Published in Coastal Environment and Water Quality (ed. by Y. J. Xu & V. P. Singh), 371-382.

30

CONSTRAINING RATES AND TRENDS OF HISTORICAL WETLAND LOSS, MISSISSIPPI RIVER DELTA PLAIN, SOUTH-CENTRAL LOUISIANA

Julie C. Bernier
ETI Professionals, Inc.
600 4th Street South, St. Petersburg, FL 33781, USA

Robert A. Morton
U.S. Geological Survey
Center for Coastal and Watershed Studies
600 4th Street South, St. Petersburg, FL 33781, USA

John A. Barras
U.S. Geological Survey
National Wetlands Research Center
Coastal Restoration Field Station
P.O. Box 25098, Baton Rouge, LA 70894, USA

ABSTRACT

The timing, magnitude, and rate of wetland loss were described for five wetland-loss hotspots in the Terrebonne Basin of the Mississippi River delta plain. Land and water areas were mapped for 34 dates between 1956 and 2004 from historical National Wetlands Inventory (NWI) datasets, aerial photographs, and Landsat Thematic Mapper (TM) satellite images. Since 1956, the emergent land area at the five study areas in south-central Louisiana has decreased by about 50%. Comparison of the water-area curve derived from the 29 TM images with water-level records from the nearby Grand Isle, Louisiana tide gauge (NOS #8761724) clearly shows that changes in land and water areas fluctuate in response to variations in regional water levels. The magnitude of water-area fluctuations decreased from the 1980s to the 1990s as former areas of wet marsh within and immediately adjacent to the wetland-loss hotspots became permanently submerged. The most rapid wetland loss occurred during the late 1960s and 1970s. Peak wetland-loss rates during this period were two to four times greater than both the pre-1970s background rates and the most recent wetland-loss rates. These results provide constraints on predicting future delta-plain wetland losses and identify Landsat TM imagery as an important source for analyzing land- and water-area changes across the entire delta plain.

30.1. INTRODUCTION

Determining the magnitude, rate, and timing of wetland loss in south Louisiana and identifying the underlying processes that cause historical wetland loss have been high-priority topics of scientific investigation throughout the 1990s (e.g., Britsch and Dunbar, 1993; Barras et al., 1994, 2003; Boesch et al., 1994; Williams and Cichon, 1994; Day et al., 2000; Morton et al., 2002, 2003, 2005; Penland et al., 2002; Gagliano et al., 2003). These issues take on even greater importance and urgency considering that the state is seeking substantial federal funding to restore parts of coastal Louisiana and to compensate for some of the historical wetland loss (LCWCRTF, 1998; USACE, 2004).

Approximately 4000 km^2 of low-lying coastal lands on Louisiana's delta plain have become submerged since the 1930s. Previous studies (Britsch and Dunbar, 1993; Barras et al., 1994, 2003) reported peak delta-plain land-loss rates of 60 to 75 km^2/yr from the 1960s to 1980s, with continued land loss to present at rates that are significantly higher than the 1930s to 1950s background rates (Fig. 1). Projections based on these studies, which show some decrease in land-loss rates since the 1980s, indicate future delta-plain land losses of approximately 1000 km^2 by 2050 (Barras et al., 2003). However, the reported rates are averaged over 10- to 20-year time periods. Improving the resolution of the land-loss curve will better constrain the timing and duration of peak land-loss rates, and incorporating more recent data will provide more accurate constraints on present land-loss trends.

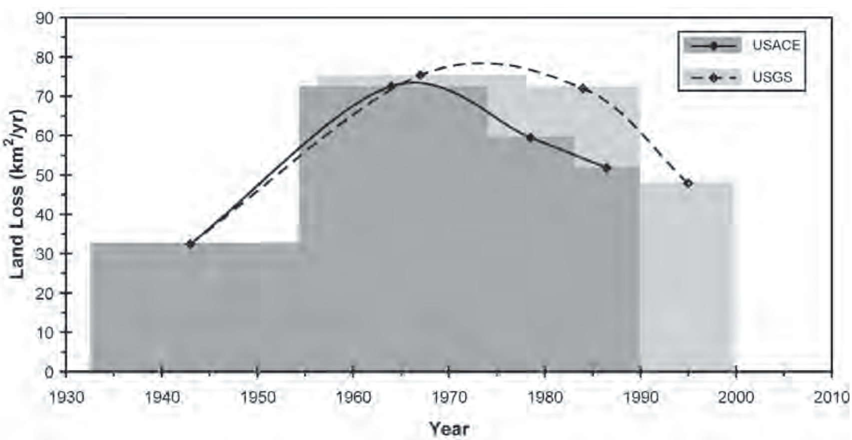

Fig. 1. Land-loss rates, Louisiana delta plain, 1932-2000. Data from the U.S. Army Corps of Engineers (USACE; Britsch and Dunbar, 1993) and the U.S. Geological Survey (USGS; Barras et al., 2003).

