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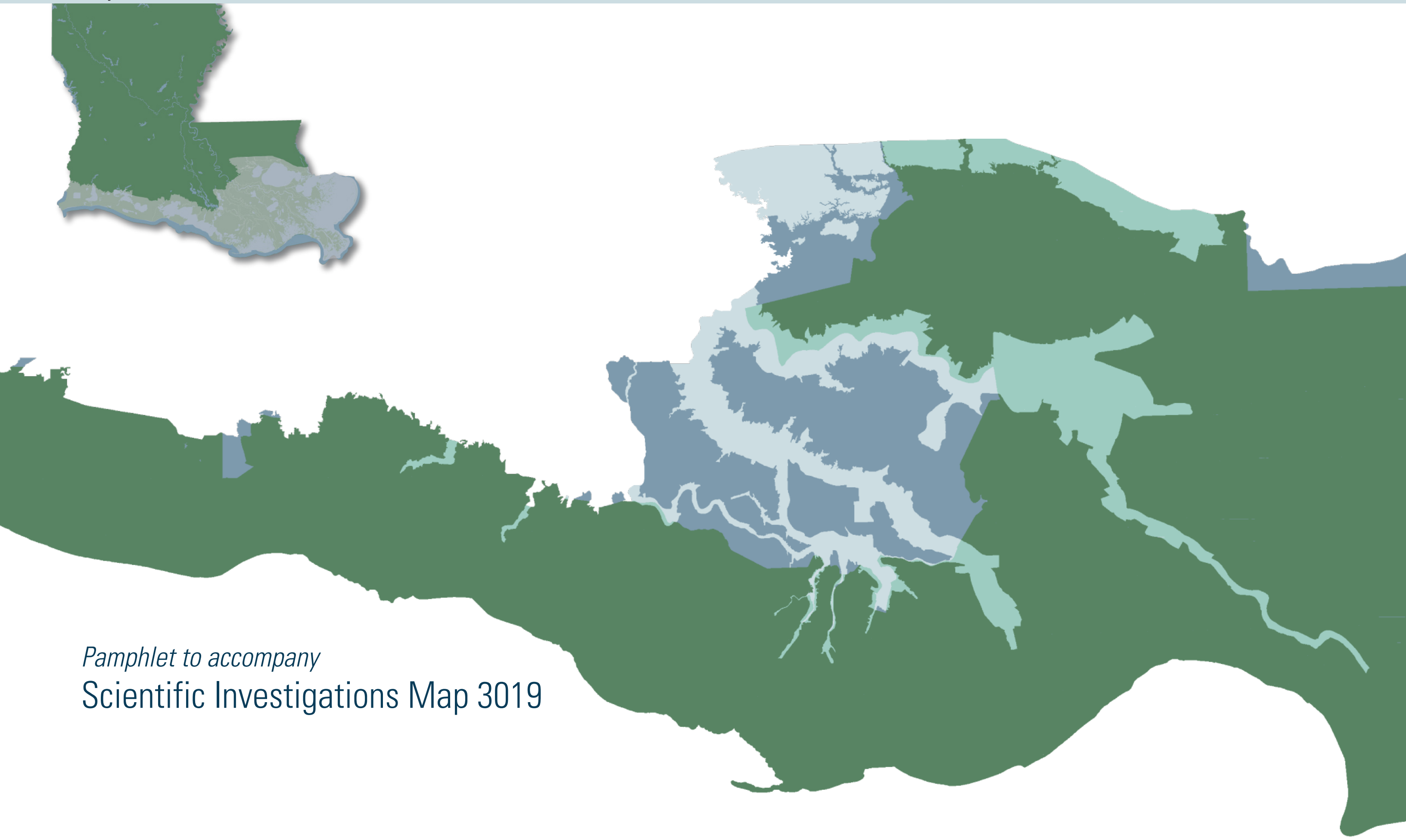
Land Area Change in Coastal Louisiana: A Multidecadal Perspective (from 1956 to 2006)

