

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

#### Introduction

The U.S. Geological Survey (USGS) analyzed landscape changes in coastal Louisiana by determining land and water classifications for 21 datasets. Coastal Louisiana has been losing wetlands because of multiple compounding and interacting stressors including sea-level rise (SLR), subsidence, storms, sediment deprivation, oil and gas extraction and infrastructure, navigation infrastructure, saltwater intrusion, altered hydrology, and others (Penland and others, 2001). 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 from 1932 to 2016. The use of 21 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.

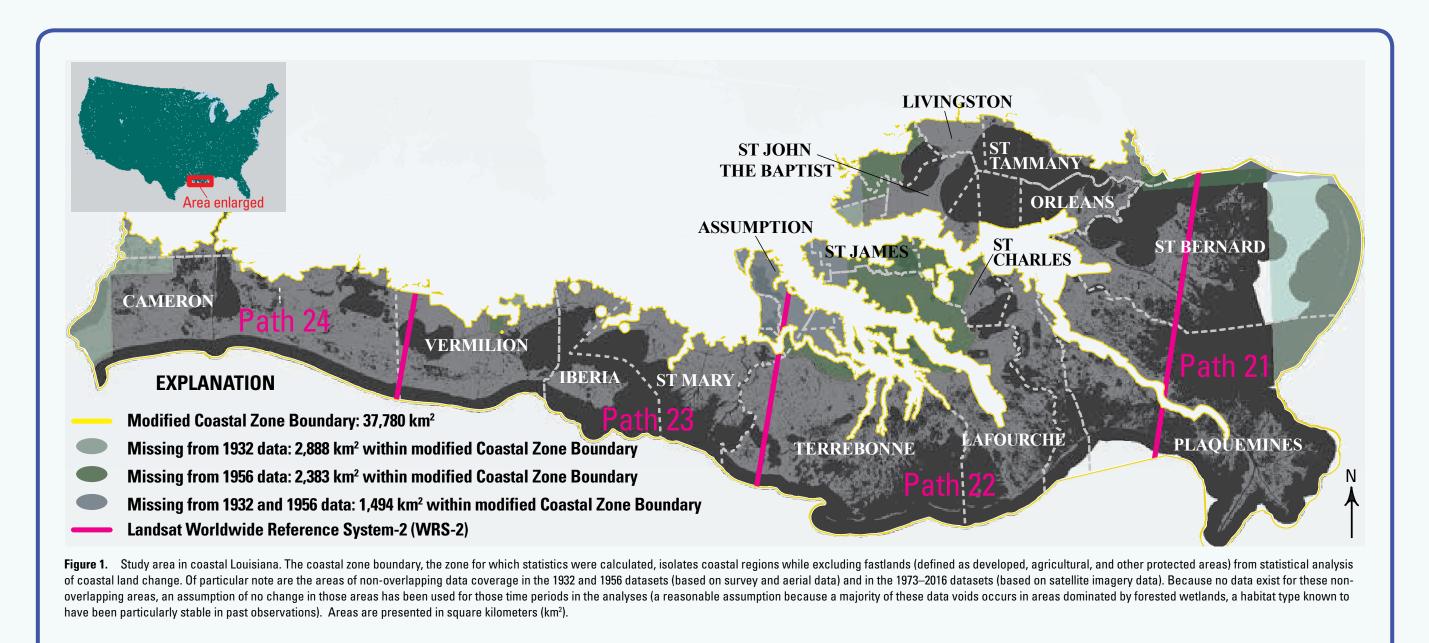
#### Study Area

The Louisiana coastal zone encompasses approximately 37,780 square kilometers (km<sup>2</sup>) of lowland plains, deltaic lobes, and open water (fig. 1). Coastal Louisiana wetlands are generally considered one of the most important environments in the United States because they support more than 30 percent of the commercial fisheries in the United States, 5 of the Nation's top 20 ports are

located in coastal Louisiana, and 20 percent of the Nation's oil and gas comes from or is transported through these wetlands (Costanza and others, 2008; Feagin and others, 2010; Gedan and others, 2011; NOAA, 2010; Twilley, 2007). This coast is also considered to be one of the most "at-risk" environments in the Nation because approximately a quarter of these wetlands have been lost in the **Methodol** past 84 years (Couvillion and others, 2011).

