Journal of Coastal Research	13	3	628–655	Fort Lauderdale, Florida	Summer 1997

Regional Variations in Shore Response along Barrier Island Systems of the Mississippi River Delta Plain: Historical Change and Future Prediction

Randolph A. McBride[1]† and Mark R. Byrnes[2]†

[1]Department of Geography
and Earth Systems Science
George Mason University
4400 University Drive
Fairfax, VA 22030, U.S.A.

[2]Aubrey Consulting, Inc.
Woods Hole Group
P.O. Box 10, 1140 Route 28A
Cataumet, MA 02534, U.S.A.

ABSTRACT

McBRIDE, R.A. and BYRNES, M.R., 1997. Regional Variations in Shore Response along Barrier Island Systems of the Mississippi River Delta Plain: Historical Change and Future Prediction. *Journal of Coastal Research*, 13(3), 628–655. Fort Lauderdale (Florida), ISSN 0749-0208.

Long-term changes in shoreline position along Louisiana's rapidly deteriorating barrier coastline were documented from 1855 to 1989 using National Ocean Service (NOS) topographic sheets and near-vertical aerial photography. An interactive computer mapping system was employed to compile and quantify shoreline data at approximately 880 shore-normal transects by magnitude, direction, and rate of change. The study area extends along the barrier coast of the Mississippi River delta plain from Raccoon Point (western Isles Dernieres) to Hewes Point (northern Chandeleur Island). Four barrier systems characterize the study area: (1) Isles Dernieres, (2) Bayou Lafourche, (3) Plaquemines, and (4) Chandeleur Islands. Long-term gulfside rates of change range from −23.1 to +0.9 m/yr, whereas bayside rates range from −5.0 to +24.0 m/yr. Louisiana barrier island systems have experienced landward migration, area loss, bayside erosion, and island narrowing as a result of complex interactions among subsidence, eustatic sea level rise, wave processes, storm impacts (cold fronts and tropical cyclones), inadequate sediment supply, and intense human disturbance (levees; oil, gas, and sulphur extraction activities; access canals; seawalls; jetties). Consequently, the structural continuity of Louisiana's barriers is weakening as the barrier shoreline continues to narrow, fragment, and finally disappear. Seven geomorphic response types characterize the barrier shoreline: 1) *lateral movement,* 2) *advance,* 3) *dynamic equilibrium,* 4) *retreat,* 5) *landward rollover,* 6) *breakup,* and 7) *rotational instability.* Although the Bayou Lafourche shoreline has the highest rates of erosion through *landward rollover* and *retreat,* the Isles Dernieres, Grand Terre Islands, and the eastern Plaquemines shoreline are experiencing the more devastating process of *breakup* and will probably disappear within the next 25 years. Consequently, these zones of *breakup* are the most critical coastal land loss areas along Louisiana's barrier shoreline and thus, further threaten productive estuarine habitats in Terrebonne/Timbalier and Barataria Bays.

ADDITIONAL INDEX WORDS: *Louisiana, barrier shorelines, geomorphic response, coastal erosion, barrier island evolution, coastal restoration, Mississippi River delta, Gulf of Mexico.*

INTRODUCTION

Louisiana's barrier shoreline provides the first line of defense against nearshore processes that would otherwise directly impact productive estuarine environments in the coastal zone. Each kilometer of barrier shoreline in Louisiana protects approximately 30 km^2 of estuarine habitat in the delta plain. Barrier shorelines formed in response to reworking of abandoned Mississippi River deltas and play an integral role in the evolution of Louisiana's complex deltaic-estuarine system (SCRUTON, 1960; ROBERTS, this volume). The four barrier island systems in Louisiana are the Isles Dernieres, Bayou Lafourche, Plaquemines, and Chandeleur Islands (Figure 1). Historically, most of Louisiana's barrier island shoreline has been in a chronic stage of deterioration resulting from the complex interaction among natural and human processes. This paper quantitatively documents the historical evolution of Louisiana's barrier shoreline and provides predicted future conditions for developing coastal restoration strategies.

Determining future shoreline positions depends on regional historical shoreline change data sets that are accurate, long-term (>80 yrs), and quantified. Although several shoreline change studies have been conducted for Louisiana's barrier island shoreline over the past 40 years (MORGAN and LARIMORE, 1957; PEYRONNIN, 1962; PENLAND and BOYD, 1981; MORGAN and MORGAN, 1983; SHABICA *et al.,* 1984), Chapter 4 of the USGS Barrier Island Erosion Atlas represents the most comprehensive investigation to date (MCBRIDE *et al.,* 1992). In the atlas, historical shorelines were compiled for the past 100 years with some shorelines dating back to the mid 1850s. Consequently, this long-term data set incorporates all physical and human processes that have affected the barrier shoreline for the past century (*e.g.,* relative sea level rise [1 cm/yr], hurricane impacts, dredging, reduced sediment sup-

---

97026 received 12 March 1997.

† Former address: Coastal Studies Institute and the Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, LA 70803, U.S.A.

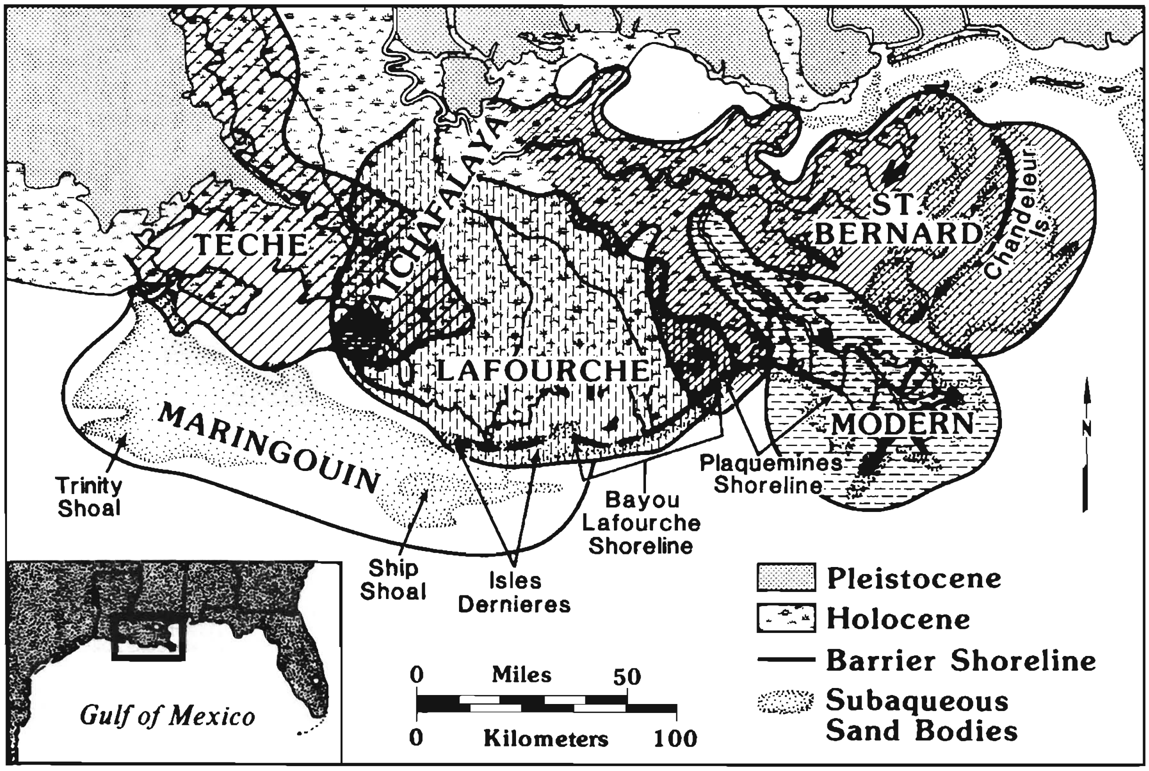

Figure 1. Study area showing the four barrier systems along Louisiana's deltaic plain (modified from Frazier, 1967).

ply from the Mississippi River, coastal engineering structures). When scientists have access to this type of historical data, shoreline positions can be more reliably projected up to 100 years into the future. The objectives of this paper are to: (1) present shoreline change data for Louisiana's barrier island shoreline (*i.e.,* magnitude, direction, and rate), (2) predict future shoreline conditions by extrapolating historical rates of change, and (3) document regional response types for the shoreline/shelf system in order to addressing comprehensive coastal restoration strategies.

METHODS

Historical Shoreline Position Change

A shoreline change mapping strategy was developed to compile changes in shoreline position derived from cartographic data sources and near-vertical aerial photography (Figure 2). Mylar- or bromide-based topographic sheets (T-sheets) available from the National Ocean Service (NOS) were used for all shorelines compiled before 1950. In Louisiana, most NOS T-sheets were published at a 1:20,000 scale. Cartographic shorelines between 1950 and 1979 were recorded from NOS T-sheets and USGS 7.5-minute quadrangles. NOS T-sheets are not available for Louisiana's shoreline after 1956. Black and white aerial photography, dated January 1988 and taken at a scale of 1:15,000, was used to construct a 1988 shoreline west of the mouth of the Mississippi River. To the east of the river mouth, the 1978 and 1989 Chandeleur Islands shorelines were interpreted using National Aeronautic and Space Administration (NASA) high-altitude color-infrared photography enlarged to scales of 1:33,000 and 1:24,000, respectively.

For accurate mapping of shoreline position, aerial photography data sources require rectification and interpretation. Delineating the land-water interface is the most important step in compiling shoreline position from photography, and requires a detailed understanding of local coastal processes, geomorphology, and human impacts operating past and present along the coastline (STAFFORD, 1971; MORTON, 1979; BYRNES *et al.,* 1991). For this study, aerial photography was registered to USGS 7.5-minute quadrangle maps using a Bausch and Lomb Zoom Transfer Scope. The high-water shoreline (HWL) was interpreted according to the location of the berm crest visible on aerial photographs. This same position is identified as the official shoreline on cartographic data (SHALOWITZ, 1964; ANDERS and BYRNES, 1991). The high-water line is the most appropriate reference for measuring change in shoreline position because its position on the upper foreshore represents the landward limit of influence by average waves and water level (LANGFELDER *et al.,* 1968). Therefore, in this study, the same shoreline reference position derived from different data sources was compiled and compared.

Shoreline data were digitized at a 1:1 scale according to original projection, ellipsoid, and datum using Intergraph's computer mapping hardware and software including a large

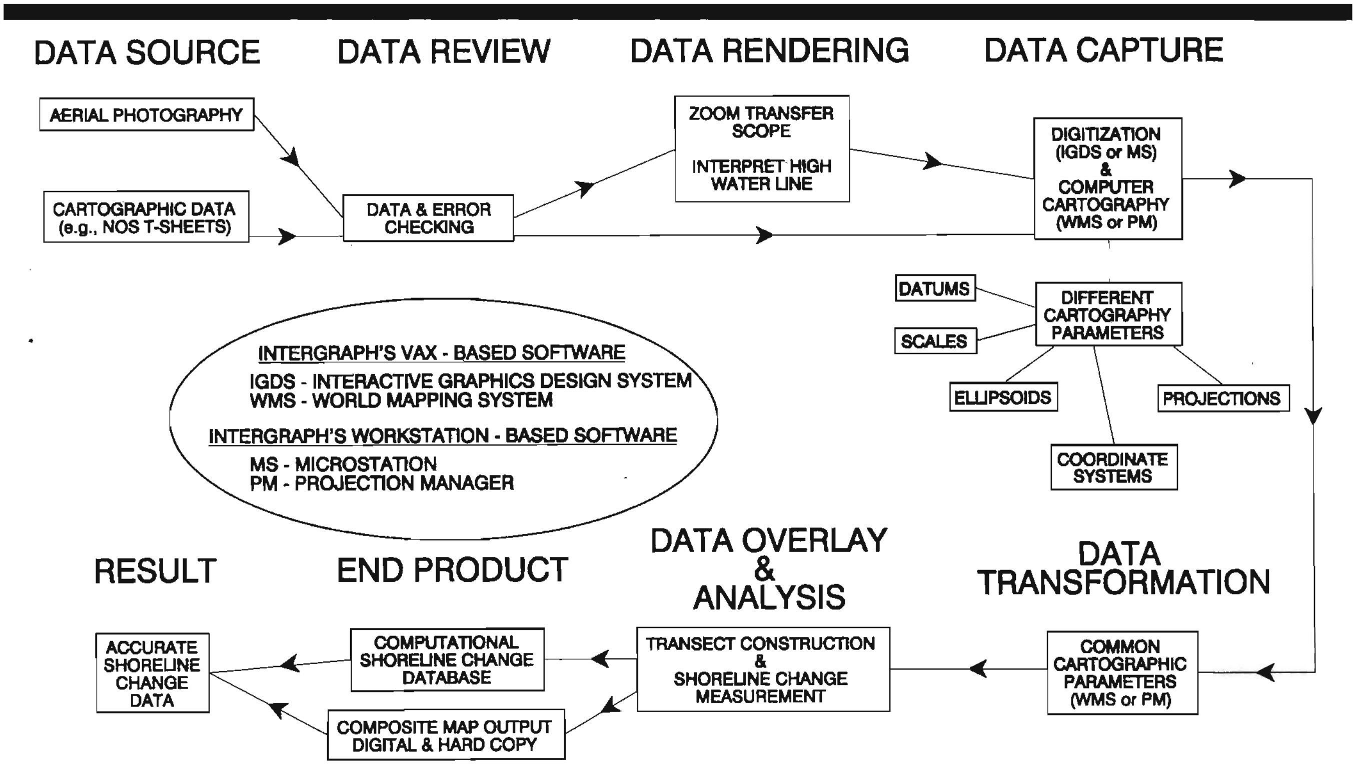

Figure 2. Shoreline change mapping strategy (modified from McBride *et al.*, 1991).

format, high-precision digitizer and cursor (Figure 2). Once in digital form, shoreline data for each year were converted to a common projection (Polyconic), coordinate system (latitude-longitude), horizontal datum (NAD 27), and ellipsoid (CLARKE 1866). About 880 shore-normal transects were established at approximately 15-second intervals (~400 m) of latitude or longitude (depending on shoreline orientation) along the gulfside and bayside shorelines. A data base consisting of distance and area values was compiled. Distance and area measurements were obtained in Polyconic projection because the majority of source maps were in Polyconic, and the properties of this projection preserve shape, area, distance, and azimuth in their true relation to the earth's surface (SHALOWITZ, 1964; SNYDER, 1987). Average rates of shoreline movement and area change were calculated by dividing absolute measurements by elapsed time. Shoreline data were then converted to Universal Transverse Mercator projection for map output. Potential error associated with this shoreline mapping technique is discussed in previous studies (MCBRIDE *et al.*, 1991; 1992).

Predicting Future Shoreline Conditions

Having 100 years of historical data increases the reliability of future predictions of shoreline conditions. Two methods were developed to predict future shoreline conditions. These methods are shoreline change extrapolation and area change extrapolation. Future shorelines of 30 and 100 years were selected because 30 years represents likely conditions within our lifetime and the duration of a typical home mortgage loan (*i.e.*, coastal infrastructure), whereas 100 years represents the life expectancy of infrastructure and captures regional trends in barrier island processes. Moreover, the historical period of record is approximately 100 years.

Shoreline Change Extrapolation

The 1988 (west of the Mississippi River) or 1989 (east of the Mississippi River) shorelines in the USGS Barrier Island Erosion Atlas (MCBRIDE *et al.*, 1992) were used as base shorelines upon which all future extrapolations were made. To determine the 30 and 100 year future shoreline scenarios, the long-term rate of change along each transect was multiplied by the respective lengths in time (*e.g.*, 10 m/yr × 30 yr = 300 m and 10 m/yr × 100 yr = 1000 m) to calculate a magnitude of change. Consequently, the 1988 or 1989 shoreline position at each transect was moved either landward or seaward depending on the direction and magnitude of change. This procedure was completed for each transect, and the new 30 and 100 year positions were connected with line segments, thus producing the predicted 2018 and 2088 shorelines. Long-term change rates were always used except on East Timbalier Island[1].

---

[1] Due to the placement of extensive rip-rap revetments along East Timbalier Island, short-term change rates were used to predict 30 and 100 year shorelines. The continuous nature of the revetments has inhibited washover processes and has caused the geomorphic response of the entire island to change over the past 30 years.

Area Change Extrapolation

Based on long-term area change information, a rate of island area decrease can be calculated to determine the projected date of disappearance of a particular island. For example, if the present area of a barrier island is 100 ha and it has been losing land at a rate of 10 ha/yr for the past 100 years, then the projected disappearance date is 10 years from now. Also, some barrier shorelines in Louisiana are moving rapidly in a lateral direction versus an onshore/offshore direction (*e.g.*, Timbalier Island). In these cases, the linear transect extrapolation method alone does not appropriately address predicted changes of the geomorphic feature. Therefore, area change extrapolation was used in combination with shoreline change extrapolation to determine both life expectancy and geographic position for Timbalier Island.

In summary, the advantages of using the shoreline change extrapolation method are: (1) it incorporates actual response of the high-water shoreline to coastal processes (*e.g.*, waves, water levels, relative sea level rise) based on the historical record, and (2) calculated future shoreline positions can be easily depicted on a map. However, the method, relative to the area change extrapolation method, cannot address certain factors that also contribute to barrier island erosion and land loss, such as inlet cutting and interior pond development. As such, the shoreline change extrapolation method tends to slightly overestimate predicted life expectancies for barrier island shorelines only. Although the method of area change extrapolation can quantify all forms of shoreline erosion and land loss processes, as well as provide projected dates of disappearance, its major disadvantage is its inability to depict predicted shoreline position (*e.g.*, 30 and 100 year scenarios) on a map. Hence, this paper presents predicted future conditions (*i.e.*, maps and tables) for Louisiana's barrier shoreline using both methods.

