Bathymetric Comparisons Adjacent to the Louisiana Barrier Islands: Processes of Large-scale Change

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ABSTRACT


This paper summarizes the results of a comparative bathymetric study encompassing 150 km of the Louisiana barrier-island coast. Bathymetric data surrounding the islands and extending to 12 m water depth were processed from three survey periods: the 1880s, the 1930s, and the 1980s. Digital comparisons between surveys show large-scale, coherent patterns of sea-floor erosion and accretion related to the rapid erosion and disintegration of the islands. Analysis of the sea-floor data reveals two primary processes driving this change: massive longshore transport, in the littoral zone and at shoreface depths; and increased sediment storage in ebb-tidal deltas. Relative sea-level rise, although extraordinarily high in the study area, is shown to be an indirect factor in causing the area’s rapid shoreline retreat rates.

ADDITIONAL INDEX WORDS: Erosion, sea-floor change, sediment budget, sea-level rise, ebb-tidal delta, Louisiana, Mississippi Delta.

INTRODUCTION

The barrier islands of Louisiana (Figure 1) are eroding at extremely high rates; in many areas the erosion rate has exceeded 20 m/year for the last 100 years (McBRIDE et al., 1992). Within the past 100 years, these barrier islands have decreased in area by more than 40%; some islands have lost 90% of their area. A few of the islands are predicted to disappear within the next two decades (McBRIDE et al., 1992). The disappearance of these barrier islands may have serious environmental consequences, including an increased rate of wetlands loss and the conversion of back-barrier estuarine habitats to a less biologically productive inner continental shelf environment (BOESCH et al., 1994).

Although the rapid erosion of the Louisiana barrier islands is well documented, the processes responsible for this erosion are not well understood. In 1986, the U.S. Geological Survey (USGS) and the Louisiana State University initiated the Louisiana Barrier Island Erosion Study to: 1) document rates of historical shoreline and bathymetric change; 2) provide geological framework information, and 3) make measurements of storm-induced sediment transport processes on the shoreface and over the barrier islands. The range of investigations carried out in support of this study is described by SALLENGER et al. (1987, 1991).

Here we summarize the results from the bathymetric-change component of the study, in which we analyze sea-floor-elevation changes along a 157 km section of deltaic-plain coast immediately west of the modern Mississippi River delta. This region (Figures 1 through 4) covers approximately 3000 km² of sea floor and extends from about 7 km landward of the barrier islands offshore to 12 m water depths in the Gulf of Mexico. Bathymetric data from three time periods, the 1880s, 1930s, and 1980s, are used to define the long-term patterns of erosion and accretion and to better understand the processes responsible for the rapid erosion of the Louisiana barrier islands.

DATA

The data sources, processing techniques, and error assessment are described in detail by LIST et al. (1994), and will only be briefly summarized here.

Data Sources

Data for the bathymetric comparisons presented here were obtained from diverse sources with a variety of densities. For the 1880s survey, a total of 63,909 soundings were digitized from U.S. Coast and Geodetic Survey (USCGS) hydrographic smooth sheets for the years 1878, 1883, 1886, 1888, 1889, 1891, and 1906. The 1930s survey consists of 315,856 soundings obtained in digital form from the National Geophysical Data Center in Boulder, CO. Data were digitized by the National Ocean Service of the National Oceanic and Atmospheric Administration (NOAA) from USCGS hydrographic smooth sheets for the years 1933, 1934, 1935, and 1936. The 1980s bathymetry was constructed from 232,289 soundings obtained in digital form from the National Geophysical Data Center in Boulder, CO. Data were digitized by the National Ocean Service of the National Oceanic and Atmospheric Administration (NOAA) from USCGS hydrographic smooth sheets for the years 1980, 1983, 1986, 1988, 1989, 1990, 1991, and 1996. The 1990s survey consists of 315,856 soundings obtained in digital form from the National Geophysical Data Center in Boulder, CO. Data were digitized by the National Ocean Service of the National Oceanic and Atmospheric Administration (NOAA) from USCGS hydrographic smooth sheets for the years 1980, 1983, 1986, 1988, 1989, 1990, 1991, and 1996. The 1980s bathymetry was constructed from 232,289 soundings obtained in digital form from hydrographic surveys conducted in 1986, 1988, and 1989 by companies under contract with the USGS. Thus, neither the 1880s, 1930s, nor 1980s bathymetries represent a synoptic coverage of sea-floor eleva-
tion, a potential, but unquantified, source of error in the study results. The 1880s, 1930s, and 1980s bathymetric data sets are maintained by the USGS, and are available for public distribution.

