Geohazards map of Mustang and North Padre Islands, Texas

By

Eleonor B. Taylor and James C. Gibeaut
Harte Research Institute for Gulf of Mexico Studies,
Texas A&M University-Corpus Christi, Corpus Christi, TX, 78412
eleonor.taylor@tamucc.edu

ABSTRACT

Barrier island communities face the unique challenge of living and planning for a dynamic coastal environment. One of the most effective steps a community can take to enhance its resilience is to assess the vulnerability of existing development and guide future growth away from hazardous areas through sensible land-use planning. From a hazards mitigation perspective, land-use planning on a barrier island requires knowledge about short- and long-term geologic processes as well as episodic events. In Texas, information on coastal flooding, erosion rates, and coastal vulnerability to sea-level rise has been available for the Gulf coast for quite some time; however, integrated and practical information about ongoing geologic processes and future evolution of the barrier islands as a geomorphic system has been scarce. In response to this need, a geohazards map has been developed for Mustang and North Padre Islands. The geohazards map shows areas on the barrier islands according to their relative susceptibility to, and mitigation of, the effects of geological processes including relative sea level rise, erosion, historic washover locations, and present and future location of critical environments, such as dunes and wetlands. The total mapped area covers 97.1 km^2. About 34% of the area was categorized as having the highest geohazard potential levels (extreme and imminent), most of which is along the bay shoreline of Mustang Island, where the largest extent of wetlands is located, and the beach/foredune system strip on the Gulf side. Approximately 27% of the area falls in the lowest geohazard potential category, which includes developed areas on North Padre and the northern end of Mustang Island, as well as undeveloped areas where the ground elevation is generally higher. The geohazards map for Mustang and North Padre Islands is presented as an interactive online tool to inform planners, decision-makers, and the public about current and future geologic challenges and limitations of living on a barrier island. Information about how the coastal landscape may evolve in the future, in conjunction with sound regulations and policies, can effectively aid communities to lay out a tangible blueprint for future adaptation efforts.

ADDITIONAL KEYWORDS: Coastal hazards, mapping, barrier island, land-use planning, coastal planning.

Submitted: 28 May 2013, revised and accepted 15 July 2013.

In the wake of economic, social, and ecological losses left by recent major storms, discussions about rebuilding, protecting, and living on the coast take center stage in the public opinion, at least for a couple months after the event. However, the dynamic geologic nature of coastal areas is often not given the prominence it deserves or, at best, it is relegated to a second plane. Coastal areas, including barrier islands, are shaped continually by geologic processes occurring at different spatial and temporal scales (Heinz Center 2000). These processes have been shaping barrier islands for millennia, but these processes only become hazardous when they intersect vulnerable infrastructure, property, or population. The idea of an ever-changing coastal setting often clashes with conventional, fixed-development patterns; nevertheless, acknowledgement of this reality and acting upon it are imperative if coastal communities want to thrive in the future.

COASTAL HAZARDS MAPPING

One of the most effective steps a community can take to enhance its resilience is to assess the vulnerability of existing development and guide future growth outside of hazardous areas through sensible land-use planning (Burby 1998; Jacob and Pacello 2011). From a hazards mitigation perspective, land-use planning requires knowledge about short- and long-term geologic processes as well as episodic events. Identifying and documenting the geologic landscape and its inherent hazards is essential for planning. Examples of coastal hazards mapping exist in Oregon and California, where hazards such as erosion, flooding, and landslides, have been documented (Ross and Morgan 1986; Moore *et al.* 1999). These coastal hazards maps provided enough detail to be successfully incorporated into comprehensive plans, facilitating rezoning and imposition of site-specific requirements in hazardous areas (Ross and Morgan 1986). In Texas, information on coastal flooding, erosion rates and coastal vulnerability to sea-level rise has been available for the Gulf coast for quite some time (FEMA 2013; Paine *et al.* 2011; Thieler and Hammar-Klose 2000). However, practical information about ongoing geologic processes and future evolution of the barrier islands as a geomorphic system has been scarce. Provisions in the Texas Open Beaches Act (TOBA) and Dune Protection Act (DPA) provide some across-the-board guidance for the preservation of protective coastal features, such as a 1,000-ft critical dune area landward of the mean high tide that requires a beachfront construction certificate for any construction activity and a beach public easement from the mean low tide to the line of vegetation (Texas Natural Resources Code 1977, 1991). However, both of these provisions apply only to the Gulf-facing shoreline, leaving bay shorelines unprotected (McLaughlin 2011). These measures are intended to preserve beaches and dunes as well as providing public access, but they have also kept new development in safer areas behind the dunes.

