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Introduction to the Special Issue on "Understanding and Predicting Change in the Coastal Ecosystems of the Northern Gulf of Mexico"

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ABSTRACT

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The coastal region of the northern Gulf of Mexico owes its current landscape structure to an array of tectonic, erosional and depositional, climatic, geochemical, hydrological, ecological, and human processes that have resulted in some of the world's most complex, dynamic, productive, and threatened ecosystems. Catastrophic hurricane landfalls, ongoing subsidence and erosion exacerbated by sea-level rise, disintegration of barrier island chains, and high rates of wetland loss have called attention to the vulnerability of northern Gulf coast ecosystems, habitats, built infrastructure, and economy to natural and anthropogenic threats. The devastating hurricanes of 2005 (Katrina and Rita) motivated the U.S. Geological Survey Coastal and Marine Geology Program and partnering researchers to pursue studies aimed at understanding and predicting landscape change and the associated storm hazard vulnerability of northern Gulf coast region ecosystems and human communities. Attaining this science goal requires increased knowledge of landscape evolution on geologic, historical, and human time scales, and analysis of the implications of such changes in the natural and built components of the landscape for hurricane impact susceptibility. This Special Issue of the Journal of Coastal Research communicates northern Gulf of Mexico research results that (1) improve knowledge of prior climates and depositional environments, (2) assess broad regional ecosystem structure and change over Holocene to human time scales, (3) undertake process studies and change analyses of dynamic landscape components, and (4) integrate framework, climate, variable time and spatial scale mapping, monitoring, and discipline-specific process investigations within interdisciplinary studies.

ADDITIONAL INDEX WORDS: *Sea-level rise, hurricanes, vulnerability, modeling, wetland loss, mapping, erosion, paleoclimate, sedimentation, marsh.*

INTRODUCTION

The coastal region of the northern Gulf of Mexico (GOM) owes its current landscape structure to an array of tectonic, erosional and depositional, climatic, geochemical, hydrological, ecological, and human processes that have resulted in some of the world's most complex, dynamic, productive, and threatened ecosystems. The northern GOM holds both renewable and nonrenewable resources that are of great economic significance to the United States, and moreover, this region supports resource-based activities that generate billions of dollars annually. Catastrophic hurricane landfalls, ongoing subsidence and erosion exacerbated by sea-level rise, disintegration of barrier island chains, and high rates of wetland loss have called attention to the vulnerability of northern Gulf coast ecosystems, habitats, built infrastructure, and economy to natural and anthropogenic threats. In addition, the GOM region is highly vulnerable to the incremental and cumulative impacts of global climate change, such as sea-level rise, more intense storms, and more variable weather patterns (Moser, Williams, and Boesch, 2012).

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The devastating hurricanes of 2005 (Katrina and Rita) motivated the U.S. Geological Survey (USGS) Coastal and Marine Geology Program and partnering researchers to pursue studies aimed at understanding and predicting landscape change and the associated storm hazard vulnerability of northern Gulf coast region ecosystems and human communities. Attaining this science goal requires increased knowledge of landscape evolution on geologic, historical, and human time scales, and analysis of the implications of such changes in the natural and built components of the landscape for hurricane impact susceptibility. Implicit in this approach is the recognition that the complexity of the Gulf coast landscape requires appropriate time and space scaled studies aimed at understanding the response of linked elements of coastal systems to multiple stressors and influences.

This Special Issue of the *Journal of Coastal Research* is intended to serve as a forum for researchers to communicate northern GOM research results relevant to the following broad objectives:

(1) Improve knowledge of prior climates and depositional environments and the resulting stratigraphy and geomorphologic framework that underpins modern processes such as land subsidence, sediment dynamics, salinization, extreme episodic hurricane impacts, wetland loss and marsh collapse, and land-cover change;
(2) Assess broad regional ecosystem structure and change over Holocene to human time scales;
(3) Undertake process studies and change analyses of dynamic landscape components; and
(4) Integrate geologic framework, climate, variable time and spatial scale mapping, monitoring, and discipline-specific process investigations within interdisciplinary studies.

