Louisiana Coastal Area (LCA), Louisiana

Ecosystem Restoration Study

November 2004

Final

Appendix B – Historical and Projected Coastal Louisiana Land Changes: 1978-2050

Historical and Projected Coastal Louisiana Land Changes: 1978-2050

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USGS Open File Report
OFR 03-334 (Revised January 2004)

U.S. Department of the Interior
U.S. Geological Survey

Outside front and outside back cover photographs:

Louisiana coastal landloss is dramatically depicted by these various views of USGS benchmark "TT 62 F," set in concrete in 1932 on dry land near the Elliot home on Bayou Couba, which is approximately 13 miles southwest of New Orleans between Lakes Cataouatche and Salvador in St. Charles Parish, LA. The benchmark now sits in approximately 2 feet of water, about 15 feet from the shoreline of Couba Island. (See map below.)

Left front cover photo (dead live oak and benchmark) was taken facing north.
Right front cover photo (man fishing near pilings and benchmark) was taken facing west.
Outside back cover is a zoomed-in picture of the benchmark's brass cap.

Benchmark legal description – Bayou Couba, near mouth of, 20 feet South, thence 5 feet West from large lone live oak, 15 feet North from center of fireplace chimney of Mr. Elliott's house, in concrete post, standard tablet stamped "TT 62 F 1932", LA south stateplane coordinates; x = 2,349,092, y = 410,266. Marker was set with a Horizontal Position ONLY.

Suggested citation:

Barras, J., Beville, S., Britsch, D., Hartley, S., Hawes, S., Johnston, J., Kemp, P., Kinler, Q., Martucci, A., Porthouse, J., Reed, D., Roy, K., Sapkota, S., and Suhayda, J., 2003, Historical and projected coastal Louisiana land changes: 1978-2050: USGS Open File Report 03-334, 39 p. (Revised January 2004).

Louisiana Coastal Area (LCA), Louisiana

Ecosystem Restoration Study - Appendix B

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LOUISIANA COASTAL AREA (LCA), LOUISIANA

ECOSYSTEM RESTORATION STUDY

APPENDIX B

HISTORICAL AND PROJECTED COASTAL LOUISIANA LAND CHANGES: 1978-2050

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Introduction

An important component of the Louisiana Coastal Area (LCA) Ecosystem Restoration Study is the projection of a "future condition" for the Louisiana coast if no further restoration measures were adopted. Such a projection gives an idea of what the future might hold without implementation of the LCA plan and provides a reference against which various ecosystem restoration proposals can be assessed as part of the planning process. One of the most fundamental measures of ecosystem degradation in coastal Louisiana has been the conversion of land (mostly emergent vegetated habitat) to open water. Thus, the projection of the future condition of the ecosystem must be based upon the determination of future patterns of land and water.

To conduct these projections, a multidisciplinary LCA Land Change Study Group was formed that included individuals from agencies and academia with expertise in remote sensing, geographic information systems (GIS), ecosystem processes, and coastal land loss. Methods were based upon those used in prior studies for Coast 2050 (Louisiana Coastal Wetlands Conservation and Restoration Task Force [LCWCRTF] and the Wetlands Conservation and Restoration Authority 1998, 1999) and modified as described here to incorporate an improved understanding of coastal land loss and land gain processes with more advanced technical capabilities. The basic approach is to use historical data to assess recent trends in land loss and land gain and to project those changes into the future, taking into account spatial variations in the patterns and rates of land loss and land gain. This approach is accomplished by developing a base map, assessing and delineating areas of similar land change (polygons), and projecting changes into the future. This report describes the methodology and compares the current land change projection to previous projections.

Data Sources

The LCA Land Change Study Group used existing historical data derived from interpretation of aerial photography and new data, based on classified Landsat 5 and 7 Thematic Mapper (TM) satellite imagery, to assess current land loss and gain trends from 1978 to 2000 for coastal Louisiana.

Data sources used in the study include:

1978 Regional Habitat Data – A coastwide raster data set based upon interpretation of 1:65,000-scale, color-infrared aerial photographs consisting of 15 land cover classes, developed from the U.S. Fish and Wildlife Service data with a minimum resolution of 25 m, was used to assess regional habitat changes (Cahoon and Groat, 1990). The regional habitat data set is derived from a vector data set characterizing detailed wetland habitats by individual 7.5 minute U.S. Geological Survey's topographic quadrangle base maps of coastal Louisiana (Wicker, 1980). Individual habitat maps used a highly detailed coding system developed by Cowardin and others (1979) to identify habitat types. Habitat data coverage is based on the 1978 coastal zone boundary and does not cover the entire LCA study area.

1990 TM Classified Data – A coastwide data set based on classified Landsat 5 Thematic Mapper (TM) satellite data used to provide a "snapshot" of coastal land and water conditions in the fall of 1990 and early spring of 1991. The data set consists of seven Landsat TM scenes acquired between October 30, 1990 and February 24, 1991.

1999 - 2002 TM Data – A coastwide data set based on classified Landsat 7 Enhanced Thematic Mapper Plus (ETM+) satellite data was developed to provide a "snapshot" of coastal land and water conditions in the fall of 1999 and the early spring of 2002. The 1999 data set consists of seven Landsat ETM+ scenes acquired between October 24 and November 27, 1999. The 2002 data set consists of seven Landsat TM scenes acquired between January 3 and February 27, 2002.

Data Preparation and Classification Methodology

LCA Trend Assessment Boundary

The LCA trend assessment area geographically comprises the entire LCA area except for fastlands (uplands). Those fastlands excluded from the analysis included ridges and areas under forced drainage dominated by agriculture or human development. However, barrier islands and other non-wetland components of the coastal ecosystem were included in the analysis. This data set was then used as a template to extract the classified satellite data to insure similar areas were compared for the trend assessments.

1978 Regional Habitat Data

A 1978 land-water data set was created by combining the 15 land cover classes into two classes, land and water. The LCA trend assessment boundary was then used to extract the 1978 land-water data contained within its (study) boundaries to create a 1978 LCA land-water data set.

TM Satellite Data

The Landsat 5 and Landsat 7 satellites are earth-observing instruments designed for land surface monitoring and change detection and are jointly operated by the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS). The satellite captures images of the same location on the Earth's surface every 16 days at approximately the same local (Central) time, 9:30 am for coastal Louisiana. Each scene covers approximately 185 km by 180 km and has a minimum ground resolution of 30 m. All Landsat TM imagery used in the LCA study was resampled to 25 m to match the 25 m spatial resolution of the historical data sets. Adjoining scenes acquired along a path are captured within a few seconds of each other. Adjacent scenes to the east and west of the current path are acquired every 16 days. Each scene has an overlap of approximately 18 km and a sidelap of approximately 40 km. Seven scenes are required to provide complete coverage of coastal Louisiana. A scene contains eight bands of imagery, each recording a discrete portion of the electromagnetic spectrum (visible to panchromatic). Each band stores data in an 8-bit format, breaking the recorded spectral data into 256 discrete levels. More information on the Landsat program is found at http://landsat7.usgs.gov/index.php. The Landsat TM satellite data were classified using a standardized methodology developed to allow quick and accurate classification of existing land and water conditions at the time of image acquisition within Louisiana's coastal wetland areas. The methodology is not designed for developing detailed land cover information from Landsat imagery and is based on edge enhancing and level slicing band 5 to identify land and water on a per scene basis. Level slicing is a technique that requires visual examination of each discrete level of spectral data to determine whether the pixels contained within the level should be categorized as water or land.

The LCA TM data classification methodology is a refinement of a methodology originally developed for the Louisiana Department of Natural Resources GIS lab (Braud and Streiffer, 1992). The classification methodology was further refined for use in trend assessments at the USGS National Wetlands Research Center (Bourgeois and Barras, 1993; Barras and others, 1994; Bourgeois, 1994) and at Louisiana State University (Braud and Feng, 1998). All of the TM data used in the LCA study were classified over a period of 9 months by the same remote sensing analyst using a standard classification methodology to insure repeatability and consistency and to minimize classification interpretation subjectivity.

Landsat Classification Methodology

Cloud-free Landsat TM 7 scenes of coastal Louisiana were obtained to provide complete coastal coverage during the fall or winter to minimize the presence of floating aquatic vegetation. Multiple along-path scenes were included whenever possible to maximize contemporaneous coastal coverage. Mosaics of same-path scenes were created to reduce the number of individual scenes requiring classification from seven to four. The band 5 (mid-infrared) subset was extracted from the mosaics to use for the land-water classification. Band 5 is commonly used for vegetation and soil moisture measurements and provides good land-water discrimination in Louisiana's coastal wetlands because of the high absorption of the mid-infrared portion of the spectrum by water and its high reflectance by vegetation (Braud and Feng, 1998). The individual band 5 reflectance values were compared for each mosaic to identify the water-land break in each band 5 subset. The individual band 5 reflectance values were recoded to create an initial land and water file for each mosaic. These reflectance values were then aggregated into component land and water classes based on the identified water-land break. A slight edge enhancement filter (Braud and Feng, 1998) was then run to increase the contrast between land and water values and to enhance shoreline discrimination. The water-land break was then identified and classified for each edge-enhanced image to identify component land and water classes. Classification, identification, and delineation of submerged and floating aquatic vegetation and exposed flats (mud flats and sand bars) were conducted to more accurately distinguish the water class. Each classified map was combined and overlaid to create a composite land and water data map. The individual files were filtered for smoothness by removing noise (unclear and erroneous pixels), and classified contiguous coastwide land and water (CWLW) data sets for 1990, 1999, and 2002 were created.

Coastwide 1999–2000/02 Land and Water Base Development Methodology

Visual examination of draft trend maps used to compare the 1990 to 1999 and 2002 CWLW data sets revealed that water levels differed in selected areas on the data sets because of meteorological effects and management practices. The 1999 data for the central Deltaic Plain were acquired on November 18, 1999 after mild frontal (cold) conditions. The 2002 imagery for the same area was acquired on February 27, 2002 after severe frontal (cold) conditions. The net effect was to lower water levels in the estuarine marshes of the central Deltaic Plain. The interior fresh marshes actually contained more open water in the 2002 imagery than in the 1999 imagery because of the late winter acquisition date of 2002 imagery, when the extent of aquatic vegetation is minimal. In the 2002 data, the area from Cote Blanche Bay west to Grand Lake contained large burns and some surface water caused by management practices. These effects were not as pronounced in the 1999 data. A decision was made to combine the 1999 and 2002 data sets to create a 2000 coastwide land and water classified mosaic (CM) to more accurately reflect "normal" land and water conditions (fig. 1). The 2000 CM served as the present land-water base data for the historical land loss-gain assessments.

Recent Trends Data Set

All recent trend assessments include the 1990 and 2000 CM data for the LCA trend assessment area. The 1978 to 1990 trend assessments were based on existing rates described in Barras and others (1994). Area statistics were generated for the 1990 and 2000 CM data and were then used to calculate the net loss rates during these periods (table 1). The LCA study area was divided into four Subprovinces (fig. 2) for analyzing without conditions.

Table 1. Net land loss trends by Subprovince from 1978 to 2000.

	1978 - 1990 Net loss sq mi*	1990 - 2000 Net loss sq mi	1978 - 2000 Cumulative loss sq mi	Annual loss sq mi/yr	% Total loss by area
Subprovince 1	52	48	100	4.5	15.2%
Subprovince 2	148	65	213	9.7	32.4%
Subprovince 3	134	72	206	9.4	31.3%
Subprovince 4	85	54	139	6.3	21.1%
Total sq mi (sq km)	419 (1,085)	239 (619)	658 (1,704)	29.9 (77.4)	100%

*1978-1990 Net loss figures were based on Barras and others (1994). The 1978 to 1990 basin level and coastwide trends used in this study were aggregated to reflect LCA Subprovinces for comparison with the 1990-2000 data. The basin boundaries used in Barras and others (1994) were based on older CWPPRA planning boundaries and are not directly comparable to the LCA boundary used to summarize the 1990 to 2000 trend data. The 1990 to 2000 net loss figures include actively managed lands for comparison purposes with the 1978 to 1990 data.

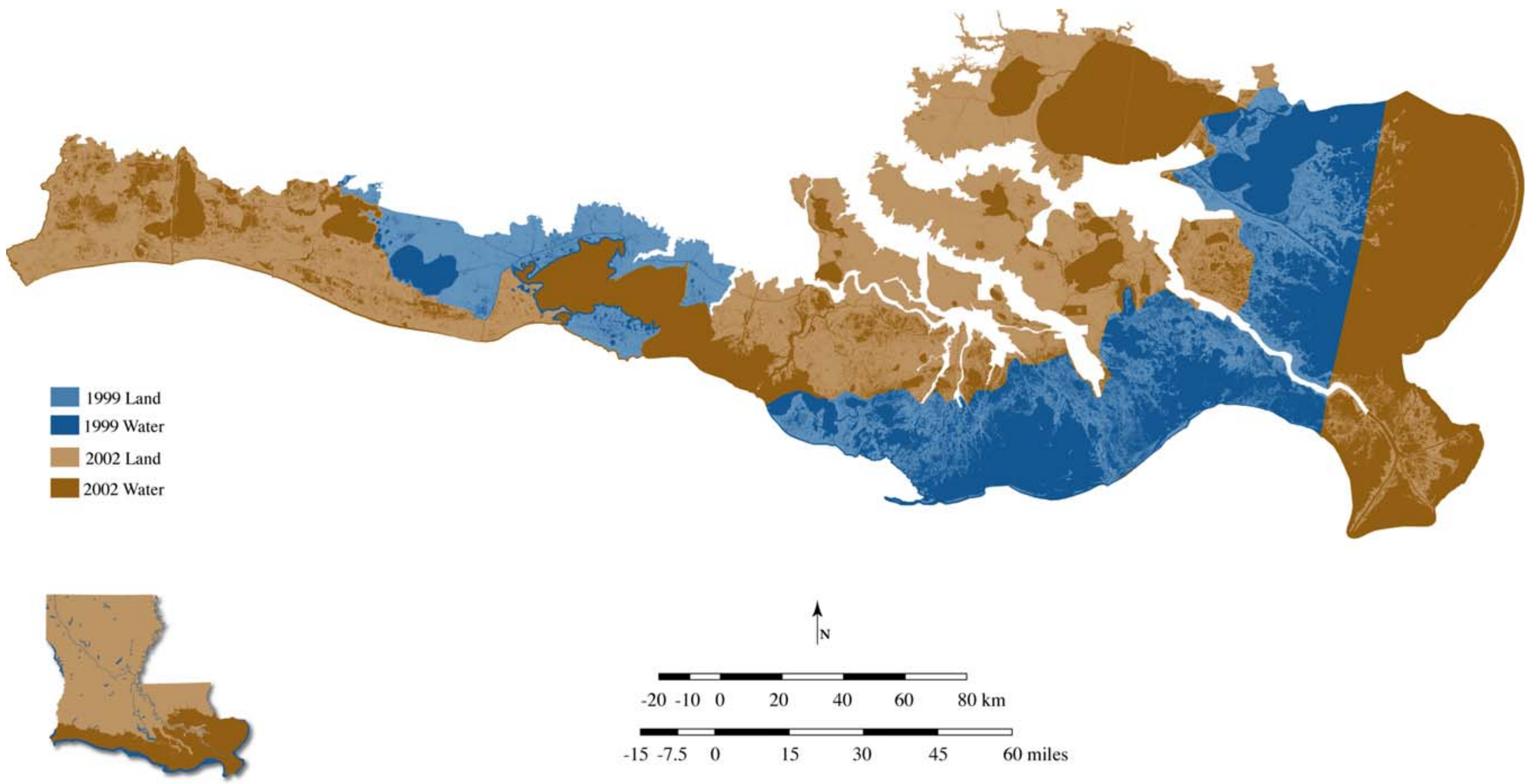

Figure 1. 1999 and 2002 data sets combined to create a 2000 Louisiana coastwide land and water classified mosaic.