HISTORICAL AND FUTURE SHORELINE CONDITIONS

When the long-term record of shoreline change is examined along Louisiana's barrier shoreline, it illustrates a coastline characterized by rapid landward movement, extensive bayside erosion, fragmentation, and massive land loss. Both long- and short-term change data are presented, but the long-term record (>80 years) of change is emphasized to document trends for Louisiana's four barrier systems. Short-term change (<25 years) shows much more variability (*i.e.*, lack of trend) and should be avoided when projecting future conditions.

In the discussion below, direction of shoreline movement along gulfside and bayside barrier shorelines is indicated by a "plus" (+) sign or "minus" (−) sign. A plus sign always indicates shoreline advance (sediment added), whereas a minus sign always means shoreline retreat (sediment subtracted). Therefore, along the gulfside, a plus sign indicates seaward movement, whereas a minus sign refers to landward movement. The opposite is true for the bayside barrier shoreline.

Isles Dernieres Barrier System

The Isles Dernieres shoreline is one of the most rapidly deteriorating barrier shorelines in the United States. Since 1887, the Isles Dernieres, once a continuous deltaic headland, has fragmented into five islands: Raccoon, Whiskey, Trinity, East, and Wine (Figure 3).

Historical Shoreline Change

Average gulfside shoreline change for the Isles Dernieres between 1887 and 1934 was −11.7 m/yr, whereas the average bay rate was −3.6 m/yr between 1906 and 1934 (Table 1). The gulfside rate decreased to −7.8 m/yr between 1934 and 1956, and remained close to that rate through 1978. On the other hand, the bayside erosion rate continued to slow from −2.1 to −1.6 m/yr for the periods 1934–56 and 1956–78. However, between 1978 and 1988, the rates of erosion on both sides of the island increased to −19.2 and −10.1 m/yr for the gulf and bay shorelines, respectively, presumably in response to the direct landfall of Hurricane Juan in 1985 and cold front impacts (wave erosion and associated freezing temperatures that killed many bayside mangroves in the winter of 1983/84). Strong winds from the north/northwest during post-cold front passage (see ROBERTS *et al.*, 1987) generate considerable wave energy along the backside of the Isles Dernieres as a result of the available fetch across Caillou Bay and Lake Pelto. The amount of fetch has slowly increased through time (*i.e.* positive feedback mechanism) in response to bay expansion caused by high rates of interior land loss (see BRITSCH and DUNBAR, 1996).

Most of the bayside shoreline of the Isles Dernieres is eroding, except for Wine Island and the spits on either end of Whiskey Island, both of which are rapidly migrating landward at about 20 m/yr. The long-term rate of bayside erosion averaged −2.4 m/yr between 1906 and 1988. Specifically, bayside erosion rates for Raccoon, Whiskey, Trinity, and East Islands were −2.4, −2.1, and −2.7 m/yr, respectively. When combined with the long-term gulfside change rate of −11.1 m/yr, the Isles Dernieres are narrowing as the two shorelines migrate toward each other, resulting in a 68% decrease in average width from 1,171 to 375 m (Table 1). Moreover, the Isles Dernieres have suffered a 78% reduction in area from 3,532 to 781 ha; a loss rate of 27.2 ha/yr (Table 1). Long-term area changes are only available for Raccoon and Wine Islands because Whiskey, Trinity, and East Islands were part of the same land mass until more recently (Table 2). Short-term area change exists for all individual islands of the Isles Dernieres between 1978 and 1988.

Future Shoreline Position

Based on long-term change rates at 184 shore-perpendicular transects (see MCBRIDE *et al.*, 1992, pg. 45), 30- and 100-year future shoreline positions were projected (Figures 4 and 5). When compared with the 1988 shoreline, the 30-year future scenario shows that the islands will continue to experience gulfside and bayside erosion resulting in island narrowing, breaching, and disappearance (Figure 4). Only the short spit located on the western side of Whiskey Island and por-

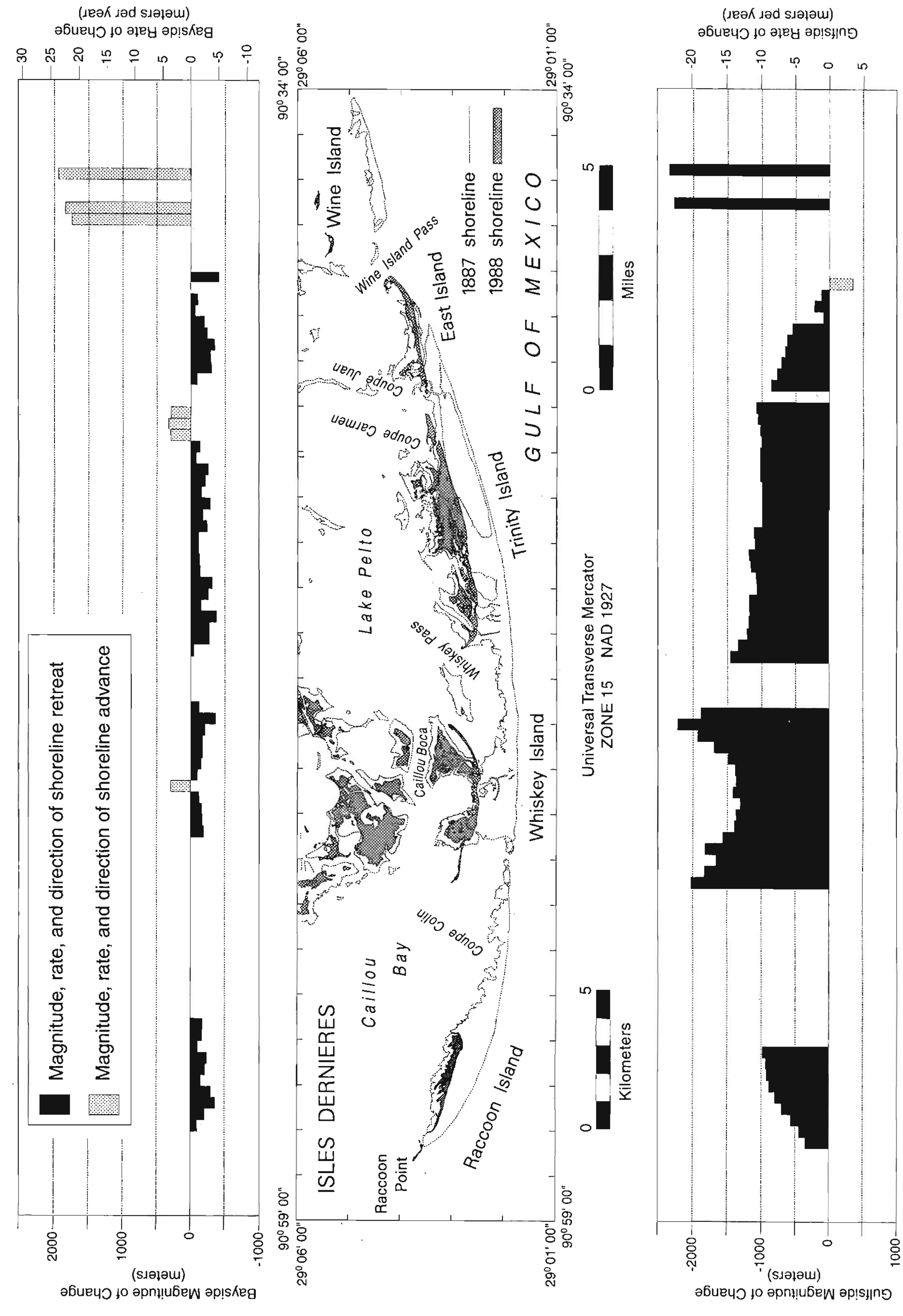

Figure 3. Shoreline changes of the Isles Dernieres barrier system between 1887 and 1988. Gulfside and bayside histograms show the magnitude (m), rate (m/yr), and direction of change (modified from McBride *et al.*, 1991).

Table 1. *Shoreline position, island width, and island area change for the Isles Dernieres barrier island system. 1 hectare (ha) = 2.47 acres; 1 meter (m) = 3.28 feet.*

Date	Island Area (ha)	Area Change Rate (ha/yr)	Projected Date of Disappearance (year)	Island Width (m)	Shoreline Position Change			
					Gulf Magnitude (m)	Gulf Rate (m/yr)	Bay Magnitude (m)	Bay Rate (m/yr)
1887	3532			1171				
1934	2015	−39.9	1985	815	−550	−11.7	−102	−3.6
1934	2015			815				
1956	1534	−21.9	2026	687	−171	−7.8	−47	−2.1
1956	1534			687				
1978	1245	−13.1	2073	585	−173	−7.9	−35	−1.6
1978	1245			585				
1988	781	−46.4	2005	375	−193	−19.2	−101	−10.1
1887	3532			1171				
1988	781	−27.2	2017	375	−1120	−11.1	−196	−2.4

tions of East Island will experience landward rollover. Within 100 years, the entire subaerial portion of the Isles Dernieres barrier island system is projected to disappear except small land fragments associated with the western end of Whiskey Island and the eastern end of East Island (Figure 5). By this time, the outer gulf shoreline will have translated landward with open gulf waves scouring interior bay bottoms and impacting mainland marshes to the north. However, if the area change extrapolation method is used, the Isles Dernieres are projected to disappear much earlier—in the year 2017 AD (Table 1).

Bayou Lafourche Barrier System

At 65 km long, the Bayou Lafourche barrier shoreline is almost twice the length of the Isles Dernieres. The central Bayou Lafourche shoreline is an abandoned deltaic headland that provides a source of sediment to downdrift flanking barriers islands and spits to the west (Timbalier, East Timbalier) and east (Elmer's Island, Grand Isle). The Bayou Lafourche barrier system was divided into two sections because of shoreline length: (1) the Timbalier Islands (Figure 6), and (2) the Caminada-Moreau Headland and Grand Isle (Figure 7). The Timbalier Islands extend from Cat Island Pass to Raccoon Pass and include Timbalier Island and East Timbalier Island. The Bayou Lafourche headland extends from Raccoon Pass to Barataria Pass.

Table 2. *Area change for Raccoon, Whiskey, Trinity, East, and Wine Islands. 1 hectare (ha) = 2.47 acres.*

Date	1887/1906–1934	1934–1956	1956–1978	1978–1988	1887/1906–1988
Island Area	833[1]	336	337	149	833
(ha)	336	337	149	81	81
	—[2]	605	433	366	—
	605	433	366	240	240
	—[3]	—	—	553	—
	—	—	553	365	365
	—[4]	—	—	175	—
	—	—	175	86	86
	160[5]	57	1	1	160
	57	1	1	10	10
Area Change	−13.1[1]	0.0	−8.5	−6.8	−8.2
Rate	—[2]	−7.8	−3.0	−12.6	—
(ha/yr)	—[3]	—	—	−16.8	—
	—[4]	—	—	−8.9	—
	−2.7[5]	−2.5	0.0	+0.9	−1.5

[1] Raccoon, [2] Whiskey, [3] Trinity, [4] East, and [5] Wine Islands

Historical Shoreline Change

Average gulfside change rates for Timbalier Island hovered around −1.3 m/yr for the periods 1887–1934 and 1934–56, but then increased to −3.1 and −7.0 for the time intervals 1956–78 and 1978–88, respectively (Table 3). Bayside change rates decreased from −2.9 to −1.3 m/yr between 1887 and 1978, then greatly increased to −14.1 m/yr between 1978 and 1988. This bayside rate trend of first slowing then rapidly increasing is identical to the Isles Dernieres. Bayside erosion is caused by an inadequate sediment supply, high rates of relative sea level rise, and the passage of cold fronts (*i.e.,* increased wave energy and intense mangrove diebacks in response to bitter cold). In addition, deterioration of Caillou and Bush Islands to the north of Timbalier Island has increased not only the exposure of the bay shoreline to incident processes, but also the available fetch across Terrebonne and Timbalier Bays. Consequently, during post-cold front passage, wind-generated waves from the north/northwest are able to attack the bayside shoreline of Timbalier Island more often (*i.e.* positive feedback mechanism).

Between 1887 and 1988, the average gulfside rate of change along Timbalier Island was −2.4 m/yr, whereas the bayside shoreline was moving twice as fast in a seaward direction at −5.0 m/yr (Figure 6; Table 3). Average island width decreased 69% from 1,341 to 415 m and area was reduced 64% from 1,485 to 542 ha. Moreover, the island is migrating rapidly to the west/northwest at about 80 m/yr, indicating the dominant influence of longshore transport processes.

To the east, the landward migration of East Timbalier Is-

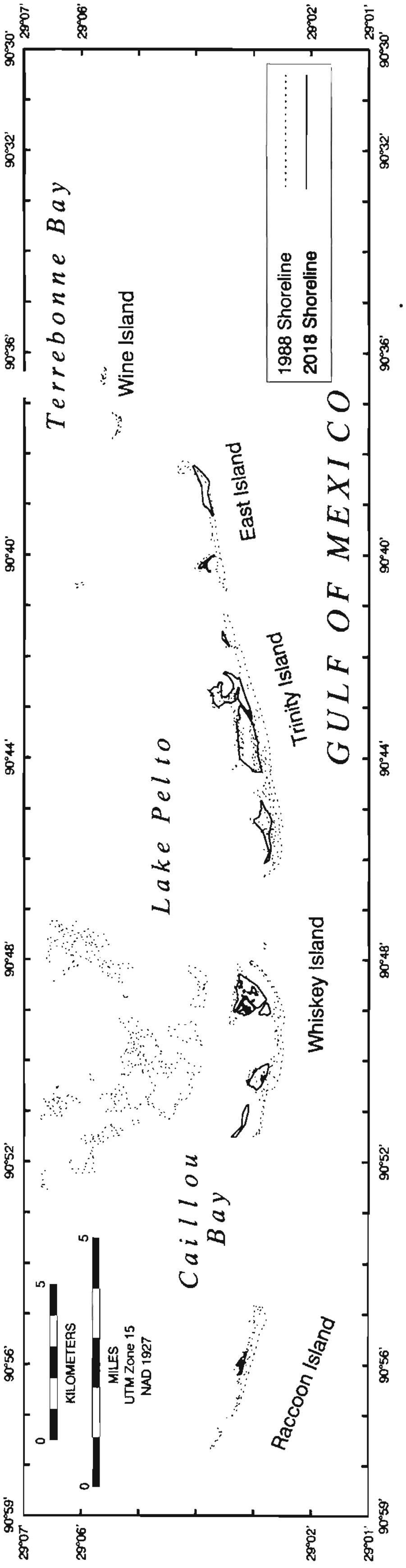

Figure 4. The Isles Dernieres barrier shoreline projected 30 years into the future (2018 AD) and superimposed on the 1988 shoreline (dotted).

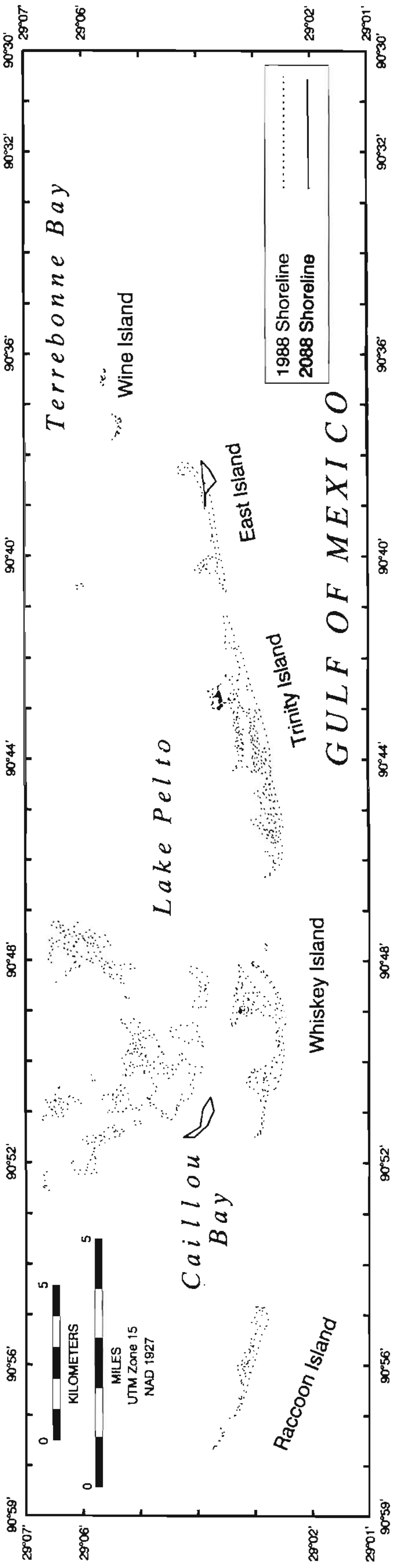

Figure 5. The Isles Dernieres barrier shoreline projected 100 years into the future (2088 AD) and superimposed on the 1988 shoreline (dotted).