PALEOCLIMATE AND HOLOCENE DEPOSITIONAL ENVIRONMENTS

Scientists agree from a variety of observations that the global climate is changing, and model results and theoretical considerations support the idea that ocean warming will affect tropical storm characteristics. Ocean sea-surface temperature (SST) changes modify atmospheric circulation, which in turn produce conditions that are favorable to hurricane formation. Northern Gulf coast climate, hurricane behavior, and precipitation patterns across central North America are influenced by SST variations in the GOM, and planktonic foraminifer assemblages in marine sediments have been widely used as paleoenvironmental proxies for past SST and upper ocean currents and structure (Imbrie and Kipp, 1971). Moreover, paleoocean temperature and salinity can be estimated based on the isotopic and trace-element composition of foraminifer tests (Anand, Elderfield, and Conte, 2003), but as noted by Poore, Tedesco, and Spear (this volume), poor knowledge of GOM planktonic foraminifer ecology inhibits the use of these techniques to estimate northern GOM paleo-SST. Using sediment-trap samples collected in the northern GOM, Poore, Tedesco, and Spear found significant differences in the seasonal occurrence of individual planktonic foraminifer taxa relative to the western Sargasso Sea. These researchers conclude based on Mg/Ca and $\delta^{18}O$ measurements that nonencrusted *Globorotalia truncatulinoides* has potential as a proxy for hindcasting environmental conditions in the northern GOM winter surface mixed-layer, and note that the species *Globigerinoides ruber* (pink) may be a useful indicator of past GOM mean annual sea-surface temperature.

Additional original findings on the potential use of trace elements as a proxy for modern and Holocene GOM SST are reported by Flannery and Poore (this volume), who measured the Sr/Ca ratios of skeletal material cored from *Montastrea faveolata* corals in the Dry Tortugas National Park. By comparing Sr/Ca analyses of modern coral samples to a local SST record, a regression equation was constructed and used to create quasi-seasonal proxy SST records for 1961 to 2008 and for a 7-year Holocene period at about 6 Ka. Both the modern and Holocene coral analyses yield clear annual Sr/Ca cycles that reveal fairly stable maxima in summer paleo-SST and more variable minima in winter. Adding to the planktonic foraminifera techniques developed by Poore, Tedesco, and Spear, Flannery and Poore also contribute a method for GOM paleoclimate reconstruction by identifying the potential to develop quasi-seasonal Holocene SST records based on Sr/Ca from *Montastrea faveolata*, a massive coral species.

Some of the most complex, dynamic, and productive ecosystems in the nation are located in the north-central Gulf Basin, especially in the delta plain of southern Louisiana, which began to form by early Holocene delta building, when sea-level rise slowed following the most recent major glaciation (Roberts, 1997; Williams *et al.*, 2011, 2012). Mississippi River Delta wetlands expanded during much of the late Holocene as the lower Mississippi River switched between distributaries and various delta lobes became active and prograded into the GOM (Coleman, 1988), creating the geologic framework for Louisiana's barrier islands and wetlands.

Twichell *et al.* (this volume) examined geologic constraints on the erosion of three northern GOM barrier island systems, the Apalachicola, Mississippi, and Chandeleur Islands off southeast Louisiana. These researchers used geophysical and coring techniques to map barrier and adjoining inner shelf stratigraphy and compared the importance of barrier lithosome and inner shelf geology on long-term rates of shoreline change on local and regional scales. This comparative interpretation revealed that the volume of sand and, secondarily, sediment grain size correlates with regional shoreline change rates along these barrier systems. Local scale long-term shoreline retreat was observed to be highest adjacent to paleovalleys incised on the inner shelf, and the overall barrier geologic framework was found to be a significant control on erosional variability at all three barrier systems.