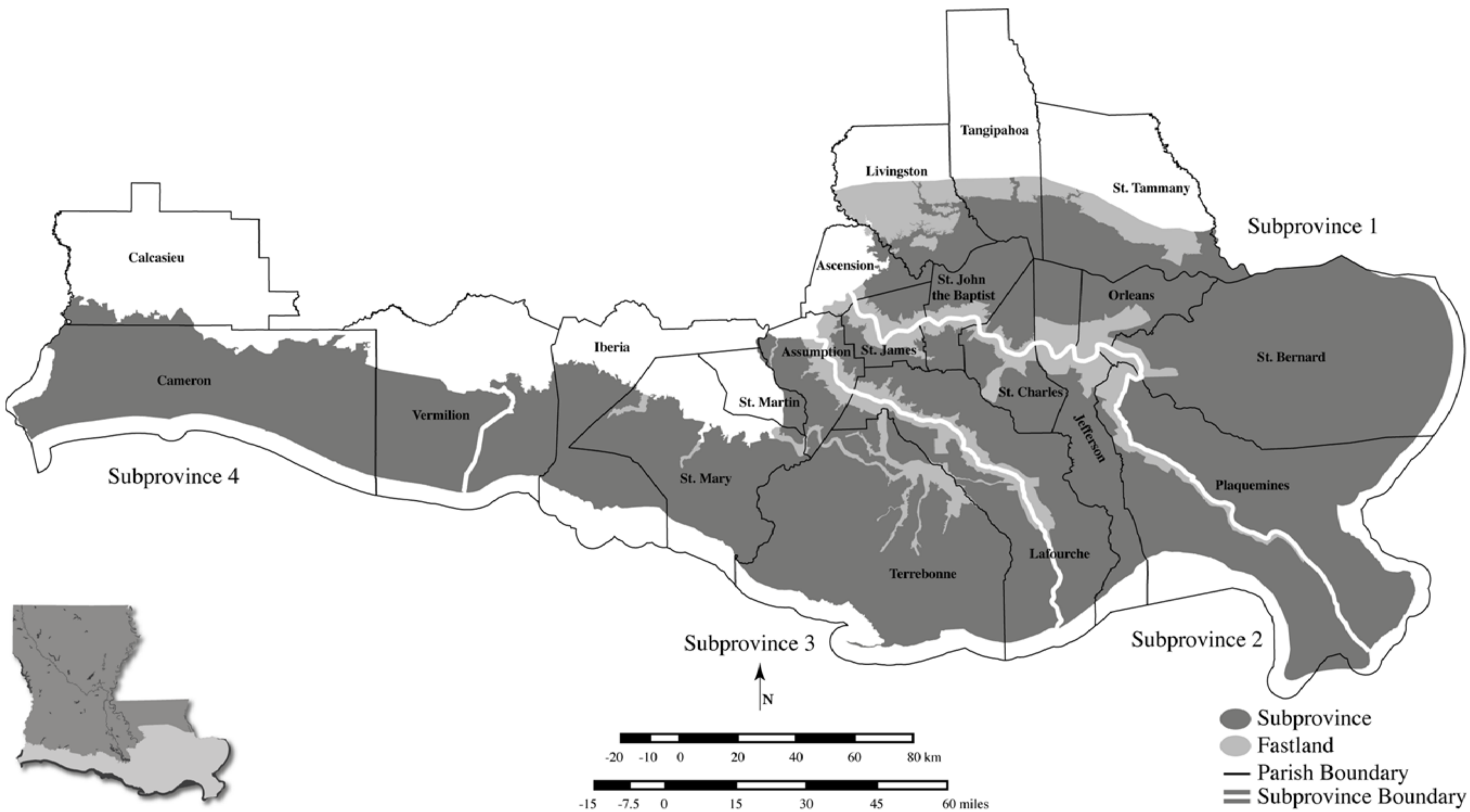

Figure 2. Louisiana Coastal Area (LCA) Subprovince boundaries.

The 1978 habitat data covered all of the LCA area with the exception of the upper portions of the Barataria and Terrebonne Basins and the western portion of the Pontchartrain Basin. Loss and gain trend rates for these missing areas were assessed by visually examining historical aerial color infared photography (1978) and USGS topographic maps (from 1960s and 1970s). The estimated loss rates observed were so low that we decided to use 1990 TM data to fill in the gaps of the 1978 data set (fig. 3).

Spatial changes were assessed by comparing and combining the 1978, 1990, and 2000 CM data sets to form a composite 1978 to 1990 to 2000 spatial trend data set that identified areas of no change and areas that converted to either water or land during the 22 year interval. The data set was then filtered to remove small areas of new water and new land caused by a spatial misregistration between the data sets (figs. 4 and 5).

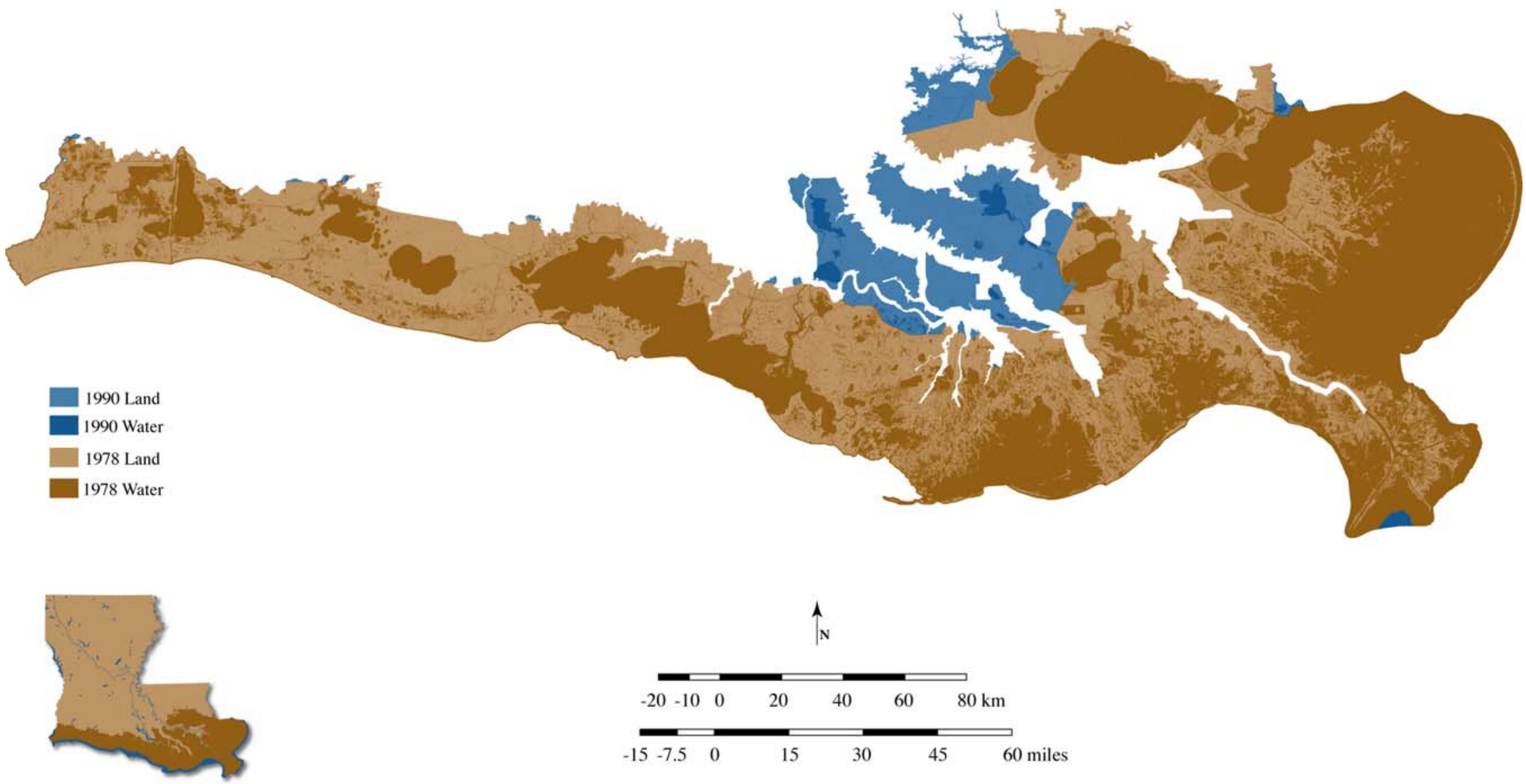

Figure 3. Louisiana coastwide trend assessment area including the 1978 habitat data and 1990 Landsat Thematic Mapper data.

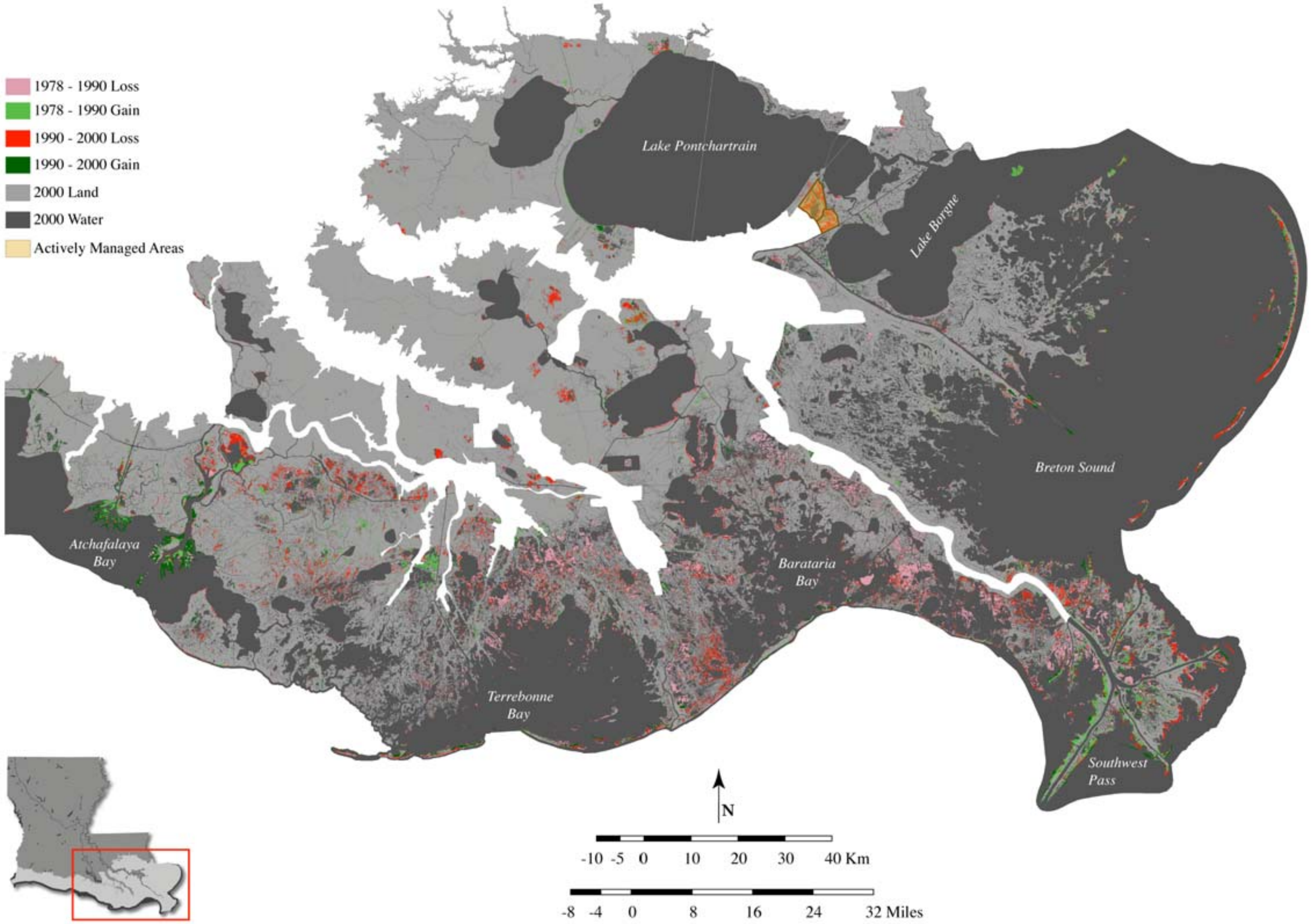

Figure 4. 1978 to 1990 and 1990 to 2000 spatial trend data set analysis for southeastern Louisiana.