The purpose of this study is to further examine the timing, magnitude, and historical trends of wetland losses by establishing detailed patterns of land- and water-area changes at five representative wetland-loss hotspots (Fig. 2) in the Terrebonne Basin of the Mississippi River delta plain in south-central Louisiana. The delta-plain ecosystem is dominated by wetlands consisting of saline, brackish, intermediate, and freshwater marshes. Other delta-plain land areas include barrier islands, beaches, natural and artificial levees, fastlands, and

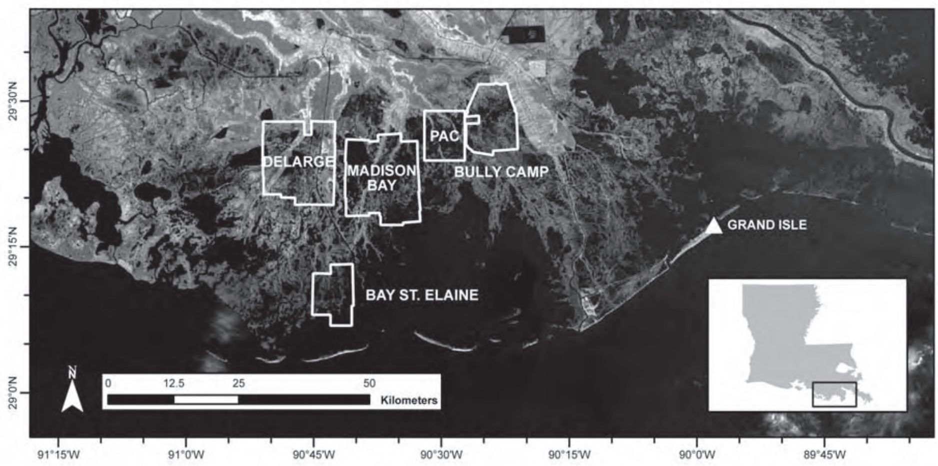

Fig. 2. Regional map of the Mississippi River delta plain in south-central Louisiana showing study area locations and the Grand Isle, Louisiana tide gauge (NOS #8761724). Landsat TM image acquired 4/16/05; visual display uses band 5 (mid-infrared). PAC = Pointe au Chien.

freshwater swamps (LCWCRTF, 1998; USACE, 2004). Because the selected study sites form only a small subset of the delta plain, land areas within the combined study area consist primarily of wetlands and levees, and essentially all land losses are wetland losses.

30.2. METHODS

30.2.1. Imagery Sources and Classification Methods

Modified National Wetlands Inventory (NWI) habitat data (Wicker, 1980; Barras and others, 1994), aerial photographs, and Landsat Thematic Mapper (TM) satellite images were used to quantify land and water areas for 34 dates between 1956 and 2005 (Table 1) for the five study areas (Fig. 2). The 1956, 1978, and 1988-1989 NWI data and the 11/1/90, 11/18/99, and 2/27/02 TM images were previously used to assess recent historical trends of land loss and land gain for coastal Louisiana (Barras et al., 1994, 2003). The 1956 land-water classification was used to establish the initial conditions for this study. Additional aerial photographs and TM images were acquired to provide better definition of temporal trends for the study areas. The 1968-1969 panchromatic (PAN) photographs and the 1974 color-infrared (CIR) photographs provided two additional datasets for assessing land- and water-area changes before 1978. Multiple TM images allowed for high-frequency (semi-annual to annual) temporal analysis of land- and water-area changes between 1983 and 2005.

The PAN and CIR photographs were rectified and the land-water distribution was classified using the methods described by Morton et al. (2005). These images were scanned from prints and often needed to be enhanced to discriminate between land and water in areas of poor contrast or sun flare. The 1:20,000 (1x1-m) spatial resolution of the PAN

Table 1. Land-water classification by date for the combined study area (Bay St. Elaine, Madison Bay, DeLarge, Pointe au Chien, and Bully Camp wetland-loss hotspots) and daily average water levels recorded at the Grand Isle, Louisiana tide gauge (NOS #8761724) for the corresponding Landsat Thematic Mapper (TM) image acquisition dates. MWL = mean water level; NWI = National Wetlands Inventory; PAN = panchromatic; CIR = color-infrared.