In response to the need for guiding development toward safer areas, a series of geohazards maps have been created for three of the most populated barrier islands on the Texas coast: Galveston, Mustang and North Padre, and South Padre Islands. The geohazards maps show areas on the barrier islands according to relative susceptibility to, and mitigation of, the effects of geological processes including relative sea level rise (RSLR), erosion, historic washover locations, and present and future location of critical environments, such as dunes and wetlands (Gibeaut *et al.* 2010). These maps present a synthesis of knowledge on barrier-island dynamics in an accessible manner, ready to be used in land-use planning or incorporated as a guide in policy-making decisions. The geohazards maps differ from coastal flooding maps in that they not only delineate hazardous areas, but also paint a picture on how the island may look in the near future; thus allowing identification of critical areas to avoid or preserve.

STUDY AREA

This article focuses on Mustang and North Padre Islands. Both are microtidal, wave-dominated, sandy barrier islands located on the central Texas coast (Hayes 1979; Morton 1994, 2010; Figure 1A). These barrier islands shelter the water of Corpus Christi Bay and the upper Laguna Madre from the Gulf of Mexico. They are relatively wide barrier islands (~2.6 km) with high, densely vegetated foredunes and secondary dunes, beaches, blowouts, and few washover channels (Morton and McGowen 1980). The central area of the islands is mostly comprised of vegetated barrier flats with interspersed fresh water marshes and ponds. The bay-edge environments include wind-tidal flats and salt marshes. Approximately 85% (58.2 km^2) of Mustang Island remains undeveloped except for a few resorts and condominiums scattered along the Gulf shore and the city of Port Aransas, located on the north end of the island. Similarly, North Padre Island is only developed from Packery Channel to the boundary between Nueces and Kleberg counties; the developed area covers ~18.2 km^2 (Figure 1B).