By John A. Barras, Julie C. Bernier, and Robert A. Morton



Pamphlet to accompany

Scientific Investigations Map 3019

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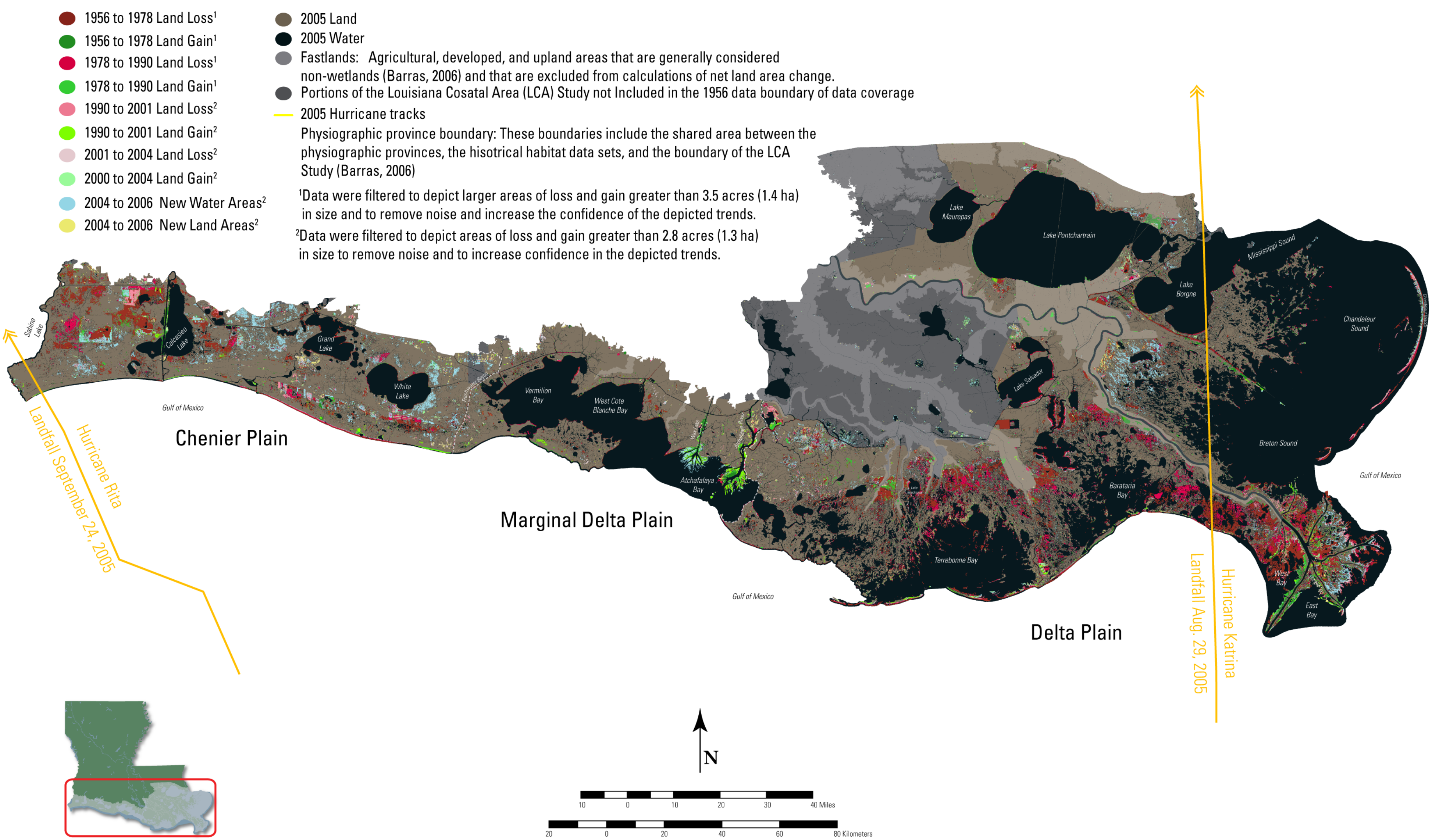
1956 to 1978 Land Loss[1]
1956 to 1978 Land Gain[1]
1978 to 1990 Land Loss[1]
1978 to 1990 Land Gain[1]
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2004 to 2006 New Land Areas[2]
2005 Land
2005 Water
Fastlands: Agricultural, developed, and upland areas that are generally considered non-wetlands (Barras, 2006) and that are excluded from calculations of net land area change.
Portions of the Louisiana Cosatal Area (LCA) Study not Included in the 1956 data boundary of data coverage
2005 Hurricane tracks
Physiographic province boundary: These boundaries include the shared area between the physiographic provinces, the hisotrical habitat data sets, and the boundary of the LCA Study (Barras, 2006)
[1]Data were filtered to depict larger areas of loss and gain greater than 3.5 acres (1.4 ha) in size and to remove noise and increase the confidence of the depicted trends.
[2]Data were filtered to depict areas of loss and gain greater than 2.8 acres (1.3 ha) in size to remove noise and to increase confidence in the depicted trends.
Hurricane Katrina
Landfall Aug. 29, 2005
Hurricane Rita
Landfall September 24, 2005
Chenier Plain
Marginal Delta Plain
Delta Plain
Sabine Lake
Calcasieu Lake
Grand Lake
White Lake
Vermilion Bay
West Cote Blanche Bay
Atchafalaya Bay
Terrebonne Bay
Barataria Bay
Lake Salvador
Lake Maurepas
Lake Pontchartrain
Lake Borgne
Mississippi Sound
Chandeleur Sound
Breton Sound
West Bay
East Bay
Gulf of Mexico
N
10 0 10 20 30 40 Miles
20 0 20 40 60 80 Kilometers

Land Area Change in Coastal Louisiana: A Multidecadal Perspective (1956 to 2006)

By John A. Barras, Julie C. Bernier, and Robert A. Morton

Introduction

The U.S. Geological Survey (USGS) analyzed changes in the configuration of land and water in coastal Louisiana by using a sequential series of 14 data sets summarizing land and water areas from 1956 to 2006 (table 1). The land-water data sets were derived from (1) modified, photointerpreted National Wetlands Inventory (NWI) data created for wetland habitat classifications and (2) Landsat Thematic Mapper (TM) satellite imagery obtained from the USGS Center for Earth Resources Observation and Science (EROS) and then classified by land and water coverage. These data sets are routinely used to provide summaries of land area and information on land change for coastal restoration projects ranging in size from a few thousand to millions of hectares. Changes in land area include both permanent and transitory losses and gains caused by local and regional environmental factors occurring at the time images were acquired. The time-dependent factors that effect land-water classification include water-level variations caused by different tidal and meteorological conditions, possible misclassification of aquatic vegetation and flats, and seasonal variations in fresh-marsh growth cycles. The purpose of this study is to provide a spatially and temporally consistent source of quantitative information on land area change across the physiographic provinces of coastal Louisiana.

Methodology

Spatial Analysis

This report presents historical changes in land area across coastal Louisiana, broken into three physiographic provinces (the term “coastal Louisiana” is used to present data on the collective area). These provinces subdivide coastal Louisiana into the Deltaic Plain on the east, the Marginal Deltaic Plain between the Atchafalaya River and Freshwater Bayou, and the Chenier Plain to the west of Freshwater Bayou. The term Marginal Deltaic Plain is sometimes used interchangeably with the Chenier Plain but is used to describe the central Louisiana coast in this study (boundaries are shown on the accompanying map; further definitions of the Deltaic and Chenier Plains can also be found in Saucier, 1994). The study area (fig. 1) conforms to the common area (29,616.7 km^2) shared by the boundaries of coverage in the 1956 and 1978 data sets and those of the 2000 Landsat TM data set used in the Louisiana Coastal Area (LCA) Study, hereafter referred to as the “2000 LCA TM data set” (Barras and others, 2003; Barras, 2006).