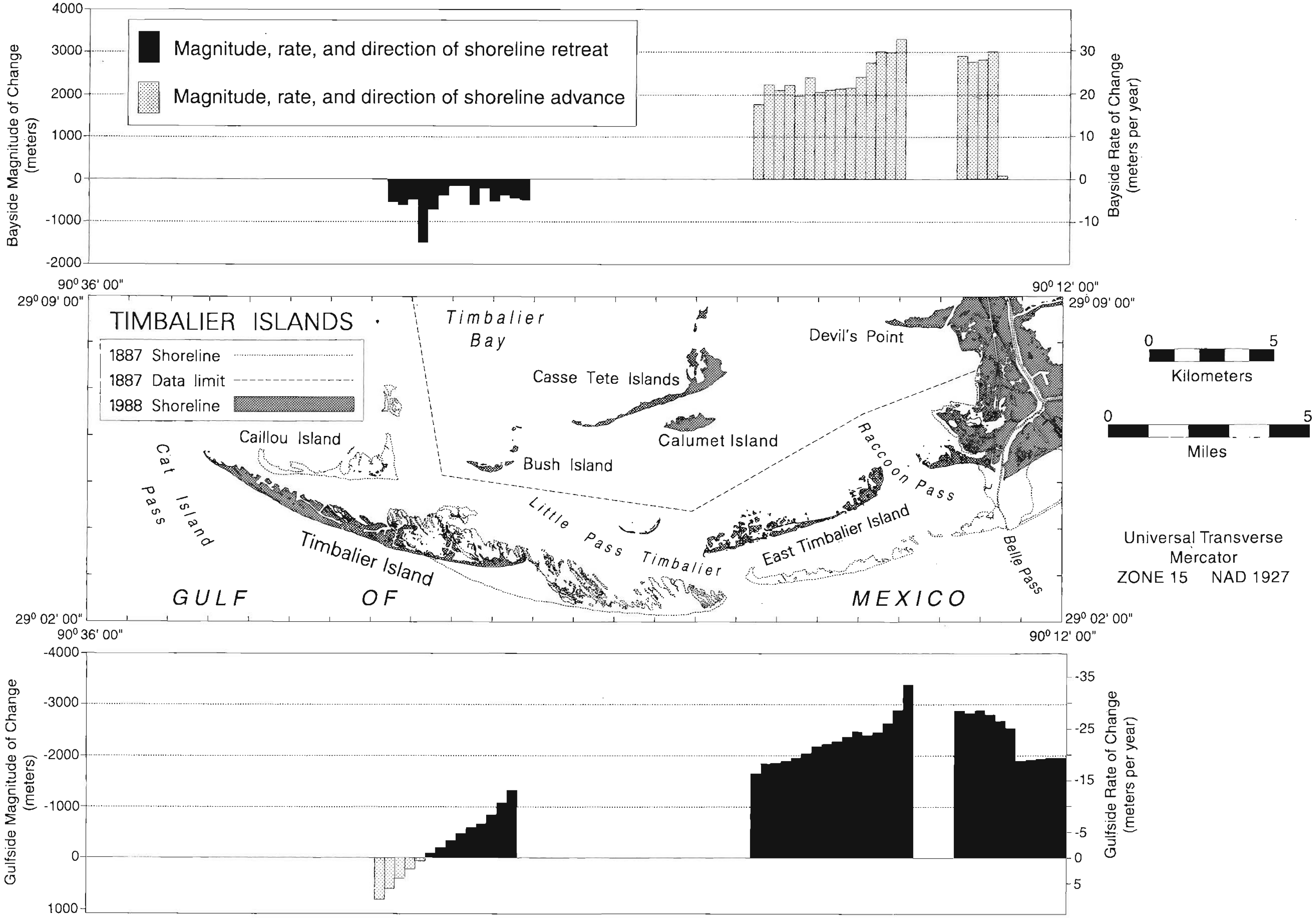

Figure 6. Timbalier Islands along the western portion of the Bayou Lafourche barrier system between 1887 and 1988 (modified from McBride *et al.*, 1991).

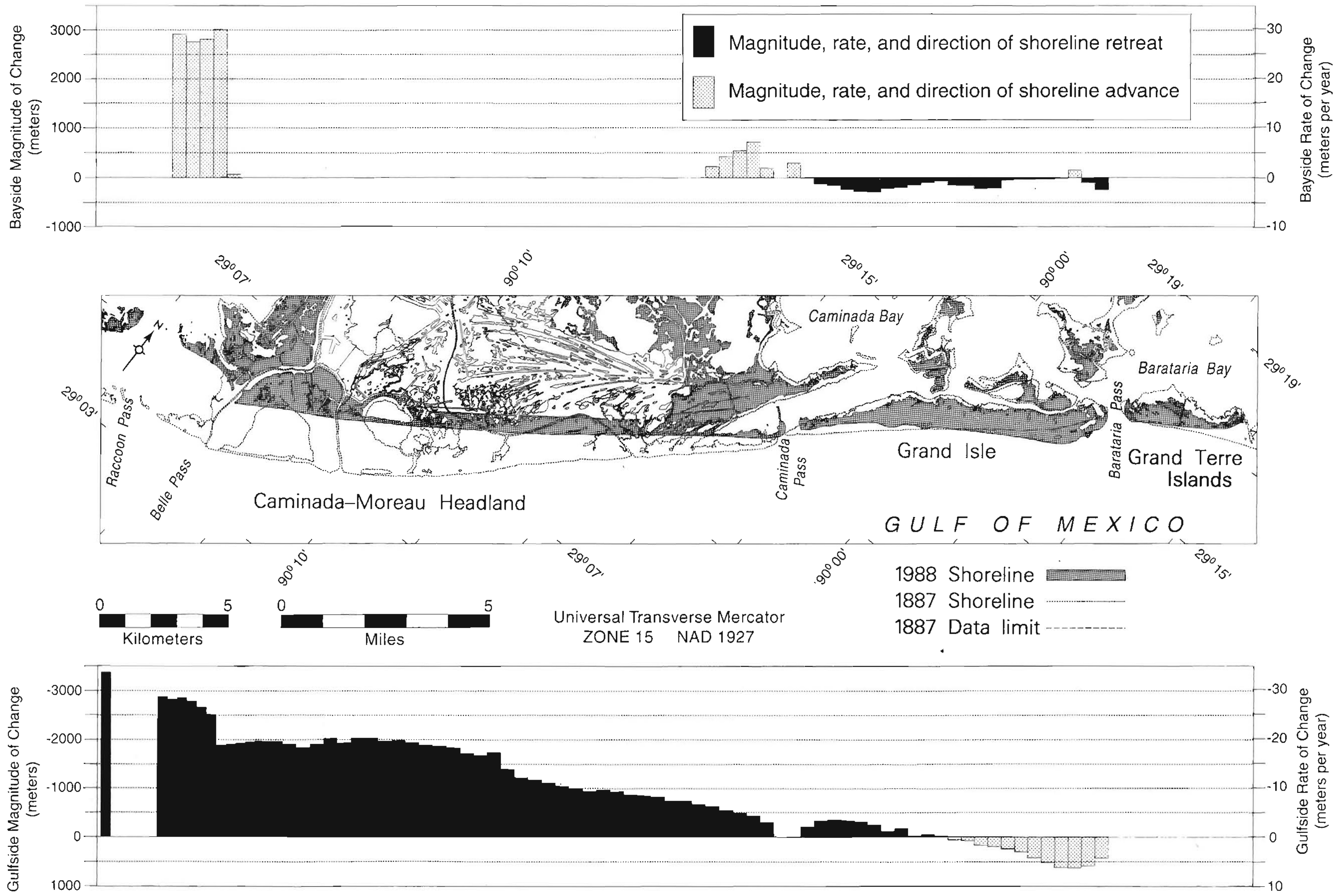

Figure 7. Shoreline changes of the Caminada-Moreau Headland/Grand Isle area along the eastern portion of the Bayou Lafourche barrier system between 1887 and 1988 (modified from McBride *et al.*, 1991).

Table 3. *Shoreline position, island width, and island area change for the Timbalier Islands barrier shoreline. 1 hectare (ha) = 2.47 acres; 1 meter (m) = 3.28 feet.*

					Shoreline Position Change			
Date	Island Area (ha)	Area Change Rate (ha/yr)	Projected Date of Disappearance (year)	Island Width (m)	Gulf Magnitude (m)	Gulf Rate (m/yr)	Bay Magnitude (m)	Bay Rate (m/yr)
				Timbalier Island				
1887	1485			1341				
1934	1071	−8.8	2056	946	−65	−1.4	−136	−2.9
1934	1071			946				
1956	915	−7.1	2085	916	−25	−1.2	−46	−2.1
1956	915			916				
1978	999	+3.8	—	850	−69	−3.1	−29	−1.3
1978	999			850				
1988	542	−45.7	2000	415	−70	−7.0	−141	−14.1
1887	1485			1341				
1988	542	−9.3	2046	415	−240	−2.4	−501	−5.0
				East Timbalier Island				
1887	193			283				
1934	93	−2.1	1978	248	−2087	−44.4	+2117	+45.1
1934	93			248				
1956	413	+14.5	—	506	−121	−5.5	+403	+18.3
1956	413			506				
1978	495	+3.7	—	547	−356	−16.2	+347	+15.8
1978	495			547				
1988	238	−25.7	1997	333	−212	−21.2	−12	−1.2
1887	193			283				
1988	238	+0.4	—	333	−2333	−23.1	+2426	+24.0
				Timbalier Islands Summary				
1887	1677			945				
1934	1164	−10.9	2041	756	−904	−16.3	+585	+12.4
1934	1164			756				
1956	1328	+7.5	—	702	−97	−3.8	+123	+5.6
1956	1328			702				
1978	1495	+7.6	—	681	−204	−9.6	+155	+7.1
1978	1495			681				
1988	780	−71.5	1999	377	−131	−14.0	−78	−7.8
1887	1677			945				
1988	780	−8.9	2076	377	−1606	−15.2	+1180	+11.7

land has been extremely rapid for the past 100 years. The average gulfside rate was −23.1 m/yr, while the bay shoreline migrated landward even faster at +24.0 m/yr (Table 3). Correspondingly, average island width increased 18% from 283 to 333 m but the island was more fragmented as a result of human activities (*e.g.*, canal dredging). East Timbalier Island also experienced fluctuations in area, increasing 23% between 1887 and 1988 from 193 to 238 ha. Increases in area, which offset recent decreases, occurred prior to extensive human interference in the early 1960s (MOSSA *et al.*, 1985); the island is now surrounded by rock-rubble revetments.

The Caminada-Moreau Headland extends 24 km between Raccoon Pass and Caminada Pass and has experienced the highest rates of shoreline erosion in Louisiana. The gulfside rate of change along the Caminada-Moreau Headland decreases progressively from west to east with rates ranging between −28.5 and −2.5 m/yr (Figure 7). Overall, the average retreat rate for the entire headland area was −13.3 m/yr between 1887 and 1988 (Table 4). Most of the sediment is transported laterally and offshore, and a smaller percentage is moved landward as washover.

Grand Isle is characterized by nearly equal amounts of shoreline retreat and advance. The average rate of gulfside change was −0.9 m/yr between 1887 and 1934, with stable to steadily increasing shoreline advance rates of 0.0 m/yr, +2.5 m/yr, and +5.2 m/yr for the periods 1934–56, 1956–78, and 1978–88, respectively (Table 4). These trends in shoreline movement represent average long-term conditions for the entire gulfside shoreline of Grand Isle. When investigated in more spatial detail, the gulf shoreline has experienced net retreat along its southwestern end (−2.6 m/yr) while remaining relatively stationary along its central portion (ranging from −0.5 to +0.6 m/yr), and accreting seaward (+3.4 m/yr) on its northeastern end (Figure 7). These trends show that Grand Isle's gulf shoreline is slowly rotating clockwise around a stable midpoint, a result of net longshore sediment transport from southwest to northeast. Over the years however, beach replenishment projects have contributed to the

Table 4. *Shoreline position, island width, and island area change for the Caminada-Moreau Headland and Grand Isle. 1 hectare (ha) = 2.47 acres; 1 meter (m) = 3.28 feet.*

					Shoreline Position Change			
Date	Island Area (ha)	Area Change Rate (ha/yr)	Projected Date of Disappearance (year)	Island Width (m)	Gulf Magnitude (m)	Gulf Rate (m/yr)	Bay Magnitude (m)	Bay Rate (m/yr)
				Caminada-Moreau Headland				
1887	—			—				
1934	—	—	—	—	−744	−15.8	+325	+6.9
1934	—			—				
1956	—	—	—	—	−253	−11.5	−6	−0.3
1956	—			—				
1978	—	—	—	—	−208	−9.5	+43	+1.9
1978	—			—				
1988	—	—	—	—	−136	−13.6	−18	−1.8
1887	—			—				
1988	—	—	—	—	−1341	−13.3	+413	+4.1
				Grand Isle				
1887	1059			882				
1934	950	−2.3	2347	841	−44	−0.9	−31	−0.6
1934	950			841				
1956	915	−1.6	2528	821	0	0.0	−15	−0.7
1956	915			821				
1978	936	+1.0	—	851	+56	+2.5	−27	−1.2
1978	936			851				
1988	960	+1.1	—	872	+52	+5.2	−32	−3.2
1887	1059			882				
1988	960	−1.0	2948	872	+89	+0.9	−104	−1.0

stability of Grand Isle (*e.g.,* COMBE and SOILEAU, 1987). When compared with other barrier islands of Louisiana, Grand Isle's gulfside shoreline shows the only stable to accreting trend (Figure 7). Other Louisiana barrier islands are characterized by high rates of erosion that all tend to be accelerating.

In contrast to gulfside shoreline movement, average bayside change rates along Grand Isle show slowly increasing erosion rates between 1887 and 1988, probably in response to the passage of cold fronts, tidal currents associated with Caminada Pass, relative sea level rise, and continued wetland loss to the north. The bay shoreline experienced greatest erosion rates to the west (up to −2.8 m/yr), slowly decreasing to the east with stable to prograding conditions at the eastern end of the island (up to +1.5 m/yr). The increased erosion rates to the west correspond to the increase in available fetch and tidal current velocities (Figure 7). Consequently, the bayside shoreline of Grand Isle currently has a larger net coastal erosion problem than the gulfside shoreline. Between 1887 and 1988, the bayside shoreline has retreated at an average rate of −1.0 m/yr, whereas the gulfside shoreline has shown net accretion (+0.9 m/yr; Table 4).

For the period 1887 to 1988, the average width of Grand Isle remained essentially stable, averaging about 850 m (Table 4). In terms of area change, Grand Isle experienced only a slight decrease from 1,059 to 960 ha between 1887 and 1988. Compared with other barrier islands along the Louisiana coast, island area for Grand Isle has remained stable.

Future Shoreline Position

Based on change rates at 164 shore-perpendicular transects (see MCBRIDE *et al.,* 1992, pg. 55), the 2018 and 2088 future shorelines were projected for the Timbalier Islands (Figures 8 and 9). Over the next 30 years, Timbalier Island will continue to migrate rapidly in a lateral direction at about 80 m/yr but will undergo island narrowing and shortening (Figure 8). Timbalier Island is projected to disappear around the year 2050 and therefore, is completely absent on the 100-year future shoreline (Figure 9). Within 30 years, East Timbalier Island is projected to develop two island breaches as it undergoes island narrowing. East Timbalier Island will most likely disappear within 100 years except for a small land fragment on the eastern end. Consequently, open gulf conditions will characterize Terrebonne and Timbalier Bays.

The 2018 and 2088 future shorelines for the Caminada-Moreau Headland/Grand Isle area were projected based on long-term change rates at 92 shore-perpendicular transects (see MCBRIDE *et al.,* 1992, pg. 65). Future trends along the headland show continued massive coastal erosion as a result of rapid retreat (Figures 10 and 11). Over the next 30 years, Grand Isle's southwestern end will continue to narrow as a result of gulfside and bayside erosion, whereas the northeastern end widens. Within 100 years, this narrowing trend will cause the southwestern end to disappear enabling Caminada Pass to widen significantly (Figure 11). Grand Isle has a long life expectancy and is not expected to disappear until

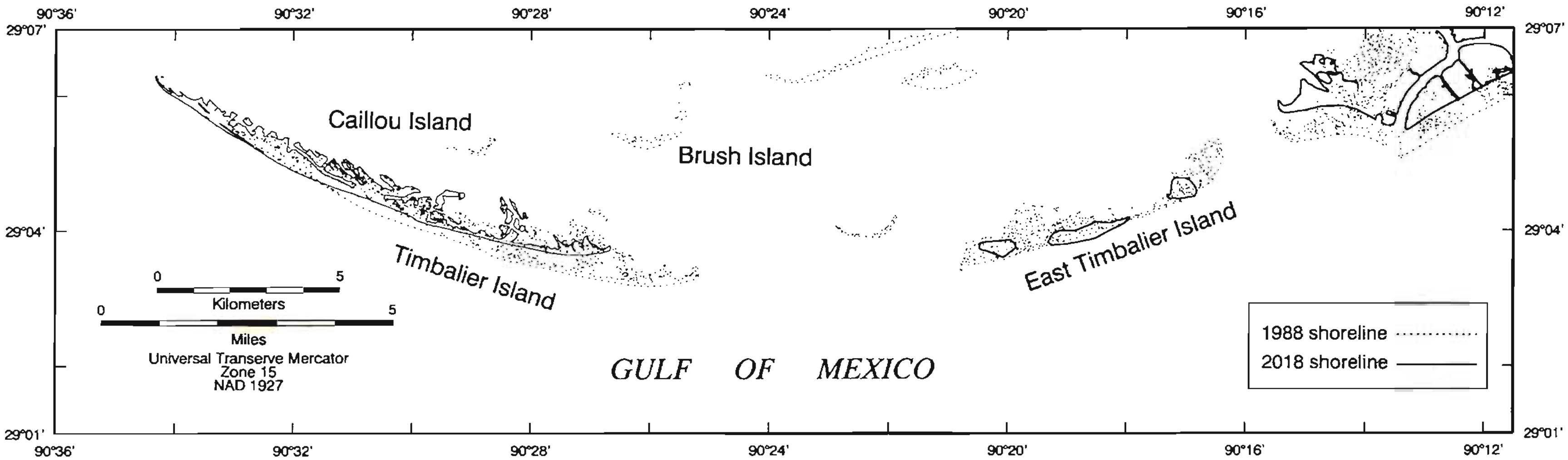

Figure 8. The Timbalier Islands barrier shoreline projected 30 years into the future (2018 AD) and superimposed on the 1988 shoreline (dotted).