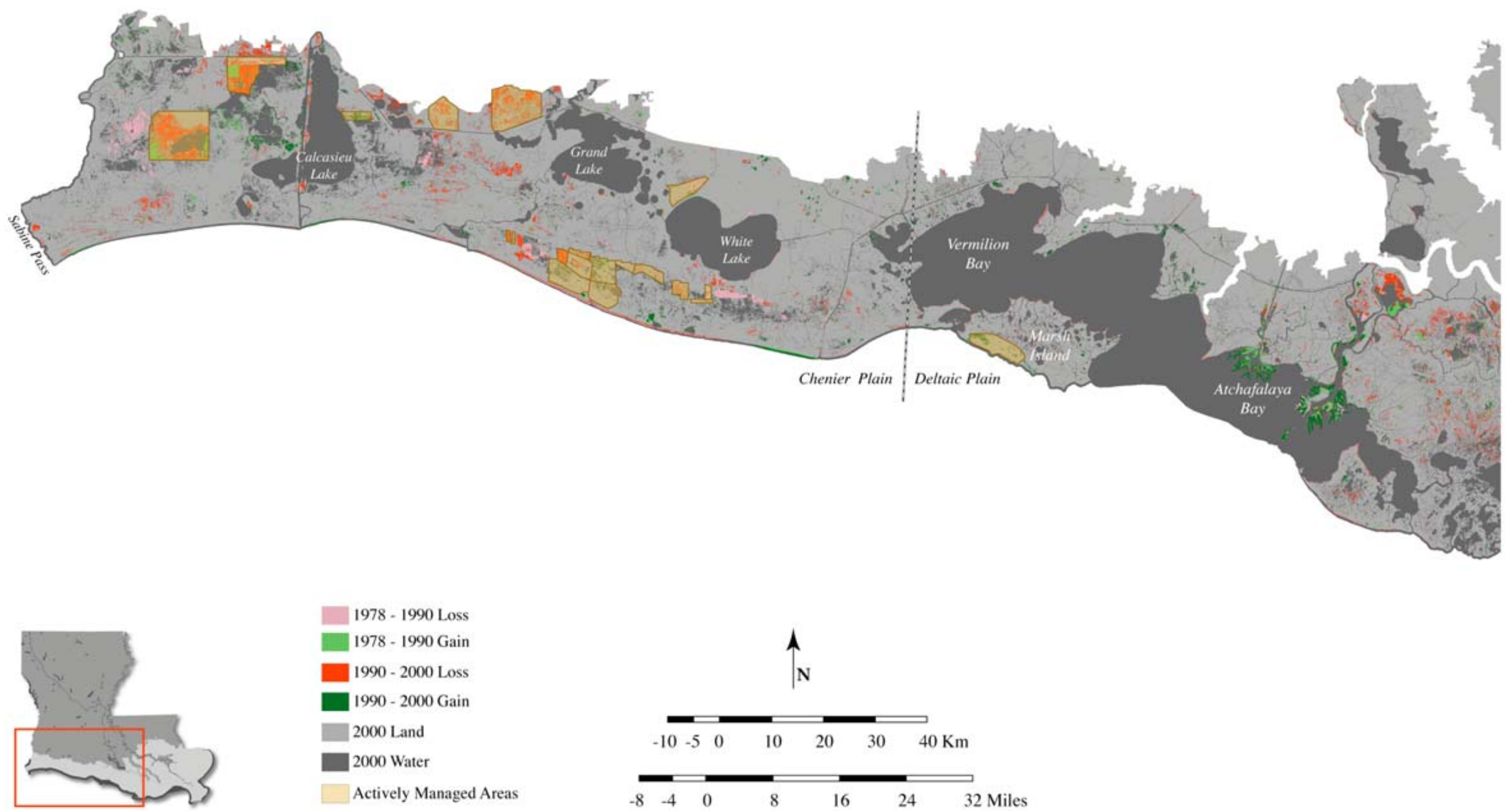

Figure 5. 1978 to 1990 and 1990 to 2000 spatial trend data set analysis for southwestern Louisiana.

Recent Trends

Wetland loss and shoreline erosion continues across much of the Louisiana coast. The trend in the 1956-1978 period was the conversion of numerous large marsh areas (> 1,000 ha) to open water. This trend continued at a lower rate in the 1978-1990 period, and further decreased in the 1990-2000 period (figs. 4 and 5). Shoreline erosion and the creation of smaller interior marsh ponding continued as the primary patterns of land loss during the last decade. Interior ponds ranged in size from 1-50 ha (about 2-125 acres), with the majority of ponds occurring within the coastal fresh marshes. Detectable shoreline erosion in larger lakes, bays, and ponds ranged from 50 to 300 m (164-984 ft). The minimum detectable spatial resolution of TM multispectral imagery is 30 m.

Therefore, to accurately detect shoreline erosion by using TM imagery, the erosion must be in excess of 50 to 60 m between the two dates at which the images are acquired. Lake Boudreaux in Terrebonne Parish (fig. 6) and Bayou Perot in Lafourche Parish (fig. 7) may have experienced shoreline erosion rates ranging as high as 15 to 25 m/yr (about 50-80 ft/yr) in the last decade. During the same period, the eastern shoreline of the active Mississippi River Delta exhibited shoreline erosion in excess of 500 m (1,640 ft) in several locations (fig. 8) while the Gulf of Mexico shoreline, south of Rockefeller Wildlife Refuge, exhibited 150 to 200 m (about 500-650 ft) of erosion (fig. 9).

In the Pontchartrain and Breton Sound Basins (fig. 4), some new interior ponds have developed, and loss around the edges of large lakes and bays is widespread. In lower Plaquemines Parish, in the vicinity of Lake Grand Ecaille the extensive loss of previous decades has continued with the exception of areas where there are almost no wetlands left to lose (fig. 10). In the Barataria and Terrebonne Basins (figs. 6, 10, and 11) land loss continues in areas that were already severely affected. Interior ponding predominates in the fresh floatant marshes, and the remnant effects of Hurricane Andrew in 1992 are indicated by sheared ponds within the floatant areas of southwest Terrebonne (fig. 12). Some small areas of gain are likely due to shifting of floatant mats. Fringing shoreline erosion predominates in the estuarine marshes, although some small areas of gain are apparent because of water level variations between the 1990 and 2000 data sets. Farther west, from west of Atchafalaya Bay to Vermilion Bay (fig. 5), shoreline erosion predominates, although some interior loss due to ponding is present. Land gain from small interior ponds is related to low water conditions around West Cote Blanche and Vermilion Bays (fig. 13).

In the Chenier Plain (fig. 5), breakup of previously intact interior marshes is apparent in many areas. Shoreline erosion is present around the larger lakes. The Gulf of Mexico shoreline experienced significant loss, with the exception of some gains just to the west of Freshwater Bayou (fig. 9). Examination of multiple dates of satellite imagery for many areas reveals varying landscapes ranging from dense marsh to open water, depending on image acquisition time.

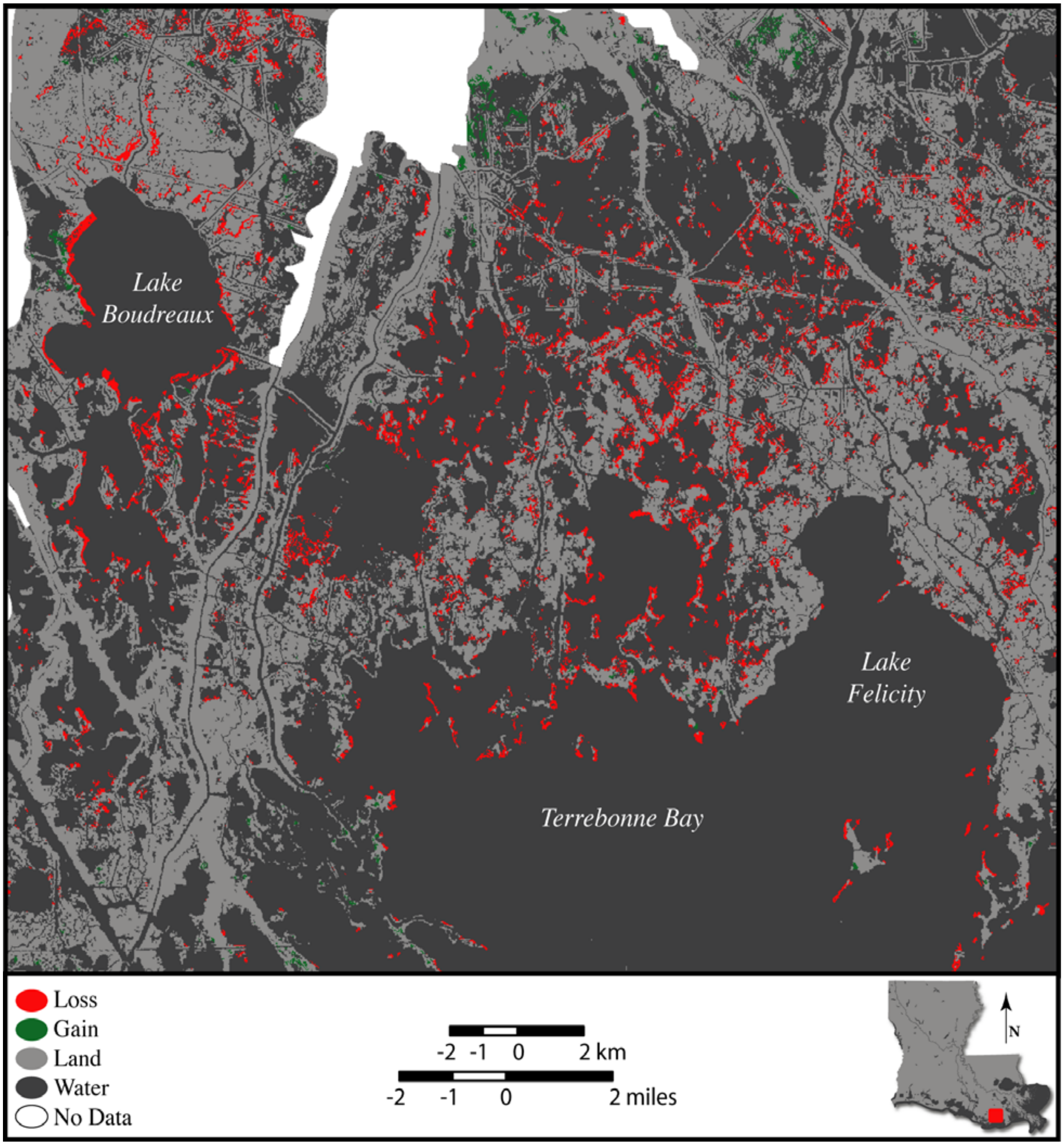

Figure 6. 1990 to 2000 spatial trend data set in the vicinity of Lake Boudreaux and Northern Terrebonne Bay in southeastern Louisiana.

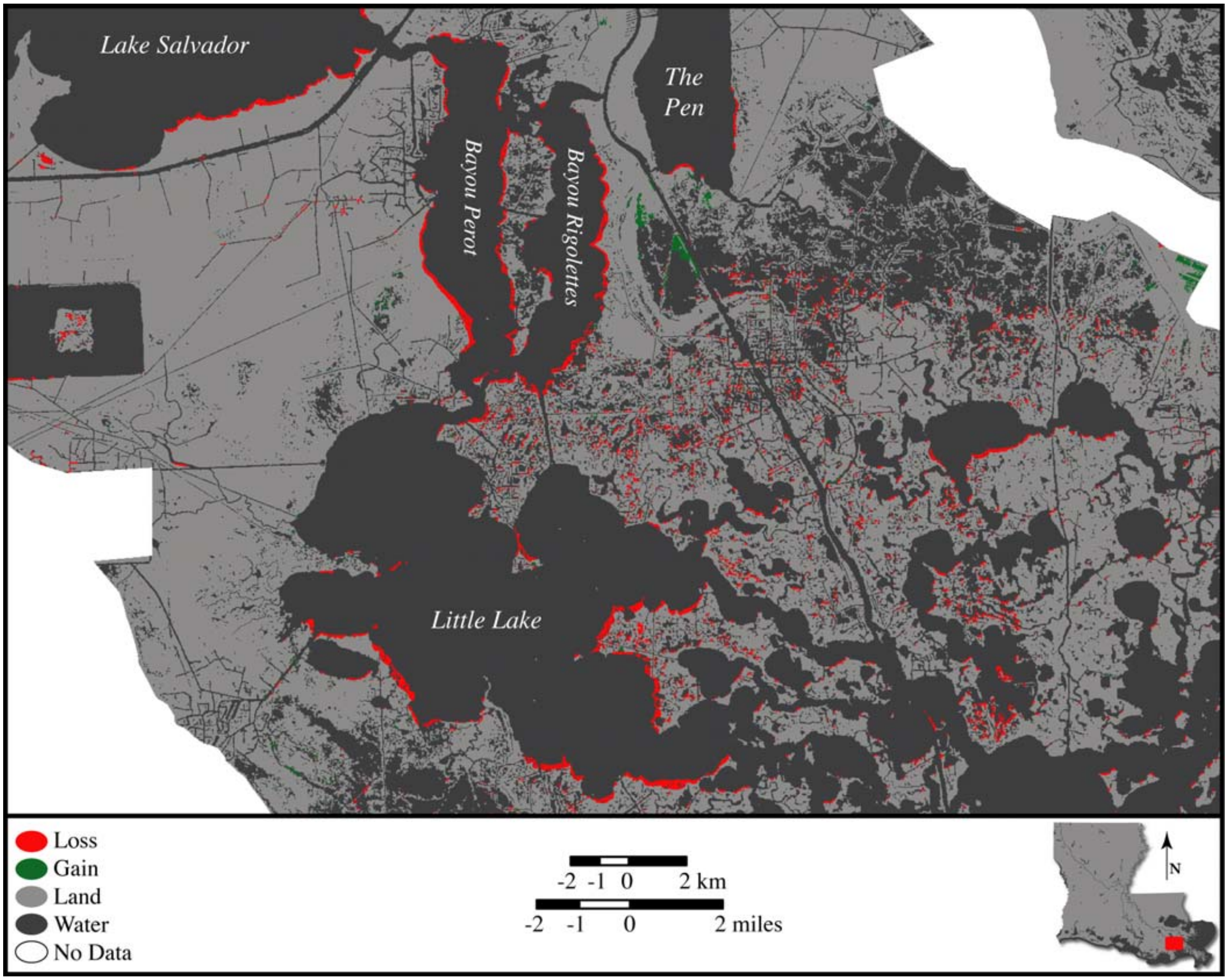

Figure 7. 1990 to 2000 spatial trend data set in the vicinity of Bayou Perot in southeastern Louisiana.

