Ecosystem impacts of Hurricane Ike on Galveston Island and Bolivar Peninsula: Perspectives of the Coastal Barrier Island Network (CBIN)

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ABSTRACT

The Coastal Barrier Island Network, an international research group, had their second meeting in Galveston, Texas, following Hurricane Ike. The goal of this meeting, as well as the first meeting in Biloxi, Mississippi, following Hurricane Katrina, was to develop a research-management-outreach framework for sustaining coastal barrier ecosystems under global change such as increased storm activity and continued anthropogenic stresses. The location of the second meeting provided an opportunity to observe first-hand post- hurricane damage on the Chenier Plain, Bolivar Peninsula, and Galveston Island. Here, we discuss the ecosystem impacts of Ike and present six major themes that emerged from the Galveston meeting for identifying critical areas for future research and science-based management decisions to sustain coastal barrier ecosystems.

ADDITIONAL KEY WORDS: Sustainability, resilience, management, collaboration, development, anthropogenic impacts, Galveston Island, Bolivar Peninsula, storms

The Coastal Barrier Island Network (CBIN – http://www.coastalbarrierisland.org/), an interdisciplinary international research group, was established under sponsorship of the National Science Foundation in 2008 to provide a forum for bio-geo-social scientists and managers to identify research questions and management strategies that will promote sustainability of ecosystem resources on coastal barriers. A recent meeting on Galveston Island, Texas, provided the opportunity to situate research and management discussions within the setting of the aftermath of Hurricane Ike. Hurricane Ike was a Category 2 hurricane with a surge of a Category 4 that made direct landfall on Bolivar Peninsula of the Gulf Coast of Texas on September 13, 2008 and impacted surrounding areas, such as Galveston Island. Many anthropogenic structures were destroyed, large quantities of sediment appear to be lost from the ecosystem, and several crucial ecosystem services were radically altered across the landscape.

ECOSYSTEM IMPACTS OF HURRICANE IKE

The ecosystem changes caused by the September 2008 Hurricane Ike on the Chenier Plain, Bolivar Peninsula, and Galveston Island can be evaluated within four general plant community zones along the cross-shore profile, from the Gulf of Mexico to landward locations of beaches, dunes, upland coastal prairies, and salt marshes. Episodic perturbations, such as those caused by Ike, lie within a longer temporal context of relative sea level rise (approximately 2 ft (0.6 m) of rise over the last 100 years) and anthropogenic alteration of the land (grazing in the past and more recently infrastructure and housing development). The following are observations from visual assessment of post-Hurricane Ike and selected preliminary data results of research by one of the authors (R. Feagin).

The Chenier Plain

Prior to Hurricane Ike, the Texas portion of the Chenier Plain (from the Sabine Pass to High Island, Texas) had a veneer of sand from the low tide line up to a slight dune ridge (approximately 2 ft (0.6 m) in height from base). This ridge protected a freshwater wetland and coastal prairie complex that extended up to 20 miles (32 km) to the north. Due to the complete loss of this sand veneer after Ike and subsequent spring tides, salt water is inundating many of the landward freshwater wetlands. If this inundation continues, the usage of these *Scirpus*, *Schoenoplectus*, and *Typha* spp.-dominated freshwater wetlands by migratory birds will be reduced, but their conversion to salt water marsh in some locations may be beneficial for fisheries production.

For years, there has been some worry by state and federal officials that a large storm would result in the radical loss of land in this area, along with the designated conservation areas such as the McFaddin National Wildlife Refuge and Sea Rim State Park. With 2005's Hurricane Rita, 2007's Hurricane Humberto, and 2008's Tropical Storm Eduardo and Hurricane Ike making landfall in this region, the repetition of storm events has created a vulnerable ecosystem. Successive disturbance and salt stress has killed many plants, putting in jeopardy the process by which sediment accretion and land accumulation occurs. As a result, a tipping point may have been reached, or is about to be reached, where these wetlands will be unable to keep pace with rising sea level. Without a healthy plant community sedimentary deposition decreases due to the loss of plants in the water column, biogenic accretion ceases due to the lack of plant detritus, and the substrate becomes exposed leading to rapid erosion.