Date	Data	Land Area (km^2)	Water Area (km^2)	Total Area (km^2)	% Land	% Water	Water Level (m NAVD88)	Predicted MWL (m NAVD88)
1956	NWI	538.80	132.03	670.83	80.32%	19.68%		
1968-1969[1]	PAN	468.52	201.84	670.36	69.89%	30.11%		
1974[2]	CIR	349.19	317.47	666.66	52.38%	47.62%		
Oct. 1978	NWI	386.53	284.21	670.74	57.63%	42.37%		
1/6/1983[3]	TM	394.20	276.63	670.83	58.76%	41.24%	-0.157	-0.105
4/6/1984	TM	399.49	271.34	670.83	59.55%	40.45%	-0.289	-0.097
9/29/1984	TM	358.26	312.57	670.83	53.40%	46.60%	-0.060	-0.093
1/19/1985[3]	TM	379.62	291.21	670.83	56.59%	43.41%	-0.178	-0.091
8/31/1985	TM	311.85	358.98	670.83	46.49%	53.51%	0.386	-0.087
3/27/1986	TM	374.04	296.79	670.83	55.76%	44.24%	-0.235	-0.083
10/8/1987[3]	TM	368.90	301.93	670.83	54.99%	45.01%	-0.161	-0.073
1/28/1988	TM	399.96	270.87	670.83	59.62%	40.38%	-0.384	-0.071
1988-1989[4]	NWI	396.09	274.61	670.71	59.06%	40.94%		
12/16/1989	TM	398.36	272.47	670.83	59.38%	40.62%	-0.290	-0.058
11/1/1990	TM	328.52	342.31	670.83	48.97%	51.03%	0.052	-0.052
10/11/1991[3]	TM	329.32	341.51	670.83	49.09%	50.91%	-0.019	-0.045
10/5/1992	TM	314.22	356.61	670.83	46.84%	53.16%	0.094	-0.039
1/25/1993[3]	TM	337.41	333.42	670.83	50.30%	49.70%	0.007	-0.037
3/17/1994	TM	329.23	341.60	670.83	49.08%	50.92%	-0.101	-0.029
11/15/1995[3]	TM	317.37	353.46	670.83	47.31%	52.69%	-0.070	-0.018
4/7/1996	TM	327.66	343.17	670.83	48.84%	51.16%	-0.092	-0.015
10/3/1997[3]	TM	311.70	359.13	670.83	46.47%	53.53%	-0.067	-0.005
2/24/1998	TM	325.87	344.96	670.83	48.58%	51.42%	-0.225	-0.002
1/26/1999	TM	323.42	347.41	670.83	48.21%	51.79%	-0.148	0.004
11/18/1999[3]	TM	289.91	380.92	670.83	43.22%	56.78%	0.020	0.010
10/11/2000	TM	295.89	374.94	670.83	44.11%	55.89%	-0.098	0.016
10/30/2001[3]	TM	296.22	374.61	670.83	44.16%	55.84%	0.021	0.023
2/27/2002	TM	325.95	344.88	670.83	48.59%	51.41%	-0.243	0.025
12/28/2002	TM	299.80	371.03	670.83	44.69%	55.31%	-0.184	0.031
10/20/2003	TM	284.05	386.78	670.83	42.34%	57.66%	0.155	0.037
11/7/2004	TM	290.24	380.59	670.83	43.27%	56.73%	0.024	0.044
4/16/2005[3]	TM	285.37	385.46	670.83	42.54%	57.46%	-0.037	0.047
10/9/2005	TM	274.23	396.60	670.83	40.88%	59.12%	0.137	0.050
10/25/2005	TM	282.10	388.73	670.83	42.05%	57.95%	-0.062	0.050

[1] 1968-1969 images acquired 12/15/68, 3/9/69, 3/16/69, 3/17/69, 3/19/69, 3/26/69, and 3/27/69

[2] 1974 images acquired 9/17/74 and 10/18/74

[3] Image-acquisition dates for which the daily, previous day, and 3- and 7-day running average water levels at the Grand Isle, Louisiana tide gauge (NOS #8761724) were within one standard deviation (0.0910 m) of the mean water-level trend line

[4] 1988-1999 NWI source imagery acquired 11/21/88 and 1/17/89

photography revealed detailed land-water patterns not visibly evident in either the small-scale (1:119,000 to 1:128,000) 1974 CIR photography or the satellite imagery (28.5x28.5-m spatial resolution).