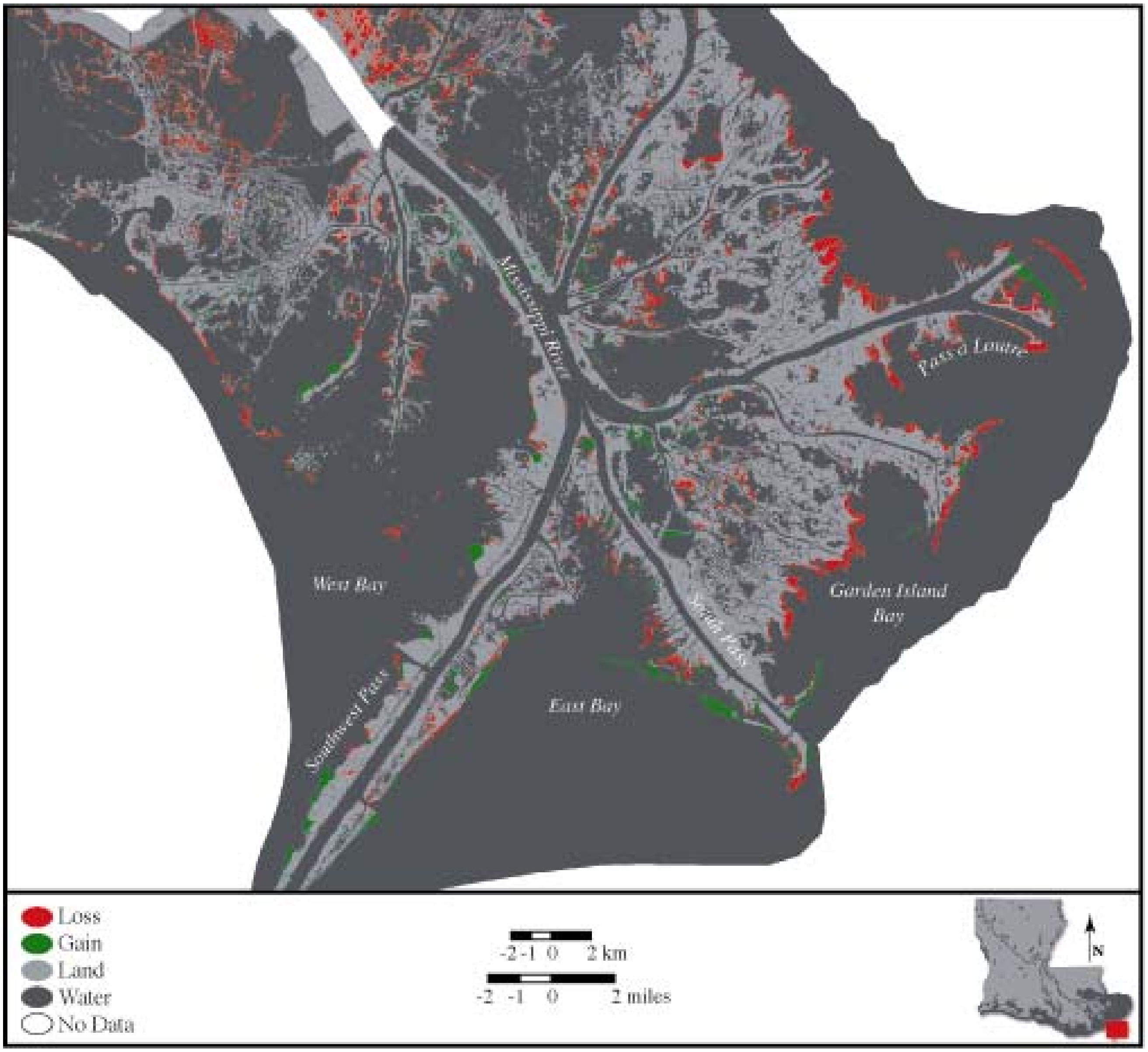

Figure 8. 1990 to 2000 spatial trend data set of the Mississippi River Delta in southeastern Louisiana.

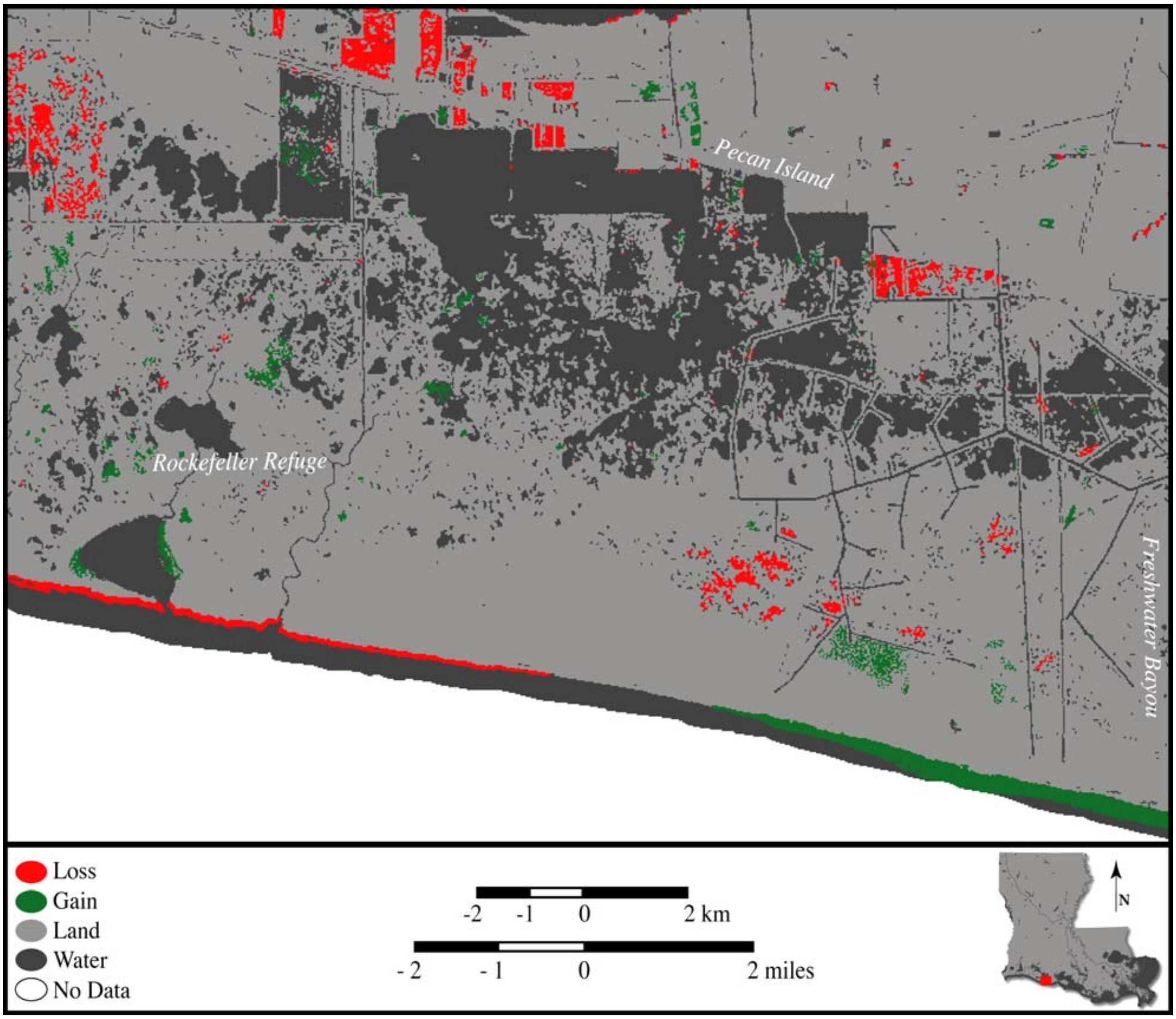

Figure 9. 1990 to 2000 spatial trend data set west of Freshwater Bayou in southwestern Louisiana.

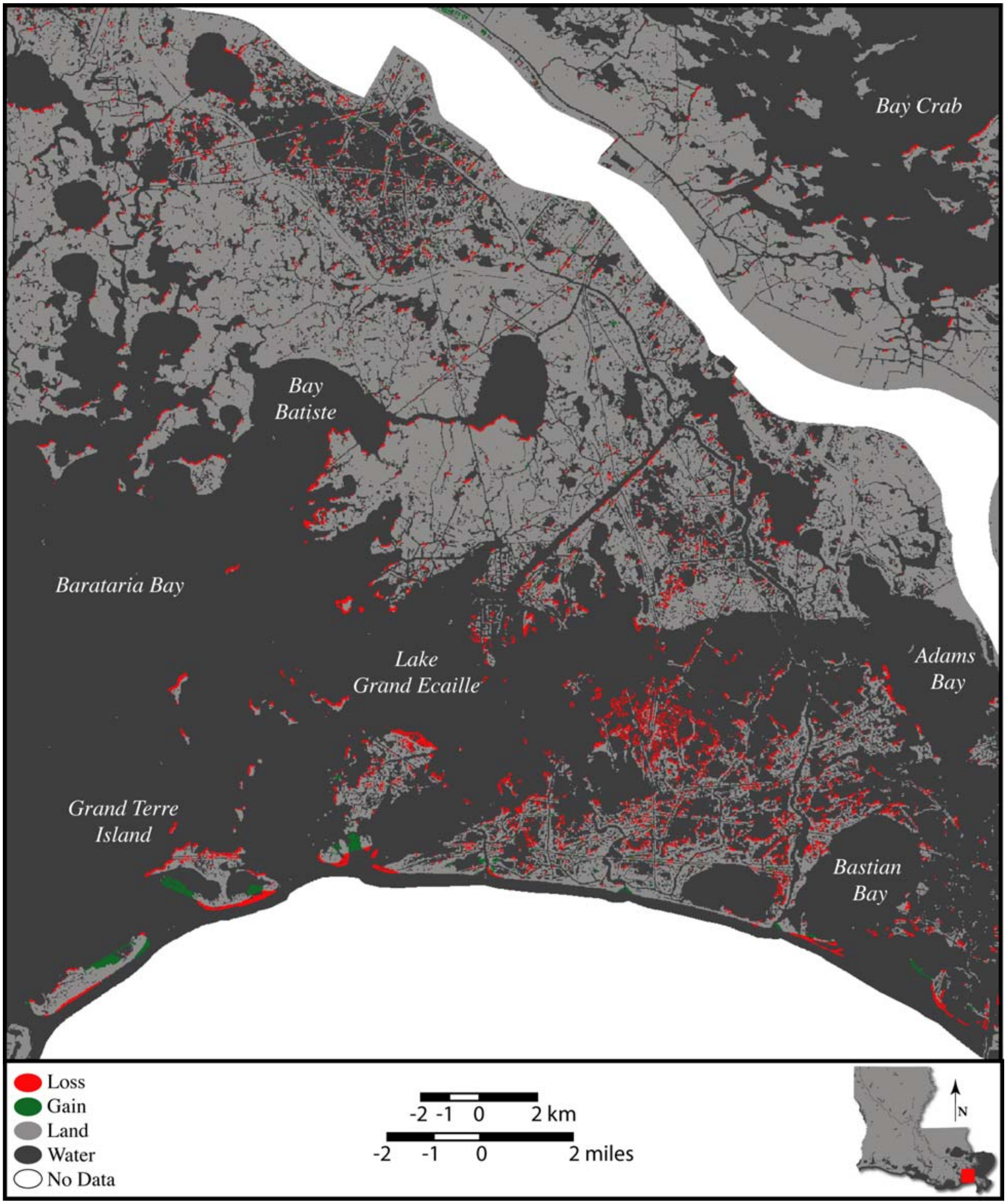

Figure 10. 1990 to 2000 spatial trend data in the vicinity of Lake Grand Ecaille in southeastern Louisiana.

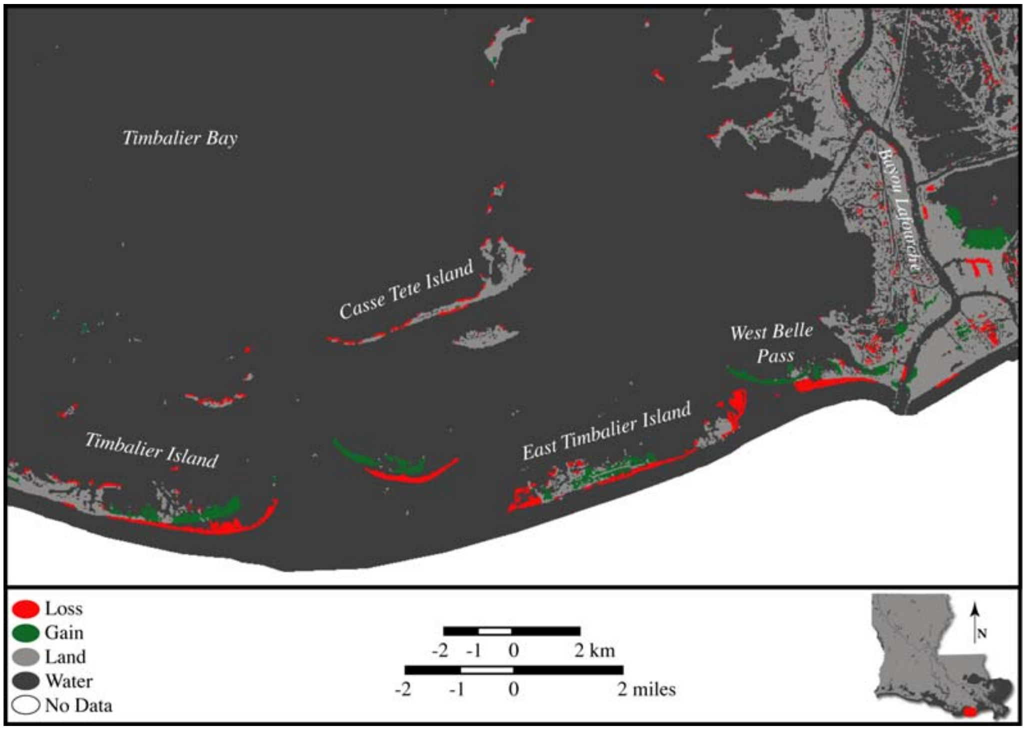

Figure 11. 1990 to 2000 spatial trend data set for southern Timbalier Bay in southeastern Louisiana.