An intriguing study by Reich, Poore, and Hickey (this volume) investigated the genesis of the Florida Middle Ground, a set of north to northwest trending ridges in the eastern GOM that previous work interpreted as derived from Holocene coral reef aggradation. In contrast, coring by Reich, Poore, and Hickey led to the finding that these ridges are composed of unconsolidated marine calcareous muddy sand beneath a boundstone that mainly consists of sessile vermetid gastropods. Radiocarbon dating shows that the cap formed during an early Holocene sea-level stillstand, and the researchers conclude that the vermetid gastropod boundstone then preserved the underlying shore parallel bars during rapid mid-Holocene sea-level rise.

HISTORICAL PERIOD CHANGE

Dramatic landscape change in the northern GOM region during the last century has reduced the level of hurricane protection afforded by coastal wetlands and barrier islands to northern GOM human populations. During the 60-year period between 1930 and 1990, coastal Louisiana lost an estimated 3,950 km^2 of wetlands. Overall, some 40% of all U.S. coastal wetlands are found in the north central Gulf coast region, and the loss of wetlands in Louisiana since 1930 is roughly equal to 80% of the total U.S. national wetland loss over the last 60 years (Boesch *et al.*, 1994; Morton, Bernier, and Barras, 2006).

Couvillion and Beck (this volume) used historical surveys and satellite observations to examine land area change in coastal Louisiana between 1932 and 2010. This study aimed to provide improved estimates of persistent wetland loss and trends broken down by hydrologic basins through the use of a comprehensive set of 17 disparate datasets. The updated land loss assessment presented by Couvillion and Beck exceeds the temporal frequency of prior analyses, and found a net land loss of 4,877 km^2 from 1932 to 2010 that totals 25% of the 1932 land area.

Focusing on the historic inorganic sedimentation and organic matter accumulation in the Mobile-Tensaw River Delta and the Mobile Bay region east of the Mississippi River Delta, Smith, Osterman, and Poore (this volume) show the importance of inorganic sedimentation in maintaining marsh accretion relative to sea-level rise. A constant-flux ^{210}Pb radiometric dating model was used to derive sediment core geochronologies and mass accumulation rates that revealed the intermittent pulses of higher inorganic sediment supply since 1960 that these researchers relate to the landfall of major hurricanes. Smith, Osterman, and Poore conclude that the approximately three-fold increase in Mobile Bay region salt marshes over the last 120 years is in part driven by storm-induced sediment fluxes, and thus provide evidence that hurricanes aid marsh accretion relative to sea-level rise. In contrast to sediment fluxes to marshes from landfalling storms, Nunnally *et al.* (this volume) investigated sedimentary oxygen consumption and nutrient regeneration in the hypoxic zone under elevated riverine nutrients and strong thermohaline stratification of the Mississippi–Atchafalaya River plume. Nunnally *et al.* observed a maximum in net ammonium release in late summer, and suggest that this released inorganic compound may enhance bottom water primary production, and also nitrification and microbial respiration that may intensify hypoxia.

PROCESS STUDIES OF DYNAMIC CHANGE

After Hurricanes Katrina and Rita in 2005, Barras (2007) reported that based on multidate satellite image analysis, immediate total land loss resulting from the combined effects of Hurricanes Katrina and Rita was 562 km^2. A follow-up analysis conducted in 2006 estimated 525.8 km^2 of land loss attributable to the 2005 storms (Barras, Bernier, and Morton, 2008). The total loss in one summer from two storms exceeded the combined sum of all land changes from the recent Hurricanes Andrew (2002), Lili (2002), and Tropical Storm Isidore (2002) (Barras, 2006). Hurricanes Gustav and Ike (2008) increased storm-induced loss by an additional 323.7 km^2 (Barras, 2009). Observations of storm-induced losses from the post-2005 storms coupled with the identification of similar features from historical storms revealed that hurricanes leave distinct morphological legacies in northern GOM wetlands (Morton and Barras, 2011). In addition, Hurricanes Katrina and Rita heavily impacted many barrier islands and mainland beaches, with major erosion and loss of back-beach marsh areas along the Chandeleur Islands off southeastern Louisiana (Sallenger *et al.*, 2009). Elsewhere, large overwash deposits formed on the landward side of barrier islands off the southwest Louisiana and Mississippi coasts (Stockdon *et al.*, 2006).