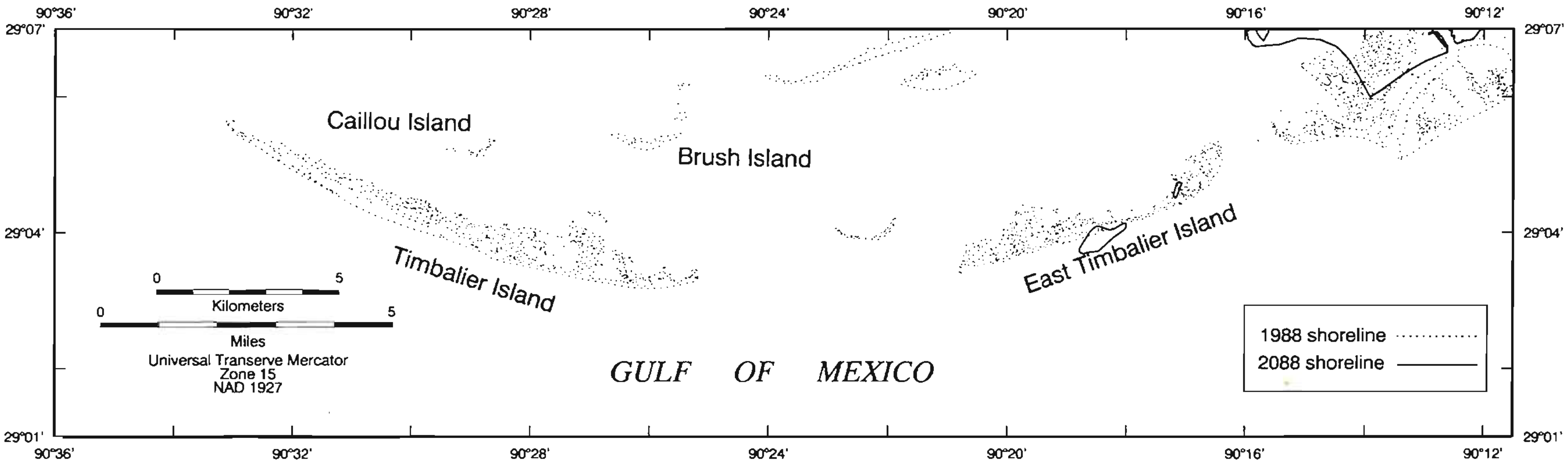

Figure 9. The Timbalier Islands barrier shoreline projected 100 years into the future (2088 AD) and superimposed on the 1988 shoreline (dotted).

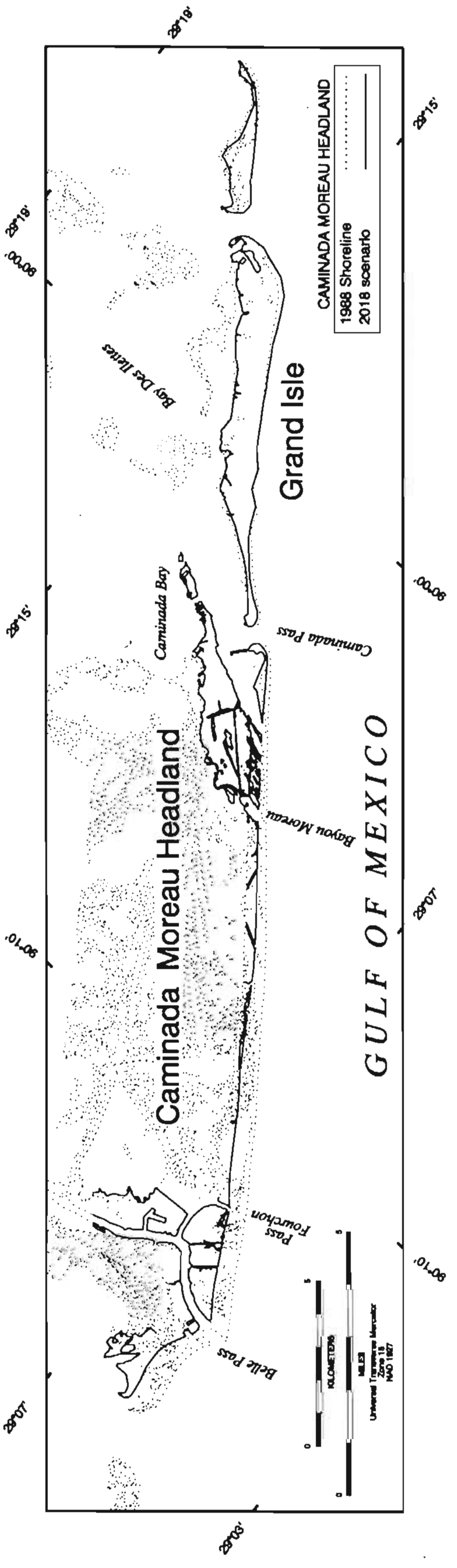

Figure 10. The Caminada-Moreau Headland/Grand Isle barrier shoreline projected 30 years into the future (2018 AD) and superimposed on the 1988 shoreline (dotted).

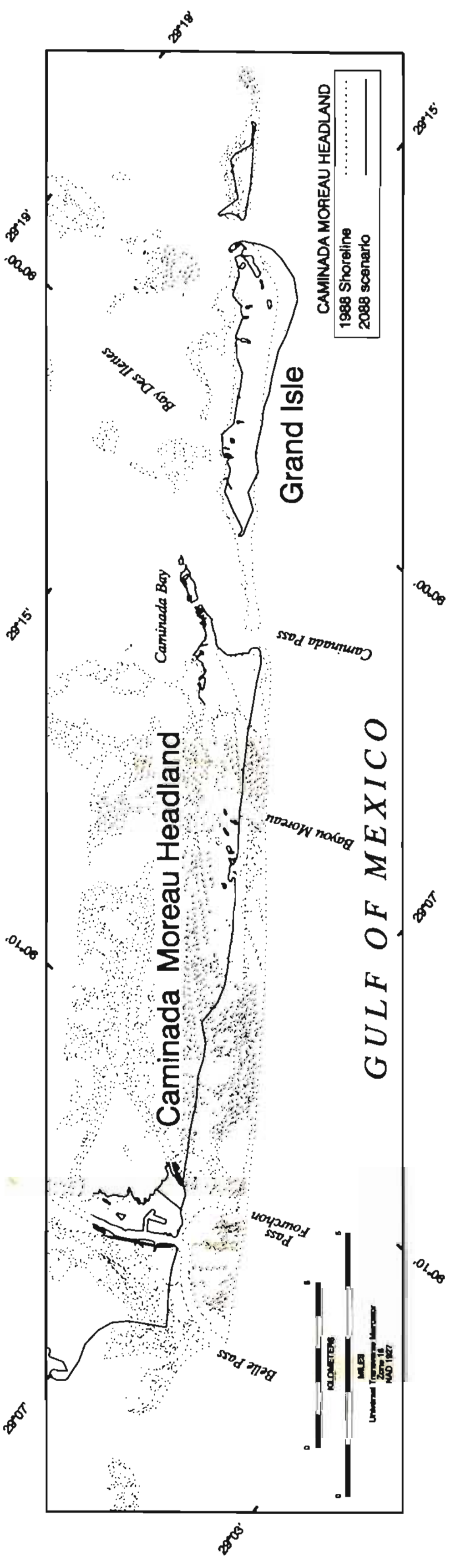

Figure 11. The Caminada-Moreau Headland/Grand Isle barrier shoreline projected 100 years into the future (2088 AD) and superimposed on the 1988 shoreline (dotted).

the year 2948 AD based on the area change extrapolation method (Table 4).

Plaquemines Barrier System

The Plaquemines shoreline is the youngest barrier system and extends 48 km from Grand Terre Islands to Sandy Point along the eastern flank of the Barataria Bight (Figure 12).

Historical Shoreline Change

Between 1884 and 1988, the average gulfside rate of change was −5.5 m/yr, while the bayside change rate was essentially stable at +0.4 m/yr (Table 5). Over the long-term, only three short segments along the Plaquemines gulf shoreline experienced shoreline advance; the western ends of Grand Terre and Shell Islands and the area east of Fontanelle Pass. The area east of Fontanelle Pass is on the updrift side of the Empire Jetties, which capture sediment from the longshore transport system. In contrast, Shell Island, which lies to the west of the jetties, experienced high shoreline retreat rates (−10.1 m/yr), culminating with an island breach (Coupe Bob) in 1979 by Hurricane Bob. In 1884, Grand Terre Island was a large continuous barrier island (Figure 12). Through time, the island experienced gulfside and bayside erosion, with contemporaneous inlet development breaking the island into three remnants by 1988. Between 1884 and 1988, the average gulfside and bayside erosion rates were −3.9 and −2.2 m/yr, respectively. The area of the Grand Terre Islands decreased 70% from 1,699 to 513 ha at a rate of −11.4 ha/yr (Table 5). For the same period of record, island width narrowed 42% from 909 to 530 m.

Future Shoreline Position

Based on long-term change rates at 149 shore-perpendicular transects (see McBride *et al.*, 1992, pg. 75), the 30-year future shoreline shows that high rates of erosion will continue to dominate the Cheniere Ronquille and Shell Island areas (Figure 13). However, by the year 2088, large parts of the Plaquemines shoreline are extrapolated to completely disappear (Figure 14). As a result, open gulf conditions will be present in most bays, such as southern Barataria Bay, Bay Joe Wise, Bastian Bay, Shell Island Bay, and Bay Coquette. The Grand Terre Islands are expected to disappear in the year 2033 AD based on area change extrapolation (Table 5).

Chandeleur Islands Barrier System

The Chandeleur Islands are the largest barrier system in Louisiana extending 72 km from Breton Island north to Hewes Point. Due to its size, the Chandeleur Islands system is divided into two sections: (1) south Chandeleur Islands (Figure 15), and (2) north Chandeleur Islands (Figure 16). The south Chandeleur Islands are comprised of Breton, Grand Gosier, and Curlew Islands, while to the north, the islands include Chandeleur, Freemason, New Harbor, and North.

Historical Shoreline Change

The southern Chandeleur Islands are fragmented into three groups of small ephemeral islands and shallow shoals separated by wide tidal inlets (Figure 15). The average rate of gulfside change for the south Chandeleur Islands between 1869 and 1922 was −11.3 m/yr (Table 6). This rate decreased twofold to −5.7 m/yr between 1922 and 1951. Between 1951 and 1978, the rate increased to −16.6 m/yr and increased further to −19.7 m/yr between 1978 and 1989. Along the bay shoreline, the average rate of change was +8.8 m/yr between 1869 and 1922, which decreased to +5.9 m/yr between 1922 and 1951. The rate increased to +9.8 and +19.8 m/yr for the periods 1951–78 and 1978–89, respectively. Overall, the average rate of gulfside change was −11.6 m/yr between 1869 and 1989, whereas the bayside rate was +10.7 m/yr, causing island width to narrow as the barriers retreated landward through overwash processes. Average barrier width decreased 40% from 384 to 232 m, and area was reduced 44% from 784 to 441 ha (Table 6).

The north Chandeleur Islands form a large, arcuate-shaped barrier island system, which shelters three groups of smaller, irregular-shaped islands that lie to the west (Figure 16). For Chandeleur Island, the average gulfside rate of change between 1855 and 1922 was −5.3 m/yr (Table 7). This increased slightly to −5.6 m/yr between 1922 and 1951 and increased nearly twofold to −10.0 m/yr between 1951 and 1978. This doubling of the gulfside rate of change between 1951 and 1978 includes the impact of Hurricane Camille, a category 5 hurricane that made landfall in 1969 at Pass Christian, MS, after crossing the Chandeleur Islands (U.S. Army Corps of Engineers, 1970; Neumann *et al.*, 1985). This large storm severely weakened the morphological structure of the Chandeleur Island system, making the arc more susceptible to subsequent storm events. For the period 1978 to 1989, the high average rate of gulfside movement was maintained and even increased to −12.2 m/yr. Contributing to this high rate of shoreline retreat were the direct and indirect impacts of Hurricanes Frederic (1979), Elena (1985), and Juan (1985).

The bay shoreline also was migrating landward. For the period between 1855 and 1922, the average rate of change was +2.2 m/yr (Table 7). This average rate increased over twofold to +5.4 m/yr between 1922 and 1951 but decreased to +3.3 m/yr for the period 1951 through 1978. Between 1978 and 1989, the average rate increased to +5.3 m/yr. For the past 134 years, the bay shoreline has migrated landward primarily in response to washover deposition associated with cold fronts and tropical cyclones. The average rate of change between 1855 and 1989 along the gulf shoreline was −6.5 m/yr, while the bayside rate for the same period was +2.9 m/yr. The gulf and bay shorelines are rapidly migrating landward, but the gulf shoreline is migrating twice as fast, resulting in island narrowing by 50% from 941 to 475 m (Table 7). Island area decreased 37% from 2,763 to 1,749 ha. Meanwhile, area changes decreased for North and Freemason Islands but remained stable for the New Harbor Islands (Table 8).

Future Shoreline Position

The 2018 and 2088 future shorelines were predicted for the south Chandeleur Islands (Figures 17 and 18) based on change rates at 120 shore-perpendicular transects (see

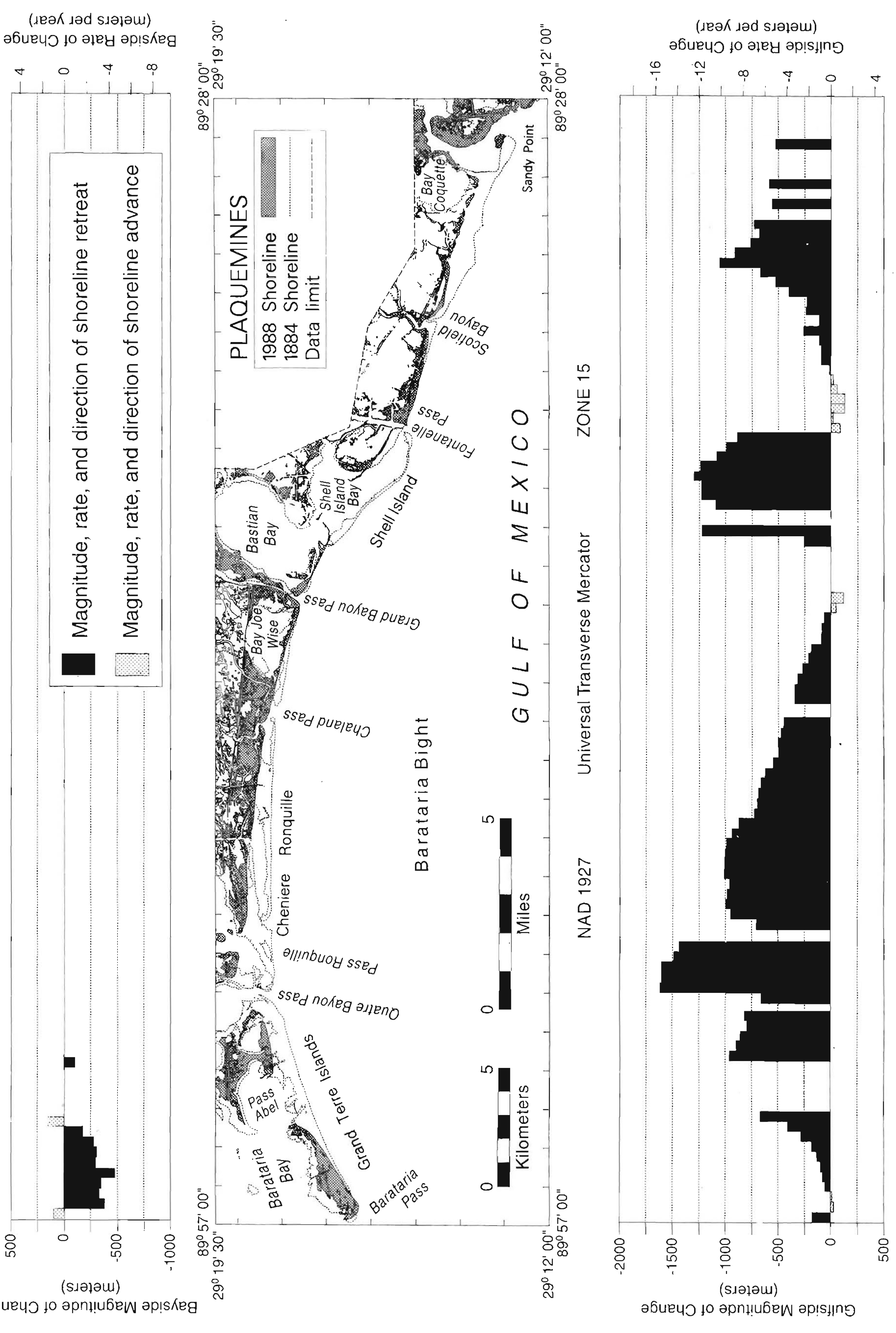

Figure 12. Shoreline changes of the Plaquemines barrier system between 1884 and 1988 (modified from McBride *et al.*, 1991).