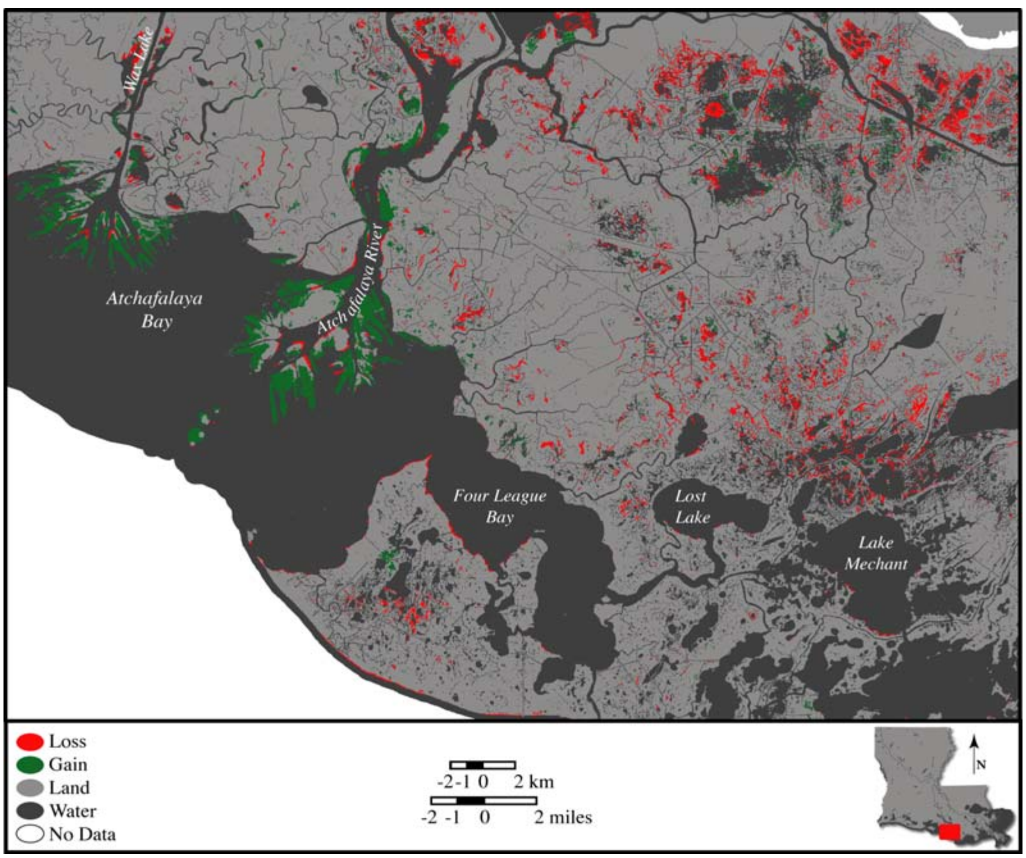

Figure 12. 1990 to 2000 spatial trend data set for southwest Terrebonne in southcentral Louisiana.

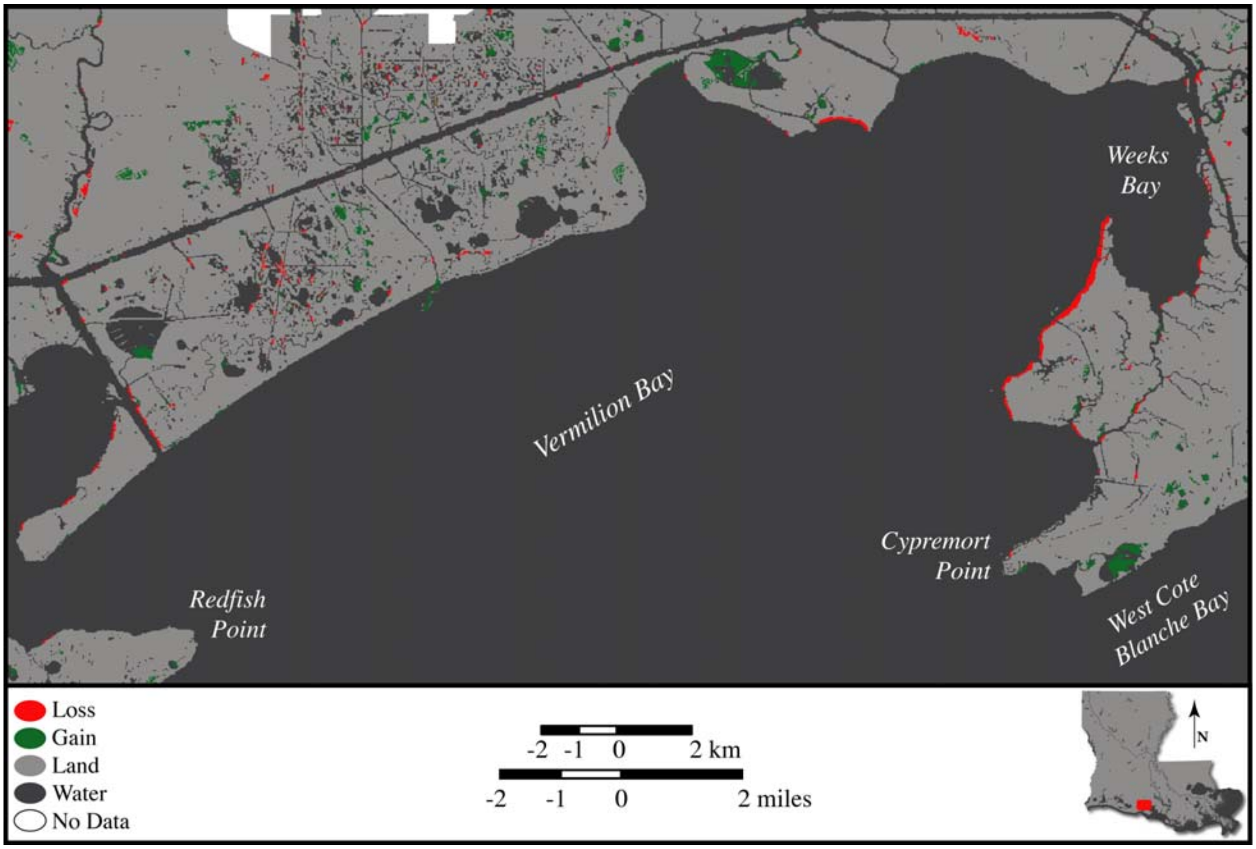

Figure 13. 1990 to 2000 spatial trend data set for northwestern Vermilion Bay in southcentral Louisiana.

Images of the entire coast show that movement of coastal sand bodies around the barrier islands continues with fragmentation in areas where restoration has not occurred. A complex pattern of erosion and land building at the Gulf of Mexico shore can be seen from Marsh Island to Sabine Pass (fig. 5) because of mudflat accretion from the Atchafalaya and the effects of jetteries and other coastal structures on sediment transport pathways.

The outlines of many restoration and marsh creation projects are readily apparent in the data as areas of land gain, such as in the Labranche wetlands (fig. 14), on west of Grand Terre Island (fig. 10), the Isles Dernieres, and with beneficial use projects near Southwest Pass (fig. 8), and in the Sabine National Wildlife Refuge adjacent to West Cove (fig. 15). Gains are also apparent from beneficial use of dredged material projects and from crevasse splay projects in the active Mississippi River Delta along Southwest Pass (fig. 8). However, at the coastwide scale, the main areas of land gain are associated with the Atchafalaya and Wax Lake Outlet deltas (fig. 12) where delta building processes continue.

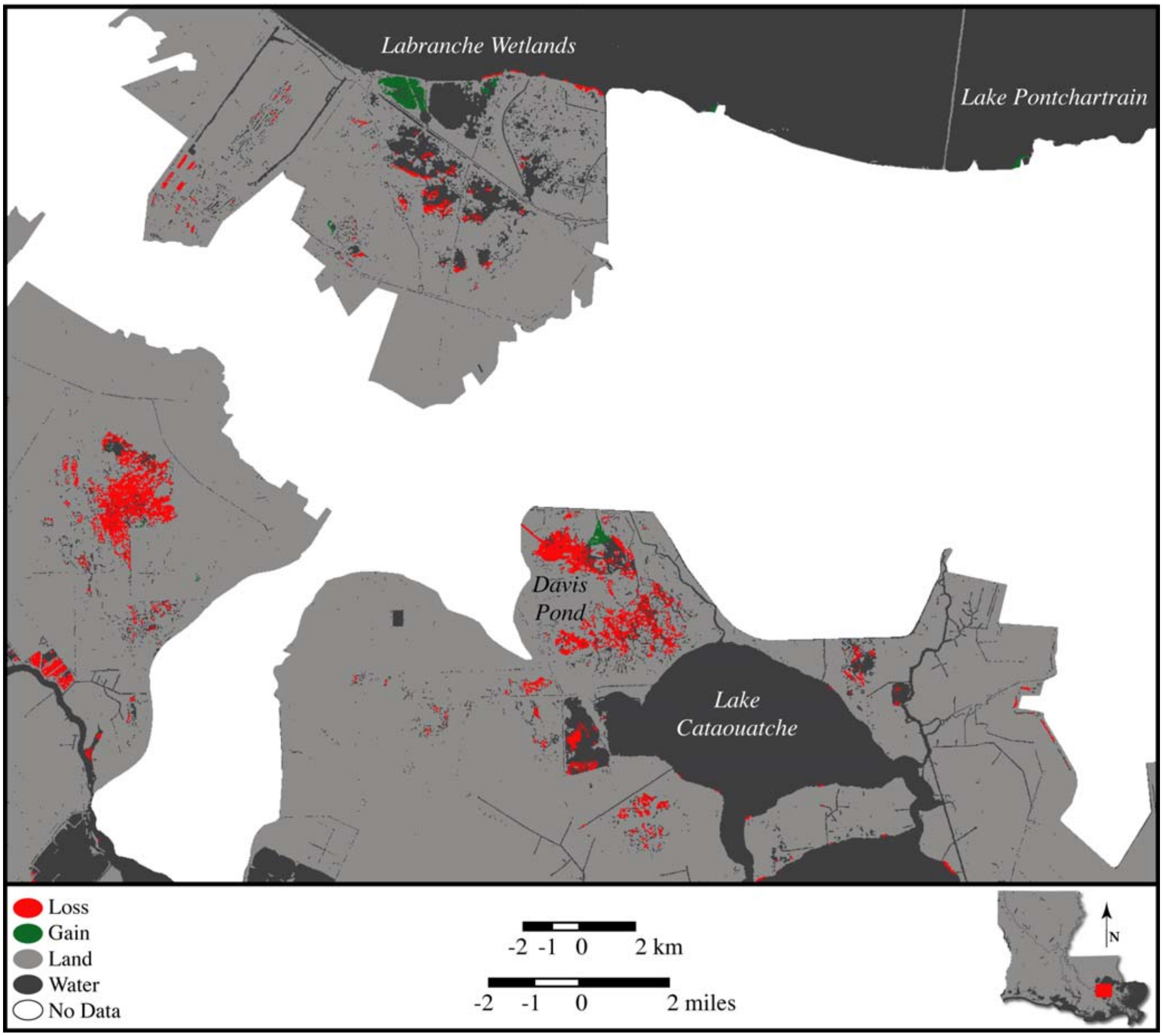

Figure 14. 1990 to 2000 spatial trend data set for the Labranche wetlands area in southeastern Louisiana.

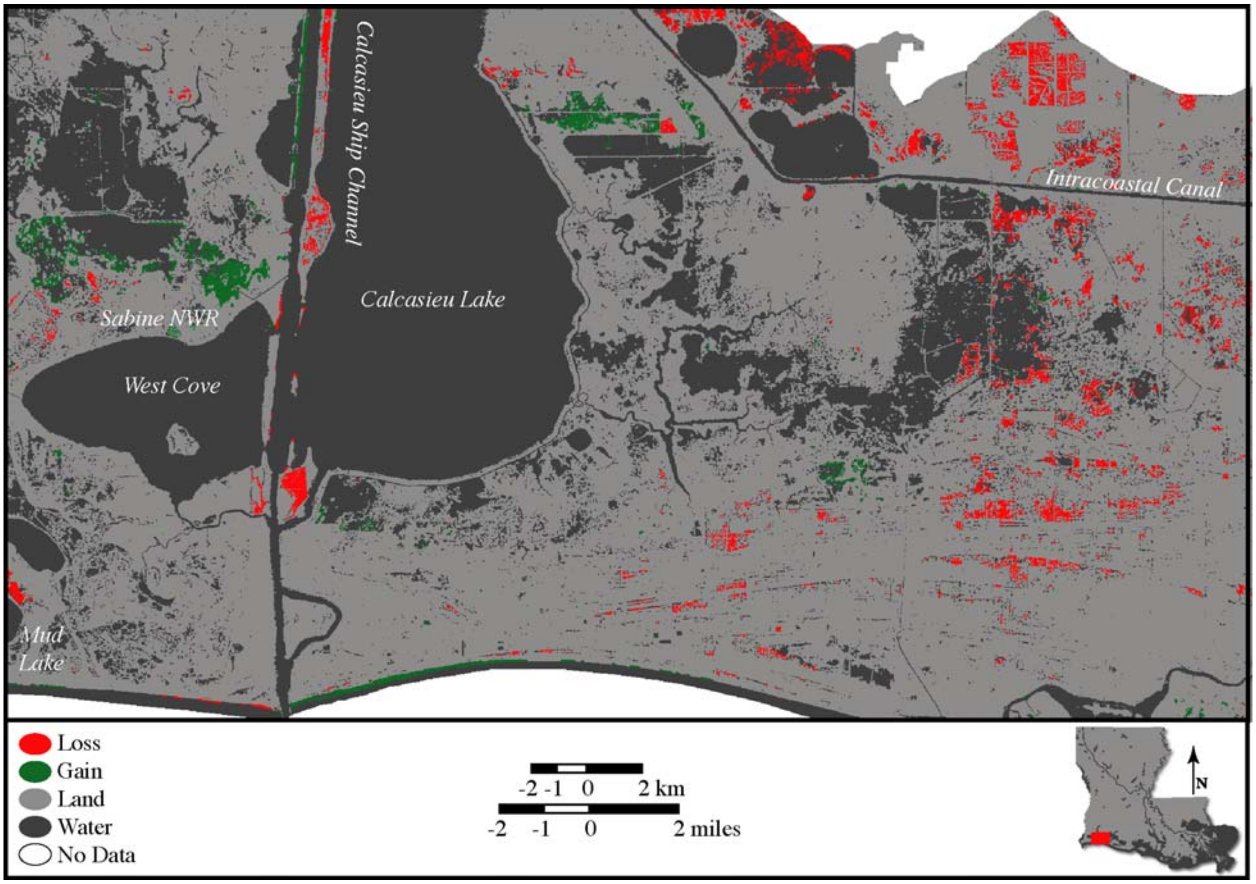

Figure 15. 1990 to 2000 spatial trend data set in the vicinity of Calcasieu Lake in southwestern Louisiana.