Palaseanu-Lovejoy *et al.* (this volume) incorporated fractional water classifications based on numerous high- and medium-resolution multispectral satellite images to improve estimates of land loss in Louisiana at sites heavily impacted by Hurricanes Katrina, Rita, Gustav, and Ike. Observing that prior studies used imagery with resolution too coarse to distinguish land loss due to hurricanes from seasonal variations and other causes of loss, these researchers examined the southwest Chenier Plain Hackberry area and the Delacroix area with high resolution *QuickBird*, *IKONOS*, and *GeoEye-1* and medium resolution *Landsat Thematic Mapper* satellite images. Impacted by Hurricanes Rita (2005) and Ike (2008), persistent land loss in the Hackberry area due to these storms was 5.8% and 7.9%, respectively, while at the Delacroix area immediately southeast of New Orleans, Hurricane Katrina (2005) caused 4.6% land loss, but Hurricane Gustav (2008) had only minor effects. A related contribution by Suir *et al.* (this volume) presents a new method for marsh classification that uses water-classified imagery to combine the 1) wetland ratio of water to land with 2) an analysis of water configuration and connectivity. This method is a more objective, automated, and quantitative approach to recognize shifts in landscape patterns, and to evaluate the evolution of regional wetland landscapes through time.

A similar study at coarser resolution and at a regional scale is reported in the chapter by Steyer, Couvillion, and Barras (this volume), who quantified damage and recovery of coastal Louisiana's broad wetland vegetation communities using a time series of Normalized Difference Vegetation Index (NDVI) *MODIS* satellite images together with *Landsat Thematic Mapper* land–water classifications. NDVI-monitored phenological variation of coastal wetland vegetation classes bracketing the 2005 landfalls of Hurricanes Katrina and Rita was compared to a 5-year NDVI seasonal baseline, and revealed major decline in vegetation density and vigor across 33% of Louisiana's wetlands in fall 2005. This regional phenological anomaly persisted over at least a full annual cycle, but by fall 2006 some degree of vegetation recovery was readily apparent.

Barrier island chains in the northern GOM, extending from Mobile Bay, Alabama, to Atchafalaya Bay, Louisiana, are eroding rapidly and many are disintegrating as a result of combined physical processes involving limited sediment availability, changes in alongshore sediment transport, land subsidence, and rising global sea level. The cumulative loss of land area and rates of land loss from these ephemeral islands are both astonishing and to some extent expected because present physical conditions are different from those that existed when the islands first formed (Morton and Sallenger, 2003).

Kish and Donoghue (this volume) report on a study of the response of Santa Rosa Island in the northeastern GOM to sea-level rise and storms since 1851. This narrow barrier island extends 75 kilometers along Florida's panhandle coast, has prominent foredunes, and has been relatively stable during historical time. After compiling numerous Santa Rosa Island shoreline maps from 1850 to present, Kish and Donoghue compared variation in shoreline position to storm history, and concluded that storm frequency and intensity exert dominant influences.

REGIONAL SEDIMENT MANAGEMENT

Prior to European settlement, numerous distributaries were active across the Mississippi River Delta, either flowing constantly or during spring flooding, and the associated wetland landscape was sustained by hydrologic pulsing that occurred across a range of time and space scales. The resulting variability in sediment fluxes was driven primarily by periodic events such as shifts among geographic centers of deltaic deposition, formation of crevasses, large floods, hurricanes, annual river floods, frontal passages, and tides (Day *et al.*, 1997, 2000). Although several major drainages, including the Atchafalaya, Mississippi, Pearl, Pascagoula, Escatawpa, and Mobile Rivers, empty into the northern GOM at present, the hydrology of the region is dominated by the Mississippi River watershed, an area of about 3 million km^2, or roughly 40% of the conterminous United States.

