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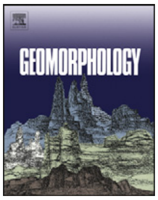

Ecomorphodynamic feedbacks and barrier island response to disturbance: Insights from the Virginia Barrier Islands, Mid-Atlantic Bight, USA

Catherine W.V. Wolner [a,*], Laura J. Moore [b,1], Donald R. Young [c,2], Steven T. Brantley [d,3], Spencer N. Bissett [c,4], Randolph A. McBride [e,5]

[a] Department of Environmental Sciences, University of Virginia, 291 McCormick Rd, PO Box 400123, Charlottesville, VA 22904-4123, USA
[b] Department of Geological Sciences, University of North Carolina-Chapel Hill, 104 South Road, Chapel Hill, NC 27599-3315, USA
[c] Department of Biology, Virginia Commonwealth University, 1000 West Cary Street, Richmond, VA 23284, USA
[d] Coweeta Hydrologic Lab, University of Minnesota, 3160 Coweeta Lab Road, Otto, NC 28763, USA
[e] Department of Atmospheric, Oceanic, & Earth Sciences, George Mason University, 3016 David King Hall, Mail Stop 5F2, Fairfax, VA 22030, USA

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ABSTRACT

Ecomorphodynamic feedbacks play an important role in the susceptibility and response of barrier islands to disturbance by overwash. Dune-building grasses, like *Ammophila breviligulata*, can help to restore areas of high relief after overwash events (i.e., resist disturbance). If overwash recurs before dunes have reestablished, however, overwash-adapted "maintainer" species, like *Spartina patens* (upright variety), may preferentially survive. Maintainer species help to preserve low, flat topography, thereby increasing the likelihood of future overwash (i.e., reinforcing disturbance). Under frequent disturbance conditions, this positive feedback may lead to overwash persistence. We explore the potential influence of the maintainer feedback on two morphologically distinct barrier islands in the Virginia Coast Reserve (VCR), located in the Mid-Atlantic Bight of the U.S. East Coast. Combined topographic and vegetation surveys show that on Hog Island (high-relief, rotating), where dunes dominated by *A. breviligulata* are ubiquitous, overwash zones are currently limited in extent and related to beach width rather than dominance by *S. patens*. Historical aerial photos and stratigraphic evidence (ground-penetrating radar, cores) indicate that gradual recovery has taken place following overwash events on Hog Island, except where the beach is narrow and eroding. Conversely, on Metompkin Island (low-relief, transgressing), overwash is widespread and dominated by *S. patens*, particularly along the rapidly migrating northern half of the island, where shell armoring is also common. Overwash has generally been more prevalent and persistent here than on Hog Island. We present a new conceptual model of the response of barrier islands to disturbance incorporating ecological and physical processes. Our findings suggest that in barrier systems where both dune-building grasses and overwash-adapted maintainer species are common (like the VCR), the maintainer feedback is likely to be a more important dynamic on islands already susceptible to frequent disturbance because of physical factors. The maintainer feedback, therefore, has the potential to accelerate large-scale shifts from dune-dominated to overwash-dominated barrier morphologies as the effects of climate change (increased storm intensity, sea level rise) cause overwash to become more frequent.

1. Introduction

1.1. Background

Barrier islands are characterized by low elevations, unconsolidated substrates, and high sensitivity to changes in sea level and storm activity. As a result, these coastal landscapes tend to be disturbance-prone, dynamic systems in which sediment is frequently redistributed and, consequently, ecosystems exhibit considerable variability. Physical parameters, such as elevation above sea level and distance from the shoreline, determine the frequency of overwash disturbance on barrier islands, which in turn influences the composition and distribution of the ecological communities that these landscapes support (e.g., Hosier and Cleary, 1977; Fahrig et al., 1994; Hayden et al., 1995; Young et al., 2011). As sea level

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* Corresponding author. Tel.: +703 292 7858.
E-mail addresses: cvw2q@virginia.edu (C.W.V. Wolner), moorelj@email.unc.edu (L.J. Moore), dyoung@vcu.edu (D.R. Young), stbrantle@umn.edu (S.T. Brantley), bissettsn@vcu.edu (S.N. Bissett), rmcbride@gmu.edu (R.A. McBride).
[1] Tel.: +1 919 962 5960; fax: +1 919 966 4159.
[2] Tel.: +1 804 828 0079; fax: +1 804 828 0503.
[3] Tel.: +1 804 239 3862.
[4] Tel.: +1 804 828 0083; fax: +1 804 828 0503.
[5] Tel.: +1 703 993 1642; fax: +1 703 993 1066.

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rise accelerates (Church and White, 2006; IPCC, 2007) and storms potentially become more intense (Komar and Allan, 2007; Bender et al., 2010; Knutson et al., 2010), overwash events on barrier islands will likely become more common, with closely linked morphological and ecological implications (e.g., Houser and Hamilton, 2009; Gornish and Miller, 2010).