deposits were delivered via the Mississippi River as a result of upper catchment glaciation and melting associated with sea-level were derived from multiple sources including (1) historical U.S. resolution by using a cubic convolution resampling method to area change is similar to that of a third order polynomial (edf = changes. As glaciers retreated (from about 12,000 until 6,000 years ago), meltwater inundated valleys and transported much of the upper catchment sediments to the lower catchment floodplains Scanner (MSS) data (1973–79); (4) Landsat Thematic Mapper makes use of a modified Normalized Difference Water Index the initial change, and anomalous changes among land and that compose coastal Louisiana today. Periodic floodwaters would carry these sediments, and as the floodwaters retreated, (OLI) (2013–2016) satellite imagery classified into land and rich sediment left behind formed a vast expanse of fertile deltaic water categories. Variable data coverage among the 1932 and 2006). The mNDWI is seen in equation 1 below: wetlands (Fisk and McFarlan, 1955). Hydrology continues to 1956 datasets and all subsequent data required an assumption of dictate the geomorphic structure and vegetation distribution of no change in the area of no data coverage in those datasets. No this landscape but in a drastically altered fashion. Flood-control change is assumed in land area from 1932 to 1956 and from 1956 Mid-infrared (MIR) is used because the wavelengths in this structures including dams and levees were built, not only in Louisiana but throughout the Mississippi River catchment, particularly after the flood of 1927. The construction of these carried by the Mississippi River as a result of dam and levee construction throughout the drainage basin (Meade and others,

the distribution of sediment within the river by redirecting or altering the amount of sediment distribution at channel mouths, along channel banks, and across floodplains. These flood-control IMAGINE AutoSync software (Hexagon Geospatial, 2016) that appropriate land/water categories by expert analyses. structures have contributed to a reduced capacity for sediment accretion and thereby reduced the ability of wetlands to maintain between images. To assess change, the geometric registration environmental variations such as seasonality and, most notably, elevation in response to SLR and subsidence.



lacking data in 1932 and 1956.

uses an automated process to align common landform features Land area estimates can vary substantially because of between datasets must be highly accurate. Misalignment of water-level variations on the date of acquisition (DOA) (table 2)

features at the same location could produce invalid land change of the data (Morton and others, 2005; Bernier and others, 2006). results. This processing step was critical in ensuring that the 1932 A composite coastal land-water dataset was developed from the Coastal Louisiana was built by sedimentary material sourced This study analyzed changes in the extent of land in coastal and 1956 data aligned with the later satellite-based data. The source-classified satellite data for each time period and was then from fluvial and tidally redistributed deposits. The bulk of these Louisiana by using 21 datasets summarizing land and water Landsat MSS data (1973, 1977, and 1979), which have a native used to derive the land area by date, basin area, and coastal area areas from 1932 to 2016 (table 1; figs. 2 and 3). The datasets 68- by 83-meter (m) resolution, were first resampled to a 30-m (table 1). To reduce some of the errors associated with apparent others, 1990, 1992); (2) National Wetlands Inventory (NWI) data data (native 30-m resolution). All satellite imagery data were then for at least two consecutive time periods (of variable length, based on aerial photography (1956); (3) Landsat Multispectral classified into land/water categories by using a methodology which depending upon availability of cloud-free imagery) following (TM) (1985–2010); and (5) Landsat Operational Land Imager (mNDWI) (Xu, 2005, 2006). The mNDWI enhances water features water categories can only occur in less than 20 percent of the while cutting down on noise from land, vegetation, and soil (Xu, remaining datasets. The mapped dataset identifies only these

mNDWI = (Green-MIR)/(Green+MIR) to 1973 in portions of the dataset that occur outside the boundaries range, 1.55–1.75 micrometers, are particularly informative and of the 1932 and 1956 data coverage. (Refer to fig. 1 for more discriminatory with regard to categorizing land and water. The information regarding the areas within the coastal basins to which green wavelength range is used as it maximizes reflectance of 1956 datasets mostly consist of forested wetlands. These areas are 2006). Initial mNDWI values were assigned to their appropriate most instances; however, the area and change summaries should classification was then used to account for areas that may be 1990; Kesel and others, 1992). Anthropogenic controls also vary be used with the implicit understanding of this assumption in areas incorrectly classified by the mNDWI alone. This step focuses on error-prone classes such as floating aquatic vegetation (FAV), Preprocessing of all datasets included use of ERDAS shadows, and bridges. These areas were manually recoded to their change as a set of polynomials in a piecewise-continuous fashion 1). As a percent of starting area, Mississippi River Delta Basin has gains in another.

