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Scientific Investigations Map 3164
Pamphlet accompanies map

Land Area Change in Coastal Louisiana (1932 to 2010)

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Introduction

The U.S. Geological Survey (USGS) analyzed landscape changes in coastal Louisiana by determining land and water classifications for 17 datasets. These datasets include survey data from 1932, aerial data from 1956, and Landsat Multispectral Scanner System (MSS) and Thematic Mapper (TM) data from the 1970s to 2010. Previous studies have analyzed land change in coastal Louisiana, but many are out of date, provide data for limited time periods, or lack the temporal frequency necessary to provide information about when the loss occurred. The purpose of this study is to provide updated estimates of persistent land change and historical land change trends for coastal Louisiana and for each hydrologic basin, as defined by the Coastal Wetlands Planning, Protection and Restoration Act Program (n.d.), for the 1932–2010 period of record. The use of 17 datasets plus the application of consistent change criteria in this study provide opportunities to better understand the timing and causal mechanisms of wetland loss that are critical for forecasting landscape changes in the future.

Methodology

This study analyzed changes in the extent of land in coastal Louisiana by using 17 datasets summarizing land and water areas from 1932 to 2010 (table 1). The datasets were derived from multiple sources including (1) historical survey data (1932); (2) National Wetlands Inventory (NWI) data based on aerial photography (1956); (3) Landsat Multi-Spectral Scanner (MSS) data (1973–79); and (4) Landsat Thematic Mapper (TM) satellite imagery classified into land and water categories (1985–2010). Variable data coverage among the 1932 and 1956 datasets and all subsequent data required an assumption of no change in the area of no data coverage (areas with no overlap) in those datasets. No change is assumed in land area from 1932 to 1956 and from 1956 to 1973 in portions of the dataset that occur outside the boundaries of the 1932 and 1956 data coverage. (Refer to figure 1 for more information regarding the areas within the coastal basins to which this assumption was applied.)

The areas missing from the 1932 and 1956 datasets mostly consist of forested wetlands. These areas are historically stable, so the assumption of "no change" is correct in most instances; however, the area and change summaries should only be used with an in-depth understanding of the impacts of this assumption in areas where there are no data in 1932 and 1956.

Preprocessing of all datasets included use of ERDAS IMAGINE AutoSyncworks (ERDAS Inc., Norcross, Ga.), a software that uses an automated process to align common landform features between images. To assess change, the geometric registration between datasets must be highly accurate. Misalignment of features at the same location could produce invalid land change results. This preprocessing step was critical in ensuring that the 1932 and 1956 data aligned with the later satellite-based data. The Landsat MSS data (1973, 1977, and 1979), which have a native 60-meter (m) resolution, were first resampled to a 30-m resolution by using a cubic convolution resampling method to facilitate comparability with later Landsat TM-based data (native 30-m resolution). Conducting this resampling prior to land-water classification is more appropriate than resampling the results of the land-water classification. All satellite imagery data were then classified into land/water categories by using a standard methodology similar to that used in previous studies (Barras, 2006, 2007; Barras and others, 2008).

Figure 1. Map of the study area in coastal Louisiana. The coastal zone boundary was modified to improve the conservation plan boundary. The conservation plan boundary delineates the zone for which statistics were calculated and sustainable coastal regions while excluding hurtlands (defined as developed, agricultural, and other protected areas) that from statistical analysis of coastal land change. Of particular note are the areas of non-overlapping data coverage in the 1932 and 1956 datasets (based on survey and aerial data) and in the 1973–2010 datasets (based on satellite imagery data). Because no data exist for these non-overlapping areas, an assumption of no change in those areas has been used. For those time periods in the analyses (a reasonable assumption since a majority of these data voids occurs in areas dominated by forested wetlands, a habitat type known to have been particularly stable in past observations). The background image is shown for reference purposes to a northern boundary delineated by the 10-m elevation contour (referenced to the North American Vertical Datum of 1988 (NAVD 88).

