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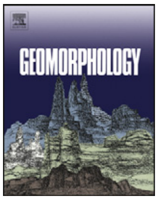

Post-storm beach and dune recovery: Implications for barrier island resilience

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ABSTRACT

The ability of beaches and dunes to recover following an extreme storm is a primary control of barrier island response to sea-level rise and changes in the frequency and/or magnitude of storm surges. Whereas erosion of the beach and dune occurs over hours and days, it can be years to decades before the beach and dune are able to recover to their pre-storm state. As a consequence, there are numerous descriptions of near-instantaneous beach and dune erosion due to storms, the immediate onshore transport of sand, and the initial phases of beach and dune recovery following a storm, but a paucity of data on long-term beach and dune recovery. A combination of previously published data from Galveston Island, Texas and new remotely sensed data from Santa Rosa Island, Florida is used in the present study to quantify the rate of dune recovery for dissipative and intermediate beach types, respectively. Recovery of the dune height and volume on Galveston Island was observed within two years following Hurricane Alicia (1983) and was largely complete within six years of the storm, despite extensive washover. In contrast, the dunes on Santa Rosa Island in Northwest Florida began to recover four years after Hurricane Ivan (2004), and only after the profile approached its pre-storm level and the rate of vegetation recovery (regrowth) was at a maximum. Results show that complete recovery of the largest dunes (in height and volume) will take approximately 10 years on Santa Rosa Island, which suggests that these sections of the island are particularly vulnerable to significant change in island morphology if there is also a change in the frequency and magnitude of storm events. In contrast, the areas of the island with the smallest dunes before Hurricane Ivan exhibited a rapid recovery, but no further growth in profile volume and dune height beyond the pre-storm volume and height, despite continued recovery of the largest dunes to their pre-storm height. A change in storm magnitude and/or frequency is a potential threat to barrier island resilience, particularly for those sections of the island where dune recovery has historically taken the longest time. Further study is required to determine how and why dune recovery varies for the dissipative and intermediate beaches of Galveston Island and Santa Rosa Island, respectively.

1. Introduction

The vulnerability of a barrier island to extreme storms depends on the elevation of the total water level (tide + storm surge + wave run-up) relative to the geometry of the coast, which is largely dependent on the height and alongshore extent of the foredune (Thieler and Young, 1991; Sallenger, 2000; Morton, 2002; Nott, 2006; Houser and Hamilton, 2009). Storm impact can have a range of visible impacts, from minor scarping at the base of the dune to overwash and/or breaching, when dune heights are relatively small compared to the storm surge (Sallenger, 2000; Hesp, 2002). Resiliency of a barrier island, or the ability to return to its previous equilibrium state (Woodroffe, 2007), is dependent on the rate of post-storm dune recovery. This rate is dependent on the transfer of sediment from the nearshore to the beach, which can occur through the landward migration and welding of the innermost nearshore bars, the alongshore migration of sand waves, the recolonization and expansion of dune-building vegetation, and/or aeolian transfer of sediment from the beach to the backshore and recovering dune. Depending on the magnitude and duration of the storm surge, erosion of the beach and dune occurs over hours and days, whereas recovery of the nearshore, beach and dune can take years to decades (Lee et al., 1998). The differential timescale of erosion and recovery makes barrier island response to sea-level rise dependent on the sequence of storm events and vulnerable to widespread erosion and washover when storms occur in quick succession (see Houser and Hamilton, 2009). The areas of the island that could exhibit significant morphological change and a transition to a new and possibly irreversible equilibrium state in the future are not those with already limited dune development and ineffective dune-building vegetation (low islands; Duran and Moore, 2013), but those sections of the island where the development of large dunes depends on the recovery of beach and the recolonization of dune-building vegetation (high islands; Duran and Moore, 2013).

Dune recovery requires the transfer of sediment from nearshore to the beach and ultimately to the dune, assuming that dune-building

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vegetation is also present. Based on 10 years of monitoring data, Morton et al. (1994) tracked the beach and dune recovery following Hurricane Alicia (1983) along Galveston Island. Calculating dune heights from the published profiles provides a time series of dune recovery in which peak dune growth is observed ~3 years after the storm and the dune reaches the pre-storm height (of ~2 m) 4–5 years after the storm (Fig. 1). Growth of the dune follows a sigmoid curve consistent with the growth models used to quantify vegetation growth (see Hugenholtz and Wolfe, 2005a,b). Specifically, the data presented in Morton et al. (1994) and several survey transects from Priestas and Fagherazzi (2010) all follow the growth model of Verhulst (1838):

$$\frac{dN}{dt} = rN\left[1-\left(\frac{N}{K}\right)\right] \tag{1}$$

where N is a system attribute (i.e. dune height), r is the growth rate, t is the time elapsed since the last disturbance, and K is the upper boundary (asymptote) of dune growth (Verhulst, 1838). Only those transects from Priestas and Fagherazzi (2010) with pre-storm dune heights of ~2 m, similar to those of Morton et al. (1994), were used in this preliminary analysis. Integration of Eq. (1) gives:

$$N_t = \frac{KN_o}{(K-N_o)e^{-n} + N_o} \tag{2}$$

where N_t is the height of the dune at time t, N_o is the initial height of the dune ($t = 0$) and e is the base of the natural logarithm. The dunes of Morton et al. (1994) and Priestas and Fagherazzi (2010) appear to follow the same logistic curve, but it is not clear why they exhibit similar recoveries given different environmental conditions. As described by Morton et al. (1994), the first stage of recovery begins immediately after the storm and can last a few weeks or up to a year, depending on the severity of the storm (Sallenger, 2000). This stage is characterized by berm reconstruction and steepening of the beach face. Specifically, sediment is returned to the beachface and the beach undergoes gradual accretion as the innermost bar migrates landward and welds to the beachface, leading to a steep beach ridge in reflective environments or a low-gradient berm in more dissipative environments. Landward migration of nearshore bars is driven by the waves as they shoal across the bar during fair-weather conditions (Elgar et al., 2001; Houser et al., 2006), with recovery and beach welding requiring several years following a large storm or multiple storms in succession (Lee et al., 1998). In lacustrine environments, the width of the backshore is closely tied to water levels, in which low water levels promote dune recovery and progradation, while high water levels allow even moderate storms to erode the foredune and reset the recovery (Saunders and Davidson-Arnott, 1990).

Following Morton et al. (1994), backbeach aggradation (around year 2 in Fig. 1) is largely dependent on deposition from swash events that exceed the elevation of the beach ridge in intermediate to reflective environments, or through the landward migration of the nearshore bars in dissipative environments. Since storm winds capable of entraining sediment are usually accompanied by elevated water levels (Ruz and Meur-Ferec, 2004; Delgado-Fernandez and Davidson-Arnott, 2011) and precipitation (Keijsers et al., 2012), it is reasonable to assume that sediment only becomes available to the dunes when the backshore expands and allows for the development/recovery of a dune ramp (Christiansen and Davidson-Arnott, 2004). While aeolian transport is possible as soon as the upper-beach and any washover deposits become dry, the expansion of the backshore is required to increase the fetch length, which controls the amount of sediment exchanged from the beach to the dune (Davidson-Arnott, 1988; Davidson-Arnott and Law, 1990, 1996; Bauer and Davidson-Arnott, 2003; Houser, 2009). Sediment emplacement in the backshore and lengthening of the available fetch can either occur between storms, when winds tend to be below the transport threshold, or during storms, through the landward migration of subtidal and intertidal bars (Houser and Greenwood, 2005, 2007), the alongshore migration of sandwaves (Law and Davidson-Arnott, 1990; Davidson-Arnott and Law, 1996) or in response to lake levels in lacustrine environments (Saunders and Davidson-Arnott, 1990). As wind speeds increase above threshold for aeolian transport, it is reasonable to expect that there is a narrow spatial or temporal window in which sediment can be transported to the dune before the storm surge extends into the backshore and the transport system begins to shut down (Delgado-Fernandez and Davidson-Arnott, 2011). In response, Bauer and Davidson-Arnott (2003) present a model to show that oblique winds are largely responsible for transport of sediment from beach to dune, assuming that there is an unlimited supply of sediment in the backshore and across the beach. The greatest potential for aeolian transport occurs on wide, low-angle dissipative beaches, while narrow reflective beaches have limited dune development due to the short and steep fetch that limits aeolian transport (Short and Hesp, 1982). Morton et al. (1994) observed that the narrow beach width on developed beaches limited dune recovery, and that only undeveloped beaches went through all stages of post-storm recovery. Along eroding coasts, the post-storm dune height was unable to reach the pre-storm height due to the lack of new sediment, with only 67% of the pre-storm volume recovered. The remaining sediment was transported alongshore and deposited as a spit at the distal end of the island.

While Morton et al. (1994) described the final stages of dune recovery as dune formation through sediment capture by vegetation or wrack (see Eamer and Walker, 2010; Ollerhead et al., 2013), followed by dune expansion and vegetation recolonization, it should be noted that dune formation can only be initiated when vegetation is able to colonize the backshore. Depending on the extent that the roots and rhizomes are impacted, post-storm recovery of vegetation can take two to eight years (Brodhead and Godfrey, 1979). Snyder and Boss (2002) found that vegetation recovery on Santa Rosa Island in northwest Florida following

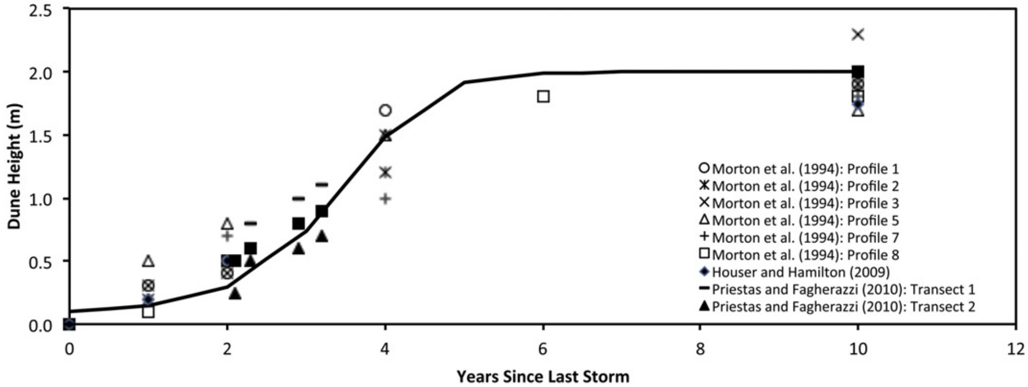

Fig. 1. Recovery of dune height (dune crest elevation–dune base elevation) presented by Morton et al. (1994) and Priestas and Fagherazzi (2010).