In addition to bathymetric data, shoreline-position data were obtained for each time period to provide a mean high water (MHW) line for better constraint of the bathymetric contours surrounding the study area’s many small islands. Shoreline data for the 1880s and 1930s time periods were digitized from USCGS topographic smooth sheets, while the 1980s shoreline was photo interpreted and digitized from National Aeronautics and Space Administration (NASA) high-altitude photography. A detailed description and analysis of shoreline data for the Louisiana barrier islands is found in McBride et al. (1992).

Processing Techniques

Standard commercial gridding routines using the minimum tension method (ISM, Dynamic Graphics, Inc.) were used to construct surface models for the 1880s, 1930s, and 1980s composite survey years. In addition to List et al. (1994), detailed descriptions of the digital processing techniques employed is found in Jaffe et al. (1991), and Hopkins et al., (1991).

Bathymetric change grids were calculated for the 1880s to 1930s and the 1930s to 1980s change periods, forming the basis for the analysis and interpretation of sea-floor change patterns and processes. Because of the approximately 1 cm/yr relative sea-level rise experienced by the study area (Penland and Ramsey, 1990), a sea-level correction was necessary to prevent a strong bias toward erosion and to permit calculations of erosional and accretionary volumes. As continuous tide records were not available for the study period, we employed an alternate means of correcting for relative sea-level using an area of sea floor which was judged to have minimal accretion or erosion (Jaffe et al., 1991). The error associated with this datum correction constitutes a large part of the overall data uncertainty.
Error Assessment

The total error associated with sea-floor change calculations is a complex combination of many potential sources of error, including sounding measurement error, tidal correction problems, vertical and horizontal datum inconsistencies, and computer gridding errors. Although some errors can be quantitatively evaluated, others, such as the tidal datum correction problem mentioned above, could only be evaluated qualitatively. Therefore, a combination of quantitative and qualitative approaches were employed to assess the likely degree of error in bathymetric comparisons (List et al., 1994). As a conservative estimate, the ±0.5 m range of sea-floor change was designated a zone of no significant change.

RESULTS

The patterns of bathymetric change and associated processes of sediment transport are described in detail by List et al. (1991, 1994), List et al. (in press), Sallengor et al. (1992), and Jaffe et al. (1997). Here we will briefly summarize the main results of these studies.

Patterns of Bathymetric Change

Bathymetric and sea-floor change maps are published in a large format atlas at scales of 1:100,000 and 1:250,000 in List et al. (1994). Examples are given here for bathymetry from the 1980s (Figure 2) and for sea-floor changes for the 1880s to 1930s (Figure 3) and the 1930s to 1980s (Figure 4).
Much of the observed erosion and accretion occurred in water depths greater than might have been expected from the study area's very low-energy wave climate (deep water, mean significant wave height of 1.1 m, Hubertz and Brooks, 1989). Offshore from the Bayou Lafourche headland and the Plaquemines shoreline, significant shoreface erosion occurs to a water depth of greater than 12 m (Figure 5). In contrast, erosion along the Isles Dernieres is restricted to water depths shallower than 4 m (Figure 5), possibly the result of the sheltering effect of Ship Shoal (Figure 1).

Major depositional areas also extend to relatively deep water. However, in contrast to erosional areas they are largely detached from changes occurring near the shoreline (which tend to be erosional throughout the study area). Adjacent to Barataria Bay (Figure 1), a major deposit of this nature appears in both the 1880s to 1930s and 1930s to 1980s change periods (area C, Figures 3 and 4). In the 1930s to 1980s change period, an elongate deposit appears seaward of the entrance to Terrebonne Bay, spanning the distance from the eastern end of Timbalier Island to the Isles Dernieres (area B, Figure 4). Interestingly, this feature is largely lacking in the 1880s to 1930s change period, although relatively small deposits with a similar east-west orientation are evident (area B, Figure 3).

Smaller areas of both deposition and erosion occur in shallower water associated with the movement of barrier islands and the formation and migration of inlets. These changes will be discussed further below.

Sediment Budget

An important issue that must be addressed before making processes interpretations from the patterns of sea-floor change concerns whether the accretionary and erosional volumes in Figures 3 and 4 balance. Sallenger et al. (1992) divided the study area into three transport cells (Figure 6) and calculated the total volume of sediment eroded and accreted for each cell. With the assumption that depositional areas are mostly sand and erosional areas only contain about
31% sand (List et al., 1991), the volumes of eroded and deposited sand were in fair agreement for all cells and both time periods (Figure 7).