The current analysis is broken into five periods: 1956 to 1978, 1978 to 1990, 1990 to 2001, 2001 to 2004, and 2004 to 2006. Land area changes from 1985 through 2006 that occur outside the boundaries of the 1956 and 1978 data sets, but within the LCA Study boundary, are depicted on the map but were not used in area and trend calculations so as to ensure measurement consistency. The 1956 through 2001 comparisons depict historical changes at decadal or greater time scales. The 2001 to 2004 comparison was used to establish the land-water configuration before Hurricanes Katrina and Rita made landfall in 2005 and to contrast immediate hurricane surge impacts, such as direct removal of wetlands or wetland flooding against short-term changes related to vegetation response and recovery over a 1-year period (Barras, 2007a; Steyer and others; 2007). The 2004 to 2006 comparison provides an assessment of changes in land area that persisted for at least 1 year after the 2005 hurricanes.

The 2006 land-water data set was developed from October 2006 through January 2007 by classifying Landsat TM satellite imagery using the same methods as in previous studies (Barras and others, 2003; Morton and others, 2005; Barras, 2007a). A 2004 to 2005 comparison of land area changes (Barras, 2006) was not used in this study because the 2005 data set, acquired between October 16 and October 25, 2005, represents conditions shortly after Hurricanes Katrina and Rita made landfall. Land area changes for each period were summarized by physiographic province and totaled for all of coastal Louisiana for all available data sets by using ERDAS IMAGINE® software (Leica Geosystems Geospatial Imaging, LLC, Norcross, Ga., 2007) (table 1). The spatial presentation of land–water changes presented on the map used data sets representing 1956, 1978, 1990, 2001, 2004, and 2006 conditions rather than trying to present changes between all 14 data sets (table 1). The 1990, 2001, 2004, and 2006 Landsat TM data sets (classified by land and water coverage)

Table 1. Land and water areas in coastal Louisiana by physiographic province, 1956–2006.

[Area measurements provided in km^2; habitat, National Wetlands Inventory Habitat Data; TM, Landsat Thematic Mapper classified imagery; LCA TM, Louisiana Coastal Area 2000 Landsat Thematic Mapper classified mosaic]

Data Set Information			Deltaic Plain			Marginal Deltaic Plain			Chenier Plain			Coastal Louisiana		
Date[1]	Julian Date	Data Source	Land	Water	Total	Land	Water	Total	Land	Water	Total	Land	Water	Total
10/1/1956	1956.8	habitat	8,951.0	11,600.7	20,551.7	1,844.1	1,916.6	3,760.7	4,359.0	945.3	5,304.3	15,154.1	14,462.6	29,616.7
10/1/1978	1978.8	habitat	7,378.9	13,172.8	20,551.7	1,761.2	1,999.5	3,760.7	3,776.2	1,528.1	5,304.3	12,916.3	16,700.4	29,616.7
1/19/1985	1985.1	TM	7,288.3	13,263.4	20,551.7	1,761.2	1,999.5	3,760.7	3,540.5	1,763.8	5,304.3	12,590.0	17,026.7	29,616.7
1/26/1988	1988.1	TM	7,490.3	13,061.4	20,551.7	1,800.1	1,960.6	3,760.7	3,600.1	1,704.2	5,304.3	12,890.4	16,726.3	29,616.7
10/1/1988	1988.8	habitat	7,249.4	13,302.3	20,551.7	1,805.2	1,955.5	3,760.7	3,618.2	1,686.1	5,304.3	12,672.9	16,943.8	29,616.7
11/1/1990	1990.8	TM	7,031.9	13,519.8	20,551.7	1,766.4	1,994.3	3,760.7	3,789.2	1,515.1	5,304.3	12,587.4	17,029.3	29,616.7
2/24/1998	1998.2	TM	6,860.9	13,690.8	20,551.7	1,719.8	2,040.9	3,760.7	3,354.1	1,950.2	5,304.3	11,934.7	17,682.0	29,616.7
11/18/1999	1999.9	TM	6,721.1	13,830.6	20,551.7	1,862.2	1,898.5	3,760.7	3,768.5	1,535.8	5,304.3	12,351.7	17,265.0	29,616.7
10/1/2000	2000.8	LCA TM	6,581.2	13,970.5	20,551.7	1,807.8	1,952.9	3,760.7	3,649.3	1,655.0	5,304.3	12,038.3	17,578.4	29,616.7
10/30/2001	2001.8	TM	6,700.3	13,851.4	20,551.7	1,807.8	1,952.9	3,760.7	3,714.1	1,590.2	5,304.3	12,222.2	17,394.5	29,616.7
2/27/2002	2002.2	TM	6,822.1	13,729.6	20,551.7	1,805.2	1,955.5	3,760.7	3,576.8	1,727.5	5,304.3	12,204.1	17,412.6	29,616.7
11/7/2004	2004.9	TM	6,617.5	13,934.2	20,551.7	1,807.8	1,952.9	3,760.7	3,747.7	1,556.6	5,304.3	12,173.0	17,443.7	29,616.7
10/25/2005	2005.8	TM	6,311.8	14,239.9	20,551.7	1,769.0	1,991.7	3,760.7	3,525.0	1,779.3	5,304.3	11,605.8	18,010.9	29,616.7
10/28/2006	2006.8	TM	6,399.9	14,151.8	20,551.7	1,800.1	1,960.6	3,760.7	3,460.2	1,844.1	5,304.3	11,660.2	17,956.5	29,616.7

[1] Represents the acquisition data for Landsat Worlwide Reference System, Path 22 and Rows 39-40 only, and provides a general date of reference for other scenes comprising each coastal land-water data set.