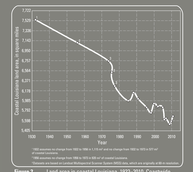

Figure 2. Land area in coastal Louisiana, 1932–2010. Coastwide, net land area decreased from 1932 to 2010 was 1,883 mi². (See table 1 for specific area measurements.)

Table 2. Water levels at a selected gage (station ID: 8761724, located near Grand Isle, La.) on the date of acquisition for imagery used in the land area estimates.

Decimal date[1]	Calendar date	Gage height, in feet[2]	Decimal date	Calendar date	Gage height, in feet[2]	Decimal date	Calendar date	Gage height, in feet[2]	Decimal date	Calendar date	Gage height, in feet[2]
		Path 21[3]			Path 22[3]			Path 23[3]			Path 24[3]
1932[4]					Not available			Not available			Not available
1956[4]					Not available			Not available			Not available
1973.9	12/5/1973	Not available		2/3/1973	Not available	12/7/1973		Not available	12/9/1973		Not available
1975.7	10/11/1975	Not available		4/13/1975	Not available	5/21/1975		Not available	3/26/1975		Not available
1977.4	7/2/1977	Not available		6/3/1977	Not available	12/3/1977		Not available	4/8/1977		Not available
1985.1	10/11/1985	0.70		1/19/1985	1.81	3/16/1985		3.94	12/3/1985		0.30
1988.1	12/4/1987	6.46		1/26/1988	5.02	12/2/1987		6.33	1/26/1988		5.97
1990.8	2/14/1991	5.97		11/1/1990	6.50	11/24/1990		6.40	10/30/1990		6.40
1995.7	10/7/1995	6.89		9/26/1995	6.86	10/5/1995		6.92	9/10/1995		6.82
1998.2	2/17/1998	0.04		2/24/1998	1.65	3/3/1998		0.14	3/10/1998		0.17
1999.9	11/27/1999	6.36		11/18/1999	6.46	11/16/1999		6.50	10/24/1999		6.73
2002.2	3/3/2002	6.00		2/27/2002	5.45	2/2/2002		5.97	1/8/2002		6.06
2004.9	10/15/2004	6.76		11/7/2004	6.46	10/13/2004		6.79	11/5/2004		6.59
2005.8	10/18/2005	5.73		10/25/2005	6.10	10/30/2005		6.07	10/23/2005		6.02
2006.8	1/25/2007	5.97		10/28/2006	6.53	11/4/2006		6.60	12/1/2006		6.23
2008.8	11/14/2008	6.46		11/7/2008	6.49	10/31/2008		6.46	11/24/2008		6.23
2009.8	11/16/2009	6.66		11/9/2009	6.69	11/22/2009		6.60	11/3/2009		6.75
2010.8	10/16/2010	6.53		10/7/2010	6.30	10/12/2010		6.56	10/25/2010		6.66

[1]Decimal date is a date and time expressed as a decimal number. For example, 1973.5 is the 183rd day of the year (July 2, 1973) because there are 365 days in the year.
[2]Gage height is a water level measured in feet above the Louisiana coast datum, which is approximately mean sea level. The datum is a surface that approximates the elevation of the Louisiana coastal zone and is used to facilitate statistical analyses. It is derived by dividing the day of the year (on the Julian system) by the number of days in the year.
[3]Path is a Landsat satellite orbit path. Gage station corresponds to the Landsat Worldwide Reference System (WRS) Grid system.
[4]Calendar dates were not available.

Table 3. Persistent land loss and land gain in coastal Louisiana by basin, as defined by the Coastal Wetlands Planning, Protection and Restoration Act Program (n.d.), 1932–2010.