areas of persistent and consistent change. For this reason, recent land changes (2015 to early 2016) cannot yet be defined as persistent because data are not available to confirm that these

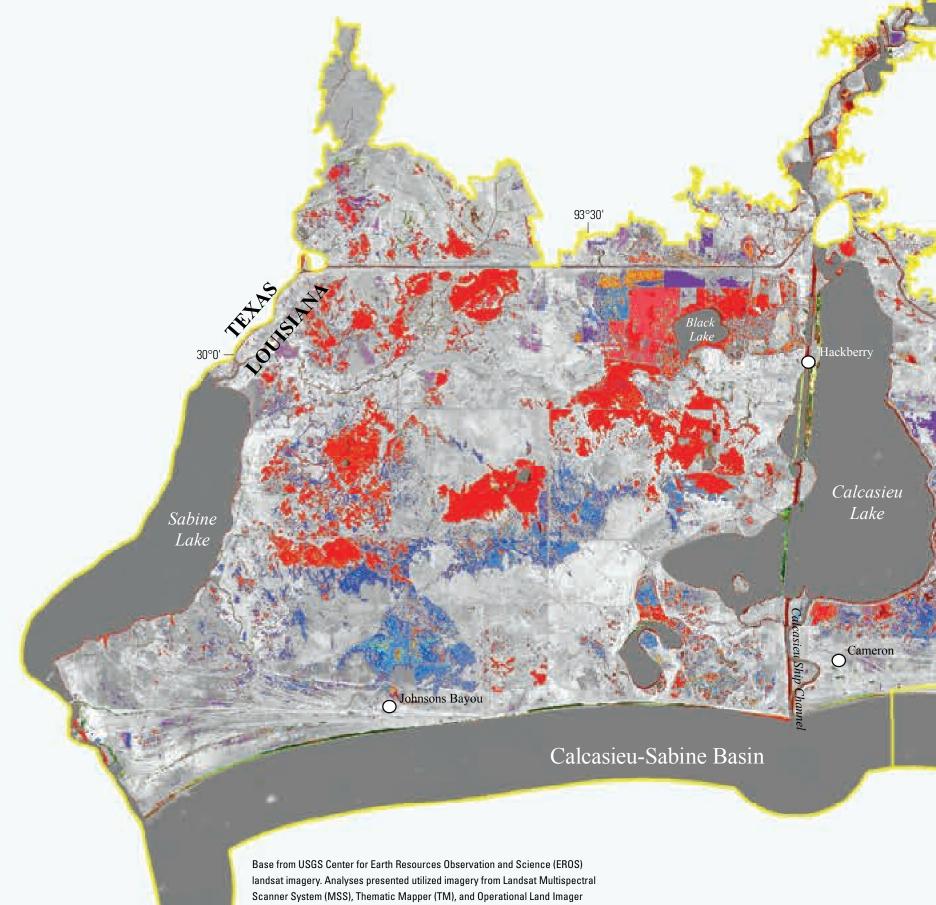
by cross-validation to prevent overfitting. One of the assumptions of these modeling methods is that