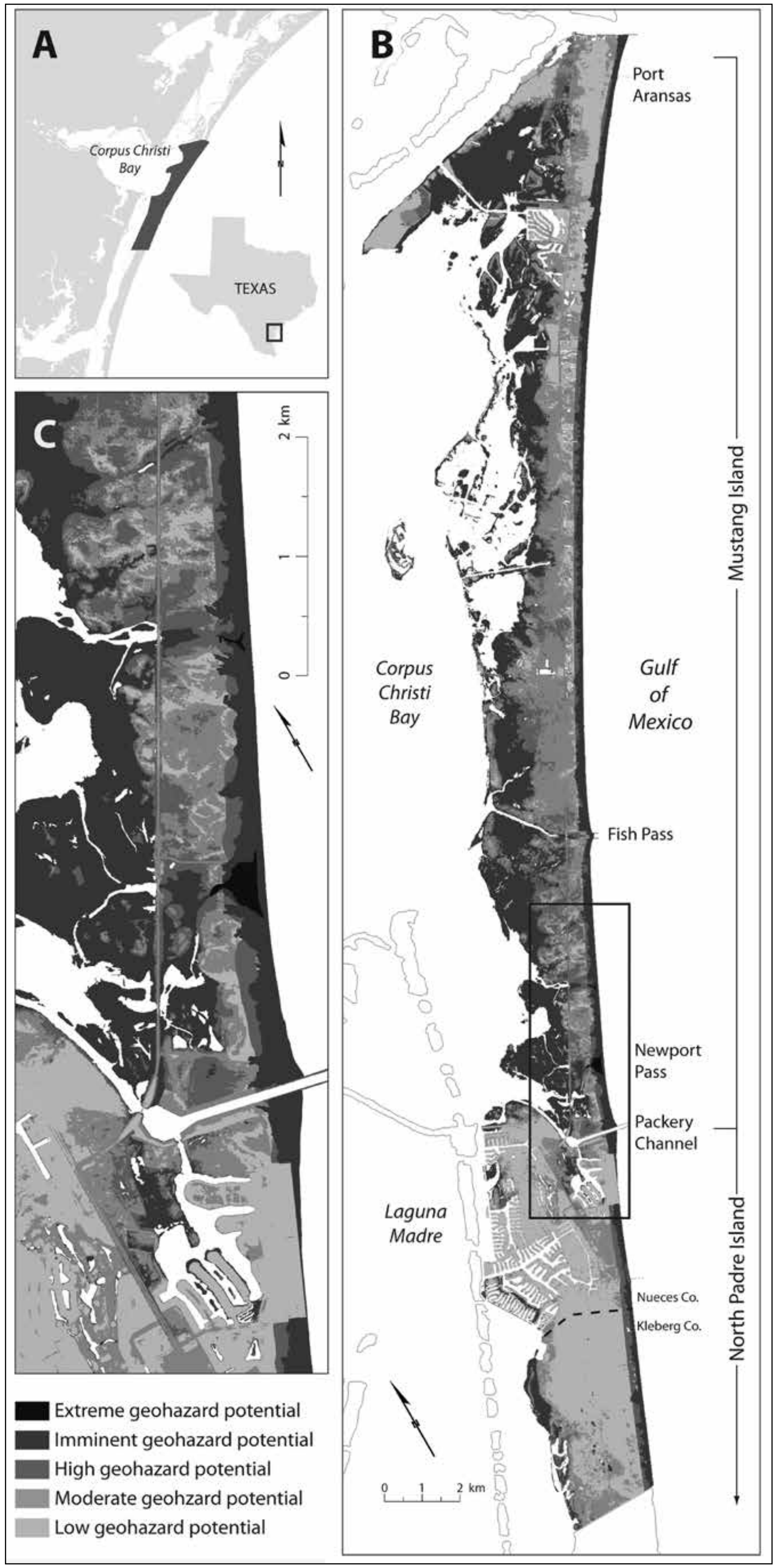

Figure 1. Maps show (A) the study area, (B) the geohazards map, and (C) a detailed view of the geohazards map in the vicinity of Packery Channel and Newport Pass. An interactive color version of the map is available at http://geohazards.tamucc.edu.

DEVELOPMENT OF THE GEOHAZARDS MAP

The development of the geohazards map follows the methodology used by Gibeaut *et al.* (2007) to create a similar map for

Table 1. Summary by geohazard potential category.

Geohazard potential	Area (km^2)	%
Extreme	0.1	0.1
Imminent	33.4	34.3
High	11.9	12.3
Moderate	25.8	26.6
Low	26	26.8
Total mapped area	97.1	100

Galveston Island, that shows hazardous areas coupled with information about the future spatial distribution of critical environments, such as wetlands, dunes, and beaches. The projection horizon for the geohazards maps is 60 years to allow for predictions that are most reliable for the data and projection methods used, as well as presenting results at a relatable human-scale. It is assumed that the observed RSLR rate of ~5.2 mm/yr will continue during the 60 years (Gibeaut *et al.* 2010; NOAA 2013).

First, a geo-environment classification layer was mapped for the entire study area. It identifies estuarine, upland, and marine-influenced environments. This layer builds on previous wetland mapping done by White *et al.* (2006). This wetland map was revised, updated, and augmented by adding upland classes using high-resolution aerial imagery, a 1-m resolution Lidar-derived digital elevation model (DEM), as well as current parcel data. The geo-environment classification layer and the DEM are used to compute elevation range statistics for different geo-environments including wetland types. Next, a wetland transition model is used to simulate how wetlands migrate inland in response to RSLR (Gibeaut *et al.* 2010). The model requires the wetland elevation range statistics to reclassify an elevation grid that is subject to RSLR inundation and vertical accretion adjustments in 1-year increments (Gibeaut *et al.* 2010).