Bolivar Peninsula

On Bolivar Peninsula, the loss of beach sand from Hurricane Ike exposed the underlying and relict Pleistocene mud deposits. Preliminary study shows collapse of the invertebrate populations that typically live within these sandy beach ecosystems, including decapods, amphipods, isopods (crabs), insects, and arachnids.

Hurricane Ike removed nearly all traces of the sand dunes (approximately 4-5 ft (1.2-1.5 m) in height). Most of the early-successional dune plant species (weedy annuals) are likely to return within the following year, although the more desirable late-successional species (dune-binding perennials) will need to be re-planted, unless we are willing to wait several years (Feagin 2005). It is likely that some sand will return and a low dune ridge will form (approximately 2 ft (1.2 m) in height). Still, we expect that after Ike the sand deficit problem of the Chenier Plain may begin to plague Bolivar Peninsula beaches and dunes in the future, where the Pleistocene mud is only covered by a veneer of sand.

The typical model of an overwash-dominated barrier suggests that beach and dune sand is deposited into the marshes on the backside of the barrier. However, Bolivar Peninsula was too wide at most locations, and the sand was therefore deposited mid-island. Aerial photography shows that in areas where navigation channels exist that cut in the cross-shore direction, effectively shortening the distance between the Gulf of Mexico and the bay, overwash extends across the peninsula. It is also possible that finer sediment was exported from the local system, as was observed with other debris.

Galveston Island

The beach on Galveston Island is sandy to much greater depths than along Bolivar Island. Ike moved beach sand to offshore bars as well as landward into overwash deposits. Though beach erosion was severe, invertebrate populations appear to have been maintained because the sandy beach remains (except for along the seawall where the swash zone intersects the structure).

On the eastern half of western Galveston Island, sand that had been eroded from the beach appears to be primarily held in overwash deposits. These deposits are located in roadside ditches or underneath houses on pilings. If left to nature, the dunes would re-form approximately 100 ft (30 m) farther landward than they had been previously, as the sand supply is adequate. However, this cross-shore location is blocked by housing, bulkheads, or the seawall along most of the island. The endangered Kemp’s Ridley Sea Turtles (*Lepidochelys kempii*) bury their eggs within embryonic dunes along this stretch of coast, and there is concern that their populations may be reduced in the year following Hurricane Ike. This concern is complicated by beaches that are undergoing re-nourishment or restoration in many locations.

As one moves farther west along the western end of Galveston Island, pre-Ike development was set back farther from the naturally-receding shoreline, allowing the dune-swale to remain intact. In these areas post-Ike, the dune transgressed landward into the swale, subsequently burying the plants in the swale. Relatively little sand was contained in overwash deposits, and housing damage was much less severe (but this could also be due in part to increasing distance from the center of the storm). The dune appears to be re-generating in the location of the old swale, with burial-adapted *Spartina patens* plants emerging from the buried swale and capturing the passing sand.

Across all of Galveston Island, the coastal prairie has been stressed from inundation by saltwater. Although shrubs such as *Baccharis halimifolia* are adapted to episodic salt stress and will typically recover by the next growing season, a minor drought occurred immediately after Ike. The combination of salt water inundation by Ike, the lack of rain after it, and the accumulation of salt in the soil caused a drop in biomass production in these ecosystems. Nearly all tree species that were inundated appear to be have died or are severely stressed. One benefit of the inundation was large numbers of invasive salt cedar, *Tamarix gallica*, appear to have been eliminated from the beach, swales, and freshwater wetlands.