Because of the scale of the available images, several years of shoreline erosion and internal marsh degradation may occur before the loss is detectable by using Landsat TM based trend analysis. However, visual examination of multiple dates of TM imagery using remote sensing software clearly shows the slow degradation of wetlands. Small islands disappear and ponds increase in size or coalesce to become larger ponds. Any such small gains experienced between 1990 and 2000 cannot be considered in this analysis but are unlikely to alter the trends and patterns identified here.

Error Assessment

Classification Accuracy

Classification accuracy assessments were performed on the 1999 and 2002 Landsat TM imagery to quantify the reliability of the data sets. The accuracy assessments were performed by an experienced image interpreter who was not involved in the classification of the source TM imagery. A stratified random sampling approach was used to create an equal number of sampling points for the land and water classes merging each data set to provide overall accuracy.

To meet sampling criteria for assigning a 95% confidence level to the accuracy assessment (Thomas and Alcock, 1984), 300 sample points (150 land samples and 150 water samples) were collected. The overall classification accuracy was 92.0% for the 1999 data set and 92.3% for the 2002 data set. Most of the incorrectly classified samples were identified as either edge samples located at the boundary of the land and water classes or samples comprising thin canals and streams that were smaller than the minimum spatial resolution of the imagery.

The classification accuracy reflects how well the land and water classes were identified from the source imagery. The accuracy assessment neither accounts for variations in land and water area caused by meteorological conditions, tides, water management practices nor for inability to accurately identify floating aquatic vegetation with respect to seasonal effects.

Positional Accuracy

Landsat TM imagery is designed for regional assessments and does not serve as a surrogate for either high-resolution aerial photography or satellite imagery with spatial resolutions of 2 to 10 m. The positional accuracy of rectified TM imagery meets national map accuracy standards at 1:24,000 to 1:100,000 scales, but the level of visual detail that can be assessed from multispectral TM imagery is limited by the 30 m spatial resolution and is best suited for scales of 1:50,000 and smaller (Welch and others, 1985). Narrow linear features such as streams, canals, pipelines, and ponds that are below 30 m in width may or may not be visible in the TM imagery. Even if visible, these linear features may not be easily classified by using automated classification techniques because mixing of pixel reflectance values between land and water.

Spatial GIS Analysis

Comparing multiple dates of Landsat scenes by using GIS spatial overlay analysis to create land and water trend data sets requires precise spatial registration between scenes. Each classified pixel in the source land and water data sets is compared on a pixel-by-pixel basis. A resultant spatial trend data set is created identifying the changes among the source land and water data sets. A change pixel can be classified as: (1) land to land - no change, (2) water to water - no change, (3) land to water - change (loss), or (4) water to land - change (gain). The pixels in both data sets should occupy the same location or the resultant trend data set will exhibit false land losses and gains that are due to misregistration (+/- 1 pixel). These positional shifts are generally uniform in nature and appear as thin strips of loss or gain bordering the shorelines of canals and ponds. Spatially comparing two georegistered mosaicked coastwide data sets, such as the 1990 and the 2000 CM data sets for Louisiana's complex coastal area, may result in a positional error of as much as 30 m because of misregistration. The original trend data sets resulting from overlay analysis almost always require some type of filtering to reduce false trend "noise" caused by slight positional errors and to isolate real trends between the source data sets.

The net loss calculations derived by comparing total land and water areas between the coastwide data sets eliminate the false noise inherent in GIS trend data, but they do not indicate where trends are occurring within the coastal area. Net trends based on simple area calculations are apparent; a land and water data set has either more land or more water. However, very complex changes may be reflected in the spatial data that cannot be determined from simple area calculations denoting land or water areas. The spatial trend data depict and quantify changes in land and water areas. Accurately interpreting and quantifying these changes requires acknowledgment that some degree of procedural error is inherent within the trend data.

Environmental and Management Factors

The errors in quantifying temporal land and water change in the Louisiana coastal wetlands using classified imagery are also associated with low water conditions and management-induced changes. The Landsat TM satellite records a digital picture of a discrete instant in time for a 180 km x 185 km section of the coast. Snapshots at different time intervals are compared to determine trends in land loss and gain for a specific time period assuming that differences caused by environmental and management conditions during image acquisition are negligible. Known factors affecting trend estimates include (1) meteorological and tidal conditions at the time of image acquisition, (2) coastal morphology, (3) vegetative vigor, (4) seasonality, (5) presence or absence of floating aquatic vegetation, (6) water management practices, particularly within the Chenier Plain (LCWCRTF, 2002), (7) prevalence of burned marsh, and (8) impacts from infrequent catastrophic events such as hurricanes and floods (Bourgeois, 1994). Analysis of Landsat TM scene acquired on October 16, 2002, after the central Louisiana coast was struck by Hurricane Lili on October 3, 2002, revealed creation of over 256.6 ha of new ponds in a formerly dense healthy marsh that had shown no significant loss since the late 1970s (Barras, 2003).

All these factors contribute to error in assessing trends in land loss or gain rates. These errors associated with landscape conditions (environmental and management operations) limit the use of single values to describe trends in land loss, but require the use of a range in values that capture many contributing factors. There are not enough current classified Landsat TM data points available to accurately assign an error range to current trend data. Conservative estimates, based on knowledge gained during the LCA trend assessment and the classified land and water data set error assessment, place the trend error range at +/- 25% for this analysis. The same factors will also affect trend interpretation based on higher spatial resolution data from photography and satellites. The higher spatial resolution will allow a more precise location of the land and water interface, to within a few meters rather than 25 m, but the classification of that interface will still be affected by environmental and management conditions prevalent during image acquisition.

Land Change Projection Methodology

The future of the Louisiana coastal landscape has been projected in many ways since the land loss issue was recognized. The methods used have varied from province-scale extrapolation of land loss trends (Gagliano and others, 1981) to projection of shoreline position decades into the future (Gagliano, 1994). Recent improvement in GIS technology and refining methodology have allowed the LCA study to develop and build better projection based on previous efforts.

Previous Method of Land Loss Projections

CWPPRA Feasibility Studies

In 1995, at the inception of the two Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) feasibility studies (Mississippi River Sediment, Nutrient, and Freshwater Diversion Reanalysis and Barrier Shoreline), the U.S. Army Corps of Engineers determined that the land loss projection methodology in both studies should be consistent. A multiagency group of marsh experts was convened in 1995. This group determined that the 1974 to 1990 land loss analysis (early results from Britsch and Dunbar, 1993) was the best estimate of future loss. The 1974 to 1983 loss rate was higher than the most recent period of 1983 to 1990. The group concluded that using a rate over a longer time period (1974 to 1990) would provide a better account for the sea level-subsidence factor. The group drew polygons around areas where causes of land loss seemed to be similar. The annual percentage of marsh loss between 1974 and 1990 was determined for each polygon. These annual percentages were used to project future land-water trends in the two CWPPRA feasibility studies (see http://www.lacoast.gov for more information).

Coast 2050

The interagency Coast 2050 Loss Projection Team was formed in 1997. The results of their work are in the Coast 2050 Plan (LCWCRTF, 1998). This team concurred with the 1995 CWPPRA group that the 1974 to 1990 loss rate was the best with which to project future loss. They drew new, smaller polygons that more accurately projected loss patterns and excluded uplands. This team made adjustments in the projected loss to account for benefits of CWPPRA projects and the Davis Pond and Caernarvon Diversions, described below.

Davis Pond

The 1984 Louisiana Coastal Area Final Environmental Impact Statement (FEIS, 1984), which covered the Davis Pond (fig. 14) and Caernarvon Freshwater Diversions, projected that 50% of the land loss in the receiving area would be prevented by the project. However, the "future without" land loss rates projected to occur at the time of the FEIS were much higher and less refined than those based on more current data sets. The Coast 2050 Loss Projection Team used the 1974 to 1990 loss rates as described above. In addition the team corrected acreages of wetland types and subtracted human-caused loss. This analysis group also incorporated information from LSU Natural Systems Laboratory hydrodynamic model runs that indicated where water from Davis Pond would flow. These simulations provide insights as to the spatial distribution of where land loss may be prevented. In order to determine the location of benefits (land preserved or created) to be added, the data from this analysis were used in conjunction with the Coast 2050 mapping units. The net effects of the Davis Pond project incorporated into the Coast 2050 future projection are 29,500 acres (11,938 ha) preserved and 3,500 acres (1,416 ha) created over the 50-year project life span.

Caernarvon

Using the same protocol as the Davis Pond analysis, the projected land loss reduction was allocated to the appropriate Coast 2050 mapping units. The net effects of the Caernarvon project incorporated into the Coast 2050 future projection are 26,100 acres (10,562 ha) preserved or created over the 50-year project life span.

Mapping the Loss

The Coast 2050 Loss Projection Team used the 1993 Landsat image to determine where within each polygon the loss might be located. The team selectively modified parts of the Landsat image, based on the brightness values, to best estimate the net acreage of marsh lost in each polygon by 2050. Each 25-m pixel on the image contained brightness values based on combining bands from the original Landsat data. Brightness was then used as the land-water boundary criteria. Areas with brightness higher than the criterion were predicted to be land in 2050, and those with lower brightness were predicted to be water in 2050.

To depict land loss on the image, the brightness criterion for land was adjusted to a higher value, which resulted in less land being depicted on the image. This adjustment was made iteratively until the amount of land in each polygon matched the acreage projected to remain in that polygon in 2050. Reducing the brightness criterion removed land from the image. The amount of land preserved by CWPPRA projects (based on their Wetland Value Assessment [WVA]) (Environmental Work Group, 1998) and the river diversions was then added to the respective image in each polygon.

This technique assumes that the areas of lower brightness on the image are areas of transition from land to water and that these areas will be lost preferentially over areas with higher brightness. This assumption thus projects spatial patterns of land loss based upon the existing balance of land and water, as reflected in the brightness of the image. Similarly, land building is also deemed to occur in the water areas with brightness values closest to those of land.

Land Change Calculations for the LCA

The sources of imagery (1978 habitat data, 1990 TM data, and 1999-2002 TM data) were used to derive recent land change rates that, in turn, were used to project future change (land-water conversion) rates and patterns. Similar to the previous method, the LCA Land Change Study Group created polygons around areas with similar loss-gain patterns. The annual percentage of land loss between 1978 and 2000, or between 1990 and 2000 where 1978 data were not available, was determined for each polygon. Those annual percentage rates were used to project future trends in land-water changes. Adjustments to future projections for Caernarvon, Davis Pond, and CWPPRA projects were based on the methods of the previous analysis.

Step 1. Background Land-Water Change Rates

The LCA Land Change Study Group delineated polygons (fig. 16) across the coastal zone through visual examination of land-to-water or water-to-land (land-water) changes during the period of 1978 to 2000. These polygons were delineated based on geography, extent of land-water change, pattern of change, suspected cause of change, and expertise and experience of the Land Change Study Group. In total, 183 polygons (fig. 16) were delineated by this analysis. By delineating areas of similar change rates and patterns, a geographic-specific change rate could be applied to each polygon to project future land-water change. The methodology used to calculate the recent historical or "background" land-water change rate for each LCA polygon was based on classified Landsat TM imagery from the following years:

Majority of LCA (study area) coast: 1978 to 2000. (Represents the most applicable data sets for determining a change rate for recent history.)

Portion of LCA (study area) coast where 1978 data were not available: 1990 to 2000 (Viewed to represent most applicable data sets for determining a change rate for recent history where 1978 data were not available.)

Majority of CWPPRA project areas: 1978 to 1990 (Some CWPPRA projects produced an immediate and one-time increase in land between 1990 and 2000; to project such land increases into the future was not considered to be appropriate. The acreage created or predicted to be created by CWPPRA projects was factored into the analysis as described below.)

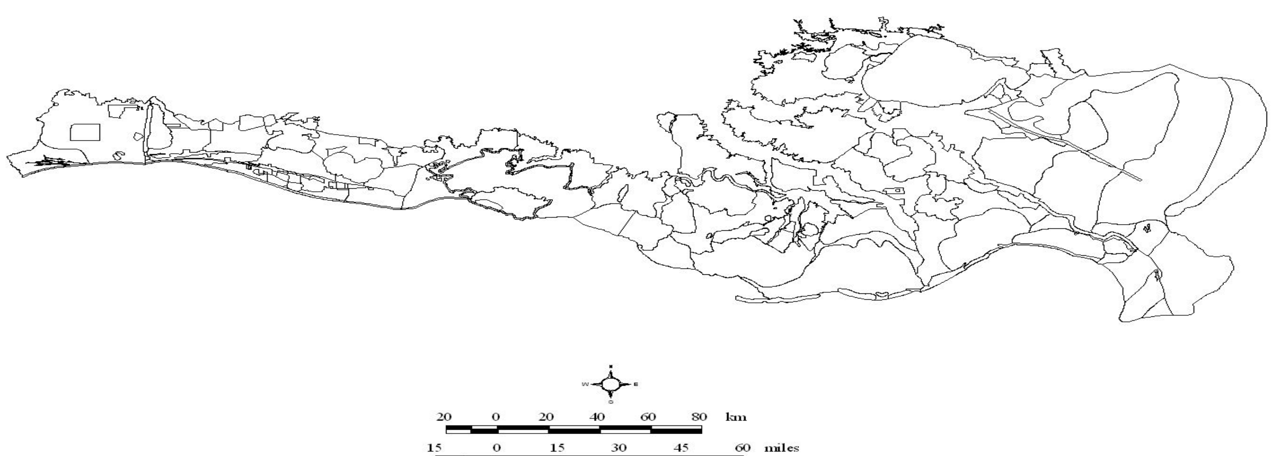

Figure 16. LCA Change Analysis Polygons.