zero covariance between the model error and the independent

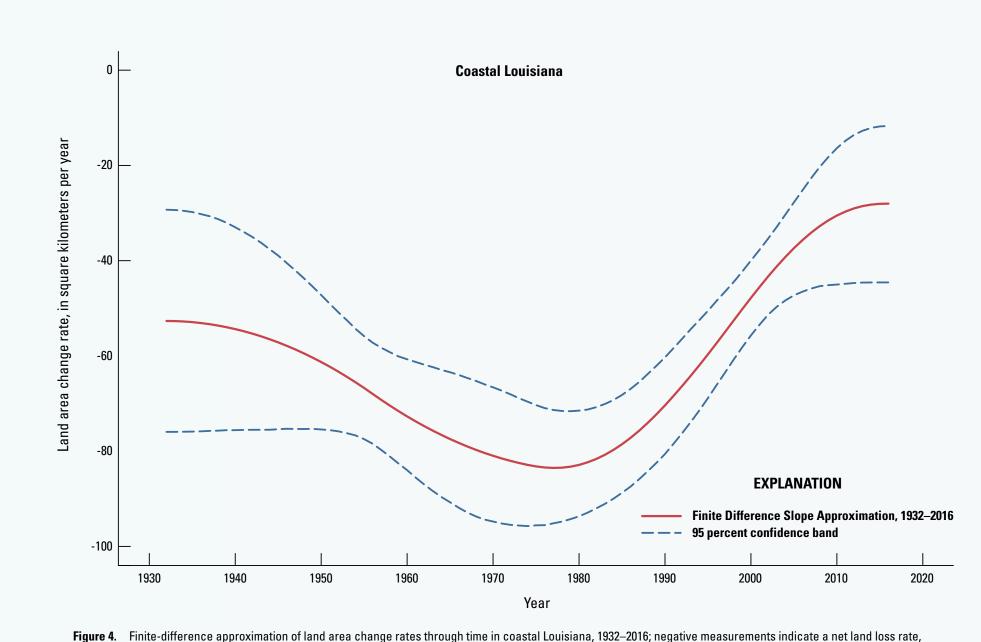
violate this assumption because of differences in data-collection

variables, which leads to biased estimates. These data clearly

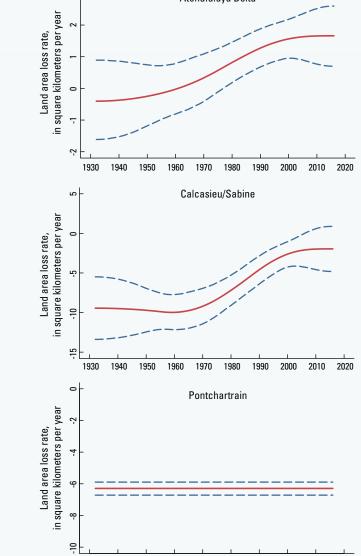
methods. To account for differences in methods across years,