Table 5. *Shoreline position, island width, and island area change for the Plaquemines barrier shoreline. 1 hectare (ha) = 2.47 acres; 1 meter (m) = 3.28 feet.*

					Shoreline Position Change			
Date	Island Area (ha)	Area Change Rate (ha/yr)	Projected Date of Disappearance (year)	Island Width (m)	Gulf Magnitude (m)	Gulf Rate (m/yr)	Bay Magnitude (m)	Bay Rate (m/yr)
Grand Terre Islands								
1884	1699			909				
1932	1058	−13.4	2011	701	−229	−4.8	−21	−0.4
1932	1058			701				
1956	901	−6.5	2095	670	−25	−1.0	−57	−2.4
1956	901			670				
1973	675	−13.3	2024	608	−122	−7.2	−35	−2.1
1973	675			608				
1988	513	−10.8	2036	530	−119	−7.9	−18	−1.2
1884	1699			909				
1988	513	−11.4	2033	530	−402	−3.9	−221	−2.2
Shell Island								
1884	127			136				
1932	175	+1.0	—	247	−184	−3.8	+353	+7.4
1932	175			247				
1956	178	+0.1	—	269	−143	−6.0	+75	+3.1
1956	178			269				
1973	144	−2.0	2045	207	−41	−2.4	−38	−2.2
1973	144			207				
1988	69	−5.0	2002	105	−363	−24.2	+309	+20.6
1884	127			136				
1988	69	−0.6	2103	105	−1055	−10.1	+822	+7.9
Plaquemines Shoreline								
1884	—			—				
1932	—	—	—	—	−265	−5.5	+103	+2.2
1932	—			—				
1956	—	—	—	—	−98	−4.1	+5	+0.2
1956	—			—				
1973	—	—	—	—	−54	−3.2	−40	−2.3
1973	—			—				
1988	—	—	—	—	−149	−9.9	+52	+3.5
1884	—			—				
1988	—	—	—	—	−571	−5.5	+43	+0.4

McBride *et al.*, 1992, pg. 83). Within the next 30 years, the South Chandeleur Islands are projected to undergo few drastic changes (Figure 17). Breton Island will most likely maintain its horseshoe shape, but will undergo continued landward migration along its central shoreline. Grand Gosier will narrow and contract in size as it continues to migrate rapidly in a landward direction at rates exceeding 20 m/yr. Curlew Island will also undergo landward migration, but island breaching could pose a problem. By the year 2088, most of Grand Gosier and Curlew Islands will probably be gone, whereas Breton Island most likely will be characterized by a central breach (Figure 18). Based on the area change extrapolation method, the projected dates of disappearance for Breton and Grand Gosier/Curlew Islands are the years 2106 and 2174 AD, respectively (Table 6). Along the south Chandeleur Islands, the two extrapolation methods are similar in the prediction of future conditions

Prediction of future shorelines along Chandeleur Island was based on long-term change rates at 172 shore-perpendicular transects (see McBride *et al.*, 1992, pg. 93). Over the next 30 years, Chandeleur Island is projected to undergo continued landward migration, but will be able to maintain itself, especially the robust north-central portion of the island (Figure 19). However, the southern end appears more vulnerable to island breaching and the backbarrier islands (Freemason, New Harbor, and North) will most likely disappear. By the year 2088, the structural continuity of the north and south ends of Chandeleur Island will become severely weakened and susceptible to inlet development (Figure 20). Although one of the healthiest barrier islands in Louisiana, Chandeleur Island will eventually have difficulty responding to relative sea level rise. If the historical rate of area decrease continues, the projected date of disappearance is the year 2219 AD (Table 7).

Summary of Shoreline Change

The distribution and rate of shoreline change along Louisiana's barrier island coast were classified (Figure 21). Gulf-

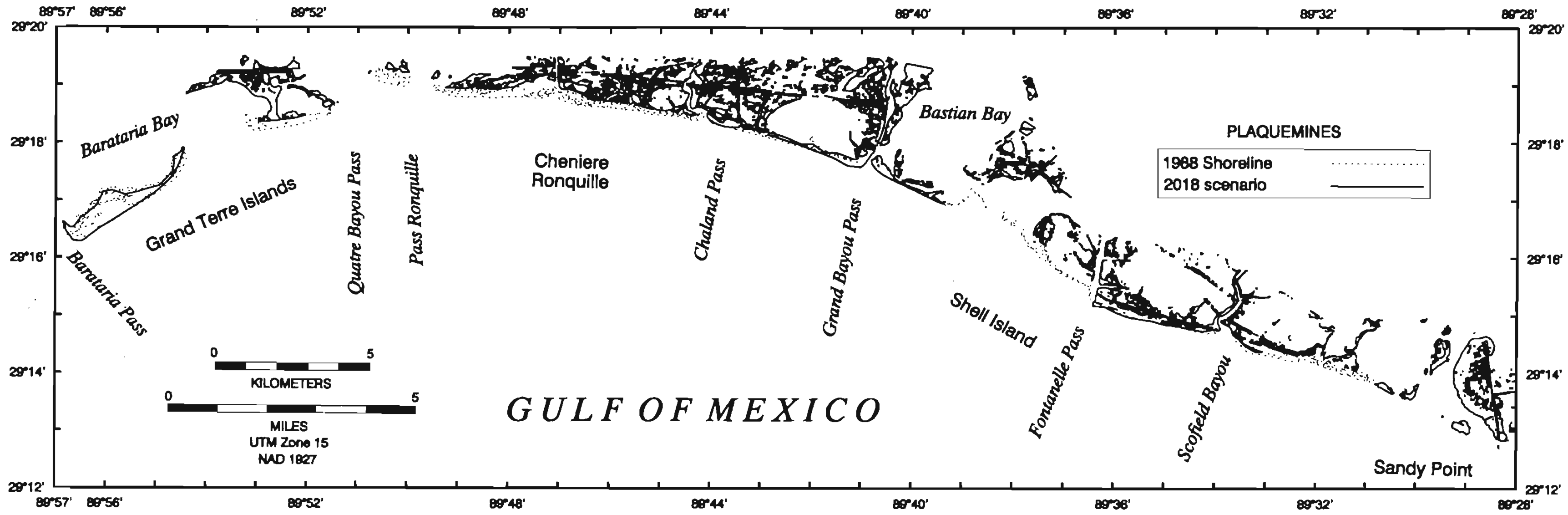

Figure 13. The Plaquemines barrier shoreline projected 30 years into the future (2018 AD) and superimposed on the 1988 shoreline (dotted).

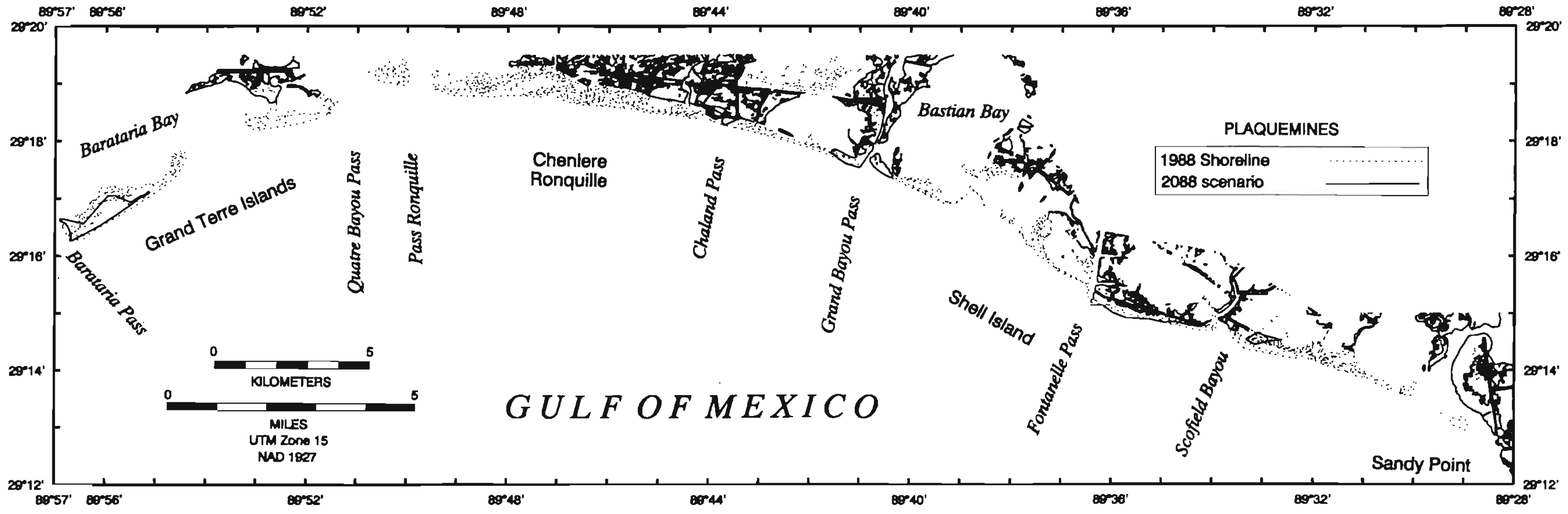

Figure 14. The Plaquemines barrier shoreline projected 100 years into the future (2088 AD) and superimposed on the 1988 shoreline (dotted).

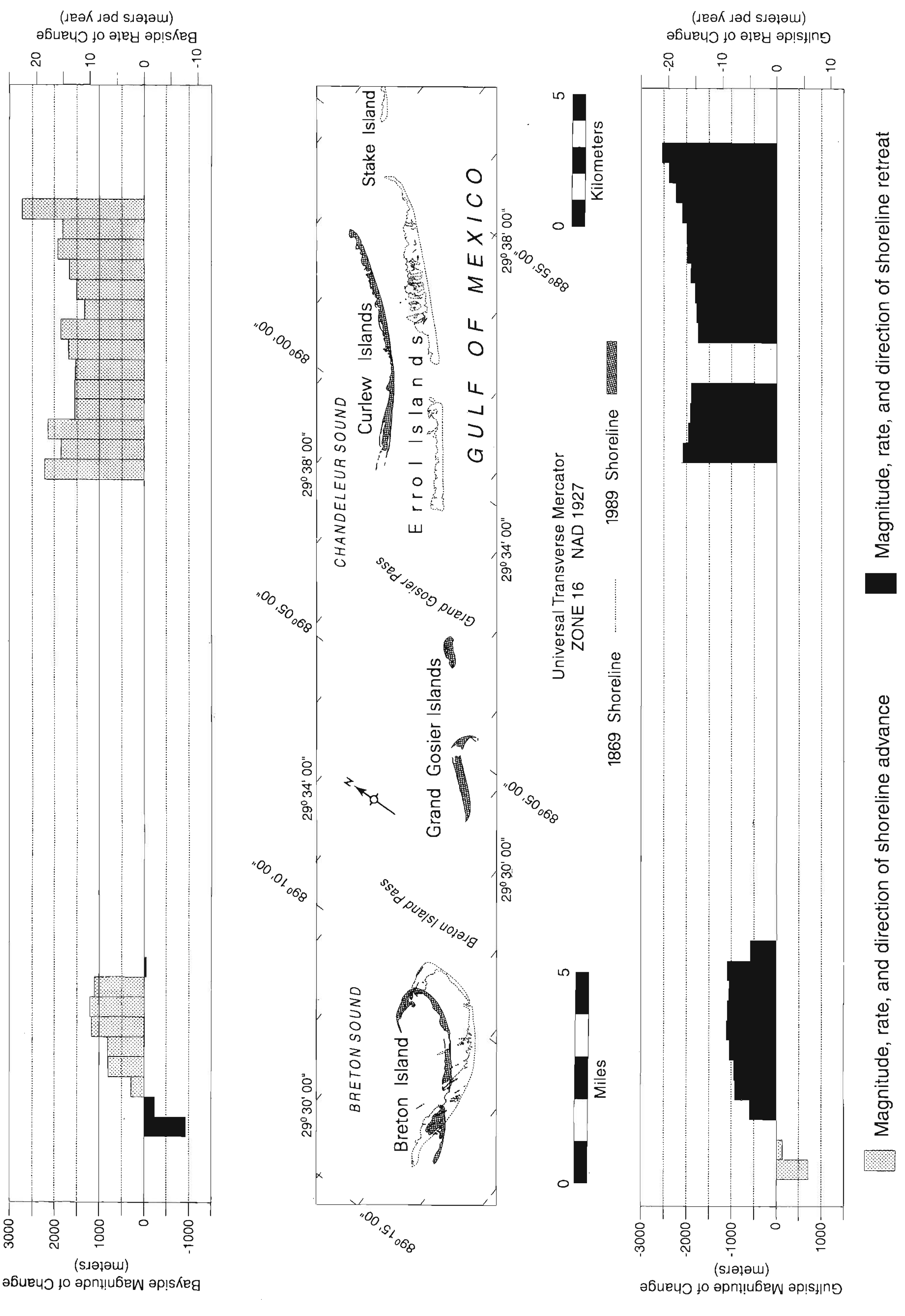

Figure 15. Shoreline changes of the south Chandeleur Islands between 1869 and 1989 (modified from McBride *et al.*, 1991).

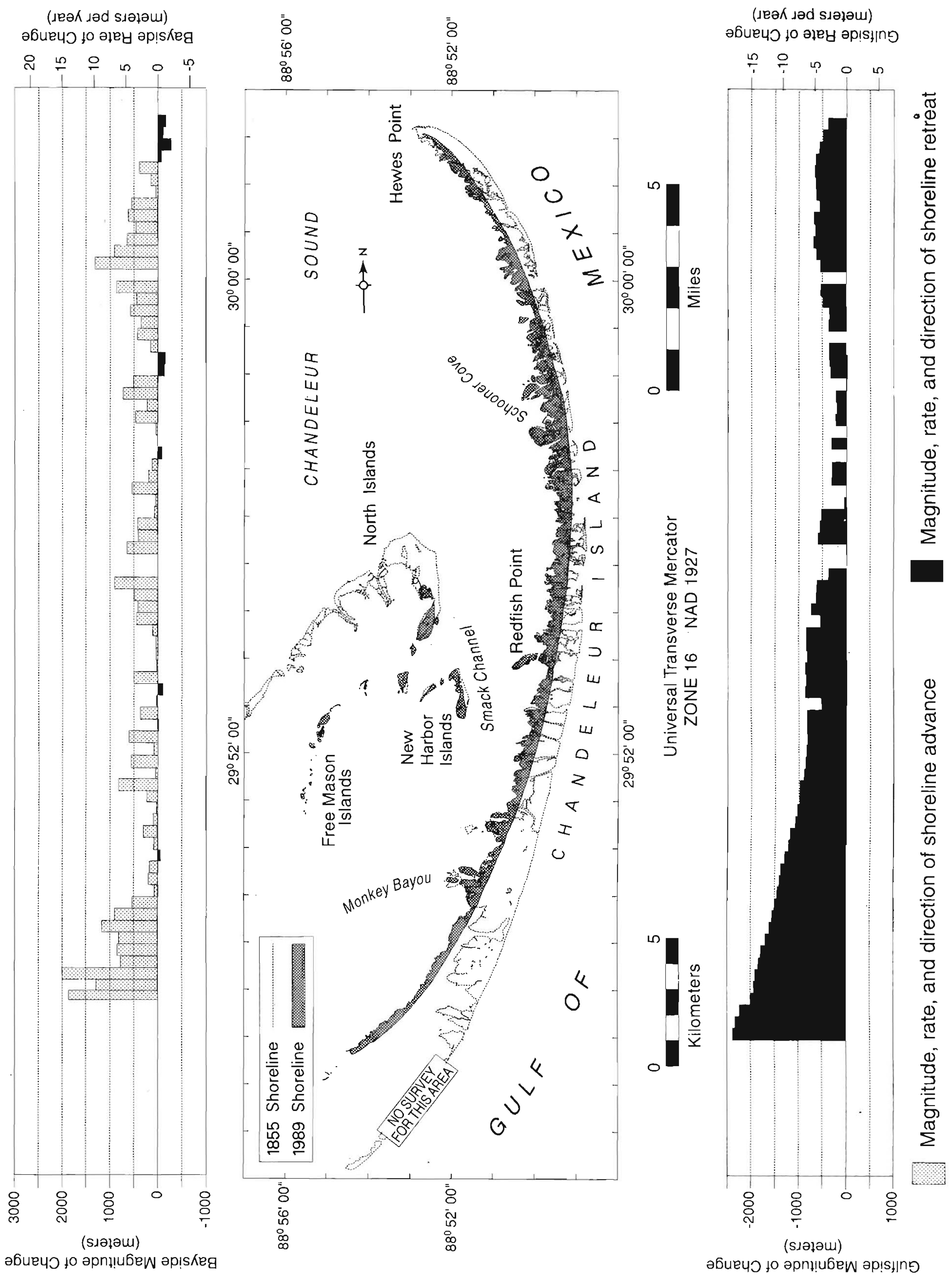

Figure 16. Shoreline changes of the north Chandeleur Islands between 1855 and 1989 (modified from McBride *et al.*, 1991).