However, because large error bars are associated with the results in Figure 7 (Salleng et al., 1992; List et al., 1994), the possibility of significant erosional or depositional areas landward or seaward of our study area cannot be discounted. Also, due to the ±0.5 m no-significant-change zone assigned the bathymetric change results (List et al., 1994), erosional or depositional areas assuming a broad, but thin, form are undetectable. Nevertheless, the sediment budget results of Salleng et al. (1992), provide some confidence for the assumption that the patterns of sea-floor change in Figures 3 and 4 encompass most of the important erosional and depositional areas, and are the result of the major processes responsible for redistributing the area’s sediments and forcing high rates of shoreline erosion. Processes interpretations presented below are based on this assumption.

Processes of Shoreface Erosion and Longshore Transport

Throughout the study area, rates of shoreline retreat reflect volumes of shoreface erosion. For example, Figure 5 shows that both the shoreline retreat and shoreface erosion are much larger along the Bayou Lafourche headland than in the Isles Dernieres. Thus an understanding of the processes controlling shoreface erosion is critical to understanding and predicting changes at the shoreline. As described by Penland et al. (1988), sediments underlying the Louisiana barrier island shoreface consist of deltaic sequences of clays to fine sands representing prodelta, delta front, beach ridge, and distributary deposits. One possible model for the rapid erosion of these largely cohesive sediments is through simple wave-induced abrision by the small component of coarser sediment that is liberated as erosion occurs (cf. Kampfhuis, 1990; Bishop et al., 1993). In this model, wave-induced currents that would nominally be below the threshold for transport of the consolidated, muddy shoreface sediments are able to effectively erode the bed due to the abrasive action of small amounts of coarser sediment. This model could help explain why the depth and rate of shoreface erosion along the Isles Dernieres is much less than along the Bayou Lafourche headland (Figure 5); the sheltering effect of Ship Shoal (Figure 1) results in less wave energy and therefore less mechanical abrision along this section of coast. Stone et al. (1995) and Stone (pers. comm.) demonstrate in modeling studies that this longshore gradient in wave energy is present in both hurricane and more moderate storm conditions. It is unlikely, however, that this wave-induced abrasion mechanism could be solely responsible for long-term erosion; continued and extensive shoreface erosion would eventually liberate enough sand to form a sandy shoreface, protecting underlying cohesive sediments from further erosion. Thus other processes (described below) must also play a role in controlling the shoreface retreat rates.

One of the most striking and unexpected bathymetric change features is the deposit labeled B in Figure 4. This deposit, representing more than one million cubic meters of sediment transport per year, appears to emanate from the Bayou Lafourche headland erosional area (area A, Figure 4) and extends in a restricted band to the eastern-most island of the Isles Dernieres. Jaffe et al. (1997), suggest that this deposit represents a newly-discovered form of inlet bypassing whereby sediments eroded from the Bayou Lafourche headland may serve as a source of new sediments for the Isles Dernieres. Sediment transport modeling demonstrates that the volume of sediment contained within this depositional band or bypassing “lobe” of sediment could only be transported by the waves and currents associated with major storms (Jaffe et al., 1997).

Although the exact processes are still uncertain, the detachment of this sediment lobe from the curvature of the coast west of the Bayou Lafourche headland, as well as the up to 8.5 m depth of this deposit, makes it unlikely that littoral processes can account for the lobe. Nevertheless, the along-coast sediment transport associated with the lobe appears to be one of the primary mechanisms of sediment removal from the rapidly eroding Bayou Lafourche headland.

Other examples of longshore transport can readily be explained by well-documented processes of littoral transport. The best example of this is along Timbalier Island, where littoral transport has resulted in spit growth and westward migration of the island, along with infilling and westward migration of Cat Island Pass (area D, Figures 3 and 4). Interestingly, Jaffe et al. (1997) show that while this mode of
westward sediment transport was dominant in the 1880s to 1930s change period, it became secondary to transport in the offshore lobe during the 1930s to 1980s change period. Nevertheless, littoral processes are clearly another important mechanism for removal of sediments from headland areas.

Influence of Sea-level Rise

One of the fundamental questions raised at the start of the Louisiana Barrier Island Erosion Study concerned the role of relative sea-level rise in forcing the region’s rapid rates of coastal erosion. As documented by Penland and Ramsey (1990), the region experiences a subsidence-induced relative sea-level rise of approximately 1 cm/yr, or five to ten times greater than estimates of the eustatic rate of sea-level rise (Douglas, 1991). A seemingly self-evident assumption was that this rapid rate of relative sea-level rise must be a principal agent of coastal erosion (Salenger et al., 1987). However, the processes through which relative sea-level rise has contributed to coastal erosion in Louisiana were poorly defined.

In a test of the most commonly applied model for predicting shoreline retreat as a function of sea-level rise (the Bruun Rule; Bruun, 1962), List et al. (in press) implement a numerical test of the Bruun Rule (following Everts, 1985) at 37 distinct locations along the study area’s coast. List et al. demonstrate a complete lack of correlation between observed and predicted shoreline retreat rates, a result reproduced here in Figure 8. This shows that simple profile readjustment in response to relative sea level changes is not a valid model for the Louisiana barrier island coast.