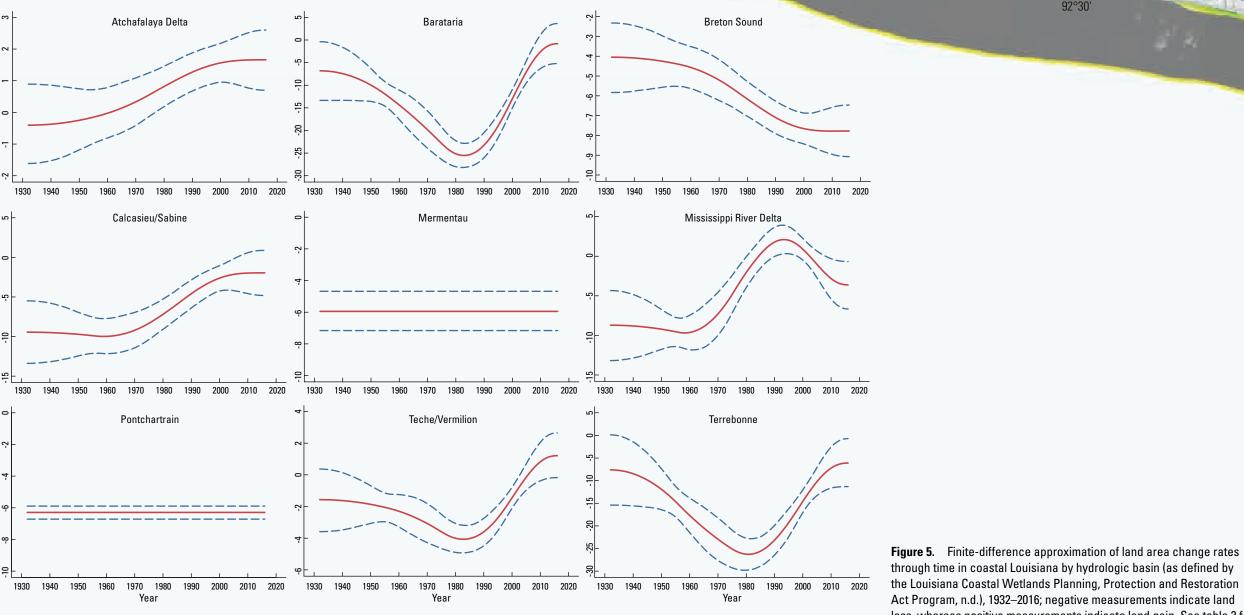


### Background imagery consists of average band 6 (mid-infrared) values from early 2016 Landsat Operational Land Imager (OLI) satellite imagery.



whereas positive measurements indicate net land gain rates. See table 3 for specific values.





EXPLANATION Finite Difference Slope Approximation, 1932–2016 — – 95 percent confidence band

Year	Atchafalaya Delta Basin			Barataria			Breton Sound			Calcasieu			Mermentau Basin			Mississippi River Delta Basin			Pontchartra	
	Change rate per year	1 SE low	1 SE high	Change rate per year	1 SE low	1 SE high	Change rate per year	1 SE low	1 SE high	Change rate per year	1 SE low	1 SE high	Change rate per year	1 SE low	1 SE high	Change rate per year	1 SE low	1 SE high	Change rate per year	1 SE
1932	-0.40	-1.69	0.88	-6.82	-13.28	-0.16	-4.05	-5.82	-2.31	-9.45	-13.26	-5.51	-5.95	-7.18	-4.72	-8.71	-13.09	-4.38	-6.29	-6.0
1956	-0.13	-0.97	0.71	-12.43	-15.14	-9.75	-4.42	-5.48	-3.34	-9.92	-12.21	-7.67	-5.95	-7.18	-4.72	-9.61	-11.44	-7.78	-6.29	-6.6
1973	0.47	-0.26	1.16	-21.66	-25.56	-17.87	-5.47	-6.41	-4.48	-8.72	-10.91	-6.55	-5.95	-7.18	-4.72	-5.91	-8.43	-3.34	-6.29	-6.6
1975	0.57	-0.13	1.23	-22.89	-26.53	-19.41	-5.66	-6.57	-4.71	-8.33	-10.46	-6.25	-5.95	-7.18	-4.72	-4.84	-7.18	-2.45	-6.29	-6.6
1977	0.67	-0.01	1.31	-24.01	-27.31	-20.79	-5.86	-6.74	-4.93	-7.90	-9.95	-5.90	-5.95	-7.18	-4.72	-3.70	-5.85	-1.47	-6.29	-6.6
1985	1.06	0.43	1.67	-25.34	-27.96	-22.71	-6.65	-7.47	-5.81	-5.91	-7.74	-4.10	-5.95	-7.18	-4.72	0.26	-1.51	2.07	-6.29	-6.6
1988	1.19	0.57	1.80	-24.36	-27.04	-21.66	-6.93	-7.74	-6.11	-5.11	-6.89	-3.33	-5.95	-7.18	-4.72	1.31	-0.49	3.14	-6.29	-6.6
1990	1.27	0.66	1.87	-23.25	-25.95	-20.50	-7.10	-7.90	-6.29	-4.59	-6.34	-2.83	-5.95	-7.18	-4.72	1.79	-0.04	3.65	-6.29	-6.6
1995	1.44	0.85	2.04	-18.96	-21.49	-16.40	-7.44	-8.23	-6.66	-3.45	-5.12	-1.80	-5.95	-7.18	-4.72	2.02	0.31	3.74	-6.29	-6.6
1998	1.52	0.93	2.12	-15.51	-17.68	-13.31	-7.59	-8.36	-6.83	-2.91	-4.51	-1.32	-5.95	-7.18	-4.72	1.49	-0.04	2.99	-6.29	-6.6
1999	1.54	0.94	2.15	-14.27	-16.35	-12.17	-7.63	-8.40	-6.85	-2.76	-4.35	-1.17	-5.95	-7.18	-4.72	1.21	-0.24	2.64	-6.29	-6.6
2002	1.60	0.95	2.24	-10.51	-12.53	-8.49	-7.71	-8.56	-6.88	-2.39	-4.10	-0.67	-5.95	-7.18	-4.72	0.17	-1.23	1.57	-6.29	-6.6
2004	1.62	0.93	2.32	-8.11	-10.39	-5.85	-7.75	-8.67	-6.84	-2.21	-4.13	-0.33	-5.95	-7.18	-4.72	-0.62	-2.21	0.96	-6.29	-6.6
2006	1.64	0.89	2.40	-5.93	-8.67	-3.23	-7.77	-8.77	-6.77	-2.09	-4.26	0.01	-5.95	-7.18	-4.72	-1.42	-3.30	0.46	-6.29	-6.6
2008	1.65	0.83	2.47	-4.05	-7.35	-0.84	-7.78	-8.88	-6.67	-2.02	-4.44	0.33	-5.95	-7.18	-4.72	-2.18	-4.40	0.06	-6.29	-6.6
2009	1.65	0.80	2.50	-3.25	-6.83	0.22	-7.78	-8.93	-6.63	-2.00	-4.55	0.46	-5.95	-7.18	-4.72	-2.52	-4.93	-0.09	-6.29	-6.6
2010	1.66	0.78	2.53	-2.56	-6.41	1.15	-7.78	-8.98	-6.59	-1.98	-4.66	0.56	-5.95	-7.18	-4.72	-2.82	-5.39	-0.24	-6.29	-6.6
2013	1.66	0.73	2.59	-1.18	-5.55	3.05	-7.78	-9.07	-6.51	-1.96	-4.86	0.82	-5.95	-7.18	-4.72	-3.45	-6.35	-0.53	-6.29	-6.6
2014	1.66	0.72	2.61	-0.96	-5.42	3.35	-7.78	-9.08	-6.50	-1.96	-4.90	0.85	-5.95	-7.18	-4.72	-3.55	-6.50	-0.58	-6.29	-6.0
2015	1.66	0.72	2.61	-0.85	-5.34	3.51	-7.78	-9.09	-6.49	-1.96	-4.92	0.87	-5.95	-7.18	-4.72	-3.61	-6.59	-0.60	-6.29	-6.6