Observing that the distributaries and related deltaic lobes of the Mississippi River are the predominant sediment source for coastal Louisiana, Morang, Rosati, and King (this volume) compiled dredging records and other data to develop a sediment budget for the Louisiana coast based on many years of data collected prior to Hurricanes Katrina and Rita. This analysis reflects the geological uniqueness of south Louisiana's complicated shallow stratigraphy built by fluvial deposition and modification by marine processes since the Holocene, and demonstrates that river sediment delivery has dropped by more than half during the last 150 years due to sediment trapping at dams and other anthropogenic factors. The synoptic sediment budget presented by Morang, Rosati, and King will aid the search for sediment sources needed to mitigate the ongoing loss of Louisiana's wetlands and barrier islands.

Byrnes *et al.* (this volume) report on a similar sediment budget analysis focused on Mississippi Sound, immediately to the east of Louisiana's coastal zone. These researchers quantified change in nearshore morphology and beaches during the 20th century, and used that information to derive the net sediment pathways and quantities needed to construct an operational sediment budget for the passes and barrier islands that extend east–west across Mississippi Sound. Byrnes *et al.* found a minimum in westward littoral sand transport along West Ship Island, and used their analysis to aid in the design of a large restoration project for Ship Island.

ASSESSING COASTAL HAZARD VULNERABILITY

The rapid historical and recent growth of coastal communities throughout the Caribbean region and along the U.S. Atlantic seaboard and Gulf coast has resulted in an ever-increasing human population and economic infrastructure that are vulnerable to catastrophic hurricane impacts and sea-level rise. Recent major hurricanes, such as Andrew (1992), Opal (1995), Georges (1998), Frances and Ivan (2004), Dennis, Katrina, and Rita, (2005), and Gustav and Ike (2008) have severely disturbed the human infrastructure and natural ecosystems of the northern GOM (Colten, Kates, and Laska, 2008).

Hurricanes, subsidence, and erosion are natural processes that are exacerbated by sea-level rise (SLR) and complicated by anthropogenic changes affecting sediment delivery to wetlands. Knowledge of rates of relative sea-level rise in the region will impact restoration and storm protection plans, and Williams (this volume) notes that those rates are quite high across much of the northern GOM, reaching nearly 10 mm yr^{-1} at Grand Isle, Louisiana, due to crustal downwarping, shallow subsidence, and subsurface fluid withdrawal in addition to eustatic sea-level rise. In his review of the anticipated impacts of sea-level rise in coastal regions, Williams points out that, due to global change, sea-level rise is becoming a major driver of coastal change and increase in vulnerability, and that the rate of eustatic rise has increased by 50% over the last two decades due to warming. Observing that low-lying coastal plains and deltas such as the Mississippi River Delta are highly vulnerable, Williams recommends that vulnerability assessments and adaptation planning on local, regional, and national scales be conducted under the assumption that global sea-level will rise 0.5 to 2.0 m by A.D. 2100.

Analyses by Gesch (this volume) and Glick *et al.* (this volume) heed the call for SLR vulnerability assessments by considering the importance of topographic vertical accuracy in a SLR prediction at Mobile Bay, and in a model study of the potential impacts of SLR on southeastern Louisiana wetlands. Gesch applied concepts that incorporate the vertical accuracy of coastal topography, minimum SLR increment, and minimum planning timeline, in a study that detailed the areas and human infrastructure vulnerable to 1.18 m of SLR by the year 2100. Gesch concluded that the use of high-accuracy airborne lidar-derived elevation data is essential for prediction of coastal inundation from SLR, storm surges, abnormal high tides, and flooding due to extreme precipitation.

Noting that roughly 37% of United States estuarine herbaceous marshes lie in coastal Louisiana where wetland loss exceeds the sum occurring in all other lower 48 states, Glick *et al.* used the Sea Level Affecting Marshes Model (SLAMM) to predict the likely impact of present and accelerated SLR rates in southeastern Louisiana. These researchers estimate that under the high SLR case of 1.9 m by the year 2100, 24% of Louisiana's 2007 wetland area would be lost, and found that that region's baldcypress-water tupelo swamp habitat is particularly vulnerable to permanent flooding following even modest SLR.