Table 6. *Shoreline position, island width, and island area change for south Chandeleur Islands. 1 hectare (ha) = 2.47 acres; 1 meter (m) = 3.28 feet.*

Date	Island Area (ha)	Area Change Rate (ha/yr)	Projected Date of Disappearance (year)	Island Width (m)	Shoreline Position Change			
					Gulf Magnitude (m)	Gulf Rate (m/yr)	Bay Magnitude (m)	Bay Rate (m/yr)
				Breton Island				
1869	332			396				
1922	271	−1.2	2148	320	−381	−7.2	+302	+5.7
1922	271			320				
1951	291	+0.7	—	292	−118	−4.1	+75	+2.6
1951	291			292				
1978	141	−5.4	2004	268	−175	−6.3	−150	−5.4
1978	141			268				
1989	164	+2.2	—	199	−43	−4.1	−13	−1.2
1869	332			396				
1989	164	−1.4	2106	199	−688	−5.7	+464	+3.9
				Grand Gosier/Curlew Islands				
1869	453			423				
1922	29	−8.0	1926	90	−888	−16.8	+502	+9.5
1922	29			90				
1951	330	+10.4	—	276	−300	−10.4	+322	+11.2
1951	330			276				
1978	162	−6.0	2005	206	−553	−19.9	+404	+14.5
1978	162			206				
1989	277	+11.1	—	249	−248	−23.9	+279	+26.8
1869	453			423				
1989	277	−1.5	2174	249	−1947	−16.2	+1806	+15.0
				South Chandeleur Islands				
1869	784			384				
1922	300	−9.1	1955	227	−601	−11.3	+464	+8.8
1922	300			227				
1951	624	+11.3	—	286	−164	−5.7	+170	+5.9
1951	624			286				
1978	303	−11.5	2004	215	−463	−16.6	+272	+9.8
1978	303			215				
1989	441	+13.3	—	232	−205	−19.7	+206	+19.8
1869	784			384				
1989	441	−2.9	2141	232	−1393	−11.6	+1281	+10.7

Table 7. *Shoreline position, island width, and island area change for Chandeleur Island. 1 hectare (ha) = 2.47 acres; 1 meter (m) = 3.28 feet.*

Date	Island Area (ha)	Area Change Rate (ha/yr)	Projected Date of Disappearance (year)	Island Width (m)	Shoreline Position Change			
					Gulf Magnitude (m)	Gulf Rate (m/yr)	Bay Magnitude (m)	Bay Rate (m/yr)
1855	2763			941				
1922	2485	−4.1	2528	670	−359	−5.3	+149	+2.2
1922	2485			670				
1951	2588	+3.6	—	678	−161	−5.6	+155	+5.4
1951	2588			678				
1978	1796	−28.5	2041	506	−278	−10.0	+91	+3.3
1978	1796			506				
1989	1749	−4.5	2378	475	−127	−12.2	+55	+5.3
1855	2763			941				
1989	1749	−7.6	2219	475	−878	−6.5	+392	+2.9

Table 8. *Area change for North, New Harbor, and Freemason Islands. 1 hectare (ha) = 2.47 acres.*

Date	1855–1922	1922–1951	1951–1978	1978–1989	1855–1989
Island Area (ha)	589[1]	391	280	110	589
	391	280	110	109	109
	72[2]	94	70	63	72
	94	70	63	75	75
	218[3]	100	52	21	218
	100	52	21	12	12
Area Change Rate (ha/yr)	−2.9[1]	−3.9	−6.1	−0.1	−3.6
	+0.3[2]	−0.8	−0.3	+1.2	0.0
	−1.8[3]	−1.7	−1.1	−0.9	−1.5

[1] North, [2] New Harbor, and [3] Freemason Islands

side shoreline movement was divided into three broad categories based on direction and rate (m/yr) of change: shoreline advance, stability, and retreat. Figure 21 illustrates that the majority of Louisiana's barrier shoreline is suffering from high rates of retreat. East Timbalier Island experienced the highest average rate (−23.1 m/yr) of erosion, whereas Timbalier Island and the Plaquemines barrier system experienced the two lowest rates at −2.4 and −5.5 m/yr, respectively (Figure 22). Over the past century, only six small areas had stable or advancing shorelines (Figure 21) including the western portions of Timbalier, Grand Terre (Barataria Pass area), and Shell islands, the eastern portion of Grand Isle, the area east of Fontanelle Pass, and the southern portion of Breton Island. These stable or accretionary areas occur because most represent the terminus of longshore sediment transport at tidal entrances. The area east of Fontanelle Pass is related to the capture of longshore sediment transport by the Empire jetties; however, shorter-term data from the past 15 years indicate erosion east of the jetties.

The bayside barrier shoreline is characterized by areas undergoing accretion and erosion (Figure 23). Between the late 1800s and the 1980s, East Timbalier Island, the Caminada-Moreau Headland at Raccoon and Elmer spits (*i.e.*, west and east ends), south Chandeleur Islands, and north Chandeleur Island experienced effective washover deposition that caused the bayside shoreline to migrate landward at rates up to +24.0 m/yr. In contrast, bayside erosion has occurred along the Isles Dernieres, Timbalier Island, and Grand Isle at rates that ranged between −1.0 and −5.0 m/yr. Change in the Plaquemines bayside shoreline indicates near stability (+0.4 m/yr) because the erosional trend along the backside of the Grand Terre Islands (−2.2 m/yr) tends to cancel out the accretion occurring along the bayside shoreline of Shell Island (+7.6 m/yr).

MEGASCALE SHORELINE/SHELF RESPONSE

When shoreline position and seafloor elevations are monitored for a given time period, coastal change can be quantified and classified into a number of response types as a function of scale. McBride *et al.* (1995) identified eight geomorphic response-types for classifying barrier coasts: (1) *lateral movement,* (2) *advance,* (3) *dynamic equilibrium,* (4) *retreat,*

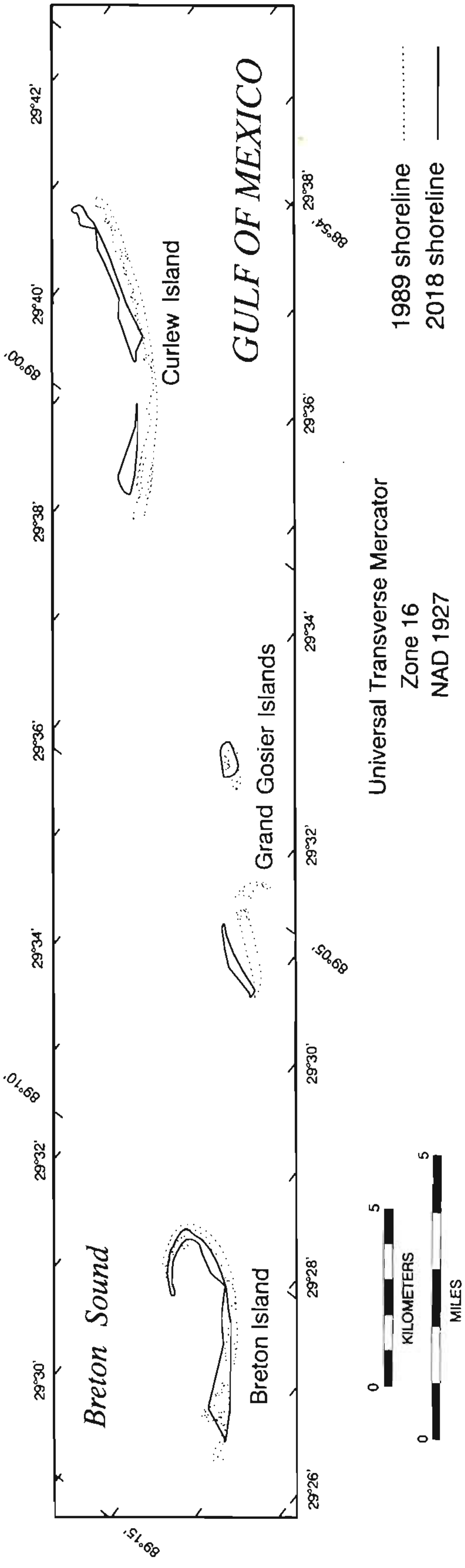

Figure 17. The South Chandeleur Islands barrier shoreline projected 30 years into the future (2018 AD) and superimposed on the 1988 shoreline (dotted).

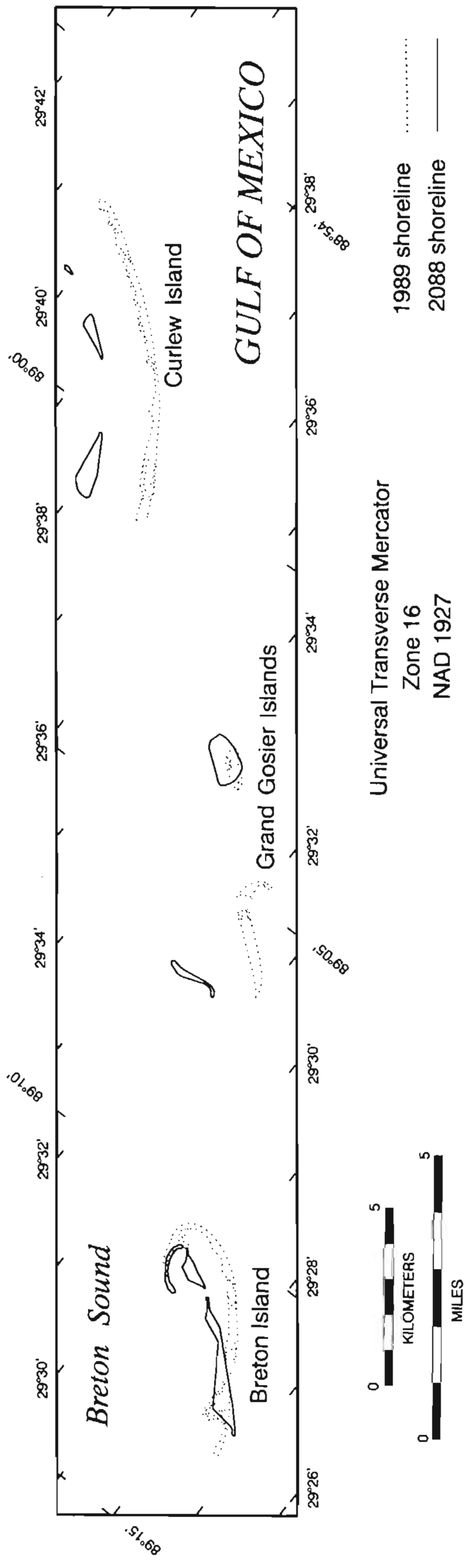

Figure 18. The South Chandeleur Islands barrier shoreline projected 100 years into the future (2088 AD) and superimposed on the 1988 shoreline (dotted).

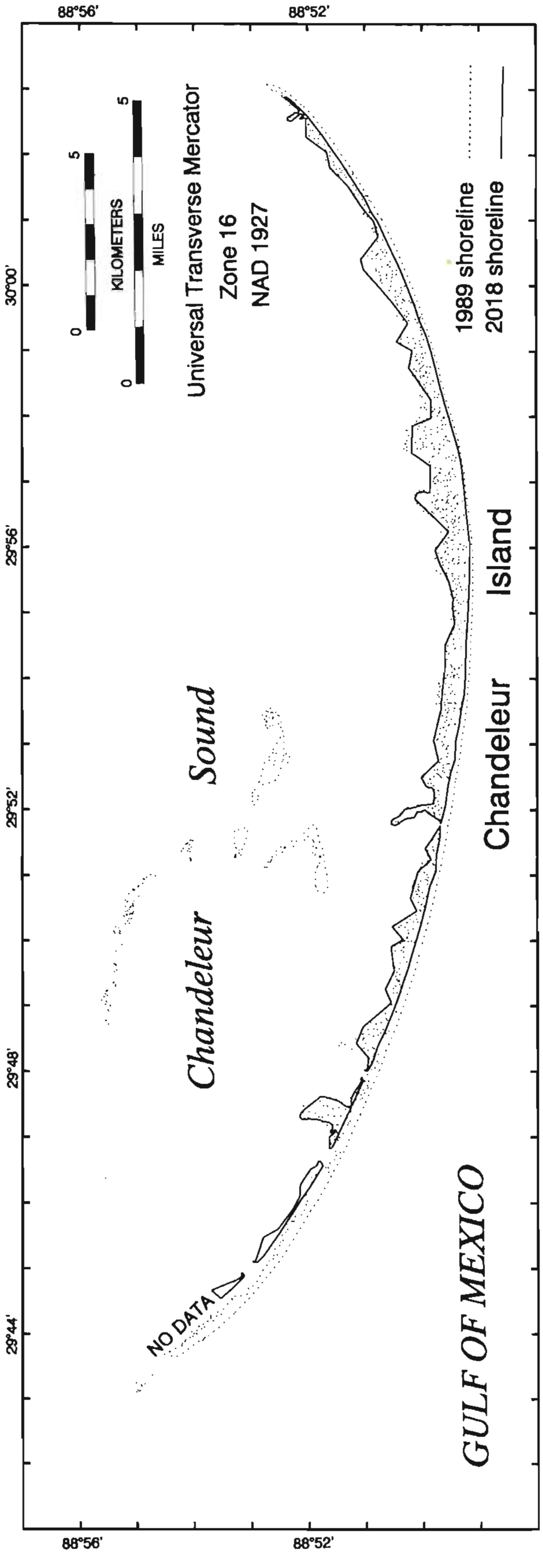

Figure 19. Chandeleur Island barrier shoreline projected 30 years into the future (2018 AD) and superimposed on the 1988 shoreline (dotted).

(5) *in-place narrowing,* (6) *landward rollover,* (7) *breakup,* and (8) *rotational instability.* Figure 24 shows the distribution of geomorphic response types along barrier shorelines of the Mississippi River delta plain. Jaffe *et al.* (1989) and List *et al.* (1991, 1994, this volume) discuss long-term bathymetric changes out to 20 m water depth for the barrier shoreline west of the Mississippi River mouth. Based on slight modification of their work, seafloor changes (volume) can be classified into three response types: (1) erosion, (2) dynamic equilibrium, and (3) accretion (Figure 25). Response types for shoreline and bathymetric change are used to classify the Louisiana coastal/shelf system at megascale (regional changes over large coastal reaches [time scale = decades to centuries, spatial scale = 10 to 100s of km]) to illustrate regional sediment transport patterns and coastal evolution.

Ship Shoal is a large, shore-parallel sand body located 15 km seaward of the Isles Dernieres. The shoal is slowly migrating landward through erosion on its seaward side (Figure 25; Zone 1, 62 × 10^6m^3) and accretion on its landward side (Zone 2, 43 × 10^6 m^3). To the north, the Isles Dernieres barrier system is experiencing *breakup* (Figure 24), which develops as an island narrows (gulfside and bayside erosion) and becomes more susceptible to island breaching during storms (McBride *et al.,* 1995). Therefore, instead of maintaining subaerial continuity, the island starts to break up and deteriorate as inlets continue to form and widen. The shoreface seaward of the Isles Dernieres is responding to rapid shoreline retreat and island breaching by undergoing net erosion to a depth of 3–5 m (Zone 3, 50 × 10^6 m^3). Although the majority of the bayside shoreline is migrating seaward, seafloor response is varied as a function of temporal and spatial variations in island breaching. A zone of seafloor erosion occurs to north of Trinity Island (Figure 25, Zone 3), but a fairly large zone of seafloor accretion is found to the north of Raccoon and Whiskey Islands (Zone 4) encompassing a volume of 12 × 10^6 m^3. Zone 4 probably is related to the lateral migration and filling of tidal inlets and/or subaqueous washover deposition. Total depositional volume on the shoreface seaward of the Isles Dernieres (18 × 10^6 m^3) is about 30% of the erosional volume (−55 × 10^6 m^3) for the Isles Dernieres, which is consistent with trends for the entire study area.

To the east, Timbalier Island is characterized by rapid *lateral movement* to the west-northwest as a result of updrift erosion and downdrift spit accretion (Figure 24). Seafloor response illustrates similar trends subaqueously (Figure 25, Zone 7 and western portion of Zone 9). In contrast, East Timbalier Island has migrated rapidly landward (up to 24 m/yr) and is classified as *landward rollover.* The Bayou Lafourche headland (also known as the Caminada-Moreau headland) is also retreating rapidly with rates up to 33 m/yr. Concurrently, the shoreface seaward of East Timbalier Island and the Bayou Lafourche headland has undergone substantial erosion with over 6 m of vertical erosion occurring on the shoreface, resulting in an eroded volume of 477 × 10^6 m^3 (Zone 9).