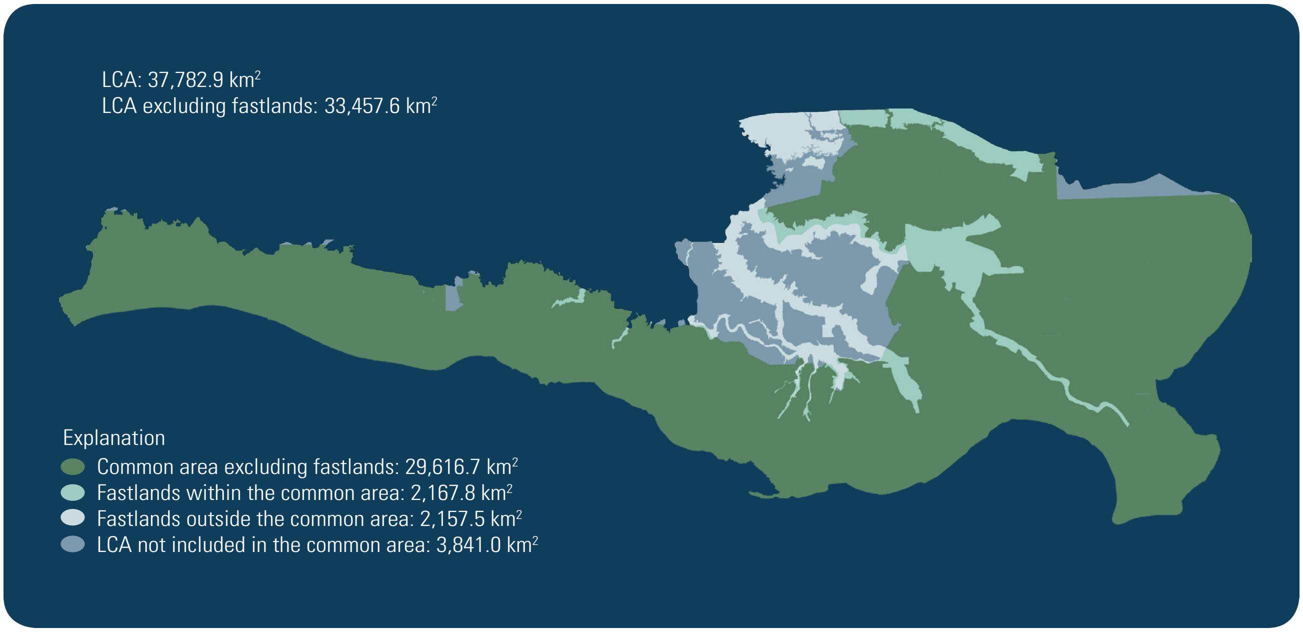


Figure 1. Map of common study area composed of overlapping data coverage in the 1956 and 1978 land and water data sets and those of the 2000 Landsat Thematic Mapper data set used in the Louisiana Coastal Area (LCA) Study (Barras and others, 2003). Also shown are fastlands, which are excluded from calculations of net changes in land area.

represent typical fall (October through December) conditions for coastal Louisiana that are temporally consistent; Landsat TM scenes are acquired within a few months during the fall and early winter. The resulting data sets for land area change in each period were processed by using a neighborhood density filter to remove changes smaller than 1.4 ha and were then overlaid with the 2006 land-water data set to illustrate gross land area changes in coastal Louisiana for the past 50 years. The filtering removed some of the "noise" caused by spatial misregistration and environmental variance between comparison intervals and increased the likelihood that the depicted loss or gain was real, even if caused by transient environmental events such as high water levels. The land and water areas (table 1) were then used to calculate net land losses or gains and to average annual loss rates (tables 2 and 3) for each map period. This information was then used to develop an annualized rate curve for net loss coastwide (fig. 2) and a graph showing net loss (fig. 3) for each province and each period.

Linear Regression Analysis

Linear regression analysis provided a more robust estimate of recent trends by comparing land area over time for all data sets (table 1) from 1985 to 2004 and from 1985 to 2006 by physiographic province across coastal Louisiana. The comparison provided estimates of land area change trends before and after Hurricanes Katrina and Rita (table 4). The linear regression analyses were performed by using GraphPad Prism version 5.0a for Macintosh (GraphPad Software, San Diego, California).

The regression analyses excluded the 2000 LCA TM data set and the 2005 data set. The 2000 LCA TM data set was excluded because it is a composite mosaic of the fall 1999 and winter 2002 data sets. It replicates and combines data sets already used in this analysis and does not represent actual 2000 land-water conditions (Barras and others, 2003). The 2005 data set was excluded in order to reduce the influence of short-term storm effects, such as surge-induced flooding, some marsh scouring, and wrack deposition. We excluded the 1998 data set from our regression analyses of the Chenier and Marginal Deltaic Plains, and we also excluded the 1999 data set from the Marginal Deltaic Plain regression. The 1998 data set was excluded because marsh flooding, visible on the source Landsat TM imagery, anomalously increased water areas. The 1999 data set was excluded because extensive, unclassified aquatic vegetation in the Atchafalaya River and Wax Lake deltas exaggerated land area measurements.

A series of graphs illustrate the linear regressions for each physiographic province of coastal Louisiana from 1985 through 2004 and from 1985 through 2006 (fig. 4). The slope of the regression line indicates the trend of annual land area change. A negative slope equates to land loss, whereas a positive slope equates to land gain. The scatter of the land area data points around the slope illustrate measurement variance

Table 2. Changes in land area and rates of land loss in coastal Louisiana by period and physiographic province, 1956–2006.

