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## Barrier Islands: Coupling Anthropogenic Stability with Ecological Sustainability

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**ABSTRACT**

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Barrier islands provide a host of critical ecosystem services to heavily populated coastal regions of the world, yet they are quite vulnerable to ongoing sea level rise and a potential increase in the frequency and intensity of oceanic storms. These islands are being degraded at an alarming rate, in part because of anthropogenic attempts at stabilization. In this article, we outline a possible sustainability strategy that incorporates the natural degree of substrate instability on these sedimentary landscapes. We recommend placing the focus for managing barrier islands on maintaining ecosystem function and process development rather than emphasizing barrier islands as structural impediments to wave and storm energy.

**ADDITIONAL INDEX WORDS:** *Barrier islands, coastal erosion, storm surge, sea level rise, coastal management, vegetation.*

## INTRODUCTION

Barrier islands are ecosystems that border coastal shorelines and physically separate the offshore oceanic province from inshore wetlands, bays, sounds, and estuaries. As their name implies, they form a protective barrier between continental shorelines and wave action that originates offshore. Barrier islands also provide the structural framework for the formation of an array of coastal and estuarine habitats that host a variety of native and migratory species, many of which have substantial economic value.

Coastlines fronted by barrier islands also include some of the greatest concentrations of human populations and accompanying anthropogenic development in the world (Schlacher *et al.*, 2007; Weinstein *et al.*, 2007). The native vegetation and geological stability of these ecosystems are coupled and vulnerable to erosion events, particularly when also disturbed by development. As a result, barrier islands are quite vulnerable to potential global warming impacts such as sea level rise (Intergovernmental Panel On Climate Change, 2007) and increase in the frequency and intensity of major oceanic storms (Emanuel, 2005; Webster *et al.*, 2004). These islands are some of the most valuable yet potentially vulnerable ecosystems on Earth (Pérez-Maqueo, Intralawan, and Martínez, 2007; U.S. Commission On Ocean Policy, 2004).

Our goal here is to outline a sustainability strategy that recognizes and incorporates the high degree of sub-

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strate instability found in these natural ecosystems. An ideal solution would involve a strategic compromise between anthropogenic development and preservation of the natural ecosystem.

## NATURAL INSTABILITY

Barrier islands have an extremely dynamic nature whereby major changes in geomorphology and hydrology can occur over days, or even hours, in response to extreme episodic storm events (EESEs) such as tropical cyclones, hurricanes, and northeasters. Of most interest to the management community are changes that occur in response to these natural hazards. Barrier island width, dune elevation, tidal prism, wave energy, and storm surge energy influence the likelihood of overwash (Claudino-Sales, Wang, and Horwitz, 2008; Leatherman, Williams, and Fisher, 1977; Morton and Sallenger, 2003), transport of sediment offshore, and formation of new inlets during storms (Fitzgerald and Van Heteren, 1999). An array of endemic, indigenous, and migratory species are adapted specifically to such transient geological conditions (Brown and MacLachlan, 2002; Ehrenfeld, 1990; Shao, Shugart, and Hayden, 1996). However, little is known concerning the nature of the adaptive physiological mechanisms associated with this high level of transience, especially in response to EESEs, although these species are expected to have unique suites of evolutionary, genetic traits that underlie these adaptations (Gutschick and Bassirirad, 2003).

It is well documented that coastal plants are specifically adapted to take advantage of the dynamic nature of sediment transport in response to long-term processes, such as sea level rise or changes in sediment budget, having become adept "ecological engineers" (Costanza, Mitsch, and Day, 2006; Crain and Bertness, 2006; Halpern *et al.*, 2007; Jones, Lawton, and Shachak, 1997). In classical works on both sand dunes (Cowles, 1899) and salt marshes (Redfield and Rubin, 1962), ecologists have shown that these plants capture sediment, elevate the substrate, and drive the successional process. For example, dunes are the result of sand accumulation, becoming larger as plant sizes, densities, and root depths increase (Tsoar, 2005) and mutualist interactions begin with mycorrhizal fungi (Koske *et al.*, 2004). As succession progresses, primary and secondary dunes aggrade through further sand deposition, eventually leading to the formation of maritime forests on elevated upland areas (Young, Shao, and Brinson, 1995). There is a great deal of research on the ecological engineering capabilities of coastal plants, yet only a few studies have explored the eco–geomorphological limits of these capabilities (Feagin, Sherman, and Grant, 2005; Kirwan and Murray, 2007; Morris *et al.*, 2002; Orson, Warren, and Niering, 1998) and none have evaluated explicitly how this engineering can mediate the quite different time scales of physical forcing experienced by barrier islands, *i.e.*, sea level rise vs. EESE.