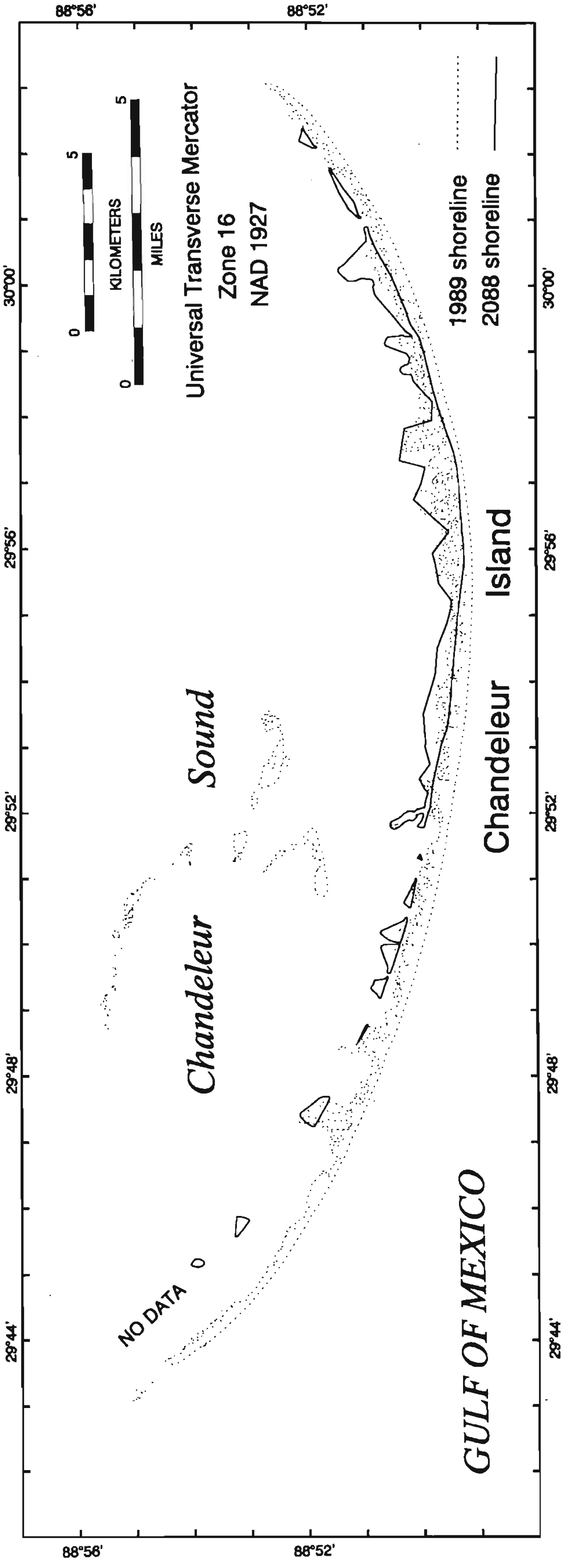

Figure 20. Chandeleur Island barrier shoreline projected 100 years into the future (2088 AD) and superimposed on the 1988 shoreline (dotted).

→

Figure 21. Classification of shoreline change rates along barrier island systems of the Mississippi River delta (from McBride *et al.,* 1992).

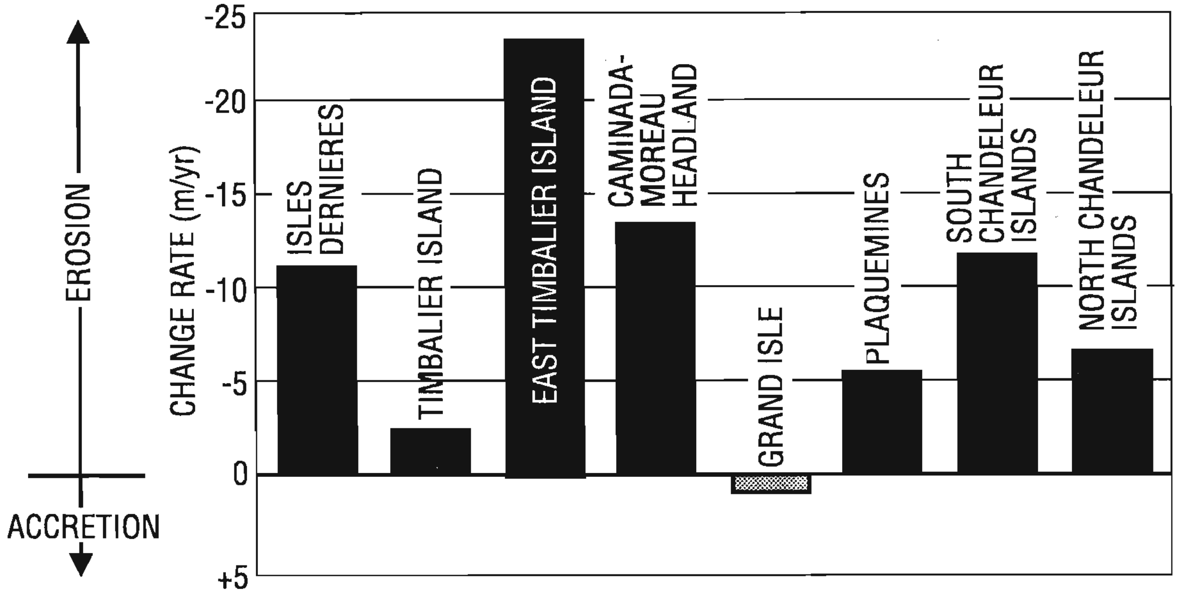

Figure 22. Long-term rates of change along gulfside barrier shorelines of Louisiana between 1855 and 1989.

The patterns of accretion flanking this extensive zone of erosion suggest several pathways of sand transport. Washover deposition and landward transport of sediment through inlets has resulted in flood-tidal delta deposition (Figure 25, Zone 8, 24 × 10^6 m^3). Longshore transport in the littoral zone has caused the westward migration of Timbalier Island, as well as infilling (Zone 7, 34 × 10^6 m^3) and westward scour (Zone 6, 15 × 10^6) of Cat Island Pass.

A more substantial depositional feature to the west of the Bayou Lafourche headland has originated through longshore transport onto the shoreface (Figure 25, Zone 5, 60 × 10^6 m^3). JAFFE *et al.* (1989) describe this feature in detail and relate it to the process of massive sand bypassing for the double inlet system at Cat Island and Wine Island Passes. The transport pathway for this sand shoal is delineated by a large depositional lobe that extends to the eastern Isles Dernieres and is possibly replenishing East Island, thereby decreasing the shoreline retreat rate.

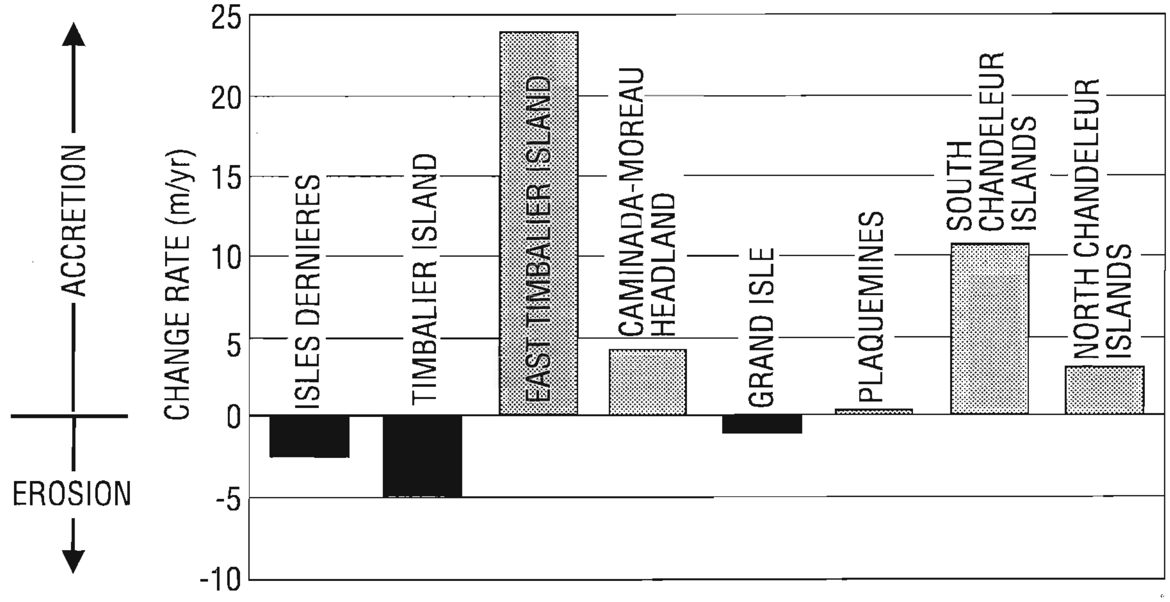

Figure 23. Long-term rates of change along bayside barrier shorelines of Louisiana between 1855 and 1989.

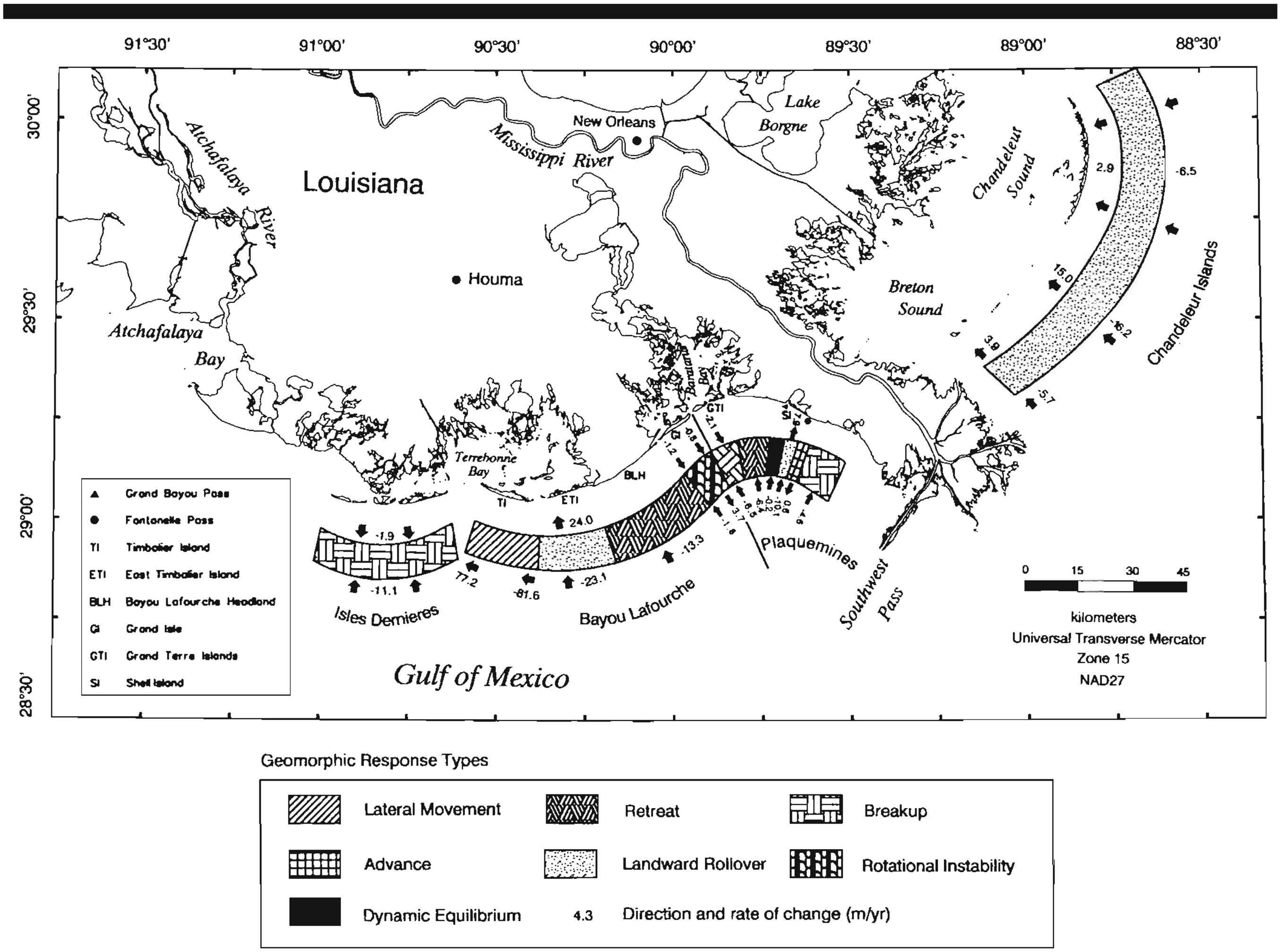

Figure 24. Megascale geomorphic response-types as well as rate and direction of change along the barrier shoreline of the Mississippi River delta based on shoreline position data between 1855 and 1989 (from McBride and Byrnes, 1995).

To the east of the Bayou Lafourche headland, a major area of deposition occurs seaward of the central Barataria Bight (Figure 25, Zone 10, 112 × 10^6 m^3). This area is bracketed by the zone of extreme shoreface erosion at the Bayou Lafourche headland (Zone 9) and a similar zone of erosion to the east along most of the Plaquemines barrier shoreline (Zone 11, 131 × 10^6 m^3). The depositional zone appears to be partially to completely composed of coalesced ebb-tidal delta deposits of Caminada Pass, Barataria Pass, Pass Abel, Quatre Bayou Pass, and Pass Ronquille. Sediments that comprise this large depocenter probably were derived from: (1) adjacent zones of shoreface erosion (Zones 9 and 11), (2) inlet deepening at Caminada Pass, Barataria Pass, and Quatre Bayou Pass, (3) erosion and break up of Grand Terre Island, (4) inlet development and deepening at Passes Abel and Ronquille, and (5) erosion of marsh sediments in Barataria Bay.

Shoreline response adjacent to Zones 10 and 11 are varied. Grand Isle has experienced retreat on its southwestern end while remaining relatively stationary along its central portion and advancing on the northeastern end. Consequently, Grand Isle is classified as clockwise *rotational instability*. *Breakup* is occurring along the Grand Terre barrier islands that front the Barataria Bay estuary and along the eastern 9.5 km of the Plaquemines barrier shoreline (Figures 12 and 24). Both of these areas are rapidly deteriorating and are characterized by gulfside erosion rates of >4.5 m/yr, bayside erosion rates of >2 m/yr, interior wetland loss, widening of existing inlets, and storm-generated cutting of new inlets. Although the Grand Terre Islands are deteriorating rapidly, the largest zone of seafloor accretion is occurring just offshore (Zone 10). One of the few areas of long-term *advance* (0.6 m/yr) along Louisiana's barrier island shoreline is found east (updrift) of the Empire jetties at Fontanelle Pass. The updrift jetty traps sand because longshore sediment transport moves in a west/northwest direction. This zone of *advance* prograded seaward at an average rate of 0.6 m/yr. As such, the barrier island downdrift (Shell Island) of the Empire Jetties receives an inadequate sediment supply causing rapid *landward rollover*, narrowing, and breaches from hurricanes (*e.g.*, Hurricane Bob in 1979 and Hurricane Juan in 1985). The juxta-

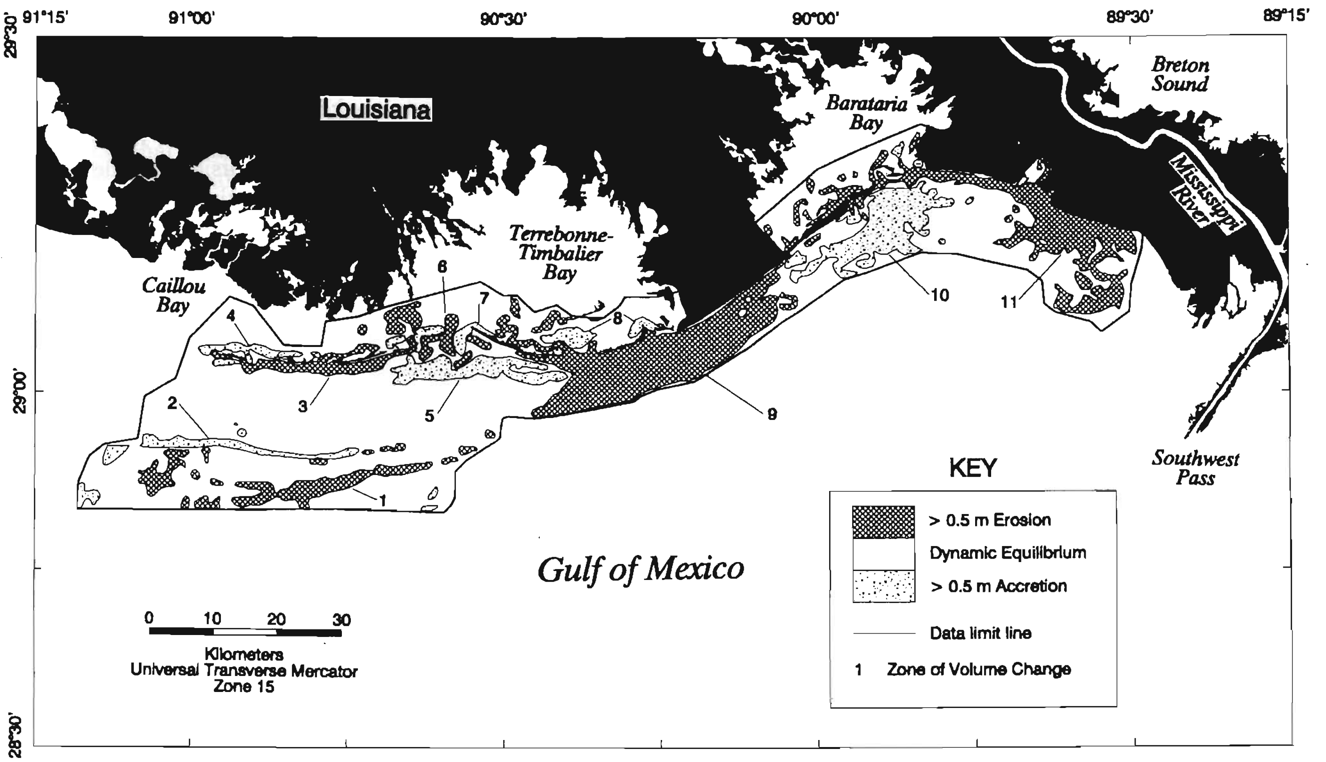

Figure 25. Megascale seafloor changes based on hydrographic data between the 1930s and 1980s (modified from List *et al.*, 1991; 1994).

position of these two geomorphic-response types produces a large downdrift coastal offset (Figures 12 and 24).