[Area change measurements provided in km^2 (negative measurements indicate land loss, while positive ones indicates land gain); percent area change equals area change per period divided by total area change from 1956 to 2006]

Period	Years	Deltaic Plain		Marginal Deltaic Plain		Chenier Plain		Coastal Louisiana	
		Area Change	Percent Area Change	Area Change	Percent Area Change	Area Change	Percent Area Change	Area Change	Percent Area Change
1956 to 1978	22.0	-1,572.1	-61.6	-82.9	-188.4	-582.8	-64.8	-2,237.8	-64.0
1978 to 1990	12.1	-347.0	-13.6	5.2	11.8	13.0	1.4	-328.8	-9.4
1990 to 2001	11.0	-331.6	-13.0	41.4	94.1	-75.1	-8.3	-365.3	-10.5
2001 to 2004	3.0	-82.8	-3.3	0.0	0.0	33.6	3.7	-49.2	-1.4
2004 to 2006[1]	2.0	-217.6	-8.5	-7.7	-17.5	-287.5	-32.0	-512.8	-14.7
1956 to 2006	50.1	-2,551.1	100.0	-44.0	100.0	-898.8	100.0	-3,493.9	100.0

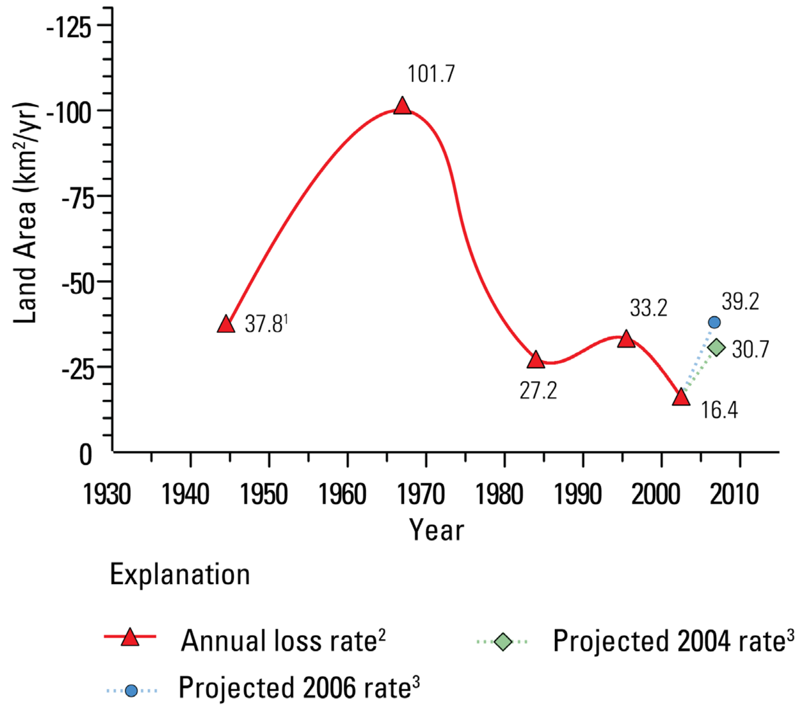
[1] The changes in this period reflect an estimate of conditions 1 year after the 2005 hurricane season as compared to the analysis conducted by Barras (2006) immediately after Hurricanes Katrina (Aug. 29) and Rita (Sept. 24) in 2005. The current analysis provides a refined estimate of loss likely caused by those two closely-timed events.

Table 3. Annual rates of land area change in coastal Louisiana by period and physiographic province, 1956–2006.

[Change rates provided in km^2/yr; negative measurements indicate rates of land loss, while positive measurements indicate rates of land gain]

Period	Years	Deltaic Plain	Marginal Deltaic Plain	Chenier Plain	Coastal Louisiana
		Change Rate	Change Rate	Change Rate	Change Rate
1956 to 1978	22.0	-71.5	-3.8	-26.5	-101.7
1978 to 1990	12.1	-28.7	0.4	1.1	-27.2
1990 to 2001	11.0	-30.1	3.8	-6.8	-33.2
2001 to 2004	3.0	-27.6	0.0	11.2	-16.4
2004 to 2006[1]	2.0	-108.8	-3.9	-143.8	-256.4
1956 to 2006	50.1	-50.9	-0.9	-17.9	-69.7

[1] The changes in this period reflect an estimate of conditions 1 year after the 2005 hurricane season as compared to the analysis conducted by Barras (2006) immediately after Hurricanes Katrina (Aug. 29) and Rita (Sept. 24) in 2005. The current analysis provides a refined estimate of loss likely caused by those two closely-timed events and will skew (increas) recent calculations of annual loss.



[1]1932-1955 annual loss rate from Britsch and Dunbar (1993).
[2]Based on time periods and annual rates listed in table 3.
[3]Based on regression rates of land loss listed in table 4.

Figure 2. Annual rates of land area change in coastal Louisiana, 1956–2006.

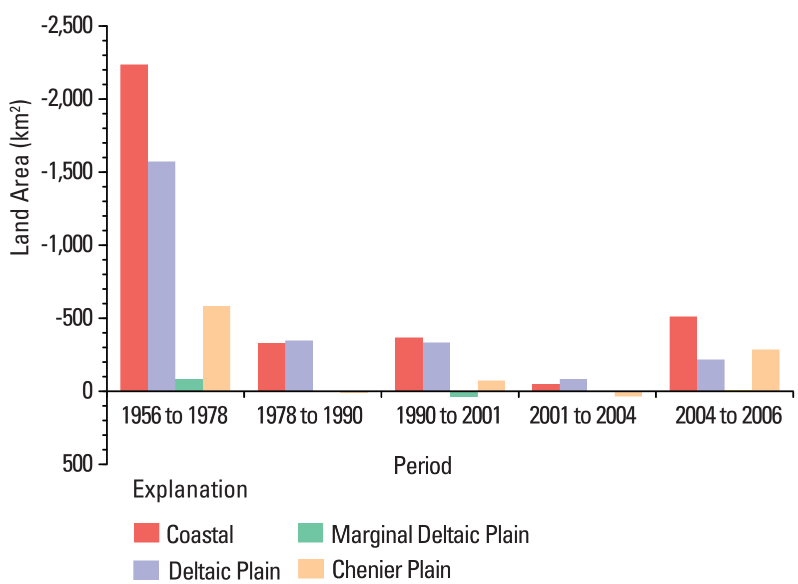


Figure 3. Net land area change by period and province, 1956–2006.