[Land area in square miles]

Basin	1932–56	1956–73	1973–75	1975–77	1977–85	1985–88	1988–90	1990–95	1995–98	1998–99	1999–2002	2002–4	2004–6	2006–8	2008–9	2009–10	Total persistent
	Loss											Loss				Negative change	
Atchafalaya Delta	-4.48	-1.92	-1.75	-0.90	-0.64	-0.99	-1.37	-1.15	-0.83	-0.49	-0.39	-0.51	-0.37	-0.66	-0.01	-0.02	-16.49
Barataria	-56.46	-70.98	-64.31	-27.84	-42.81	-16.80	-26.30	-26.76	-18.56	-17.81	-9.12	-8.95	-13.76	-13.86	-3.94	-4.31	-421.71
Breton Sound	-30.94	-11.34	-9.95	-9.58	-7.97	-5.67	-8.28	-9.64	-6.93	-6.47	-4.26	-5.48	-29.32	-12.25	-0.98	-1.79	-160.87
Calcasieu-Sabine	-8.41	-66.70	-17.30	-15.08	-9.39	-6.19	-4.22	-6.90	-7.15	-5.19	-2.85	-1.39	-22.00	-21.74	-1.30	-0.72	-196.94
Mermentau	-18.68	-24.35	-7.00	-8.31	-10.01	-6.59	-5.49	-6.58	-5.74	-3.96	-4.03	-2.76	-22.26	-6.13	-0.43	-0.60	-134.37
Mississippi River Delta	-34.06	-61.93	-10.51	-9.61	-4.86	-2.64	-5.64	-4.41	-1.89	-1.02	-1.02	-3.46	-10.11	-6.90	-0.14	-0.03	-152.02
Pontchartrain	-34.41	-32.50	-12.74	-12.84	-9.47	-6.88	-9.67	-11.07	-7.85	-6.68	-4.20	-5.70	-15.14	-7.24	-1.26	-1.60	-179.25
Teche-Vermilion	-14.68	-8.40	-4.43	-4.22	-3.06	-3.23	-2.23	-2.81	-3.37	-3.15	-1.71	-3.23	-3.78	-4.31	-0.29	-0.29	-64.61
Terrebonne	-75.28	-46.25	-45.65	-30.87	-35.11	-22.97	-27.54	-30.43	-23.12	-22.50	-11.99	-9.63	-18.27	-21.40	-12.31	-4.49	-459.99
Total	-277.41	-324.39	-173.55	-148.35	-123.32	-71.78	-92.18	-99.94	-73.83	-67.29	-39.57	-41.20	-135.82	-94.69	-20.65	-12.77	-1,788.24

Basin	1932–56	1956–73	1973–75	1975–77	1977–85	1985–88	1988–90	1990–95	1995–98	1998–99	1999–2002	2002–4	2004–6	2006–8	2008–9	2009–10	Total persistent
	Gain											Gain				Positive change	
Atchafalaya Delta	0.89	1.12	0.63	0.32	1.77	1.17	0.60	2.47	0.76	4.74	0.98	1.12	2.28	2.08	3.77	2.22	29.95
Barataria	1.11	0.10	0.05	0.43	0.24	0.05	0.08	0.15	0.29	0.09	0.30	0.31	1.23	0.18	0.35	0.52	5.91
Breton Sound	1.34	0.32	0.01	0.12	0.20	0.06	0.16	0.14	0.38	0.20	0.31	0.27	1.15	0.19	0.29	0.49	6.03
Calcasieu-Sabine	1.87	1.60	0.18	0.26	0.74	0.19	0.19	0.57	0.20	0.28	0.40	0.86	0.81	0.51	0.08	0.19	9.02
Mermentau	1.71	0.57	0.12	0.10	0.28	0.13	0.53	1.16	0.70	0.18	0.35	0.28	0.64	0.19	0.04	0.11	6.87
Mississippi River Delta	2.43	0.60	0.01	0.24	2.32	1.10	1.56	0.65	0.83	1.63	1.43	0.63	2.62	2.12	0.37	2.16	23.74
Pontchartrain	1.59	1.69	0.61	0.17	0.30	0.16	0.28	0.20	0.16	0.07	0.32	0.30	1.11	0.44	0.27	0.46	8.31
Teche-Vermilion	1.64	0.34	0.01	0.04	0.13	0.05	0.05	0.16	0.09	0.10	0.12	0.14	0.31	0.24	0.13	0.31	3.85
Terrebonne	2.96	0.21	0.25	0.31	0.49	0.26	0.24	0.28	0.40	0.76	0.47	0.37	1.67	0.67	0.66	0.43	10.42
Total	15.53	6.52	2.82	4.10	6.68	3.17	3.21	5.79	3.80	8.03	4.66	4.27	11.82	8.83	5.95	9.71	104.11

[1]Values are rounded to two decimal places; values shown in red and in italics, zero.