Thatcher, Brock, and Pendleton (this volume) combine physical variables related to coastal vulnerability to SLR with economic factors that describe the concomitant societal risk due to SLR to derive a novel Coastal Economic Vulnerability Index (CEVI) that was applied to the Louisiana–Mississippi–Alabama coastal zone. High variability in the CEVI was apparent along the central northern GOM coastal zone, and thereby coastal reaches in particular need of long-term planning to enhance resiliency to SLR were identified. Thatcher, Brock, and Pendleton suggest that CEVI analysis will allow coastal managers at local, state, and national levels to prioritize scarce resources for restoration and protection and direct mitigation activities towards areas that are especially susceptible to SLR inundation.

SUMMARY

The northern GOM contains some of the world's most complex, dynamic, productive, and threatened ecosystems, and supports resource-based activities that generate billions of dollars annually. As noted by Yanez-Arancibia *et al.* (this volume), an ecosystem-based management approach that incorporates humans as a driving force of ecological change is needed in this region, where human activities and natural processes are tightly coupled. The devastating hurricanes of 2005 motivated the USGS Coastal and Marine Geology Program and partnering researchers to pursue studies aimed at understanding and predicting landscape change and the associated storm hazard vulnerability of northern Gulf Coast region ecosystems and human communities. This Special Issue of the *Journal of Coastal Research* communicates northern GOM research results that (1) improve knowledge of prior climates and depositional environments, (2) assess broad regional ecosystem structure and change over Holocene to human time scales, (3) undertake process studies and change analyses of dynamic landscape components, and (4) integrate geologic framework, climate, variable time and spatial scale mapping, monitoring, and discipline-specific process investigations within interdisciplinary studies. The guest editors hope that the findings reported in this Special Issue will aid coastal scientists and planners who seek to integrate framework, climate, variable time and spatial scale mapping, monitoring, and discipline-specific process investigations within future interdisciplinary studies.

LITERATURE CITED

Anand, P.; Elderfield, H., and Conte, M.H., 2003. Calibration of Mg/Ca thermometry in planktonic foraminifera from a sediment trap time series. *Paleoceanography*, 18(2), 1050.

Barras, J.A., 2006. Land Area Change in Coastal Louisiana after the 2005 Hurricanes—A Series of Three Maps. *U.S. Geological Survey Open-File Report 2006-1274*, scale 1:250,000, 3 sheets.

Barras, J.A., 2007. Land area changes in coastal Louisiana after Hurricanes Katrina and Rita. *In:* Farris, G.S.; Smith, G.J.: Crane, M.P.; Demas, C.R.; Robbins, L.L., and Lavoie, D.L. (eds.), Science and the Storms–the USGS Response to the Hurricanes of 2005. *U.S. Geological Survey Circular 1306*, pp. 97–112.

Barras, J.A.; Bernier, J.C., and Morton, R.A., 2008. Land Area Change in Coastal Louisiana, a Multidecadal Perspective (from 1956 to 2006). *U.S. Geological Survey Scientific Investigations Map 3019*, scale 1:250,000, 1 sheet, 14 p. pamphlet.

Barras, J.A., 2009. Land Area Change and Overview of Major Hurricane Impacts in Coastal Louisiana, 2004–08. *U.S. Geological Survey Scientific Investigations Map 3080*, scale 1:250,000, 1 sheet, 6 p. pamphlet.

Boesch, D.F.; Josselyn, M.N.; Mehta, A.J.; Morris, J.T.; Nuttle, W.K.; Simenstad, C., and Swift, D.J.P., 1994. *Scientific Assessment of Coastal Wetland Loss, Restoration and Management in Louisiana.* Journal of Coastal Research, Special Issue No. 20. West Palm Beach, Florida: Coastal Education and Research Foundation, 103p.