of the spline (edf = 1 is linear, edf = 2 is quadratic, and so on). We This analysis indicates wetland change rates averaged -83 km<sup>2</sup>/yr "at-risk" positions in the landscape which are consequently less failing to weight the data resulted in overfitting. Specifically, non- in the rate since that time (fig. 4). Britsch and Dunbar (1993) and even stable wetlands may be impacted by a single event or R<sup>2</sup> values but generated slightly larger out-of-sample prediction loss after 1978. error on average. This suggests that weighting data successfully The rate of wetland change in most basins has changed Figures 2 and 3 display the change in land area over time, and Pontchartrain, were best fit by a linear model (edf = 1), calculated from the fitted models by using finite-difference approximation. The uncertainty of the finite differences was calculated by posterior simulations. Each fitted model was simulated 10,000 times, and the finite-difference estimates of

## Land Area Changes

calculated and displayed on the graphs.

These analyses show that coastal Louisiana has experienced a net land area change of approximately -4,833 km<sup>2</sup> (modeled estimate: -5,197 +/- 443 km<sup>2</sup>) from 1932 to 2016 (fig. 2, table 1), roughly the size of the land area of the State of Delaware. This net change in land area amounts to a decrease of approximately 25 percent of the 1932 land area. Although this decrease in net land area is pervasive throughout much of the coast and the time period analyzed, the land area of recent data points (2013–16) is approximately equivalent and, in some cases, slightly greater than The model which best approximated the coastwide net land Army Corps of Engineers land loss data (1932) (Dunbar and facilitate comparability with later Landsat TM- and OLI-based phenomena, two approaches were utilized. Changes must persist 2.903 ( $R^2=0.923$ ) ( $R^2=0$ area data from hurricane-induced effects are evident as low outliers. Also evident is a perceived "stability" in coastwide net land area in recent years.