Small portion of CWPPRA project areas where 1978 data were not available: 1990 to 2000. (Fortunately, none of the CWPPRA projects in this area produced the immediate and one-time increases in land referenced above.)

The compound rate function (formula 1) was used to calculate the annual land-water change rate. Change rates (land-water conversion) were not calculated for actively managed areas. These areas were masked out for each of the data sources because active water management can produce misclassification of land versus water. For example, when an area is intentionally flooded for management purposes, the area would likely be classified as water, potentially showing up as land loss when a true loss did not actually occur. (Note: These areas were excluded from the source data so they would not be used in generating the change rates.) Actively managed areas were depicted as they appeared in the 2000 source with no change in the 50-year projection.

Formula 1. Compound rate function used to calculate the annual land-water change.

Number of years = 22, except for 1990 data source where number of years = 10.
r = rate of annual land-water change.

IF (water2000 - water19(78 or 90) = 0) then — no net change

$r = 0$

IF (water2000 - water19(78 or 90) < 0) then — net land gain

$$r = \left(\left(\frac{water2000}{water19(78or90)}\right)^{\frac{1}{\#ofYears}}\right) - 1$$

OR if (water2000 - water19(78 or 90) > 0) then — net land loss

$$r = \left(\left(\frac{land2000}{land19(78or90)}\right)^{\frac{1}{\#ofYears}}\right) - 1$$

Effect of Existing Authorized Projects

CWPPRA Project Area Background Land Change Rates and Benefits

Except as noted above, land change within CWPPRA project areas was based on 1978 and 1990 classified Landsat imagery. The benefits of CWPPRA projects (funded-for-construction as of October 2002) are accounted for in the 50-year projection in the following manner. Small polygons that reflect the CWPPRA project area were drawn within the larger LCA polygons. The projected net land acreage gain of the CWPPRA project at the end of 20 years, based on WVA, was then added to the polygon in the year 2020.

The land acreage was added at year 20 because that is the standard life of CWPPRA projects, and addition at this point assumes that all funded-for-construction CWPPRA projects were built in 2000. Each CWPPRA polygon was adjusted for the first 20 years to include either the 1978 to 1990 or 1990 to 2000 change rates (background change rate). Because of the 20-year life for CWPPRA projects, the background change rate is applied to the entire polygon for the remaining 30 years of the LCA projection, for example, years 2020 to 2050 (fig. 17). CWPPRA projects not funded for construction as of October 2002 were not considered in this analysis. The Coastwide Nutria Control Program was not considered in the analysis because of the lack of geographic specificity of the predicted benefits.

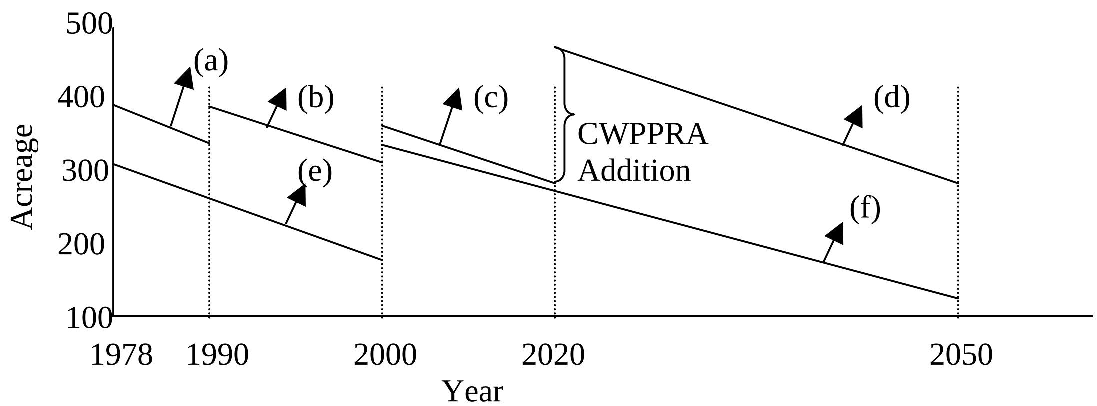

Figure 17. Application of change rate in CWPPRA and LCA sites from 1978 to 2050.

Note: (a) Estimated change rate for the1978 to 1990 time interval that was applied to all CWPPRA sites.
(b) Estimated change rate applied to the CWPPRA sites that needed the 1990 to 2000 time interval.
(c) The change rate applied to the first 20 years of CWPPRA projects; this change rate is taken from either (a) or (b).
(d) The change rate applied to the last 30 years of CWPPRA projects; this change rate is the same as (c).
(e) Estimated change rate from 1978 to 2000 for all non-CWPPRA projects.
(f) The change rate applied to the LCA polygons for 50 years.

Davis Pond and Caernarvon Benefits

The benefits of the Davis Pond and Caernarvon projects are accounted for in the 50-year projection by adding land acreage to the appropriate rate change polygon(s) at year 50 of the projection. The land acreage is added at year 50 because that is the standard life of Water Resources Development Act (WRDA) projects, and this assumes that those projects were built in 2000. The land acreage added at year 50 is the projected 50-year net acreage for each project as determined through the above-described project-specific projections.

Production of Land Loss Maps for LCA

The 2000 Landsat image was used to determine the location of land loss within each polygon. Similar to the previous method, brightness values were used as the land-water boundary criterion. However, in the previous land-water trend analysis, each polygon of the Landsat image was manually adjusted for brightness by summing the lower histogram values until the expected land-water acreage was achieved. The new automated method uses Environmental Systems Research Institute's (ESRI) ArcView Avenue code to adjust the histogram threshold. This new threshold was then applied to the Landsat image to make the image lose or gain land based on the change rate criteria.

Step 2. Projected Loss-Gain Rates

The 50-year projected land-water change for each LCA polygon is calculated based on the compound rate function (formula 2). A grid (cell) for each LCA and CWPPRA polygon with actively managed areas masked out was created from the 2002 TM image (band 5).

Formula 2. Compound rate function used to calculate the 50-year projected land-water change.

Number of years = 50, except for CWPPRA sites

IF (water2000 - water19(78 or 90) < 0) then net land gain

$$water2050 = water2000 * (1 + Rate)^{years}$$
$$land2050 = (land2000 + water2000) - water2050$$

OR, IF (water2000 - water19(78 or 90) > 0) then net land loss

$$land2050 = land2000 * (1 + Rate)^{years}$$
$$water2050 = (land2000 + water2000) - land2050$$

Band 5 of the TM image was used because it shows the most contrast in the land-water interface. The TM data were used to find the water threshold level based on the projected loss or gain. Assuming that low reflectance values on the TM scene equate to water, the water threshold is achieved by summing the low end values of the histogram until the projected value is reached. For example, with a projected land loss of 100 acres (40.5 ha), the threshold would be set to 2 as seen in the following histogram.

Threshold	Histogram Values	Acreage	Sum
...	...	...	...
3	1000	154.44	317.09
2	500	77.72	162.65
1	450	69.49	84.93
0	100	15.44	15.44

Acreage was calculated by multiplying the histogram value by 25 x 25 x 0.0002471054. The 25 m value represents the resolution of the TM imagery used (25 is the meter size of each raster pixel, multiplied together to get square meters, then multiplied by the factor 0.0002471054 to convert square meters into acres). Once threshold values have been determined each TM grid histogram is reclassified. In this example, threshold 0 and 1 would be predicted to be water in 2050 and threshold 2 and above would be predicted as land.

Step 3. Mapping Future Loss-Gain

All reclassified LCA and CWPPRA grids along with the actively managed areas were merged back together into the final 50-year projected grid. The final grid and the classified 2000 imagery were then used in a land-change analysis to determine the final land loss and gain (fig. 18). The assessment of the methodological error shows that the projected acreages of the modified Landsat imagery are within 3% of the calculated numbers of land change.

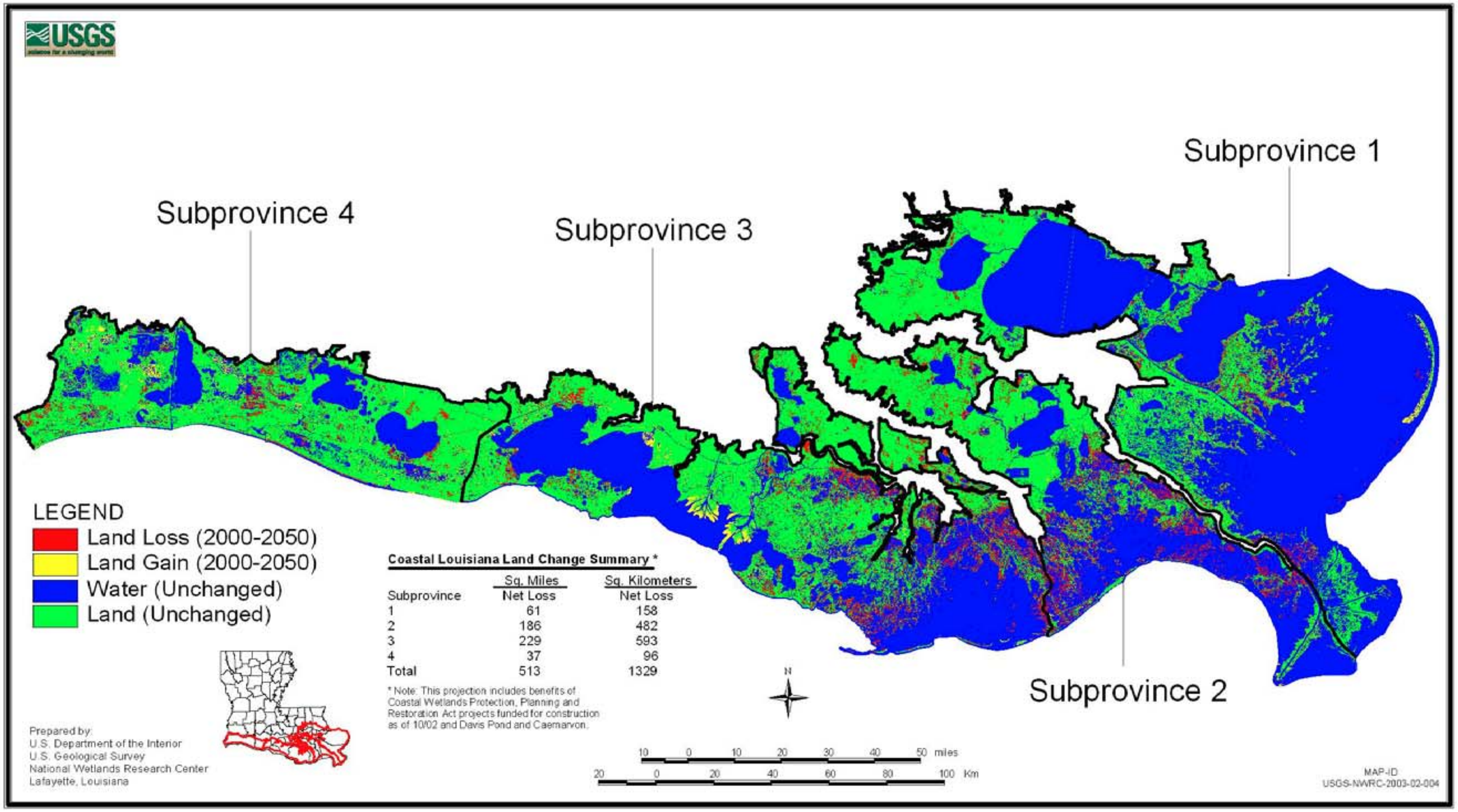

Figure 18. Projected coastal Louisiana land changes from 2000 to 2050.

Limitations of Approach

Extreme Events

This projection methodology assumes that the events and processes contributing to land loss or gain within the polygons from 1978 to 2000 continue into the future. Therefore, it includes the effects of extreme events only if they occurred during the period 1978 to 2000. The method is not truly probabilistic as it uses the actual occurrence rather than the average return period of the events that affected the coast during that time. The period does include tropical storms and hurricanes impacting the Louisiana coast, for example, Hurricane Juan in 1985 and Hurricane Andrew in 1992. The effects of the events, both in eroding shorelines and providing sediments to increase marsh elevation, are part of the projection. Similarly, the effects of both flood and low water years on the Mississippi River that occurred between 1978 and 2000 are projected to occur with the same frequency and magnitude in the future. Thus, the effect of flood years (including 1983, 1993, and 1997) that likely contributed to land gain in the Atchafalaya Delta area are included without offsetting the effects of low water years such as 1989 and 1992. The drought conditions of 1999-2001 are partially reflected in the projection. For example, the meshing of data sets from late 1999 and early 2002 for the base years reflects the inclusion of the effects of the drought. Given the uncertainties regarding the return period of drought events of this magnitude, it was not possible to fully incorporate the effects of intense drought in projecting trends on land loss or gain rates.

Assumptions on Loss-Gain Processes and Polygon Scale and Approach

A fundamental assumption of this approach to land change projections is that the processes causing land loss and land gain will continue into the future at the same rate and at the same spatial scale that they occurred at in the recent past. The use of 1978 to 2000 as a base period to derive the future land change rate is important as it largely postdates a period of massive human alteration of the coastal landscape associated with dredging of canals for oil and gas exploration and for navigation. Thus, the direct effects of these extensive dredging activities are not reflected in the rates that are projected. Indirect and ongoing effects of these activities that may result in land loss, such as altering marsh hydrology or basin-scale salinity gradients, are projected to occur in the future at the average rate that they have in the past 2 decades.