## ANTHROPOGENIC STABILITY

One of the most conspicuous boundaries between landscapes modified by humans and those formed by natural processes occurs at the seaward edge of private property adjacent to beaches (Mitteager, Burke, and Nordstrom, 2006). For example, in the United States, nearly all state laws created in response to the federal Coastal Zone Management Act of 1972 demarcate the public–private property division as the high tide line, resulting in a desire by landowners to "hold the line" between the beach and their backyards (Archer *et al.*, 1994). In contrast, the *Ley de Costas* (Law of Coasts) in Spain states that there should be a minimum distance of 100 m between shoreline and human structures. When necessary for effective shoreline protection, another 100 m can be added to this limit. Under this law, all sandy beaches and coastal dunes are public domain (Ley 22/1988, de 28 de Julio, de Costas). In India, there is currently a similar political effort to legally define the coastal zone and place it under federal jurisdiction (Sridhar *et al.*, 2006). A similar situation occurs in Mexico, where the coastal zone is also clearly defined (although routinely defied by private stakeholders). Ultimately, static legal definitions of the coastal zone enforce linear restrictions to the natural interplay of sediments and represent a threat to ecosystem functioning. Also, inevitable conflicts ensue once sea levels rise or EESEs strike.

While such laws attempt to manage human interactions with the land–sea interface, they are fundamentally rooted in the anthropogenic desire for stability. In the U.S. example, this leads to patchy vegetative stabilization that is most often managed privately and a lack of any governmental control over the larger landscape-scale sedimentary dynamics since dune formation would occur landward of the high tide line. In contrast, in Spain, because the Ley de Costas defines this line further landward, a large number of private houses (300,000) located at the beach are likely to be bought by the government to enable such control to be asserted. Returning to the India example, its laws are currently espoused as a response to the 2004 Indian Ocean tsunami and have facilitated a vast effort toward planting nonnative forests as "bioshields" for stabilization of the coastal areas (Mukherjee *et al.*, 2009). Ultimately, this approach to stabilization impairs the long-term functioning of the ecosystem, primarily because nonnative species are not adapted to the dynamism of the sedimentary environment and are unable to promote accretion (Feagin, Mukherjee, *et al.*, 2009). Furthermore, this new demarcation of the coastal zone by the government effectively results in the resale of land to private entities (Rodriguez *et al.*, 2008) and allows the undocumented and customary land rights of indigenous residents to disappear (Menon and Sridhar, 2007). In Mexico, development for tourism is intensive and extensive, and the laws that do exist are not enforced.

## ECOLOGICAL SUSTAINABILITY

What is the minimum level of landscape stability needed for human occupation of these naturally dynamic ecosystems? Is there a compromise solution that will incorporate both anthropogenic desires for structural stability and natural substrate instability of the system (Nordstrom, 2008) and that will lead to ecosystem sustainability? While precise answers to these questions do not currently exist, functional solutions will come by acknowledging that the dynamism and transience of these ecosystems at the landscape scale are paramount and

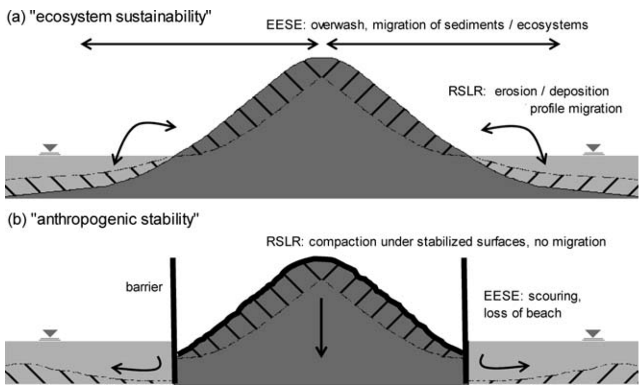


Figure 1. "Sustainability" and "stability" are often contradictory terms, as shown on a cross-section of a typical barrier island landscape. Native vegetation is adapted to the movement of sediments during extreme episodic storm events (EESE) and builds elevations through the process of succession, countering relative sea level rise (RSLR). Anthropogenic barriers such as paved surfaces, housing, hotels, bulkheads, and seawalls inhibit the natural sedimentary exchange between the land and the sea, interrupt ecosystem migration and processes of "ecological engineering" by plants, and result in net sediment and elevation loss.

overriding (Figure 1). Yet, how do we implement such a management strategy?

To begin, we must stop biasing our decisions toward the use of human-engineered structures on coasts at the expense of using native vegetation to achieve the same purpose (Nordstrom, 2000; Psuty, 2004). It is much less expensive and easier to guide vegetative succession (manage productivity and species mix) and coupled sedimentary processes (accretion) to build the elevation and structure of a landscape and thus counter selected long-term processes, such as sea level rise.