To simulate the inland migration of beaches and dunes due to RSLR, long-term shoreline-change rates and an estimation of the width required for the development of beaches and foredunes are used to project the position of the shoreline, beaches, and foredunes in 60 years. A projected 2071 shoreline was developed using long-term shoreline-change rates along the study area (-0.83 ± 0.7 m/yr). The shoreline-change rates calculations included digitized shorelines from 1937-2011. The future location of critical beach and dune environments was identified as an area extending 173 m landward of the projected shoreline, which corresponds to the current average beach and foredune complex width along Mustang and North Padre Islands. Finally, the original geo-environments layer was reclassified into five geohazard level categories by combining elements from the wetland transition model output, future shoreline and beach/dunes positions, historic washover locations, and DEM.

GEOHAZARDS MAP

The geohazards map shows five geohazard potential categories: extreme, imminent, high, moderate, and low (Figure 1B & 1C). Historic storm washover channels were designated as extreme geohazard potential areas. Areas mapped as having imminent geohazard potential include the presently existing critical environments of regularly flooded estuarine wetlands, freshwater wetlands, and the beach/foredune system. Areas of future critical environments are designated as having a high geohazard potential and include uplands projected to become critical environments in 60 years. Areas designated as having moderate geohazard potential are uplands that are neither currently, nor are expected to become, critical environments during the next 60 years but are less than 1.5 m NAVD88 in elevation, causing them to be inundated during a tropical storm or Category 1 hurricane. Remaining upland areas have a low geohazard potential because of their elevation greater than 1.5 m NAVD88 and interior location to the island, making them overall less susceptible to geohazards. The distinction between moderate and low geohazard potential classifications is based on ground elevation. Areas below 1.5 m NAVD88 are more likely to be inundated by a 10- or 20-year storm that has a theoretical storm surge elevation ranging from 1.34-1.91 m NAVD88 (Krecic *et al.* 2011). As a result, these areas are deemed more hazardous than areas above 1.5 m NAVD88.

RESULTS

The total mapped area covers 97.1 sq km. Close to 0.1% of the mapped area was assigned the extreme geohazard potential category, which includes historic washover locations at Newport Pass and near Fish Pass. About 34.3% of the mapped area falls in the imminent geohazard potential category, most of which is along the bay shoreline of Mustang Island, where the largest extent of wetlands is located, and the beach/foredune system strip on the Gulf side. The high geohazard potential category, which are areas projected to become imminent geohazard areas in 60 years, covers 12.3% of the mapped area, concentrated on the low-lying areas between Packery Channel and Fish Pass (Figure 1B) as well as a buffer landward of the beach and foredune system. About 26.6% of the mapped area falls in the moderate geohazard potential category, found mostly in the central area of Mustang Island. The remaining 26.8% of the mapped area was categorized as having a low geohazard potential and includes developed areas on North Padre and the northern end of Mustang Island, as well as undeveloped areas where the ground elevation is generally higher.

Results are summarized by geohazard potential category in Table 1. (An interactive version of this geohazards map is available online at http://geohazards.tamucc.edu/.) The interactive mapping tool, in addition to displaying geohazard areas, has the option to overlay different information such as historic and projected shoreline-change rates, geo-environments, upland land-use classes, platted parcels, and a lidar-derived DEM. The goal of this tool is to present geohazards and coastal change information in one place and in the spatial context that planning decisions usually take place.

DISCUSSION

Close to one-third of the mapped area is classified as current critical environments or future critical environments. In other words, an extent of ~34 sq km is expected to be either inundated or have transitioned into a different environment in 60 years provided that development does not obstruct the landward migration of wetlands, beaches, and dunes. This expectation of change not only has profound implications in terms of how the community will prepare and address the impending transformation of the barrier island landscape, but also highlights the magnitude of the situation. On the other hand, a little over half of the total mapped area is not expected to become a critical environment in 60 years and some sections are high enough to escape flooding from at least low-intensity storms. These areas are generally more stable and safer for urban development. However, we must emphasize that with the right storm or slight changes in future erosion, sedimentation, or RSLR rates, the vulnerability of relatively less hazardous areas can be adversely impacted. Overall, barrier islands are a hazardous place to develop communities and infrastructure.