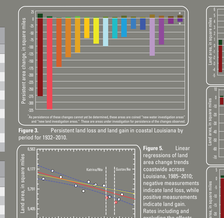

Figure 3. Persistent land loss and land gain in coastal Louisiana by period for 1932–2010.

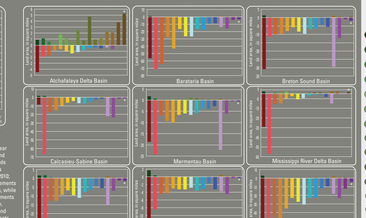

Figure 5. Linear regressions of land area change trends coastwide across Louisiana, 1985–2010, negative measurements indicate land loss, while positive measurements indicate land gain. Rates including and excluding the effects of the hurricanes of 2008 and 2008 are shown for comparison.

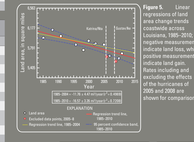

Figure 4. Persistent land loss and land gain across Louisiana by basin (as defined by the Coastal Wetlands Planning, Protection and Restoration Act Program, n.d.) and period for 1932–2010.

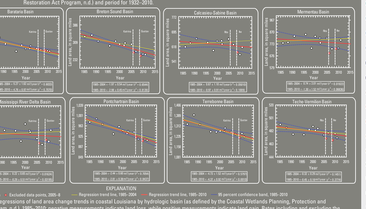

Figure 6. Linear regressions of land area change trends in coastal Louisiana by hydrologic basin (as defined by the Coastal Wetlands Planning, Protection and Restoration Act Program, n.d.), 1985–2010, negative measurements indicate land loss, while positive measurements indicate land gain. Rates including and excluding the effects of the hurricanes of 2005 and 2008 are shown for comparison.

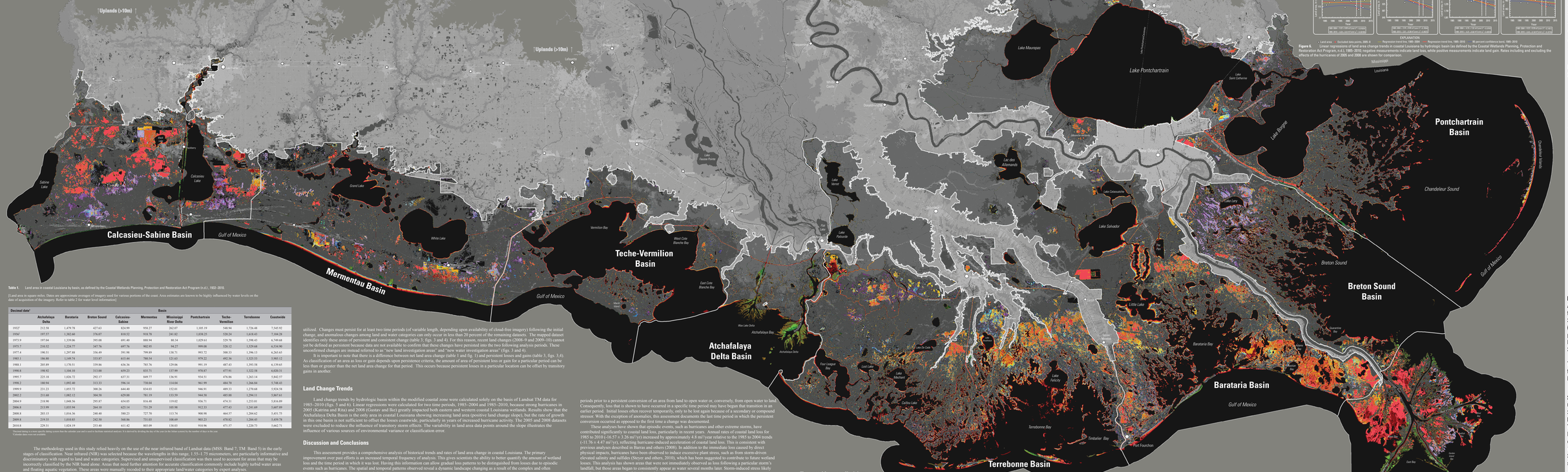

Table 1. Land area in coastal Louisiana by basin, as defined by the Coastal Wetlands Planning, Protection and Restoration Act Program (n.d.), 1932–2010.