The Landsat TM data consisted of cloud-free to nearly cloud-free TM 4, 5, and 7 scenes. All scenes were converted from radiance to reflectance values prior to land-water classification. The scenes were then classified applying the same methods used to develop the original TM land-water data sets (Barras et al., 2003). The multi-band TM imagery provided better spectral discrimination of marsh “wetness” than either the PAN or CIR photography. Wet marsh is a sub-category of land that appears wetter than the surrounding marsh in the TM imagery due to the absorption of mid-infrared and near-infrared wavelengths but has a higher spectral reflectance of the infrared bands than water. A RGB visual display combination of TM spectral bands 4 (near-infrared), 5 (mid-infrared), and 3 (visible red) can be used to discriminate between water, wet marsh, and emergent marsh (land) areas. Wet marsh is usually located adjacent to ponds and in areas where the emergent marsh is fragmenting into networks of broken marsh and open water. The extent of wet marsh varies depending on water level, marsh elevation, spectral-reflectance variations linked to the seasonal marsh-vegetation growth cycle, and density of vegetative cover.

All classified land-water datasets were resampled to a standard 25x25-m cell size to provide a consistent spatial resolution for assessing changes in land and water area over time. A thematic raster data set was created containing the minimum shared area for each study area encompassed by all land-water datasets from 1956 to 2005. The maximum extent of the compared area for each site was controlled by the availability of the 1968-1969 PAN frames. A composite land-water summary was created for the combined study area for each image-acquisition date.

30.3. ANALYTICAL METHODS

Historical land-water changes are assessed by comparing changes in the distribution and total size of land and water areas between selected image dates. Average annual rates of change are derived for each period by dividing the total change in water or land area by the number of years between observations. Ideally, environmental conditions effecting the land-water distribution at the time of image acquisition should be similar, and there should be no major differences in classification methods that might increase or decrease the interpreted land or water area.

The interpretation of land- and water-area trends derived from the historic NWI habitat data and aerial photographs between 1956 and 1978 were based on decadal or multi-decadal comparisons due to the high cost of obtaining and interpreting coast-wide photography. The aerial photographs were often acquired over a period of several days due to weather conditions and acquisition-platform capabilities. As a result, water levels likely fluctuated between frames. These effects could not be quantitatively assessed because accurate daily water-level data and multiple photographs bracketing known high- and low-water conditions were not available for this time period.

Determining the present average land and water areas and current land-loss rates requires developing classification methods that account for natural variations in land and water areas. One approach to obtaining recent trend estimates is to acquire and classify multiple images separated by short periods using a standard acquisition platform. Ranges and averages of land and water areas can be compared over time and general trends can be described, regardless of short-term fluctuations in land and water areas (Fig. 3). An overall increase in average water area through time indicates continued land loss as low-lying wetlands become permanently submerged.

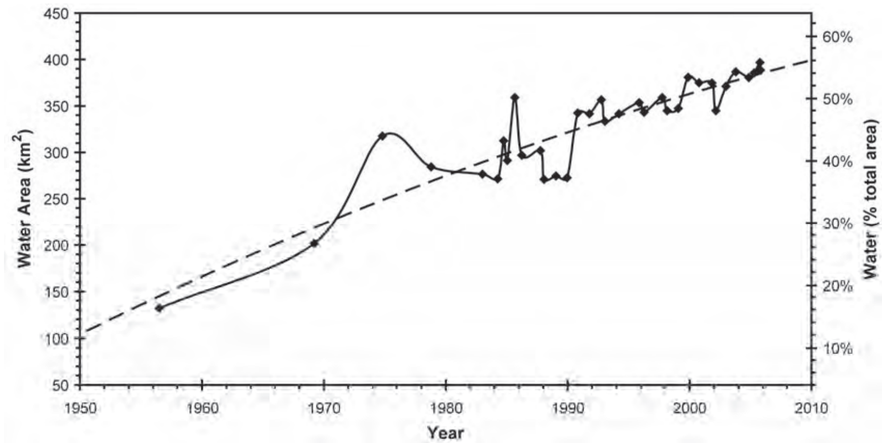

Fig. 3. Composite historical water area from 1956 to 2005 for the Bay St. Elaine, Madison Bay, DeLarge, Pointe au Chien, and Bully Camp wetland-loss hotspots. Although water-area fluctuations are evident, the trend line shows a general increase in open water area through time, indicating continued wetland loss.