However, rapid relative sea-level rise can be linked to the area’s rapid coastal erosion through several less direct processes. Rapid disintegration of wetlands (Britsch and Dunbar, 1993), thought by many to be due to a sedimentation rate inadequate to keep pace with relative sea-level (Boesch et al., 1994), probably plays a major role in the wholesale conversion of delta plain barrier complexes to open water. When the bay-side marsh platform is converted to open water, sand-deficient barriers in Louisiana cannot maintain their subaerial expression as they retreat (Figure 9). Bathymetric change data suggest that several areas have begun to convert to open water through this sea-level-rise related process, in particular Isles Dernieres and the Plaquemines shoreline (Figure 1). This transformation is consistent with the barrier island evolution model of Penland et al. (1988), in which a Stage 2 detached barrier island chain evolves to a Stage 3 inner shelf shoal.

Changes in relative sea-level also have a strong influence on tidal inlets, which have rapidly grown in both number and size over the last 100 years, causing fragmentation and accelerated erosion of the islands (McBrine et al., 1992; also Figure 10 here). This inlet-forming process is likely the direct result of increases in tidal prism, as a function of the disintegration of large areas of mainland marsh (Levin, 1993). However, as shown by Levin (1993), inlets in some areas are widening not through increases in tidal prism but due to a deficiency of sand-sized sediment in Mississippi delta plain barriers which are no longer supplied through headland erosion (Penland et al., 1988, model, Stage 2).

In addition to increases in the number and size of tidal inlets, the volume of sediment stored in ebb-tidal delta complexes (and therefore lost from the shoreline) also seems to be increasing in response to relative sea-level rise. This relationship was quantified in the Barataria Bay area by List et al. (1991, 1994) through a comparison between changes in Barataria Bay’s tidal prism and the volume of sediment stored in the associated ebb tidal delta complex over the last 100 years (Figures 10 and 11). This increased sediment storage in the Barataria ebb tidal deltas takes the form of broad areas of accretion in the patterns of sea-floor change (area C,
Figure 10. Co-evolution of Barataria Bay tidal prism and associated ebb-tidal deltas. \( P \) is the tidal prism, calculated from Barataria Bay historical shorelines and a tidal range of 0.34 m (NOAA, datum reference for Grand Isle). The dashed part of the 1890's shoreline represents missing data that were estimated from trends in available data. \( V \) is the volume of sediment stored in the ebb-tidal delta complex, based on the method of Walton and Adams (1976). (After List et al. 1991).
Figures 3 and 4), with the morphology of the ebb-tidal delta evident in the contours of Figure 2).

CONCLUSIONS

Historical sea-floor comparisons have led to results that were not anticipated from an examination of shoreline changes alone. Longshore transport appears to play a major role in the rapid erosion of Louisiana's barrier island coast. This longshore transport occurs both along the shoreline through well-documented littoral processes, and, apparently, at shoreface depths through processes that are poorly understood. However, the volume of sand available for longshore transport is probably limited by the rate at which sand is liberated from the predominantly mud-size sediments of the shoreface.

Relative sea-level rise also plays a major role in the coast's evolution, though not through the simple readjustment of the profile following the Bruun Rule. Rather, the effect of relative sea-level rise stems from the disintegration of coastal wetlands, eliminating the platform over which the sand-starved barriers migrate, accelerating the formation and enlargement of tidal inlets, and increasing the volume of sediment stored in ebb-tidal delta.

These results, derived from 100 years of historical bathymetric data, show that the rapid rates of shoreline erosion along Louisiana's barrier islands cannot be viewed independently of the large-scale processes of erosion and sediment redistribution occurring on the shoreface and in the back-barrier wetlands. Baring efforts on a truly massive scale, it is doubtful that human intervention could significantly slow down or reverse these natural erosional processes. Erosion mitigation efforts should therefore work within the natural system, recognizing and accounting for the long-term, pervasive nature of coastal erosion in Louisiana through techniques designed to permit continued landward migration of the islands while reducing their fragmentation and areal loss.

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Figure 11. Volume of sediment stored in the Barataria Bay ebb-tidal delta complex as a function of Barataria Bay tidal prism for the 1880s, 1930s, and 1980s. Data are superimposed on data collected by Walton and Adams (1976) for U.S. ebb-tidal deltas. (From List et al., 1994).
is thanked for contributions to the figures. Any use of trade names in this publication is for descriptive purposes only and does not imply endorsement by the USGS.

LITERATURE CITED