[Land area in square miles. Dates are approximate averages of imagery used for various portions of the coast. Area estimates are known to be highly influenced by water levels on the date of acquisition of the imagery. Refer to table 2 for water level information]

Decimal date[1]	Basin									
	Atchafalaya Delta	Barataria	Breton Sound	Calcasieu-Sabine	Mermentau	Mississippi River Delta	Pontchartrain	Teche-Vermilion	Terrebonne	Coastwide
1932[2]	212.58	1,479.78	427.63	824.99	938.27	862.07	1,105.19	548.94	1,726.48	7,545.92
1956[2]	197.17	1,302.60	376.07	810.32	918.70	741.82	1,038.27	520.26	1,618.63	7,180.28
1973.9	197.64	1,339.06	395.08	691.40	888.94	80.34	1,029.63	529.78	1,598.43	6,749.68
1975.7	210.32	1,224.77	347.76	697.76	902.95	94.27	999.08	525.12	1,529.68	6,534.90
1977.4	196.51	1,297.88	356.49	591.98	799.89	138.71	993.72	500.33	1,396.13	6,265.65
1985.1	196.80	1,149.74	333.87	631.44	780.54	121.63	979.22	492.36	1,325.33	5,980.12
1988.1	205.89	1,170.51	339.86	636.36	785.76	129.06	991.19	487.43	1,393.58	6,139.65
1990.8	198.92	1,104.19	313.60	639.21	835.71	137.99	970.87	477.91	1,322.58	6,020.31
1995.7	223.18	1,026.72	292.17	637.31	848.77	136.91	934.51	476.86	1,261.14	5,842.37
1998.2	180.94	1,092.40	313.33	596.14	738.04	114.04	961.99	484.70	1,266.84	5,748.43
1999.9	231.23	1,055.72	300.26	644.40	834.03	132.01	946.91	489.33	1,270.68	5,924.58
2002.2	211.68	1,082.12	304.38	629.88	761.19	133.59	944.54	485.88	1,294.11	5,867.41
2004.9	218.90	1,048.56	295.87	654.05	816.48	119.02	936.71	474.31	1,253.01	5,816.89
2006.8	213.99	1,035.94	284.10	625.14	731.29	105.90	912.33	477.43	1,241.40	5,607.88
2008.8	203.15	1,016.36	248.40	580.21	727.70	113.74	900.98	464.57	1,204.62	5,451.75
2009.8	219.33	1,010.83	242.50	568.86	731.03	108.69	903.23	470.82	1,204.45	5,459.78
2010.8	229.31	1,024.19	253.40	611.42	803.09	138.03	910.96	471.57	1,228.73	5,662.71

[1]Decimal date is a date and time expressed as a decimal number. For example, 1973.5 is the 183rd day of the year (July 2, 1973) because there are 365 days in the year.
[2]Calendar dates were not available.

The methodology used in this study relied heavily on the use of the near infrared band of Landsat data (MSS: Band 7; TM: Band 5) in the early stages of classification. Near infrared (NIR) was selected because the wavelengths in this range, 1.55–1.75 micrometers, are particularly informative and discriminatory with regard to land and water categories. Supervised and unsupervised classification was then used to account for areas that may be incorrectly classified by the NIR band alone. Areas that need further attention for accurate classification commonly include highly turbid water areas and floating aquatic vegetation. These areas were manually recoded to their appropriate land/water categories by expert analyses.