A second approach is to identify those data points that are most representative of "average" water-level conditions, and use this subset to quantify trends in land- and water-area changes. Analysis of the 29 TM data points, representing a 22-year period, provides a clearer understanding of the effects of water-level variations on land-water classification over annual and decadal time scales. Variations in water levels recorded at the National Ocean Service (NOS) Grand Isle, Louisiana tide gauge (NOS #8761724) correlate well with the shape of the classified water-area curve (Fig. 4). Image-acquisition dates for which the classified TM data forms peaks on the water-area curve (e.g., 8/31/85, 10/5/92, and 10/9/05) correspond to dates on which peak water levels were recorded at NOS #8761724. Conversely, image-acquisition dates for which the classified TM data forms lows on the water-area curve (e.g., 4/6/84, 1/28/88, 12/16/89, and 2/27/02) correspond to recorded low water levels at NOS #8761724. These relationships may reflect some seasonal effects: the high water area/high water level images were acquired during the late summer and early fall whereas the low water area/low water level images were acquired during the winter and early spring.

Water-level readings from NOS #8761724 were used to identify Landsat TM acquisition dates that represented "average" water-level conditions. Daily and monthly average water levels at NOS #8761724 from 1981 to 2005 were computed from the raw hourly records. A linear regression of the monthly averages represents the best estimate of

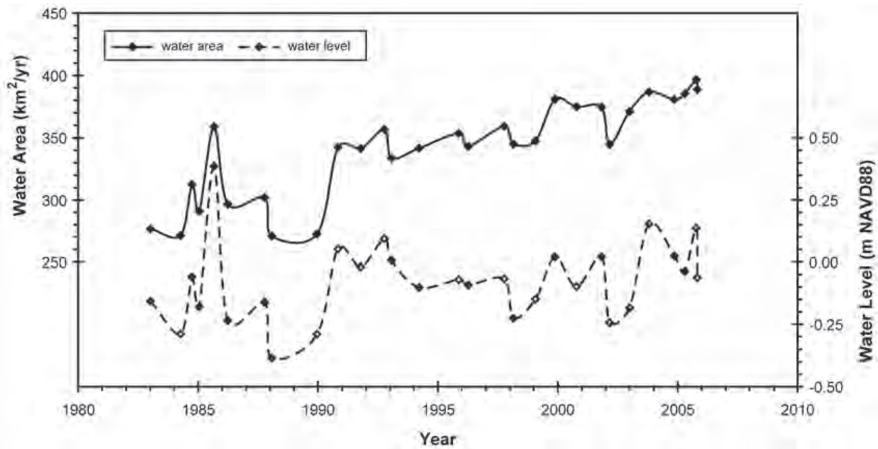

Fig. 4. Composite historical water area from 1983 to 2005 for the Bay St. Elaine, Madison Bay, DeLarge, Pointe au Chien, and Bully Camp wetland-loss hotspots compared to daily average water levels recorded at the Grand Isle, Louisiana tide gauge (NOS #8761724) for the corresponding Landsat TM image acquisition dates.

"average," or expected, water levels through time. "Average" water-level data points were defined as those TM acquisition dates for which the daily, previous day, and 3- and 7-day running averages all were within one standard deviation (0.0910 m) of this mean water-level trend line (Table 1, Fig. 5). The classified land and water areas from these dates were

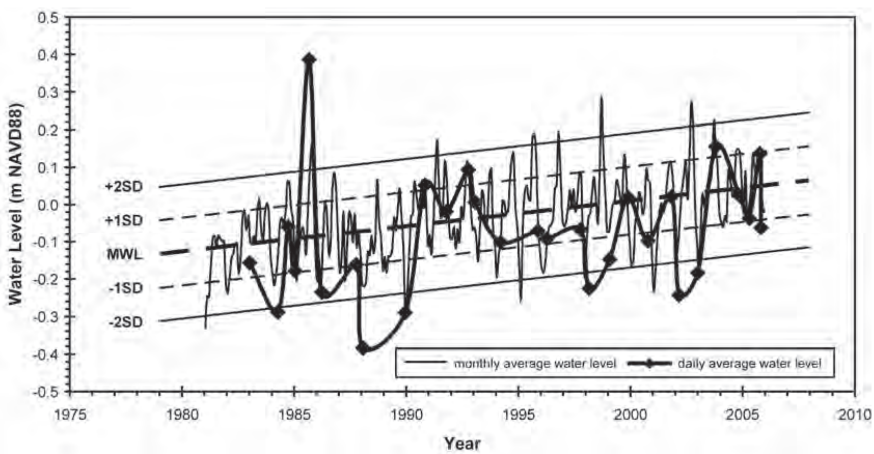

Fig. 5. Monthly mean water level from 1981 to 2005 compared to daily average water levels for Landsat TM image acquisition dates at the Grand Isle, Louisiana tide gauge (NOS #8761724). Similar plots were generated using daily average water levels from one day prior to image acquisition and 3- and 7-day water-level averages. MWL = monthly mean water level.

