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# Geologic framework influences on the geomorphology of an anthropogenically modified barrier island: Assessment of dune/beach changes at Fire Island, New York

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ABSTRACT

Antecedent geology plays a crucial role in determining the inner-shelf, nearshore, and onshore geomorphology observed in coastal systems. However, the influence of the geologic framework on a system is difficult to extract when evaluating responses to changes due to storms and anthropogenic modifications, and few studies have quantified the potential for these influences in dune/beach environments. This study evaluates topographic change to the dune/beach system at Fire Island, New York over a ten year period (1998-2008) at two sites representing eastern and western reaches of the island where morphology has been shown to vary. The sites are situated along swaths of coast eroding differentially and where the inner shelf geologic framework differs substantially. Fewer large storms occurred in the first half of the study period, compared with the later part of the study period which includes several severe and prolonged extratropical storms. Additionally, a major beach replenishment project was conducted at one of the study sites. Topographic data from LiDAR and RTK GPS surveys are used to construct high-resolution 3D surfaces, which are used to determine volumetric change and to extract 2D alongshore features and profiles for analysis. The study sites help to further characterize morphologic differences between eastern and western reaches of the island. The western site displays higher sand volumes, lower dunes, and a lower gradient profile slope when compared with the eastern site. In addition to these fundamental morphologic differences, the two sites also differ significantly in their response to coastal storms and in the fact that their replenishment histories are different. The replenished areas show reduced vulnerability to storms through minimal volume loss and shoreline accretion that should be considered when evaluating the response of replenished areas to episodic events. We propose that site-specific differences evident throughout the study period can be linked to alongshore variations in the framework geology of the system. Anthropogenic modifications may have intensified differences already inherent in the system.



## 1. Introduction

Understanding the underlying geology of a coastal system is key to predicting how it will respond to natural and human-induced changes on a range of temporal scales (Nordstrom, 1994, 2004; Park et al., 2009). In order to better understand the natural response of a system to external forcings, changes to coastal systems have typically been measured in regions that are largely unaltered by anthropogenic activity. However, as coastal populations continue to increase, finding unimpacted regions for study is not only increasingly difficult, it is impractical, as the value and desire for coastal property make human development and coastal regions inextricably linked (Nordstrom, 1994, 2004). If anthropogenic modifications are substantial enough to alter the behavior of a system, it is important to understand not only the antecedent geology and natural behavior of the system, but also on what timescale anthropogenic modifications are of sufficient magnitude to disrupt this signal.

Fire Island is a moderately developed barrier island that is part of the barrier system along the southern shore of Long Island (Fig. 1). Seventeen communities lie within the boundaries of Fire Island National Seashore (FIIS), a number of which are experiencing moderate to severe erosion of the dunes and beaches fronting homes. In response to resident concerns, the National Park Service (NPS) has allowed anthropogenic modifications such as beach scraping and beach replenishment in some of the communities on a case-by-case basis, without a complete understanding of long-term impacts of such activities, if any, on the dune/beach system. The research reported here provides an assessment of dune/beach change on Fire Island that can be used to better understand the response of a barrier island system to anthropogenic modifications, as well as how onshore, nearshore and inner-shelf geology may be influencing the geomorphology of the dune/beach system.

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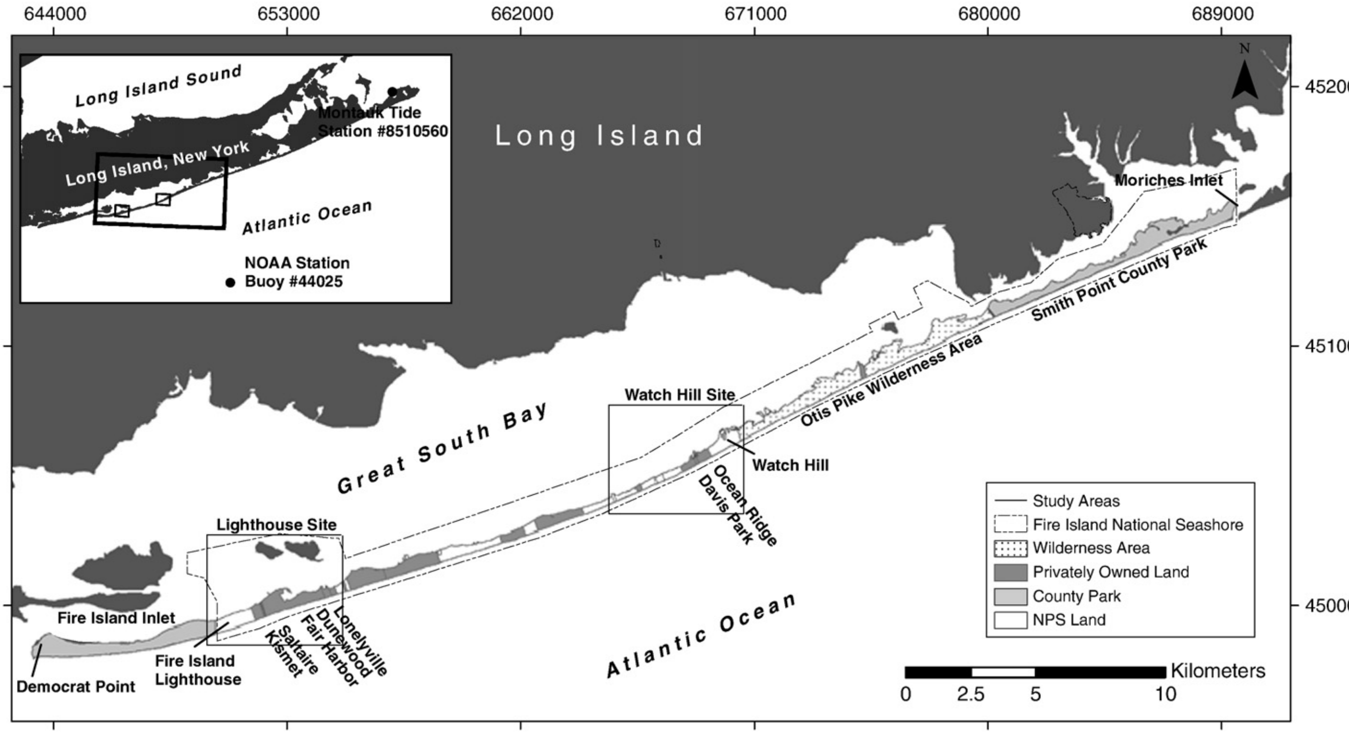