Land Area Changes

The resulting land area data were summarized by time period and by basin (table 1 and fig. 2). These analyses show that coastal Louisiana has experienced a net change in land area of approximately -1,883 mi² from 1932 to 2010. Land area estimates can vary substantially because of environmental variations such as seasonality and, most notably, water-level variations on the date of acquisition (DOA) of the data (Morton and others, 2005; Berner and others, 2006). (Refer to table 2 for more information regarding the water levels on the DOA for the data used in these analyses.) To reduce some of the errors associated with apparent land change caused by misclassification or transient environmental phenomena, two approaches were utilized. Changes must persist for at least two time periods (of variable length, depending upon availability of cloud-free imagery) following the initial change, and anomalous changes among land and water categories can only occur in less than 20 percent of the remaining datasets. The mapped dataset identifies only these areas of persistent and consistent change (table 3; figs. 3 and 4). For this reason, recent land changes (2008–9 and 2009–10) cannot yet be defined as persistent because data are not available to confirm that these changes have persisted into the two following analysis periods. These unconfirmed changes are instead referred to as "new land investigation areas" and "new water investigation areas" (figs. 3 and 4).

It is important to note that there is a difference between net land area change (table 1 and fig. 1) and persistent losses and gains (table 3, figs. 3,4). An classification of an area as loss or gain depends upon persistence criteria, the amount of area of persistent loss or gain for a particular period can be less than or greater than the net land area change for that period. This occurs because persistent losses in a particular location can be offset by transitory gains in another.

Land Change Trends

Land change trends by hydrologic basin within the modified coastal zone were calculated solely on the basis of Landsat TM data for 1985–2010 (figs. 5 and 6). Linear regressions were calculated for two time periods, 1985–2004 and 1985–2010, because strong hurricanes in 2005 (Katrina and Rita) and 2008 (Gustav and Ike) greatly impacted both eastern and western coastal Louisiana wetlands. Results show that the Atchafalaya Delta Basin is the only area in coastal Louisiana showing increasing land area (positive land change slope), but the rate of growth in this one basin is not sufficient to offset the losses coastwide, particularly in years of increased hurricane activity. The 2005 and 2008 datasets were excluded to reduce the influence of transitory storm effects. The variability in land area data points around the slope illustrates the influence of various sources of environmental variance or classification error.

Discussion and Conclusions

This assessment provides a comprehensive analysis of historical trends and rates of land area change in coastal Louisiana. The primary improvement over past efforts is an increased temporal frequency of analysis. This gives scientists the ability to better quantify the amount of wetland loss and the time period in which it was lost. Having this information can allow gradual loss patterns to be distinguished from losses due to episodic events such as hurricanes. The spatial and temporal patterns observed reveal a dynamic landscape changing as a result of the complex and often interactive effects of natural and human-induced processes.

Variability in land area estimates can often be attributed to temporary wind and water level fluctuations present at the date and time of acquisition of the aerial and satellite imagery. Morton and others (2005) found that water area varied by as much as 5 percent over short time periods, largely as the result of environmental variability. The 17 dates of imagery analyzed provide a more robust estimate of change by reducing the inclusion of land area fluctuations caused by environmental variability.

The desire to reduce errors associated with environmental variability was a driving force behind the development of the persistence criteria utilized in this analysis. An area must experience a change in land/water category, and that change must persist for at least two time periods following the initial conversion before that area is classified as "loss" or "gain". The temporal resolution, as well as the persistence criteria used in this analysis, ensures that the data presented are more likely to represent permanent changes compared to previous studies; however, it is important to note when examining wetland loss/gain by time period that wetland areas often fluctuate between land and water categories. These fluctuations can take place for multiple time periods prior to a persistent conversion of an area from land to open water or, conversely, from open water to land. Consequently, loss that is shown to have occurred in a specific time period may have begun that transition in an earlier period. Initial losses often recover temporarily, only to be lost again because of a secondary or compound stressor. With the exception of anomalies, this assessment documents the last time period in which the persistent conversion occurred as opposed to the first time a change was documented.