used to calculate the post-1983 land-loss rates averaged over approximately 4-year time periods (Fig. 6). By using those images that were acquired on "average" water-level days, the effects of extreme seasonal or meteorological conditions on the land-water classification are minimized.

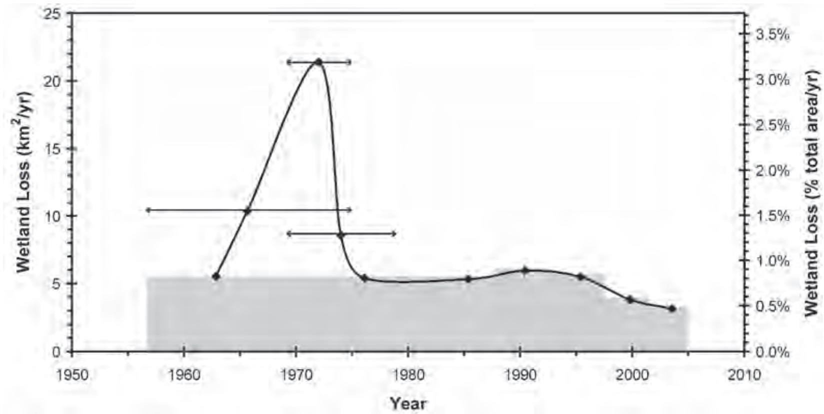

Fig. 6. Rate of wetland loss for the combined study area from 1956 to 2005. The post-1983 rates were calculated from Landsat TM imagery acquired on dates for which the daily, previous day, and 3- and 7-day running average water levels at the Grand Isle, Louisiana tide gauge (NOS #8761724) were within one standard deviation of the mean water-level trend line. Peak wetland-loss rates are two to four times higher than the pre- and post-1970s background rates.

30.4. RESULTS

Total wetland loss in the combined study area is about 250 km^2, or about 50% of the 1956 land area. Analysis of land- and water-area changes for the combined study area (Fig. 3) reveals a pattern of increasing land-area loss from the 1950s through the late 1960s, rapidly accelerating land loss in the 1970s, and short-term fluctuations between land loss and land gain from the 1980s to present. Net water area varied by as much as 10% between observed high- and low-water conditions since 1983 based on the TM data. The derived wetland-loss curve (Fig. 6) shows a rapid increase in wetland-loss rates from the late 1960s to 1970s. Wetland-loss rates during this time period were two to four times higher than the pre-1970s rates. In contrast, average wetland-loss rates since the 1980s are of similar magnitude to the pre-1970s rates.

30.5. DISCUSSION

30.5.1. Historical Land-Water Changes, 1956-2005

The ability to interpret the effects of water-level variations during the 1960s and 1970s was hampered by the lack of a standard image acquisition platform with multiple data points, the necessity of combining data from multiple image-acquisition dates to cover the entire study area, and the unavailability of daily water-level data. The 1974 data were likely acquired under high-water conditions based on the total water area and visual comparison with later images. Comparison of the 1974 CIR imagery and the original 1978 CIR photographs used to develop the NWI habitat data suggests that the 1978 data were acquired under lower water-level conditions; however, visual review of the original imagery suggests that the NWI classification methodology also appears to have underestimated the total water area.

Between 1983 and 1989, only the 8/31/85 water area exceeded the 1974 water area for the combined study area (Fig. 3). The 8/31/85 peak water area and the corresponding extreme elevated water levels recorded at the Grand Isle tide gauge (Figs. 4 and 5) were likely effected by Hurricane Elena, which was located offshore of southeastern Louisiana in the Gulf of Mexico. The counter-clockwise easterly winds would have pushed water onshore along the Louisiana coastline. Excluding this data point, the average water area for 1983 to 1989, including the NWI habitat data, was about 5% less than the 1974 water area. The TM data may underestimate water area compared to the aerial photography (Ramsey and Laine, 1995), and/or the 1974 photography may reflect anomalous high-water conditions. High-water conditions in 1974 may have resulted from incomplete recovery of the delta-plain wetlands after severe flooding from the Mississippi River in 1973 and/or remnant elevated water levels following landfall of Hurricane Carmen near Morgan City, Louisiana on 9/8/74.