Second, we should begin to investigate more deeply the hypothesis that vegetated barrier island ecosystems can modify and control the sedimentary dynamics in response to gradual forcings like sea level rise (as long as the rate is not too fast) but cannot resist discrete, intense forcings such as EESEs (Brinson, Christian, and Blum, 1995; Jentsch, Kreyling, and Beierkuhnlein, 2007; Michener *et al.*, 1997). Recent work supports this hypothesis for salt marsh ecosystems (Feagin, Lozada-Bernard, *et al.*, 2009). For sand dune or other ecosystems where vegetation has appeared to reduce landscape-scale erosion in response to EESEs (Figure 2), it is important to understand whether the mechanism involved is primarily the direct attenuation of wave energy by plant cover or is more directly a function of the higher substrate elevations engineered by plants prior to the storm. If plants reduce the surge water level during EESEs (not just the wave height–to–water depth ratio), then more inductive field work is needed to quantify this effect during and following EESEs (Feagin, Mukherjee, *et al.*, 2009). If the mechanism of protection or erosion mitigation is primarily a function of substrate elevation, then substrate accumulation (indirect protection effect by ecological engineering over time) is paramount and must receive more research focus (Feagin, 2008; Feagin, Lozada-Bernard, *et al.*, 2009). If the hypothesis that plants can manage gradual physical changes in the sedimentary

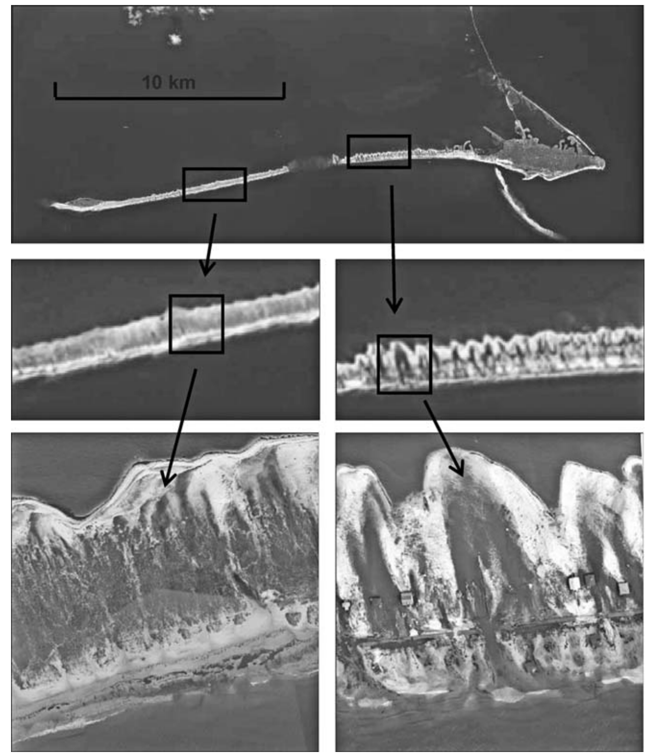


Figure 2. Did vegetation *directly* reduce erosion during Hurricane Katrina? Areas on Dauphin Island, Alabama, with native vegetation appeared to have less overwash (left images) than areas that had been disturbed by anthropogenic development (right images). Was there less erosion in the undeveloped areas primarily because of the wave energy attenuated by the plants during the storm, or was it primarily a function of the high dunes created by plant succession prior to the storm? The answer has serious management implications, as described in the text. (Courtesy of National Aeronautics and Space Administration and Alabama Department of Economic and Community Affairs.)

environment up to some threshold force (which EESEs exceed) is generally correct for barrier island species, then ecosystem management should emphasize landscape-scale sedimentary modification rather than short-term, structural prevention of erosion at a specific location.

Third, from an economic perspective, vegetation management should not focus on stabilization during EESEs. We know that coastal ecosystems contribute 77% of global ecosystem services, a value of about $33 trillion *per* year (Martínez *et al.*, 2007), and barrier islands are an integral part of approximately 12% of these coastal ecosystems (Pilkey and Fraser, 2003). Moreover, beaches and dunes support a U.S. tourism industry valued at $322 billion *per* year, more than 25 times the contribution of the National Park Service system to the U.S. economy (Houston, 2008). Engineered protection structures, dikes, seawalls, houses, buildings, and plantations of nonnative species do provide excellent stabilization for this valuable landscape. Land is limited and extremely valuable on barrier islands, and if better stabilization can be had with a seawall or dike that occupies less space than natural defenses such as dunes or wetlands, and the land's property value outweighs its ecosystem service value, then barrier islands inevitably will be developed. For example, the substrate stability and property value of barrier islands could potentially increase if we backfilled them to above the height of the native vegetation and then designed parking lots and buildings to withstand EESEs. However, these important ecosystems will be lost if all valuation is placed upon direct storm protection or stabilization value, simply because the land is worth so much to developers. Thus, we need to explore economic valuation techniques that can account quantitatively for the value of ecosystem services that manage the natural instability over the long term, thereby sustaining the entire island metastructure rather than only site-specific structural impediments for deflecting storm energy or stabilizing substrate (Williams *et al.*, 2009).