Table 4. Rates of Land area change in coastal Louisiana, derived from linear regressions of change rates versus time, by physiographic province, 1985–2006.

[Change of area slope (rate) provided in km^2; SD, standard deviation; slope SD provided in km^2; confidence intervals of slope are provided in km^2 at 95 percent confidence; Sy.x, the standard deviation of the vertical distance of the data points from the regression line and is provided in km^2; r^2, coefficient of correlation]

Area	Period	Change of Area Slope (Rate)	SD of Area Slope	Confidence Intervals of Slope	Sy.x	r^2	No. of Data Points
Coastal[1]	1985-2004	-30.7	± 5.7	-44.7 to -16.8	117.0	0.83	8
	1985-2006	-39.2	± 7.6	-57.2 to -21.2	177.0	0.79	9
Deltaic Plain[2]	1985-2004	-38.9	± 5.6	-52.3 to -25.6	116.8	0.87	9
	1985-2006	-41.5	± 5.0	-53.0 to -29.9	116.6	0.90	10
Marginal Deltaic Plain[3]	1985-2004	1.6	± 0.9	-0.6 to 3.9	17.3	0.41	7
	1985-2006	1.4	± 0.7	-0.4 to 3.1	16.4	0.38	8
Chenier Plain[1]	1985-2004	4.9	± 4.7	-7.2 to 17.0	93.9	0.22	8
	1985-2006	-0.3	± 5.2	-13.1 to 12.5	120.3	0.00	9

[1] Excludes the 1998, 2000 LCA TM, and the 2005 data sets.

[2] Excludes the 2000 LCA TM and the 2005 data sets.

[3] Excludes the 1998, 1999, 2000 LCA TM, and the 2005 data sets.

that may be associated with water area fluctuations caused by environmental effects or by classification error. Prior studies have linked variations in water area measurements based on classified TM imagery to changes in water levels (Morton and others, 2005; Bernier and others, 2006). The excluded data points are shown to illustrate their relationship to the included data points. The regression lines were extended to 2015 to produce short-term projections based on the preceding 21 years of data. Projection beyond 2015 was not attempted because of uncertainties related to recovery from the 2005 hurricane season and the potential for other episodic events that could skew rates of land area change.

Discussion

A comparison of land area change trends, based on analysis by linear regression, by physiographic province for 1985 to 2004 shows that the majority of coastal land loss since 1985 occurred on the Deltaic Plain (-38.93 ± 5.63 km^2/yr). Over the same period, the Marginal Deltaic Plain showed a slight land area increase (1.63 ± 0.87 km^2/yr), primarily the result of growth in the Atchafalaya River and Wax Lake delta complexes, and the Chenier Plain was relatively stable (4.89 ± 4.72 km^2/yr). These trends in small land gains slightly offset the trends of land loss in the Deltaic Plain, thus reducing the overall rate of coastal land loss (-30.71 ± 5.70 km^2/yr). Annual rates of coastal land loss for 1985 to 2006 (-39.19 ± 7.61 km^2/yr) increased by more than 8 km^2/year relative to the 1985 to 2004 trends, reflecting hurricane-induced acceleration of coastal land loss.

Comparison of annualized loss rates from 1956 to 1978 with those from 1978 to 1990 and from 1990 to 2001 shows a significant decrease in rates of land loss after 1978 (table 2; fig. 3), which is also supported by comparison with the 1985 to 2004 trend shown by the current linear regression (table 2). Britsch and Dunbar (1992) also indicate a trend of decreasing loss after 1978, but the rates they report are higher than those we are reporting in the current study. The post-1978 rates of loss reported here are similar to those rates that Britsch and Dunbar report for 1932 to 1955, when loss is estimated to have been -37.8 km^2/year (fig. 2). Morton and others (2005) have constrained the time period of rapid loss to the mid-1960s and mid-1970s for a 256-km^2 study area within the south-central Deltaic Plain. This refinement of data for the 1956 to 1978 interval is necessary because this period lacks the temporal resolution to show such short-term spatial changes. Previous studies of land loss based on Landsat TM imagery classified by land and water and on NWI data sets reported higher but decreasing rates of loss from 1978 through 2000; however, these results depended on comparison of hybrid data sets created by merging (Barras and others, 1994) or mosaicing source data sets (Barras and others, 2003), resulting in higher loss rates. These higher rates for 1978 through 2000 could not be replicated in this study by analysis of more temporally and methodologically consistent data sets (table 3; fig. 2; and fig. 3) or by the analysis of multiple data sets by linear regression (table 4; fig. 4).