In Galveston's salt marshes dominated by *Spartina alterniflora*, we recorded no net accretion from Ike. Unfortunately, Galveston's marshes are rapidly shrinking due to both relative sea level rise (wetland accretion and sedimentation unable to keep pace with water level rise) and wave erosion along their edges, and it appears that Ike did not provide supplementary material to fill the accretion deficit. Rather, we recorded erosion at a rate of approximately 1.5 times greater than normal. Housing, infrastructure, and other human-constructed barriers may have prevented overwashed sand from reaching these back-bay locations, but it is more likely that Galveston is simply too wide as a transgressive barrier island.

IDENTIFIED THEMES

In the context of viewing Hurricane Ike's impact upon coastal ecosystems, the following six major themes emerged within the CBIN meeting on Galveston Island. We believe we have identified critical areas for future research and science-based management decisions for the Atlantic Ocean and Gulf of Mexico coasts of the USA.

1. *There are critical differences between natural and human-dominated barrier island landforms and ecosystems due to biophysical processes, spatial and temporal dynamics, and anthropogenic modifications.*

Coastal ecosystems are the product of biotic and abiotic processes and interactions. Biophysical processes include longshore drift, sediment transport, island retreat, vegetation succession, and episodic destructive storms. Social forces that serve to reduce or redistribute sediment to the beach and dune system can alter the size, location, and heterogeneity of both landforms and species and their behavior. Thus, it is not only necessary to consider the processes themselves that give rise to the assemblages of landforms and species in the coastal zone, but also the interactions between natural processes and human modifications that can enhance or inhibit ecosystem function (Nordstrom et al. 2007).

Hurricane Ike destroyed many buildings on Bolivar Peninsula and Galveston Island (Figure 1). At some locations, we saw examples of how natural forces, combined with human management efforts, exacerbated the destructive impact of Ike. On sections of Bolivar Peninsula, overwash deposits were evident along the main highway. The locations of many overwash breaches corresponded to the positioning of gaps in the geotube barrier (large textile tubes filled with sand) that had been placed along many sections of the beach (Figure 2). Though the connection between the anthropogenic modifications and natural processes is not always as clear as this example, it demonstrates the importance of developing models of natural-human processes and feedbacks on developed coastal barrier systems.

2. *The processes that influence vulnerability and resilience of coastal barrier ecosystems must be better understood across a broad spectrum of spatial and temporal scales (micro- to macro-scale).*

In coastal systems, sustainability is often understood in terms of resilience (Turner et al. 2003), more specifically, whether a system can re-establish its structure and function when re-worked by social and natural processes occurring at various scales (global climate, regional pollution, local storms, development practices). Thus, vulnerability and resilience of coastal barriers need to be examined across a spectrum of spatial and temporal scales when assessing the ultimate effectiveness of management decisions.

The time scales to be considered are dependent upon the processes that are being analyzed. For many stakeholders, conditions 25 years into the future are unpredictable, and thus are often ignored. Since hurricanes are episodic events, their impacts should be incorporated into long-term planning. Coastal sediment budgets and longshore drift should also be calculated at broad spatial and temporal scales. For example, the seawall in Galveston was designed to protect landward infrastructure, but has subsequently disturbed the sediment transport dynamics. The Houston- Galveston Ship Channel jetties to the east of the seawall have prevented sand from being transported to the down-drift beaches, which has ultimately prevented sand from being moved farther to the west end of the Galveston. Beach fill that was placed in front of the seawall has been transported to the west end of the island, but it cannot make up for the impact of the jetties on sediment flow. Chronic sand deprivation has caused flanking or excessive recession of the shoreline on the western end of the seawall, leading to local failure of the seawall during Hurricane Ike.

