire Island barrier. Whereas the foredune is eroded and driven inland under the conditions of a general negative sediment budget of the barrier island beach, the opportunity exists to recover the volume and dimensions of the foredune in an inland position, thereby maintaining the sediment budget of the foredune. Thus, the foredune is retained in the dune-beach profile and in the barrier island topography as the island undergoes a narrowing. The foredune continues to shift spatially as the major component of the barrier island surface morphology and continues to exist until the last phases of foredune evolution which is at that time associated with a strong negative beach and dune sediment budget and development of washover topography (PSUTY 2004).

7 Conclusions

The coastal foredune is a very dynamic and contributory element in evolution of barrier islands. The morphological sequence of an episodic destructive event of the foredune on Fire Island and its volumetric recovery while being displaced inland has importance to the preservation of barrier island topography as the island narrows. The sinuosity of the Fire Island foredune crestline records past occurrences of erosion and inland displacement at a number of scales. Each scale represents a set of conditions of foredune mobility and sediment migration. At the meso-scale, the Talisman-Barrett Beach episode portrays one element of the dune-beach interaction mechanism that relates shoreline processes, foredune scarping, and sediment transfers to general foredune evolution. The intermediate mode of the beach morphodynamics system generates the passage of a shoreface circulation cell that intermittently scarps the foredune and displaces the centroid of the landform landward. This event permits the localized inland transfer of great quantities of sediment in the locales of foredune elevations. The recurrence of this mechanism affecting portions of the foredune on an annual to decadal basis contributes to the inland displacement of the barrier island and its accompanying foredune morphology. This mechanism assists in the persistence of the foredune feature in the landscape as the barrier island adjusts to reduced sediment availability and sea-level transgression. It may also be the mechanism that permits foredunes in other locales to persist while being displaced inland.

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