Our analyses of land area changes from 2004 to 2006 (bracketing one year before and after the 2005 hurricane season) demonstrate that episodic events can accelerate land loss. From 2004 to 2006, water area increased coastwide by 512.8 km^2, which is a loss of land that is equal to almost

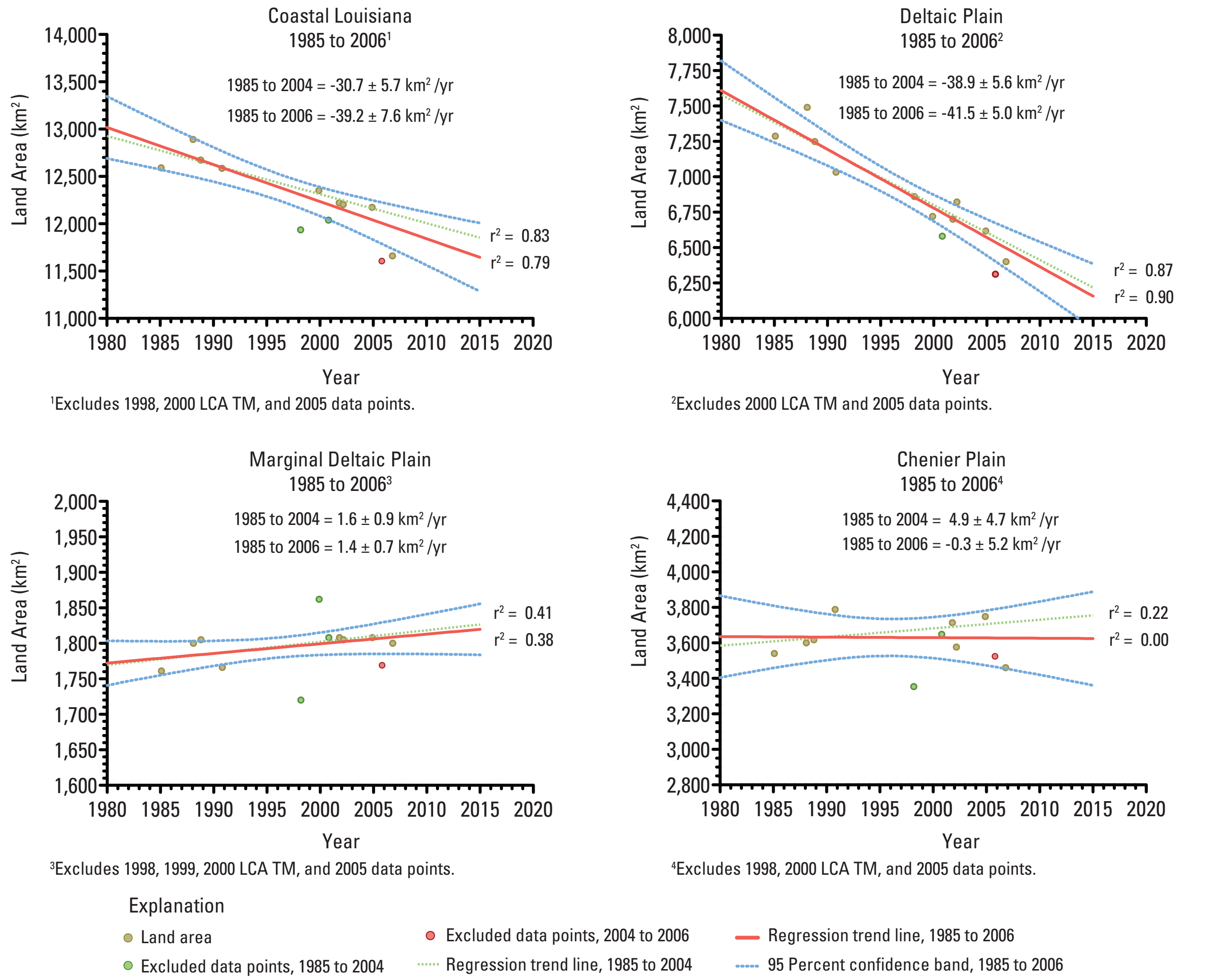


Figure 4. Linear regressions of land area change trends in coastal Louisiana by physiographic province, 1985-2006. (Negative measurements indicate land loss, while positive measurements indicate land gain.)

70 percent of the cumulative loss from 1978 to 2004 (743.3 km^2). Hurricane Rita, specifically, increased water area on the Chenier Plain by 287.5 km^2, an amount of land loss that is equal to approximately half that experienced from 1956 to 1978 (582.8 km^2) and greatly exceeding the loss rate from 1978 to 2004 (28.4 km^2). Together, Hurricanes Katrina and Rita increased water area (indicating land loss) in coastal Louisiana by 567.2 km^2 between 2004 and 2005 within the study area (Barras, 2006; fig. 1). This increase in water area was followed, between 2005 and 2006, by a decrease in water area (indicating land gain) by 54.4 km^2 coastwide, showing some limited recovery of land during this brief period. This gain of land from 2005 to 2006 is equal to approximately 10 percent of the land loss (562.0 km^2) estimated for 2004 to 2005 in Barras (2006). Given the potential influence of episodic events such as hurricanes, annualized rates of land change should be examined for such influences, especially considering that discriminating permanent loss from transitory loss caused by an episodic event may require several years of observations. For example, some of the increased water area resulting from Hurricane Rita may reflect temporary rather than permanent conditions because it was located (1) in impounded areas that may recover over time depending on management strategies or (2) in flooded agricultural areas included within the northern portion of the LCA Study boundary.

The quantitative results of this study address landscape-scale changes; however, caution should be exercised when applying landscape-level trends to hydrologic basins or smaller areas that may encompass diverse temporal and spatial histories of land loss and gain. Analyses of shorter time frames are more likely to show transitory environmental effects than permanent changes. For example, when Morton and others examined 23 annual data sets of Landsat TM imagery (classified by land and water) acquired from 1983 through 2004, they found that water area varied by as much as 5 percent over short periods. Thus, the decadal or greater changes presented on the map in this study more likely represent permanent changes, whereas the changes in the 2001 to 2004 period more likely reflect short-term environmental effects.