3. *Economic valuation tools such as cost-benefit analysis and rapid assessment methods utilizing remote sensing, GIS, and field-validation techniques can be used to generate collaborative solutions for advocates of different stakeholder perspectives.*

Potential conflicts in coastal management decisions often center on the controversies between desires for anthropogenic development and ecological sustainability. Achieving sustainable outcomes requires an approach that is inclusive rather than exclusive. Much controversy stems from a lack of a methodology for comparing the relative values of multiple stakeholder perspectives over different time scales. As one possible solution, quantification of the monetary value of ecosystem services can be incorporated into the economic market, including costs due to the destruction of resources with high economic value (Costanza and Farley 2007). Examples of ecosystem services include infrastructure protection by established dune systems, fisheries habitat created by healthy aquatic environments, and flood protection by functioning wetlands.

A geohazards map of Galveston Island has been produced by the Bureau of Economic Geology (Gibeaut et al. 2007) to show critical areas of the island that are prone to environmental destructions (Figure 3). The map classifies areas of imminent threat that should be excluded from future developmentwhile outlining alternative areas for development of low threat. Additionally, the natural dune and beach ridge that can provide natural protection to housing, and the areas of recent overwash which should be avoided for development, are identified. The data from the map along with data on the potential for a repeat of a Hurricane Ike- type storm, the value of tourism, and the overall impact to the ecosystem service values of the area (such as the fisheries benefits of the marsh, or the value of undeveloped coastal prairie uplands to migratory birds) can enable more informed decisions that will benefit the overall community and ecosystem.

An efficient method based upon remote sensing, GIS and field validation techniques provides promise for understanding such a dynamic ecosystem. An index or proxy for rapid assessment of the current vulnerability and resilience of an area should be developed to allow managers, public-policy decision-makers, and scientists to more easily compare different circumstances and areas. Two examples include the U.S. Geological Survey National Assessment of Coastal Change program (http://coastal.er.usgs.gov/coastal-classification/) and the U.S. Environmental Protection Agency Index of Biotic Integrity used to assess streams (http://www.epa.gov/bioindicators/html/ibi-hist.html).

4. *We need new mechanisms for communicating more effectively with stakeholders (decision makers, government agencies, teachers, local public, developers, etc.) about emerging science and the implementation of management strategies.*

The scientific community has established many concepts of how to manage barrier island ecosystems for sustainability, but it is difficult to reconcile these concepts with the reality that stakeholders and decision makers must face on the ground. New mechanisms for communication and dialogue about emerging barrier island science, plus the implementation of management strategies are needed (Daniels and Walker 2001). Tangible products such as maps, pamphlets, and websites are recommended tools to provide communities with information for sound decision making in the future.

On Bolivar Peninsula, community discussion has focused on whether to rebuild mid-to-low income housing developments that were completely destroyed by Hurricane Ike or to allow these areas to evolve naturally instead of rebuilding and continuing the pattern of developing the same doomed structures, begun after 1961 Hurricane Carla (Moore 2009). Many local residents indicated their right and desire to rebuild. Ecologically, development should probably not have taken place on such a low-lying barrier; however, economically, developers tend to act within their own self interest and build on these highly priced real-estate areas. There is a disconnect between stakeholders of different perspectives. We at CBIN have an opportunity to promote dialogue among scientists and stakeholders in which all parties can learn from each other. The future of barrier islands will depend on communication with local residents and decision makers on how to best rebuild after events like Hurricane Ike. The lessons learned from the destruction can be used to build a strong constituency of local support for best management practices to prevent future loss.

5. *We need to address the idea of managing for stabilization versus sustaining natural processes, along with a more integrated application of restoration alternatives that would include native flora and fauna.*

Most management practices do not consider the variety of options that lie between the stabilization of barrier islands by anthropogenic means versus allowing the geo-biological processes to take their natural course. For example, a dune system with natural vegetation could be established to protect infrastructure while also developing a functioning ecosystem. Natural sediment exchanges on barrier islands can result in a resilient ecosystem; however, many building practices have constrained natural processes without coordinating anthropogenic activities with natural sedimentary and biotic dynamics (Phillips and Jones 2006).