Overwash occurs when storm surge and wave runup combine to overtop the dune or berm crest (Sallenger, 2000), leveling the existing topography and spreading sediment into the backbarrier. The process of overwash is crucial in determining whether barrier islands will survive as sea level rises: sediment transport by overwash facilitates landward migration, which can help a barrier maintain its elevation relative to sea level (e.g., Hayden et al., 1980). If sea level rises too rapidly, sediment supply is insufficient, or topographic recovery is inhibited by recurrent overwash, a barrier island may not be able to adjust quickly enough, ultimately disintegrating as sea level rise progresses (e.g., FitzGerald et al., 2006; Moore et al., 2010).

Barrier islands vary in susceptibility and response to disturbance by overwash, depending in part on morphological and vegetative characteristics. High-relief barrier islands tend to be dominated by dune-building grasses like *Ammophila breviligulata* (Fig. 1a). Like other dune-building grasses, *A. breviligulata* thrives at higher elevations and aids vertical accretion by trapping sand as it grows upward through gradual aeolian deposition. In this way, *A. breviligulata* expands its own preferred habitat in a positive feedback, generally on the time scale of years. On the northeastern U.S. coast, for instance, *A. breviligulata* builds characteristically tall, continuous dunes, facilitated by the guerrilla growth style of its vertically- and laterally-propagating rhizomes. These *A. breviligulata* dunes restrict large-scale overwash to only the most severe storm conditions (i.e., resist disturbance). In the relatively rare event that overwash does occur, recolonization by *A. breviligulata* – particularly through the dispersal of seeds and rhizomes in wrack – gradually leads to the reestablishment of the dune horizon (Godfrey et al., 1979; Leatherman and Zaremba, 1987), given sufficient supply of sand.

Fig. 1. a) Tall, continuous dunes built by *A. breviligulata*. b) Overwash flats stabilized by *S. patens*.

In contrast, barrier islands that are characterized by low, discontinuous, or absent dunes are susceptible to frequent overwash. Where these low-relief barriers occur on the southeastern U.S. coast, the strand grass *Spartina patens* (upright variety) is common on the widespread overwash flats that result from recurrent disturbance (Hosier and Cleary, 1977; Godfrey et al., 1979; Ritchie and Penland, 1988; Fig. 1b). This variety of *S. patens* is especially well-adapted for survival in overwash zones: it can regenerate upwards through thick layers of sediment rapidly deposited by overwash (Ehrenfeld, 1990), is tolerant of saline flooding (Silander and Antonovics, 1979), and thrives in wetter soils (i.e., lower elevations on barrier islands). *S. patens* does not contribute significantly to dune building, but rather stabilizes low, flat topography (Godfrey and Godfrey, 1976; Stallins, 2005) with its turf-like mat of roots and rhizomes.

Godfrey et al. (1979) proposed that while the dominance of *A. breviligulata* in high-relief barrier systems contributes to disturbance resistance, the dominance of *S. patens* (upright variety) in low-relief barrier systems reinforces frequent disturbance by maintaining low topographic roughness. Similarly, Stallins and Parker (2003) and Stallins (2005) suggested a weak positive feedback in which overwash-adapted species that do not build significant dunes (e.g., *S. patens*) may be more successful under conditions of repeated disturbance. Such species, they argued, promote the maintenance of low-relief topography by stabilizing sediment and rendering it unavailable for dune building. The maintenance of low-relief topography increases the likelihood of overwash, further favoring the success of the overwash-adapted species.

Whereas physical factors (e.g., relative sea level rise rate, antecedent geology and topography, sediment supply, wave climate, shoreline orientation, etc.) may play a primary role in establishing the vulnerability of a barrier island to disturbance, the two ecomorphodynamic feedbacks described above also mediate disturbance via dune building and overwash maintenance. These feedbacks have been compared separately in distinct barrier systems (Godfrey et al., 1979; Stallins and Parker, 2003) that vary physically and ecologically as well as in disturbance-forcing conditions (e.g., hydrodynamics, climate). Until now, they have not been considered comprehensively within a single barrier island chain where *A. breviligulata* is the dominant relief-promoting species, but where *S. patens* (upright variety) is also common.

In such systems, we hypothesize that the dune-builder feedback is likely to be the primary ecomorphodynamic influence on barrier morphology when disturbance (overwash) is rare, because *A. breviligulata* can effectively (re)create high-relief habitat for itself in the absence of disturbance (generally on time scales of years). As the frequency of disturbance increases, we hypothesize that the influence of the maintainer feedback will increase as well. This is because overwash-adapted maintainer species are likely to preferentially survive when disturbance recurs at similar or shorter intervals than the time scale needed for dune-building grasses to reestablish topographic relief (as long as the recurrence interval does not become so short that *no* vegetation can survive). Although the time scale of dune recovery can vary between environments, we emphasize that it is the *relationship* between this time scale and the frequency of disturbance events that affects whether the maintainer feedback is likely to be at work (Fig. 2), rather than the absolute number of years.

Ultimately, dominance by maintainer species may effectively lengthen the time needed for dune recovery by decreasing the space available for dune-building grasses and limiting the availability of sand for aeolian transport. Over longer time scales (decades to centuries), the balance between the dune-builder and maintainer feedbacks will likely influence large-scale barrier morphology by contributing (along with physical processes) to the development or maintenance of topography, thereby modulating or intensifying the response of barrier islands to climate change.

Our objectives are to: 1) infer where and under what conditions the maintainer feedback is likely to be at work, 2) add insight into the mechanisms by which ecological and physical processes work separately and