Fourth, we need to develop laws analogous to Section 404 of the Clean Water Act (which protects wetlands from being developed or backfilled) to protect undeveloped beaches, sand dunes, maritime forests, and other critical barrier island habitats. Because these landscapes are being developed at such a fast rate, and the economic calculus for their land use is currently biased toward anthropogenic development, their preservation for posterity should be a legislative priority.

Fifth, we need to bring about a change in legal mindset about how to actively manage developed barrier islands. We must reconfigure the legal conception of these landscapes, rather than placing a linear boundary between public and private property upon them. Setbacks are certainly an option (Pilkey and Young, 2005) in the context of modified state laws in the United States, similar to the Ley de Costas in Spain, but we need to think creatively about using ecologically defined boundaries. For example, the state of Texas defines the public–private property line as the ecological reality of the native vegetation line (Open Beaches Act, Texas Natural Resources Code §61.011; see Feagin, 2005). While this law has several gaps that need to be addressed, it allows a functioning dune ecotone to form that provides energy absorption between the beach and the leading edges of personal property, enhancing the ecological resistance and resilience (recovery rate) of a developed shoreline to EESEs. Further by law, when this sand dune plant zone and vegetation line shifts landward, so does the location of the public–private boundary. With this approach, land speculators and real estate developers must accommodate the reality of a retreating beach ecotone. Governmental entities could also provide tax incentives for more mobile living structures that will accommodate shifting substrates on at least a decadal scale. Statutory modification of the public–private line in currently undeveloped areas could be a major goal for coastal managers and policymakers.

Sixth, federal governments should purchase as many undeveloped islands and contiguous marginal properties as possible. In the United States, beyond the original Coastal Barrier Resources Act of 1982 that prevented federal assistance for activities supporting commercial development of barrier islands and designated certain parklands and national seashores to be preserved, no federal framework exists today for sustaining these ecosystems. In the United States, many barrier island ecosystems are still undeveloped. Extending federal ownership to these undeveloped properties will be less expensive than using taxpayer monies (under the National Flood Insurance Program and other granting programs, subsidies, and tax incentives; *e.g.*, Bagstad, Stapleton, and D'agostino, 2007; Cordes and Yezer, 1998) to subsidize recovery efforts for vacation homes that will inevitably be blown or eroded away again. To reverse this tragedy of the commons, a large-scale declaration of eminent domain may be required, as is currently occurring in Spain. Undoubtedly, such a declaration will find steep resistance in a society founded upon a strong notion of individual property rights. Compromises could be made whereby we work to armor our most developed and valuable properties against repeated flood losses due to EESEs and simultaneously declare undeveloped barrier islands off-limits to new permanent structures and subsidized flood insurance. One possibility for the United States could include tying annual funds, grants, or subsidies related to the Coastal Zone Management Act, National Flood Insurance Program, and National Oceanic and Atmospheric Administration, by state, to the amount of barrier island land that has been contributed to federal ownership. In locations such as India where coastal zone laws are still being developed, such programs should respect the customary yet undocumented uses of land, pay a fair rate for the land, and occur only in undeveloped locations. Any acquired land should be used only for public good and should remain nontransferable to private entities.

Seventh, we need to begin rethinking our cultural view of these ecosystems. The challenge may require that we adopt only a new vision of these landscapes rather than any major restructuring of the landscapes. Why did we start calling these features "barrier islands" instead of "ephemeral islands" or "migrating islands"? Although we recognize that past lexicon is difficult to change, how might something as simple as a different name have affected our desires to stabilize these islands? We will need to deepen our understanding and alter our management practices to ensure their future sustainability.

## CONCLUSIONS

Barrier islands are naturally unstable, migrating, and changing in response to factors such as sea level rise and EESEs. They are now being degraded at an alarming rate, in part because of human efforts to force stability upon them. We should aim for sustaining the natural sedimentary processes that occur across barrier island landscapes, rather than trying only to stabilize the substrate—we must find a way to adapt to the dynamism.

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