Along the central portion of the Plaquemines shoreline, a zone of *dynamic equilibrium* characterizes the Grand Bayou Pass area. Most inlet areas tend to depict erratic shoreline behavior but over the past 104 years, Grand Bayou Pass and adjacent shorelines have remained relatively stationary (−0.2 m/yr). Further west, a 13-km-section of coastline is dominated by landward movement and classified as *retreat* (Figure 24). This section of coast is a deltaic headland associated with one of the abandoned Plaquemines delta lobes.

MANAGEMENT ISSUES AND RESTORATION STRATEGIES

Historical change and future prediction of barrier shoreline evolution along the Louisiana deltaic plain is complex and challenging when considering regional coastal management/restoration strategies. Geomorphic response is dominated by *landward rollover, retreat,* and *breakup* as a consequence of high rates of relative sea level rise, inadequate sediment supply, and storm impacts. As a result, the outer barrier shoreline is rapidly migrating landward, narrowing, and deteriorating. However, the present problems of barrier island erosion and wetland loss are not atypical for the Louisiana deltaic plain.

Although recent human activities have exacerbated the erosional problem (*e.g.,* oil and gas industry, dredge canals, dams and levees along the Mississippi River), the Mississippi River delta plain has built and destroyed itself numerous times over the past 18,000 years in response to a rising eustatic sea level of approximately 120 m. Known as the *delta cycle,* delta lobe evolution first goes through a *constructional phase,* then a *destructional phase* as a result of the delta switching process (see ROBERTS, this volume). Currently, the Louisiana deltaic plain is primarily characterized by *destructional phase* deltas, except portions of the modern bird's foot and Atchafalaya deltas. Therefore, the only way to reverse the present regional destruction of Louisiana barrier islands and interior wetlands is to recreate what created the islands and wetlands in the first place—delta building (*i.e.,* progradation) during the *constructional phase.*

Deltas prograde because sediment supply overwhelms all other physical factors such as wave energy and relative sea level rise. In the Louisiana delta plain, swamps, wetlands, and interdistributary bays are a consequence of delta progradation, and occur in low-energy areas behind the leading edge of the delta. The leading edge is characterized by an active delta and/or a deltaic headland with flanking barrier islands that attenuate wave energy. The combination of good sediment supply, wave energy attenuation, and correct salinity conditions enabled this deltaic-estuarine-barrier system to flourish in the past. These factors must be duplicated on a regional scale if present-day coastal erosion and landloss trends are to be reversed. Therefore, a regional, dual restoration approach is proposed that stresses the re-introduction of massive amounts of sediment throughout the entire deltaic-estuarine-barrier system: (1) numerous fresh-water/sediment diversions and (2) massive barrier shoreline replenishment. The shoreline replenishment component would reverse the current deterioration of Louisiana's barrier shoreline and would provide the necessary protection for wetland creation behind the outer shoreline through freshwater/sediment diversions. The following discussion will only focus on massive barrier shoreline replenishment due to the scope of this thematic issue.

Two important factors impacting Louisiana deltaic barriers include (1) an inadequate sediment supply and (2) a lack of stable subaerial backbarrier platforms upon which barrier islands can migrate landward. In natural healthy settings, barrier islands can readily respond to relative sea level rise if an adequate sediment supply and an appropriate backbarrier platform exist. Consequently, coastal restoration activities should include barrier systems that are expected to migrate landward. The concept of a stationary shoreline is not feasible in the deltaic plain in light of high relative sea level rise rates and low sediment supply. Under these conditions, massive sand replenishment and backbarrier platform enhancement will be needed to offset degradational impacts for moderate- to long-term (30–50 years) restoration efforts. Stationary hard structures such as gulfside segmented breakwaters, seawalls, and revetments cannot address the natural process of relative sea level rise, thus requiring more stringent design criteria that likely will lead to a high cost/benefit ratio. Moreover, the life expectancy of hard structures will be short as the shoreline continues to migrate landward and subside.

Along Louisiana's barrier shoreline, the primary sources of high-quality sand in sufficient quantities are located alongshore at tidal inlets and offshore. Three particular sand resource targets are proposed for borrowing sand because they are active sediment sinks and therefore, constantly receive sediment input (*i.e.,* renewable resource). As shown in Figure 25, these sand resource targets are 1) the leeward side of Ship Shoal (Zone 2), 2) the Cat Island Pass area (Zones 5 and 7), and 3) the ebb-tidal deltas of Barataria Bight and seaward (Zone 10). When compared with the native beach sediments, Ship Shoal represents the best sand resource target, followed by Cat Island Pass, and then Barataria Bight (see PENLAND *et al.,* 1990; BYRNES and GROAT, 1991). Sands associated with Ship Shoal and Cat Island Pass would be best for beach building and dune construction because they are characterized by low overfill ratios. On the other hand, muddier sediments associated with Barataria Bight (Zone 10) are more appropriate for backbarrier platform and wetland creation. Whenever possible, sand resource targets located landward of the barrier shoreline should be avoided because no new sediment is added to the barrier-estuarine system, and the backbarrier platform needs to be shallower not deeper for barrier rollover (*i.e.,* robbing Peter to pay Paul).

CONCLUSIONS

Louisiana's barrier island systems have undergone landward migration, bayside erosion, area loss, and island narrowing as a result of complex interactions among subsidence, eustatic sea level rise, wave processes, storm impacts (cold fronts and tropical cyclones), inadequate sediment supply, and intense human disturbance (levees; oil, gas, and sulphur extraction activities; access canals; seawalls; jetties). Consequently, the structural continuity of Louisiana's barrier shoreline continues to weaken as the barrier islands continue to narrow, fragment, and finally disappear. In the past 100 years, total barrier island area in Louisiana has declined 55% at a rate of 63 ha/yr. This deteriorating trend will continue if no action is employed to artificially restore and strengthen the fragile barrier island coastline.

The highest average gulfside rates of landward migration occurred along the Bayou Lafourche barrier system at East Timbalier Island and the Caminada-Moreau Headland. In general, gulf shorelines in Louisiana show rapid rates of shoreline retreat. Only the gulfside shoreline of Grand Isle, which has received beach replenishment through the years, shows a net seaward advance. As far as bayside barrier shoreline movement, East Timbalier Island also had the highest average rate of landward movement. Overall, bayside shorelines tend to show either rapid landward movement or erosion. Bayside erosion is a problem along the Isles Dernieres, Timbalier Island, Grand Isle, and Grand Terre Islands.

Over the long-term, primary factors driving bayside erosion along Louisiana barrier islands are the combined effects of: (1) high rates of relative sea level rise (~1 cm/yr), (2) an inadequate sediment supply (*i.e.,* ineffective washover deposition), (3) wave erosion during post-cold front passage, (4) wetland and island land loss to the north of the outer barrier shoreline, which allows the bayside barrier shoreline to be more exposed to incident processes, and (5) tidal currents. This is the first time that a study has documented the existence, magnitude, areal extent, and importance of bayside erosion along Louisiana barrier islands. Bayside erosion provides an important piece to the geologic puzzle in understanding barrier island evolution in Louisiana and possibly other deltaic environments (modern and ancient) that are characterized by high relative sea level rise rates.

Seven geomorphic response-types are found along barrier shorelines of the Mississippi River deltaic plain. The four most common types are *landward rollover, breakup, retreat,* and *lateral movement.* Barrier shorelines experiencing *breakup* (Isles Dernieres, Grand Terre Islands, and eastern Plaquemines shoreline) are expected to be converted to open water within the next 25 years. Consequently, they are the most critical areas of coastal land loss along Louisiana's barrier shoreline and thus require immediate coastal restoration.

Megascale strategies for managing coastal response should rely on shoreline and bathymetric change information for planning and implementing restoration efforts because it reflects the combined effect of all processes influencing regional, long-term trends. In addition, these data provide a mechanism for estimating the coastal sediment budget, the most influential factor affecting coastal change. Large coastal restoration programs can utilize this megascale change information in the following manner: (1) identify areas of greatest need for protection and restoration, (2) help determine type of coastal protection needed, and (3) evaluate project performance (hard or soft structures) by comparing post-project rates of shoreline change with long-term historical trends (*i.e.*, baseline control data set).

ACKNOWLEDGEMENTS

This research was funded in part by the U.S. Geological Survey's National Coastal Geology Program, the Louisiana Department of Natural Resources—Coastal Restoration Division, and T. Baker Smith and Son, Inc. The authors gratefully acknowledge the technical support of Matteson Hiland, Rhonda Brewer, Chris Copley, Brian Savell, and Karen Westphal. Ms. Kui Xu, Liyun Ye, Lisa Duvic, and Jerry Moreau of the LSU Coastal Studies Institute are thanked for their cartographic assistance. The authors thank Matthew Taylor and three anonymous reviewers for critically reviewing earlier drafts of the manuscript.

LITERATURE CITED

ANDERS, F.J. and BYRNES, M.R., 1991. Accuracy of shoreline change rates as determined from maps and aerial photographs. *Shore and Beach*, January, pp. 17-26.

BRITSCH, D.L. and DUNBAR, J.B., 1996. *Land loss in coastal Louisiana: Terrebonne Bay, LA.* Technical Report GL-90-2, Map 6 of 7 (1:125,000 scale), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS and U.S. Army Engineer District, New Orleans, Louisiana.

BYRNES, M.R. and GROAT, C.G., 1991. *Characterization of the development potential of Ship Shoal sand for beach replenishment of Isles Dernieres.* Final Report to the U.S. Minerals Management Service, Office of Marine Minerals International Affairs, Herndon, Virginia, 164p.

BYRNES, M.R.; MCBRIDE, R.A., and HILAND, M.W., 1991. Accuracy standards and development of a national shoreline change database. *In*: KRAUS, N.C; GINGERICH, K.J., and KRIEBEL, D.L. (eds.) *Coastal Sediments '91* (American Society Civil Engineers, New York), 1, 1027–1042.

COMBE, A.J. and SOILEAU, C.W., 1987. Behavior of man-made beach and dune–Grand Isle, Louisiana. *Coastal Sediments '87* (American Society Civil Engineers, New York), pp. 1232–1242.

FRAZIER, D.E., 1967. Recent deposits of the Mississippi River, their development and chronology. *Transactions of the Gulf Coast Association of Geological Societies,* 17, 287–311.

JAFFE, B.E.; SALLENGER, A.H., JR., and LIST, J.H., 1989, Massive sediment bypassing of a wide tidal inlet: Cat Island Pass, Louisiana. *Gulf Coast Association of Geological Societies, Transactions,* 39, 403–411.

LANGFELDER, J.; STAFFORD, D., and AMEIN, M., 1968. *A reconnaissance of coastal erosion in North Carolina.* Department of Civil Engineering, North Carolina State University, Raleigh, North Carolina, 127p.

LIST, J.H.; JAFFE, B.E., and SALLENGER, A.H., JR., 1991. Large-scale coastal evolution of Louisiana's barrier islands. *In*: KRAUS, N.C., GINGERICH, K.J., and KRIEBEL, D.L., (eds.), *Coastal Sediments '91* (American Society of Civil Engineers, New York), 1, 1532–1546.

LIST, J.H.; JAFFE, B.E.; SALLENGER, A.H., JR., and HANSEN, M.E., this volume. Bathymetric comparisons adjacent to the Louisiana barrier islands: processes of large-scale change. Special Thematic Issue. *Journal of Coastal Research,* 13(3).

LIST, J.; B.E. JAFFE, A.J.; SALLENGER, JR.; S.J. WILLIAMS; R.A. MCBRIDE, and P.S. PENLAND, 1994. *Louisiana Barrier Island Erosion Study—Atlas of seafloor changes from 1878 to 1989*: Miscellaneous Investigations Series I-2150-B, Scales 1:250,000 and 1: 100,000, US Geological Survey, 82p.

MCBRIDE, R.A. and BYRNES, M.R., 1995. A megascale systems approach for shoreline change analysis and coastal management along the northern Gulf of Mexico. *Transactions, Gulf Coast Association of Geological Societies,* 45, 405–414.

MCBRIDE, R.A.; BYRNES, M.R., and HILAND, M.W., 1995. Geomorphic response-type model for barrier coastlines: a regional perspective. *Marine Geology,* 126, 143–159.

MCBRIDE, R.A.; PENLAND, P.S.; HILAND, M.W.; WILLIAMS, S. J.; WESTPHAL, K.A.; JAFFE, B.E., and SALLENGER, A.H., JR., 1992. Analysis of barrier shoreline change in Louisiana from 1853 to 1989 (Chapter 4). In: WILLIAMS, S. J., *et al.,* (eds.), *Louisiana Barrier Island Erosion Study—Atlas of Barrier Shoreline Changes in Louisiana*: USGS Miscellaneous Investigations, Series I-2150-A, pp. 36–97.

MCBRIDE, R.A.; HILAND, M.W.; PENLAND, P.S.; WILLIAMS, S.J.; BYRNES, M.R.; WESTPHAL, K.A.; JAFFE, B., and SALLENGER, A.H., JR., 1991, Mapping barrier island changes in Louisiana—techniques, database, and results. *In*: KRAUS, N.C *et al.,* (eds.), *Coastal Sediments '91* (American Society of Civil Engineers, New York), 1, 1011–1026.

MORGAN, J.P. and LARIMORE, P.B., 1957. Changes in the Louisiana shoreline. Transactions, *Gulf Coast Association of Geological Societies,* v. 7, p. 303–310.

MORGAN, J.P. and MORGAN, D.J., 1983. *Accelerating retreat rates along Louisiana's coast.* Louisiana Sea Grant College Program, Center for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana, 41p.

MORTON, R.A., 1979. Temporal and spatial variations in shoreline changes and their implications, examples from the Texas Gulf Coast. *Journal of Sedimentary Petrology,* 49, 1101–1112.

MOSSA, J.; PENLAND, P.S., and MOSLOW, T.F., 1985. Coastal structures in Louisiana's Barataria Bight. *Coastal Geology Technical Report No. 1,* Louisiana Geological Survey, Baton Rouge, Louisiana, 28p.

NEUMANN, C.J.; CRY, G.W.; CASO, E.L., and JARVINEN, D.R., 1985. *Tropical cyclones of the North Atlantic Ocean, 1871–1980.* Washington D.C.: U.S Government Printing Office, 174p.

PENLAND, P.S. and BOYD, R., 1981. Shoreline changes on the Louisiana barrier coast. Institute of Electrical and Electronic Engineers, *Oceans,* 81, 209–219.

PENLAND, P.S.; MOSSA, J.; MCBRIDE, R.A.; RAMSEY, K.E.; SUTER, J.R.; GROAT, C.G., and WILLIAMS, S.J., 1990. Offshore and onshore sediment resource delineation and usage for coastal erosion control in Louisiana: the Isles Dernieres and Plaquemines barrier systems. *In*: Hunt, M.C., *et al.,* (ed.), *Studies Related To Continental Margins.* Texas Bureau of Economic Geology and U.S. Minerals Management Service, pp. 74–86.

PEYRONNIN, C.A., JR., 1962. Erosion of the Isles Dernieres and Timbalier Islands. *Journal of the Waterways and Harbors Division* (American Society of Civil Engineers), 88, WWI, 57–69.

ROBERTS, H.H., this volume. Dynamic changes of the Holocene Mississippi River delta plain: the delta cycle. Special Thematic Issue. *Journal of Coastal Research,* 13(3).

ROBERTS, H.H.; HUH, O.K.; HSU, S.A.; ROUSE, L.J., and RICKMAN, D., 1987. Impact of cold-front passages on geomorphic evolution and sediment dynamics of the complex Louisiana coast. *Coastal Sediments '87* (American Society of Civil Engineers, New York), pp. 1950–1963.

SCRUTON, F.P., 1960, Delta building and the deltaic sequence. *In*: SHEPARD, F.P.; PHLEGER, F.B., and VAN ANDEL T.H., (eds.), *Recent Sediments, Northwest Gulf of Mexico: API Project 51,* American Association of Petroleum Geologists, Tulsa, Oklahoma, pp. 82–102.

SHABICA, S.V.; DOLAN, R.; MAY, S., and MAY, P., 1984. Shoreline erosion rates along barrier islands of the north central Gulf of Mexico. *Environmental Geology.*, 5 (3), 115–126.

SHALOWITZ, A.L., 1964. *Shoreline and Sea Boundaries.* US Department of Commerce, Coast and Geodetic Survey. Washington, D.C.: US Government Printing Office, v. 1, 383p.

SNYDER, J.P., 1987. Map projections—a working manual. *USGS Professional Paper 1395,* U.S. Government Printing Office, Washington D.C., 383p.

STAFFORD, D.B., 1971. An aerial photographic technique for beach erosion surveys in North Carolina. *CERC Technical Memorandum 36.* U.S. Army Corps of Engineers, 115p.

U.S. ARMY CORPS OF ENGINEERS, 1970. *Report on Hurricane Camille, 14–22 August 1969.* Mobile District, 149p.