An effort should be made to blend both natural and human-centered perspectives into the management of barrier islands. An example of collaboration can be seen with plans for rebuilding Texas Highway 87 that was destroyed over a quarter of a century ago (Figure 4). The road was overwashed by surge and sand during Hurricane Ike, causing salt water intrusion to the landward wetland. Government transportation agencies have considered rebuilding the highway as it is the only direct route between High Island and Sabine Pass; however, there has been consistent opposition from the natural resource agency counterparts, as the area is home to a vital migratory bird sanctuary on the major Central Flyover. After Ike, the transportation and natural resource agencies are now working together to determine a better management plan for the road, such as using it as an elevated barrier to replace the lost sand and prevent salt water intrusion, thus sustaining the freshwater wetland ecosystem.

6. *In the future, there is potential for the development of a unified conceptual framework for managing soft-sediment coasts, although there is much work to be done towards reaching this goal.*

By taking into account barrier island connectivity at multiple temporal and spatial scales, it should be possible to work towards a unified conceptual framework for soft-sediment coasts. Many questions remain to be answered before we can fully develop this broad framework.

One question is at what scale should we focus the development of policies? Is it better to start at the local scale and work upward to create our policies (bottom-up) or to start with concepts such as “stabilization versus sustainability” and work towards the specifics (top-down)? Another question is how should development best evolve over our entire coastline? Can we develop our coasts in a way that maintains ecosystem functioning while creating smart growth development? For example, suggestions could be made to isolate development to areas less vulnerable to storm destruction, such as High Island on Bolivar and landward of the seawall on Galveston, while attempting to preserve low lying areas as natural parks to be used by all.

The use of new management strategies is imperative for implementing the framework on a broad scale. For example, a policy could implement the complete restriction of permanent structures along the beach front and allow only portable housing or prevent overdevelopment in risky areas. Another strategy would be to reform tax, subsidy and insurance policies to discourage development (Bagstad et al. 2007). A systems approach framework would allow for a stronger and more precise management strategy that would take into consideration the overall ecological integrity of a barrier island and the coast as a whole.

CONCLUSION

Hurricane Ike has provided examples of infrastructure and environmental impacts that occur when natural forces are combined with the presence of anthropogenic modifications. Specifically, Hurricane Ike modified the beach, dunes, upland coastal prairies, and salt marshes of the Chenier Plain, Bolivar Peninsula, and Galveston Island. Modifications to the ecosystem were severe and these examples can be used to develop better management strategies for the future.

Six major themes emerged from the CBIN meeting that are intended to serve as focus points for developing better management strategies. The themes consist of balancing natural and human processes, incorporating at broad spatial and temporal scales to assess ecosystem sustainability and resilience, initiating multiple stakeholder communication and collaboration, utilizing natural restoration ideas for stabilization of barrier islands, and developing a comprehensive unified conceptual framework to manage our coastal ecosystems. We hope that these themes incorporate an extensive concept of ecosystem functioning perspectives, inclusive dialogue between interested stakeholders and economic concepts of ecosystem services. Consideration of these major themes is expected to assist society in producing sound management strategies for future of our barrier islands.

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Figure Legend

Figure 1. Damage caused by Hurricane Ike on Galveston Island. A. A house with its side ripped off. B. Destruction along the beach. C. A first row of houses was completely destroyed, leaving this second row as beachfront property. D. Remnants of a beach front house on the west end of Galveston Island.

Figure 2. Aerial view of Bolivar Island pre- and post- Hurricane Ike (courtesy of Texas General Land Office). Arrows point to the locations of geotubes. Overwash fans in the post-hurricane image correspond to the gaps in geotextile tubes notated by the circles. Inset is an on-the ground picture of the destroyed geotextile tube (photograph by Heather Joesting).

Figure 3. Example of a map product for exhibiting vulnerable areas of the coast.

Figure 4. Ike’s storm effects extended the destruction of Texas Highway 87 to the Bolivar Peninsula.

Figures

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