These analyses have shown that episodic events, such as hurricanes and other extreme storms, have contributed significantly to coastal land loss, particularly in recent years. Annual rates of coastal land loss for 1985 to 2010 (-16.57 ± 3.26 mi²/yr) increased by approximately 4.8 mi²/year relative to the 1985 to 2004 trends (-11.76 ± 4.47 mi²/yr), reflecting hurricane-induced acceleration of coastal land loss. This is consistent with previous analyses described in Barras and others (2008). In addition to the immediate loss caused by direct physical impacts, hurricanes have been observed to induce excessive plant stress, such as from storm-driven elevated salinity and sulfides (Steyer and others, 2010), which has been suggested to contribute to future wetland losses. This analysis has shown areas that were not immediately observed as loss following a particular storm's landfall, but those areas began to consistently appear as water several months later. Storm-induced stress likely contributed to at least some of the observed losses.

Excluding the high rates of wetland loss due to recent hurricanes, rates of wetland loss had been decreasing from the high rates observed in the 1970s. Britsch and Dunbar (1993) observed a similar trend of decreasing loss after 1978. Though the wetland loss in coastal Louisiana is a dire situation, this observed decrease is at least a measured source of positive news, as past trends are often indicative of potential future losses.

An interesting finding of this analysis may be observed in the increase in net land area in the 2009 and 2010 datasets, as seen in figure 2. Though it may be intuitive to interpret this land area increase as recovery from the low, hurricane-influenced land area estimates of 2008, the potential influence of environmental variability dictates caution before interpreting this pattern as "recovery." Discriminating the permanence of these increases from the transitory effects of environmental variability may require several additional years of observations.

The temporal frequency of land change provided by this study is allowing scientists to further investigate the causal mechanisms of the loss which has occurred. These investigations will provide improved information to develop tools to monitor ecosystems, forecast possible impacts, and plan protection and restoration activities. These data can help support the development of strategies to adapt to our changing environment.

EXPLANATION

- 1932–56 land gain[1]
- 1956–73 land gain[1,4]
- 1973–75 land gain[1,4]
- 1975–77 land gain[1,4]
- 1977–85 land gain[1,4]
- 1985–88 land gain[1]
- 1988–90 land gain[1]
- 1990–95 land gain[1]
- 1995–98 land gain[1]
- 1998–99 land gain[1]
- 1999–2002 land gain[1]
- 2002–4 land gain[1]
- 2004–6 land gain[1]
- 2006–8 land gain[1]
- 2008–9 land gain[1,3]
- 2009–10 new land[1,3]
- 1932–56 land loss[2]
- 1956–73 land loss[2,4]
- 1973–75 land loss[2,4]
- 1975–77 land loss[2,4]
- 1977–85 land loss[2,4]
- 1985–88 land loss[2]
- 1988–90 land loss[2]
- 1990–95 land loss[2]
- 1995–98 land loss[2]
- 1998–99 land loss[2]
- 1999–2002 land loss[2]
- 2002–4 land loss[2]
- 2004–6 land loss[2]
- 2006–8 land loss[2]
- 2008–9 land loss[2,3]
- 2009–10 new water[2,3]

Background imagery (inside modified Coastal Zone Boundary)

- Developed[5]
- Uplands[5]
- Persistent forested wetland[5]
- Persistent wetland[5]
- Persistent water

Background imagery (outside modified Coastal Zone Boundary)

- Developed[5]
- Uplands[5]
- Persistent forested wetland[5]
- Persistent wetland[5]
- Persistent water

— Basin boundary

[1]Gain is determined by the last date a particular pixel transformed from water to land and remained land throughout the period of observation.
[2]Loss is determined by the last date a particular pixel transformed from land to water and remained water throughout the period of observation.
[3]Because this data is from the most recent year in the ending dataset, some of these effects may be temporary phenomena.
[4]This date range contains at least one date in which the landwater data were created from Landsat Multispectral Scanner System (MSS).
[5]Land cover categories based on 2006 data. "Persistent" is defined as not having undergone a consistent change in landwater category during the observation period.

Image source:
Analyses presented utilized imagery from Landsat Multispectral Scanner System (MSS) and Thematic Mapper (TM) satellites. Landsat imagery is provided by the USGS Center for Earth Resources Observation and Science (EROS).

The background image depicts data from Landsat TM that are classified by types of land and water coverage.

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