After 1990, the water area from the TM data consistently exceeded the 1974 water area, indicating that some marsh areas that were previously alternately exposed or submerged under varying water-level conditions had become permanently submerged. At the same time, the average water area increased to over 50% of the total study area, corresponding to the submergence of remnant wet marsh that was exposed during low water events in the 1980s. Permanent submergence of previously emergent wet marsh is also suggested by comparing the magnitude of water-area fluctuations between 1983 to 1990 and 1991 to present. From 1983 to 1990, the total water area varied by 5 to 10%; since 1991, the total water area has varied by only 2 to 5% (Fig. 3). Between these same time periods, however, the average range of water-level variations recorded at the Grand Isle tide gauge did not change significantly. Thus, by the 1990s, some areas of wet marsh were completely submerged and no longer exposed under low-water conditions.

30.6. HISTORICAL SUBSIDENCE OF DELTA-PLAIN MARSHES AND FORMATION OF WETLAND-LOSS HOTSPOTS

The image analysis enables quantification of land- and water-area changes and visual depiction of the resultant temporal trends, but interpretation of the classified land-water data and trends also requires examination and comparison of source photography and satellite imagery at local and regional scales to visually verify changes. The five study sites were previously identified (Morton et al., 2005) as areas of extensive wetland losses ("hotspots") in south-central Louisiana for which visual review of historical imagery indicated that emergent marsh areas converted to open water very rapidly during the late 1960s to mid 1970s. Morton et al. (2003, 2005) described the shallow subsurface stratigraphy at each of the five study areas from sediment vibracores taken near the center of each wetland-loss hotspot. Correlation of recent peat deposits showed that subsidence was the primary mechanism of wetland loss at these locations. The uppermost peats from recently-submerged cores are similar in thickness to the uppermost peats from adjacent emergent-marsh core locations, indicating that subsequent erosion of the delta-plain marsh was relatively minor. This is consistent with the observed pattern of wet marsh submergence, with permanent submergence occurring only after the land has subsided beyond some critical threshold. Although some shoreline erosion occurs within the study areas, subsidence and water-level effects appear to have a greater impact on observed water area and wetland loss in the interior marshes.

The timing and patterns of regional land- and water-area changes provide insight into how local wetland-loss histories fit into the overall patterns of wetland loss. Visual examination of selected (unclassified) aerial photographs from 1940, 1953, and 1957, as well as the original 1978 CIR photography, showed that between 1940 and 1957, the regional landscape was dominated by unbroken interior marsh between distributary levees, and the 1953 and 1957 landscape closely resembled the 1956 land-water conditions. Some marsh-surface fragmentation was apparent within future hotspot areas by 1968-1969. Large historic wetland-loss hotspots characterized by widespread marsh fragmentation and well-developed ponds with large tracts of adjacent wet marsh were well-defined by 1974. The 1974 and 1978 landscape more closely resembled the mid-1980s landscape than it did the 1968-1969 landscape, indicating that that much of the historic wetland loss occurred before 1978. Some areas identified as water in 1974 were exposed as marsh in 1978, indicating that water-level fluctuations effected land-loss interpretations. Areas that were identified as water in 1974 and land in 1978 were generally permanently submerged by the late 1980s or early 1990s, often after repeated cycles of exposure and submergence. Remnant emergent-marsh islands, natural levees, and spoil mounds are often the only remaining areas of exposed land within the historic wetland-loss hotspots.

The study sites fall within scene 2240 (path/row) of the Landsat TM World Reference System. Visual analysis of multiple 180x185-km scenes under varying meteorological and water-level conditions between 1983 and 2005 shows that persistent wet marshes were commonly located next to former or developing wetland-loss hotspots. Wet marshes located within and adjacent to historic (1970s) delta-plain wetland-loss hotspots typically became permanently submerged and converted to open water between 1983 and 2005. Identification of persistent wet marsh over multiple periods indicated that new wetland-loss hotspots also formed after 1983 but were not as large or as numerous as those that formed between 1956 and 1978.