More chronic regional-scale problems such as subsidence and altered patterns of sediment delivery from the Mississippi River are projected to have the same effects in the future as in the past. Although recent data (Morton and others, 2002) suggest that extensive hydrocarbon extraction from subsurface reservoirs led to localized high rates of subsidence in previous decades, the greatest volumes of hydrocarbons were extracted in the 1960s and 1970s, at least in the fields examined by Morton and others (2002). The extraction likely reactivated faults leading to subsidence, but the timing of fault movement relative to mineral extraction has yet to be clearly identified. Thus, it is possible that during the 1980s such localized high subsidence was still occurring and resulting in land loss. Such land loss is incorporated in the rate projected into the future.

However, the spatially explicit projection methodology means that rates of land loss (or gain) are projected to continue only within the boundaries of individual polygons. Thus, any high rates associated with these withdrawal effects and not expected to continue into the future will be projected only within individual polygons.

Where small, very localized areas of high loss (or gain) occur within otherwise relatively stable areas of the coast, it is frequently not possible to identify them as separate polygons for projection. In these cases, the rate of the entire polygon will include both the locally high rate and the average rate, which will be projected across the whole area. Thus, the projected loss may not occur in the immediate vicinity of the past loss but will be distributed across the polygon. This is an artifact of the spatial scale at which the methodology allows us to project land loss. The goal of the method is to provide a spatially explicit projection. However, it cannot project in detail all the complex patterns of coastal land loss and gain occurring across the coast.

CWPPRA Projects

The attempt to incorporate the benefits of funded-for-construction (as of October 2002) CWPPRA projects relied on assumptions that produced some accompanying limitations. All funded-for-construction CWPPRA projects were assumed to be constructed in 2000. However, some land creation projects were built prior to 2000, hence their net land acreage is "double counted," first in the 2000 data base and then again at year 20 of the projection. This "double counting" is estimated at 4,500 acres (1,821 ha), and could result in a slight overestimate of land acreage at the end of the 50-year projection. Furthermore, not all funded-for-construction CWPPRA projects were constructed by 2000 and some may not ever be constructed. Therefore, their estimated net land acreage may be added in sooner than actually realized, if ever realized, and could result in a slight over projection of land acreage at the end of the 50-year projection. A second assumption is that all funded-for-construction CWPPRA projects will achieve 100% of their estimated net land acreage at the end of 20 years. However, some CWPPRA projects may have been slightly reduced in scope during the design phase without a reevaluation of benefits and not all projects perform as well as predicted. Either of these situations could result in a slight overestimate of land acreage at the end of the 50-year projection. Another assumption states that for all funded-for-construction CWPPRA projects, the project area will resume a "background" change rate after 20 years, but some CWPPRA projects can be expected to produce benefits beyond year 20. Resuming the "background" change rate could result in a slight underestimate of land acreage at the end of the 50-year projection. In addition, the Coastwide Nutria Control Program has received some implementation funding; however, it was not considered in the analysis because of the lack of geographic specificity of predicted benefits and the present level of funding being limited to 5 years. Should the project accomplish its estimated benefits (about 15,000 net acres [6,070 ha] of land at the end of 20 years), the coastwide projection of land acreage could be slightly underprojected.

Uncertainties

This projection method can only incorporate the effects of events that occurred in the past. Therefore, the effects of future changes in climate and climate variability are not directly incorporated into the projection. The effects of potentially important factors such as sea-level rise are assumed to continue at the same rate that they have in the past. This assumption may not be as problematic as it might appear. Louisiana coastal wetlands have been subjected to high rates of relative sea-level rise for centuries, which is due, in part, to high subsidence rates associated with the compaction and dewatering of deltaic sediments. The effect of historical subsidence and relative sea-level rise over the last 2 decades is incorporated into the projection. Some Louisiana marshes have adjusted to these high rates, in some cases over 1 cm/yr, while others are experiencing stress which may in part be driven by the relative sea-level rise. Morris and others (2002) recently predicted that in areas of high sediment loading, such as those in Louisiana, the limiting rate of relative sea-level rise for salt marshes is, at most, 1.2 cm/yr. Future increases in eustatic sea-level are projected to be approximately 20 cm by the year 2050 (Field and others, 2001). While many Louisiana marshes may currently be at their saturation limit, with respect to the relative sea-level rise scenario they may further deteriorate remarkably under future sea-level rise conditions. Morris and others (2002) considered tidal flooding to be the primary determinant of sediment deposition rather than the episodic high water events associated with frontal passages, tropical storms, and hurricanes. These factors likely contribute to the sustainability of existing Louisiana marshes, and it is not known how marshes will accommodate future increases in relative sea-level rise. Thus, although these projections do not take future increased sea-level rise into account, there is sufficient uncertainty regarding how Louisiana marshes might respond to these increases making their inclusion in the projection challenging.

In addition to sea-level rise, future changes in climate will influence the quantity and timing of freshwater delivery to coastal estuaries. Future changes in the flow regime of the Mississippi River are important considerations for the design and operation of river diversions to restore the coast of Louisiana. However, the existing diversions, Caernarvon and Davis Pond, divert a very small amount of current river discharge. Therefore their operation will likely only be minimally affected by climate change. In Subprovince 3, the effect of the Atchafalaya River, in both delta building and rejuvenation of adjacent wetlands, is considered in this projection to proceed at the same rate as in the last several decades. As the effect of climate change on runoff in the Mississippi Basin, and therefore the Atchafalaya, ranges from increasing discharge to decreasing discharge depending on the model used (Scavia and others, 2002), it is difficult to assess how such changes could influence the land building processes important in Subprovince 3. Whatever the net effect of climate change on basin runoff, most climate projections agree that precipitation regimes in the future will be characterized by more frequent high-intensity rainfall events and that runoff regimes will therefore become more intense. In most drainages, these “flashfloods” will most likely produce increased sediment runoff, depending on concomitant changes in land cover conditions. Thus, for the coastal zone, while there is uncertainty regarding the future discharge and sediment delivery regimes on an annual basis, the future conditions may include periodically increased sediment delivery. With higher or lower river discharge, greater relative sediment delivery will support land building and wetland rejuvenation in the area influenced by the Atchafalaya River. As with sea-level rise, the exact changes that will occur on the coast associated with future climate change have not been explicitly included in this projection. These exact changes cannot be estimated until there is increased understanding of the climate change scenarios and landscape response. However, as shown in this discussion, some aspects of coastal dynamics may not be as sensitive to conditions associated with climate change as they are to the many human modifications to the coast that have resulted in the degradation of the system.

Projected 2000-2050 Land Change Summary

The projected 2000-2050 land changes, based on the analysis described above, project total land loss as 674 sq mi (1,746 sq km) and total land gain as 161 sq mi (417 sq km). These gains were from the following sources: CWPPRA projects, 54 sq mi (140 sq km); Caernarvon diversion, 25 sq mi (65 sq km); Davis Pond diversion, 53 sq mi (137 sq km); Atchafalaya Delta building, 14 sq mi (36 sq km); and Mississippi River Delta building, 15 sq mi (39 sq km). Thus, the projected net land loss is 513 sq mi (1,329 sq km) (table 2). Land loss curves depicting land loss from 1956-2050 project gross loss (without projected gain) at 2,199 sq mi (5,695 sq km) and net loss (with projected gains) at 2,038 sq mi (5,278 sq km) (fig. 19).

Table 2. Projected net land loss trends by Subprovince from 2000 to 2050.

	Land in 2000 sq mi	Land in 2050 sq mi	Net Land loss sq mi	% Land loss between 2050 and 2000	Land loss sq mi/yr	% Total loss by area
Subprovince 1	1,331	1,270	61	4.61%	1.23	12%
Subprovince 2	1,114	928	186	16.68%	3.71	36%
Subprovince 3	1,975	1,746	229	11.59%	4.58	45%
Subprovince 4	1,431	1,394	37	2.59%	0.74	7%
Total sq mi (sq km)	5,851 (15,154)	5,338 (13,825)	513 (1,329)	8.77%	10.26 (26.57)	100%

Note that total percentage of land loss is the percentage of total net land loss (513 sq mi) in 2050 to the existing land (5,851 sq mi) in 2000.

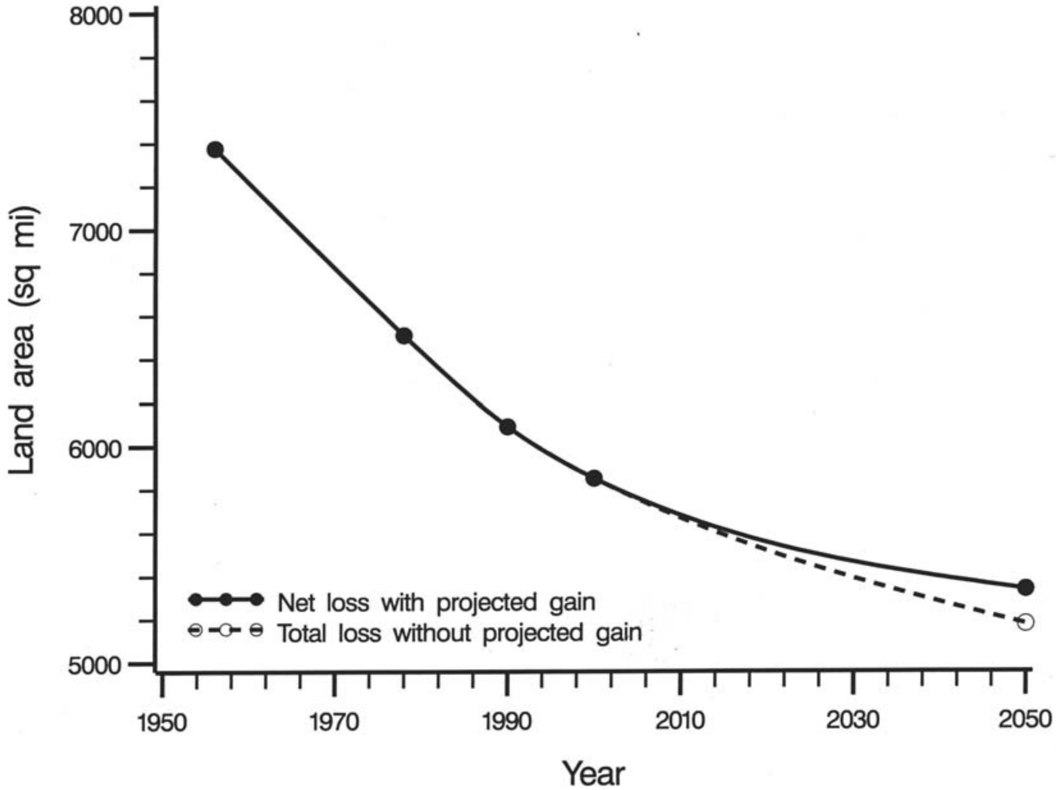

Figure 19. Projected coastal Louisiana land loss from 1956 to 2050.

Note: With the projected gain, the net loss from year 1956 to 2050 is estimated to be 2,038 sq mi (5,278 sq km) whereas without the projected gain, the estimated total loss amounts to 2,199 sq mi (5,695 sq km).

Comparisons with Previous Projections

This projection of land-water conditions presented here (table 2, fig. 18) uses the same fundamental methodology as the projection included in the Coast 2050 Plan (LCWCRTF, 1998). However, the projected magnitude of change by 2050 is the net loss of 513 sq mi (1,329 sq km), rather than the almost 1,000 sq mi (2,590 sq km) projected in 1998. There are several reasons for this change in projection:

- The 1998 projection was based on land loss rates between 1974 and 1990. The base period for the current projection is 1978 to 2000 and thus the lower rates in the 1990s project lower rates into the future.
- The spatial patterns of land loss between 1974 and 1990 projected in the earlier analysis were based on data derived from aerial imagery, and the procedure used to develop the maps focused on land loss rather than land gain (Britsch and Dunbar, 1993). Thus, the 1974 to 1990 data encompassed only "gross loss" and did not include any land gain occurring in the study area. The current analysis includes both loss and gain and the net result of both processes is projected forward in a spatially explicit manner.
- The Britsch and Dunbar (1993) data set was based on analysis of aerial photography and was largely restricted to the nonforested areas of the coast. Little data were

available for the upper basins, dominated by cypress-tupelo swamps and bottomland hardwoods. In the 1998 analysis, expert judgment was used to estimate the future loss in these areas and resulted in an estimate of over 360 sq mi (932 sq km) of swamp loss (out of the 1,000 sq mi [2,529 sq km]). In the current analysis, the Landsat TM (satellite databases) used for 1990 and 2000 covered the entire area. Therefore, using the same methodology, quantitative projections for the entire LCA area were possible.

- The loss shown in actively managed areas in the Britsch and Dunbar (1993) data was projected in the 1998 analysis. The current projection, however, excluded these areas because the LCA Land Change Study Group recognized that, at the time of the imagery, their classification as either land or water reflected the prevailing management regime rather than any trajectory of change in the coastal landscape.

The LCA Land Change Study Group considers that the net contribution of these four factors, and other minor differences in the projection methodology, account for the differences in the magnitude of the future loss projection. Most of these changes in the projection procedure represent a more thorough consideration of the factors contributing to coastal land change as a result of our increasing understanding of the coast and the use of improved technology.

Acknowledgments

Authors of this report would like to thank Dr. Bill Good, Dan Lewelyn, and Honora Burras of LA-DNR; Charles Demas and George Arcement of USGS-WRD; Pete Bourgeois and Clint Padgett of USGS-BRD; and Marty Floyd of USDA-NRCS for their reviews and comments with valuable suggestions for improvement. We express our gratitude to Dr. Robert Twilley of the University of Louisiana at Lafayette for his extensive and detailed review. We also thank Beth Vairin of USGS-BRD and Lana Wiggins of Johnson Controls World Services, Inc. for editing the manuscript at various stages.

Thanks are also extended to Dr. John Day (Louisiana State University) and Dr. Buddy Clairain (USACE), Co-chairs, in addition to the other members, of the Louisiana Coastal Area (LCA) National Technical Review Committee for providing comments and suggestions during the preparation of the report. Jay Grymes (Louisiana State Climatologist) and Gregory Steyer (Ecologist, USGS-BRD) provided ancillary hydrologic and climatic data that were used in calculating land loss rates.

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