With information such as the geohazards map, communities can start looking into strategies that will better help them preserve critical environments and adapt in the near future. For example, the state of Florida is currently encouraging the inclusion of "adaptation action areas" into local comprehensive plans (Florida Department of Economic Opportunity 2013). These "adaptation areas" are an optional designation that local governments can use to highlight areas that are prone to experience coastal flooding and likely to be impacted by RSLR (Florida Department of Economic Opportunity 2013). This designation prioritizes areas in need of adaptation planning and actions, such as protection, accommodation, or retreat. A similar designation, complementing the current TOBA and DPA provisions, could stem from the Mustang and North Padre Islands geohazards map. The map could be used to identify areas likely to change, and therefore in need of an adaptation plan or strategy to provide hazards protection as well as future preservation of these environments.

Both geohazards maps for Galveston and South Padre Island have been used and incorporated in local planning activities and documents. The city of Galveston uses the map as background information to evaluate new development permits and support planning decisions in critical dune areas (within 1,000 feet from the mean high tide) on the west end of the island (D. Henry and C. Sanchez, pers. comm. June 2013). Moreover, the city of Galveston has cited the map in its recently adopted comprehensive plan as a primary reference to complement existing zoning regulations for the protection of beaches, dunes, and bay wetlands, as well as to develop and implement an open space preservation program (HDR 2011). The Galveston geohazards map has been also used in the preparation of the city's Hazard Mitigation Plan (City of Galveston 2011). In addition, the South Padre Island geohazards map has been used to evaluate alternative beachfront development practices as part of the Cameron County Erosion Analysis report (Worsham and Ravella 2013).

CONCLUSIONS

The geohazards map for Mustang and North Padre Islands is an accessible tool to inform planners, decision-makers, and the public about current and future geologic challenges and limitations of living on a barrier island. The geohazards map integrates information about geological processes and future spatial distribution of coastal environments to present a picture of how Mustang and North Padre Islands may look in the near future along with the associated geohazards potential of different sections of the islands. Such a map provides valuable input to land-use planning activities that require site-specific information to identify areas and plan for their appropriate use or future conservation. Information about how the coastal landscape may evolve, in conjunction with sound regulations and policies, can effectively aid communities to lay out a tangible blueprint for future adaptation efforts.

ACKNOWLEDGEMENTS

The wetland transition model was funded by the Texas Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA07NOS4190144. Additional research activities for this paper were funded with qualified outer continental shelf oil and gas revenues by the Coastal Impact Assistance Program, Bureau of Ocean Energy Management, Regulation, and Enforcement, U.S. Department of Interior Award M11AF00025. The views and conclusions contained in this paper are those of the authors and should not be interpreted as representing the opinions or policies of the U.S. Government.

REFERENCES

Burby, Raymond J., ed., 1998. *Cooperating with Nature: Confronting Natural Hazards with Land-Use Planning for Sustainable Communities*. The National Academies Press, Washington, DC, 356 p.

City of Galveston, 2011. *City of Galveston Hazard Mitigation Plan*. Galveston, TX, http://www.cityofgalveston.org/administration/emergency/hazard_mitigation.cfm.

Federal Emergency Management Agency 2013. "NFIP Information for the State of Texas." http://www.riskmap6.com/Community.aspx?sid=5.

Florida Department of Economic Opportunity 2013. "Adaptation Planning." http://www.floridajobs.org/community-planning-and-development/programs/technical-assistance/community-resiliency/adaptation-planning.

Gibeaut, J.C., E. Barraza, and B. Radosavljevic 2010. *Estuarine Wetland Habitat Transition induced by relative sea-level rise on Mustang and North Padre Islands, Texas: Phase 1*. Coastal Bend Bays & Estuaries Program, Corpus Christi, TX, 52 p.

Gibeaut, J.C., T.A. Tremblay, R. Waldinger, E.W. Collins, R.C. Smyth, W.A. White, T.L. Hepner, J.R. Andrews, and R. Gutiérrez 2007. *Geohazards Map of Galveston Island, Texas*. Bureau of Economic Geology, University of Texas-Austin, Austin, TX. http://www.beg.utexas.edu/coastal/GalvHazIdx.php.