**Fig. 1.** Fire Island and the various management regimes present alongshore. Study areas shown in boxes. Southern shore of Long Island barrier system (inset).

Spatial changes to the dune/beach system at Fire Island are investigated from December 1998 to October 2008, a period when some significant storms impacted the coast and consequent erosion mitigation measures were employed. Data collected prior to, immediately after, and years after major modifications to the system, whether natural (storms) or human-induced, provide a better understanding of island response to changes over short (months, seasons) to long (years, decades) time periods. Change is assessed specifically by: 1) determining volume and slope changes using three-dimensional (3D) topographic surfaces; 2) extracting two-dimensional (2D) features such as the shoreline, dune toe, and dune crest from continuous surfaces to evaluate change rates of these features; and 3) statistically comparing changes to features such as beach width, dune crest elevation, and slope from 3D surfaces to assess morphological variations alongshore. While pronounced differences due to anthropogenic modifications to the system in the last decade have exacerbated short-term profile differences, this paper also examines the role of antecedent geology in predisposing the island to long-term differences in behavior from the east to the west.

## 2. Regional setting

Fire Island is a 50 km-long island that is central in the barrier system along the Long Island South Shore (Fig. 1). The wave-dominated, microtidal region has a mean tidal range of 1.3 m (http://www.ndbc.noaa.gov/station_page.php?station=44025) (NOAA, 2008). A prominent south-easterly wave direction drives net longshore transport westward (Taney, 1961; Kana, 1995). The south shore of Long Island is a sediment-poor region relative to other barrier systems; there is no riverine contribution to the area, and the major source for sediment input is longshore transport which carries material eroded from updrift bluffs, beaches, and the continental shelf. Fire Island is oriented northeast-southwest and is bounded by two engineered inlets: Moriches Inlet to the east, and Fire Island Inlet to the west. Democrat Point, which lies at the opening to Fire Island Inlet, was an actively prograding spit prior to construction of the Fire Island Inlet jetty in 1941, with the spit extending at a rate of 68 m/yr (Leatherman, 1985, 1989; Psuty, et al., 2005a). The foredune crestline is characterized as variable and sinuous alongshore, with a generally eroding trend over the last 30 years (Psuty and Silveira, 2009). Relict parallel backdune ridges which extend from the Fire Island Lighthouse to the inlet are evidence of recurved spit formation processes (Leatherman, 1985). Arcuate dune ridges elsewhere on the island indicate areas where historic inlets have existed; several former inlet sites on the eastern reach of the island have been identified between Watch Hill and Smith Point County Park (Leatherman, 1985).

The eastern and western reaches of Fire Island appear to be responding differently to sea level rise (Leatherman, 1985; Schwab et al., 2000). The eastern reach of the island has migrated landward through the creation of inlets and subsequent bayside marsh accretion, a typical migration pattern for transgressive barriers on the U.S. East Coast (Leatherman, 1979). However, moving west from the Watch Hill area to Democrat Point, the island shows no evidence of historical inlets and has not migrated landward as rapidly as the eastern reach over the last ~1000 years (Leatherman, 1985, 1989). Overwash processes have increased island elevations, but with minimal landward migration, the western segment of the island is remaining relatively stationary and gradually narrowing through erosion on both ocean and baysides (Williams, 1976; Leatherman, 1985, 1989).

Watch Hill appears to be the flexure point beyond which the western reach bulges seaward and the migration patterns between the two reaches begin to differ. Several reasons for these differences in migration rates have been proposed, including: 1) the proximity of the eastern reach to major storm tracks, leaving it more vulnerable to breaching, which in turn, yields landward migration (Leatherman, 1985); 2) a change in longshore transport energy around the point of island curvature; and 3) the presence of offshore sand ridges in the western reach, which may supply sediment and consequently slow landward migration (Schwab et al., 2000). While possible, the first explanation seems less likely as the barriers further west from Fire Island do not seem to be exhibiting a similar lack of migration. It is likely that changes in longshore transport energy around the Watch Hill flexure point contribute to different patterns in migration, but this