Coleman, J.M., 1988. Dynamic changes and processes in the Mississippi River Delta. *Geological Society of America Bulletin*, 100, 999–1015.

Colten, C.E.; Kates, R.W., and Laska, S.B., 2008. Three years after Katrina: Lessons for community resilience. *Environment: Science and Policy for Sustainable Development*, 50(5), 36–47.

Day, J.W., Jr.; Martin, J.F.; Cardoch, L., and Templet, P.H., 1997. System functioning as a basis for sustainable management of deltaic ecosystems. *Coastal Management*, 25(2), 115–153.

Day, J.W., Jr.; Shaffer, G.P.; Britsch, L.D.; Reed, D.J.; Hawes, S.R., and Cahoon, D., 2000, Pattern and process of land loss in the Mississippi Delta: A spatial and temporal analysis of wetland habitat change. *Estuaries*, 23(4), 425–438.

Imbrie, J. and Kipp, N.G., 1971. A new micropaleontological method for quantitative paleoclimatology: Application to a Late Pleistocene Caribbean core. *In:* Turekian, K.K. (ed.), *Late Cenozoic Glacial Ages*. New York: Yale University Press, pp. 71–181.

Morton, R.A. and Barras, J.A., 2011. Hurricane impacts on coastal wetlands: A half-century record of storm-generated features from southern Louisiana. *Journal of Coastal Research*, 275, 27–43.

Morton, R.A. and Sallenger, A.H., Jr., 2003, Morphological impacts of extreme storms on sandy beaches and barriers. *Journal of Coastal Research*, 19(3), 560–573.

Morton, R.A.; Bernier, J.C., and Barras, J.A., 2006, Evidence of regional subsidence and associated interior wetland loss induced by hydrocarbon production, Gulf Coast region, U.S.A. *Environmental Geology*, 50(2), 261–274.

Moser, S.C.; Williams, S.J. and Boesch, D.F., 2012. Wicked challenges at land's end: Managing coastal vulnerability under climate change. *Annual Review of Environment and Resources*, 37, 51–78.

Roberts, H.H., 1997. Dynamic changes of the Holocene Mississippi River delta plain: The delta cycle. *Journal of Coastal Research*, 13, 605–627.

Sallenger, A.H., Jr.; Wright, C.W.; Howd, P.; Doran, K., and Guy, K., 2009. Chapter B. Extreme coastal changes on the Chandeleur Islands, Louisiana, during and after Hurricane Katrina. *In:* Lavoie, D. (ed.), Sand Resources, Regional Geology, and Coastal Processes of the Chandeleur Islands Coastal System—An Evaluation of the Breton National Wildlife Refuge. *U.S. Geological Survey Scientific Investigations Report 2009-5252*, pp. 27–36.

Stockdon, H.; Fauver, L.; Sallenger, A.H., Jr., and Wright, W., 2006. Impacts of Hurricane Rita on the beaches of western Louisiana. *In:* Farris, G.S.; Smith, G.J.: Crane, M.P.; Demas, C.R.; Robbins, L.L., and Lavoie, D.L. (eds.), Science and the Storms–the USGS Response to the Hurricanes of 2005. *U.S. Geological Survey Circular 1306*, pp. 119–123.

Williams, S.J.; Flocks, J.; Jenkins, C.; Khalil, S., and Moya, J., 2012. Offshore sediment character and sand resource assessment of the northern Gulf of Mexico, Florida to Texas. *Journal of Coastal Research*, Special Issue No. 60, pp. 30–44.

Williams, S.J.; Kulp, M.; Penland, S.; Kindinger, J.L., and Flocks, J.G., 2011. Mississippi River Delta Plain, Louisiana coast and inner shelf: Holocene geologic framework and processes, and resources. *In*: Buster, N.A. and Holmes, C.W. (eds.) *Gulf of Mexico Origin, Water and Biota: Vol. 3, Geology*. College Station, Texas: Texas A&M University Press, pp. 175-193.