30.7. CONCLUSIONS AND IMPLICATIONS

Analysis of historical photographs and satellite images from five wetland-loss hotspots in south-central Louisiana show that delta-plain wetland losses had initiated by the late 1960s. Rapid acceleration of wetland loss and the development of large wetland-loss hotspots with associated wet marsh occurred during the 1970s. The late 1970s through 1980s were characterized by continued wetland loss. During the 1980s and 1990s, land and water areas fluctuated significantly, reflecting variations in regional water levels. The magnitude of the land- and water-area fluctuations decreased in the 1990s relative to the 1980s, corresponding to complete submergence of former wet-marsh areas that occurred within and immediately adjacent to historic wetland-loss hotspots. The most recent wetland-loss rates are significantly lower than the 1970s peak rates and are similar in magnitude to the pre-1970s background rates.

Although wetland-loss rates for discrete periods are probably not linear, average annual wetland-loss rates based on historical data provide constraints for estimating future wetland losses and are important for assessing the feasibility of wetland-restoration projects in coastal Louisiana. The Landsat TM satellite imagery does not have the high spatial resolution of most aerial photographs; however, it offers a relatively inexpensive way of monitoring both short- and long-term changes in land and water areas across a broad geographic area. In addition, the standardized filtering and classification process produces rapid and reproducible results. The identification of wet marsh areas as potentially high-risk areas for future wetland loss offers a previously-unrecognized predictive tool that can be incorporated into marsh-management and wetland-loss mitigation plans.

REFERENCES

Barras, J.A., Bourgeois, P.E., and Handley, L.R., 1994. Land loss in coastal Louisiana 1956-90. National Biological Survey, National Wetlands Research Center Open-File Report 94-01, 4 p.

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. U.S. Geological Survey Open-File Report 03-334, 39 p.

Boesch, D.F., Josselyn, M.N., Mehta, A.J., Morris, J.T., Nuttle, W.K., Simenstad, C.A., and Swift, D.J.P., 1994. Scientific assessment of coastal wetland loss, restoration and management in Louisiana. Journal of Coastal Research, Special Issue 20, 103p.

Britsch, L.D., and Dunbar, J.B., 1993. Land-loss rates: Louisiana coastal plain. Journal of Coastal Research 9:324-338.

Day, J.W. Jr., Shaffer, D.P., Britsch, L.D., Reed, D.J., Hawes, S.R., and Cahoon, D.R., 2000. Pattern and process of land loss in the Mississippi Delta, a spatial and temporal analysis of wetland habitat change. Estuaries 23:425-438.

Gagliano, S.M., Kemp, E.B., Wicker, K.M., Wiltenmuth, K.S., and Sabate, R.W., 2003. Neo-tectonic framework of southeast Louisiana and applications to coastal restoration: Transactions – Gulf Coast Association of Geological Societies 53: 262-276.

Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority (LCWCRTF), 1998. Coast 2050: Toward a sustainable coastal Louisiana. Louisiana Department of Natural Resources, Baton Rouge, LA, 161p.

Morton, R.A., Bernier, J.C., Barras, J.A., and Ferina, N.F., 2005. Rapid subsidence and historical wetland loss in the Mississippi delta plain: likely causes and future implications. U. S. Geological Survey Open-file Report 2005-1216, 116p.

Morton, R.A., Tiling, G., and Ferina, N.F., 2003. Causes of hotspot wetland loss in the Mississippi delta plain. Environmental Geosciences 10:71-80.

Morton, R.A., Buster, N.A., and Krohn, M.D., 2002. Subsurface controls on historical subsidence rates and associated wetland loss in south-central Louisiana. Transactions – Gulf Coast Association of Geological Societies 52:767-778.

Penland, S., Beall, A.D., Britsch, L.D., and Williams, S.J., 2002. Geologic classification of coastal land loss between 1932 and 1990 in the Mississippi River delta plain, southeastern Louisiana. Transactions – Gulf Coast Association of Geological Societies 52:799-807.

Ramsey, E.W. III and Laine, S.C., 1997. Comparison of Landsat Thematic Mapper and high resolution photography to identify change in complex coastal wetlands. Journal of Coastal Research 13:281-292.

USACE (U.S. Army Corp of Engineers), 2004. Louisiana Coastal Area (LCA) Final Report–Ecosystem Restoration Study, 296p.

Wicker, K.M., 1980. The Mississippi deltaic plain habitat mapping study. U.S. Fish and Wildlife Service, Office of Biological Services, FWS/PBS-79/07.

Williams, S.J. and Cichon, H.A., 1994. Processes of coastal wetland loss in Louisiana. U.S. Geological Survey Open-File Report, no. 94-0275, 226p.