The influence of transitory changes stemming from the 2005 hurricane season and other factors is evidenced by many of the land area changes depicted on the map in this study. For example, our analysis of the 2004 to 2006 period shows large new water areas bordering the eastern shoreline of White Lake in the Chenier Plain that were not present immediately after Hurricane Rita's land fall in 2005 (Barras, 2006), but visual review of intervening Landsat TM images acquired between 2004 and 2008 show that the area began to appear as a persistent wet spot several months after Rita's landfall. In a similar fashion, the water areas immediately west of Grand Lake depict some shallow areas of burned marsh that were flooded after Hurricane Rita that had not regrown by the fall of 2006, but based on past observations of marsh recovery after burning, it is likely that these areas will revegetate, unless they were damaged by high salinity introduced by Rita's surge. In another instance of what are likely short-term environmental effects of the 2005 hurricane season, the Wax Lake delta appears to have incurred significant land loss from Hurricane Rita's surge; however, it seems that some of this loss can be attributed to a significant amount of aquatic vegetation being removed (Barras, 2007b, fig. 18*A*). Considering that the Wax Lake delta displayed a similar pattern of vegetation removal after Hurricane Lili's landfall on October 3, 2002 (Barras 2007b, fig. 18*B*), after which vegetation rapidly recovered by 2004, it seems likely that some of this loss in the Wax Lake delta will be recovered. Finally, one more example of short-term environmental effects can be demonstrated by considering areas of scattered land gain in the saline marsh immediately fringing Terrebonne Bay and Lake Felicity, located south of Pointe au Chien. The appearance of land gain in these areas can be attributed to the environmental conditions present when the Landsat TM imagery was acquired on October 28, 2006, soon after the passage of a weather front with 13-knot northerly winds. These winds exposed the bottoms of shallow ponds that were misclassified as land (rather than as flats) during the land-water classification process. Landsat TM images acquired under calmer conditions at normal water levels would show these areas of land gain as shallow ponds. Such land area fluctuations that are induced by temporary wind and water levels should be noted when interpreting land changes over short time periods. They may also skew trend measurements over longer periods if comparing imagery acquired under differing water level conditions.

Although many of the recent land area changes that fall within a short-term historical view are likely to be temporary (such as the ones we have discussed), we have evidence that some of the recent changes we have detected will be permanent. Following are some examples of those cases. Nearly instantaneous surge impacts from Hurricane Katrina are evident along the Chandeleur Islands and the eastern side of the Mississippi River Delta, northwest of Delacroix, and west and southeast of Slidell (Barras, 2007b, figs. 1, 2*A*, 3*A*, 5*A*, 7*A*, and 8*A*). Hurricane Ivan (Sept. 16, 2004) caused shoreline erosion near Garden Island Bay in the southeastern Mississippi River Delta (Barras, 2007b, fig. 3*D*). Storm surge from Tropical Storm Isadore (Sept. 26, 2002) or Hurricane Lili (Oct. 3, 2002) formed new ponds and expanded existing ponds to the south and east of Big Mar (Barras 2007b, fig. 9). Surge impacts from Hurricane Lili were subsequently expanded by Hurricane Rita's surge just north of Marone Point to the west of the Wax Lake Outlet (Barras 2007b, figs. 19*A*, 19*B*, 19*C*). Hurricane Andrew's (Aug. 26, 1992) surge impacts are evident between Lake Decade and Four League Bay and are incorporated within the 1990 and 2001 comparison interval. These surge impacts expanded existing ponds that were formed by rapidly submerging marsh between 1956 and 1978. The surge impacts from Hurricane Andrew were reactivated and expanded by subsequent surge impacts from Hurricanes Lili and Rita, respectively (Barras, 2007b, figs. 16*C*, 16*B*, and 16*A*).

Taking a broad historical view provides an in-depth understanding of land area changes over time. From this view, our analyses of recent losses caused by hurricanes indicate that these often commingled with or exacerbated older losses formed during the 1956 to 1978 period. Degraded marsh areas fringing ponds formed by the rapid submergence of marsh between the mid-1960s and the mid-1970s (Morton and others, 2005) within the south-central Deltaic Plain were removed by Hurricane Rita's surge (Barras, 2007b figs. 13*A*, 13*B*, 13C, 14*A*, 14*B*, 14*C*, 15*A*, and 15*B*). Other 1956 to 1978 loss areas located in primarily fresh marshes and not directly impacted by hurricanes exhibit a peppering pattern of multiple losses and gains caused by seasonal variation in vegetation. The marsh immediately northwest of Lake Cataouatche exhibits this pattern, as do the marshes northwest of Lake Decade and east of the Atchafalaya River. Land-water changes after 1978 within these areas remained largely contained within the initial 1956 to 1978 loss zone. Another observation provided by our historical review is that the majority of the widespread, nontransitory land gains depicted on the map over the past 50 years, with the exception of the progradation of the Atchafafalaya River and Wax Lake deltas, are primarily related to sediment placement and landward migration of barrier islands.

Conclusions

The 1956 to 2006 map showing multidecadal changes, along with the linear regressions of land area change presented in this study, provide a comprehensive and concise presentation of historical trends and rates of land area change in coastal Louisiana. Rates of land loss dropped more rapidly than previously estimated after the 1970s, remaining relatively stable through 2004. The spatial depictions of land area change reveal a complex and interwoven mosaic of loss and gain patterns caused by natural and human-induced processes operating at varied temporal and spatial scales, resulting in fluctuating contributions to coastal loss. Short-term comparisons show that land-water area measurements in areas undergoing loss may fluctuate before these areas convert to open water; conversely areas gaining land or recovering from surge impacts may also exhibit similar short-term area fluctuations. Our analysis also shows how the immediate impacts of extreme storms can alter the long-term, time-averaged trends of landscape change. The cumulative hurricane impacts observed here suggest that hurricanes contribute significantly to coastal land loss, ranging in scale from specific localities to entire hydrologic basins, and cause permanent pond formation at varying spatial scales and temporal frequencies.

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