H. John Heinz III Center for Science, Economics, and the Environment 2000. *The Hidden Costs of Coastal Hazards: Implications for Risk Assessment and Mitigation*. Island Press, Washington, DC, 220 p.

Hayes, M.O., 1979. "Barrier island morphology as a function of tidal and wave regime." In *Barrier islands: From the Gulf of St. Lawrence to the Gulf of Mexico,* ed. S. P. Leatherman, Academic Press, New York, NY, 1-27.

HDR Engineering 2011. *City of Galveston Comprehensive Plan*. Prepared for the city of Galveston, http://www.cityofgalveston.org/documents/GALV_Comp_Plan_Adopted_Final_11_1027_webres.pdf.

Jacob, J.S., and T. Pacello 2011. "Coastal Hazards and Smart Growth." *APA Zoning Practice*. American Planning Association, Washington, DC, 7 p.

Krecic, M., D. Stites, D. Arnouil, J. Hall, and W. Hunt, 2011. "Economic and Natural Resource Benefits Study of Coastal Erosion Planning and Response Act (CEPRA) Cycle 5 and 6 Projects." In *A Report to the 82nd Legislature Coastal Erosion Planning & Response Act*. Texas General Land Office, Austin, TX, 180 p.

McLaughlin, R.J., 2011. "Rolling Easements as a Response to Sea Level Rise in Coastal Texas: Current Status of the Law After Severance v. Patterson." *J. Land Use & Environmental Law,* 26, 365–503.

Moore, L.J., B.T. Benumof, and G.B. Griggs 1999. "Coastal Erosion Hazards in Santa Cruz and San Diego Counties, California." *J. Coastal Res.,* 121-139.

Morton, R.A., 1994. "Texas Barriers." In *Geology of Holocene Barrier Island Systems,* ed. R.A. Davis, Springer-Verlag, New York, NY, 75-114.

Morton, R.A., 2010. "Texas." In *Encyclopedia of the World's Coastal Landforms,* 53-60.

Morton, R.A., and J.H. McGowen 1980. *Modern depositional environments of the Texas coast*. Guidebook. University of Texas-Austin, Bureau of Economic Geology. Austin, TX.

National Oceanic and Atmospheric Administration 2013. "Mean Sea Level Trend 8774770 Rock-

PROFESSIONAL SERVICES

port, Texas." http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8774770%20Rockport,%20TX.

Paine, J.G., S. Mathew, and T. Caudle 2011. *Texas Gulf Shoreline Change Rates through 2007.* Bureau of Economic Geology, University of Texas-Austin, Austin, TX. http://www.beg.utexas.edu/coastal/presentations_reports/begTexasGulfShorelineReport2011_highRes.pdf.

Ross, M.E.. and M. Morgan 1986. "Coastal geologic hazards and land-use planning in northwestern Oregon." *Environmental Geology and Water Sciences,* 8 (4), 221-227.

Texas Natural Resources Code 1977. Sec. 63.012. http://www.statutes.legis.state.tx.us/Docs/NR/htm/NR.63.htm.

Texas Natural Resources Code 1991. Sec. 61.013. http://www.statutes.legis.state.tx.us/Docs/NR/htm/NR.61.htm.

Thieler, E.R., and E.S. Hammar-Klose 2000. *National assessment of coastal vulnerability to future sea-level rise: Preliminary results for the U.S. Gulf of Mexico Coast.* U .S. Geological Survey, Open-File Report 00-179, http://pubs.usgs.gov/of/2000/of00-179/.

White, W.A., T.A. Tremblay, R.L. Waldinger, and T.R. Calnan 2006. *Status and Trends of Wetland and Aquatic Habitats on Texas Barrier Islands Coastal Bend.* University of Texas-Austin, Bureau of Economic Geology, Austin, TX, 64 p.

Worsham, W.L., and P.A. Ravella 2013. *Cameron County Erosion Analysis: Study of Future Shoreline Change and Public Cost Implications of Beachfront Development.* Prepared for the Texas General Land Office, http://www.myspi.org/egov/documents/1360864805_6422.pdf.