> All basins, with the exception of Atchafalaya Delta Basin, have experienced a net decrease in wetland area during the period of observation (1932–2016) (fig. 3). In terms of total area, Terrebonne Basin has experienced the greatest decrease in wetland area  $(-1,302 \text{ km}^2 \text{ observed}; -1,352 \text{ +/-} 136 \text{ km}^2 \text{ modeled})$ , followed by changes have persisted into the two following analysis periods. Barataria Basin (-1,120 km<sup>2</sup> observed; -1,177 +/- 106 km<sup>2</sup> modeled), These unconfirmed changes are instead referred to as "new land Calcasieu-Sabine Basin (-517 km<sup>2</sup> observed; -578 +/- 100 km<sup>2</sup> investigation areas" and "new water investigation areas." modeled), Mermentau Basin (-488 km<sup>2</sup> observed; -500 +/- 90 km<sup>2</sup>

trend in land area over the period of observation. The function of modeled), Mississippi River Delta Basin (-375 km<sup>2</sup> observed; across the span of years. Trends computed from this spline experienced the greatest percentage decrease in wetland area (-55 This analysis has fostered an ability to examine variability

was set to a maximum of five, but its final value was determined percent observed and modeled), Pontchartrain Basin (-17 percent 0.245 (fig. 3). Mississippi River Delta Basin, another basin in each data point provides equally precise information about the was the only basin to experience an increase (+3 percent observed; response variable. When this assumption is violated, there is non-+9 percent modeled) in land area, as a percentage of starting area, across the entire period of record (table 1).

### Change in Land Change Rates through Time

between 1973 and 1984 were given three-quarters weight of data (Katrina, Rita, Gustav, and Ike), recent wetland loss rates have decrease. Although there is still a substantial area of wetlands Doyle and others, 2015).

**Figure 5.** Finite-difference approximation of land area change rates

through time in coastal Louisiana by hydrologic basin (as defined by

Act Program, n.d.), 1932–2016; negative measurements indicate land

specific values

-5.88

loss, whereas positive measurements indicate land gain. See table 3 for

-3.61 0.45 -7.62 -15.30 0.00 -52.66 -75.13 -29.82

-83.19 -95.38 -70.74

-83.51 -94.87 -71.87

-70.38 -80.37 -60.55 -59.66 -68.97 -50.5

-39.23 -48.78 -30.09

-35.67 -46.81 -25.17

-31.54 -45.28 -18.56

-30.52 -45.09 -16.80

-2.09 -2.99 -1.19 -15.25 -18.58 -11.84 -67.98 -78.71 -57.05

-3.38 -4.54 -2.22 -24.29 -28.73 -19.82 -82.47 -95.42 -69.23

1.13 -0.22 2.49 -6.34 -11.45 -1.20 -28.53 -44.62 -13.08 1.18 -0.19 2.56 -6.20 -11.41 -0.96 -28.22 -44.57 -12.54

21 -0.18 2.60 -6.12 -11.37 -0.84 -28.06 -44.58 -12.26

whereas figures 4 and 5 and table 3 display approximations of suggesting that the rate of change has not changed significantly the rates of land area change over time. Rates of change were over the period of record in those basins (fig. 5). The remaining bodies or to reestablish once vegetated areas. Some of these areas basins were best fit by non-linear functions. Barataria, Terrebonne, and Teche-Vermilion Basins follow a similar pattern to that of the coastwide trend of loss rates increasing to a peak in the late 1970s, followed by a reduction in loss rates since that time. In Breton the rates were calculated by using the function derivSimulCI() Sound Basin, wetland loss rates have continued to increase and (Simpson, 2016). The 15.9 and 84.1 percentiles (representing the have only recently begun to suggest a decrease in that rate (fig. 5). expected value +/- 1 standard deviation) of each rate estimate were Calcasieu-Sabine Basin experienced the highest rates of wetland loss prior to the 1970s, with rates slowly decreasing since that time, with the exception of hurricane-induced losses in 2005 and 2008. The Mississippi River Delta Basin experienced a reduction in wetland loss rate since the 1960s, reaching a point of wetland land change slope) since 1961 (fig. 5). Prior to 1961, this basin was hydrocarbon production in that area after 1974. of the Wax Lake Outlet in 1942, sediment deposition increased, activity and subsidence due to active faulting (Dokka, 2006; and a subaerial active delta emerged after the flood of 1973.

#### Discussion

The spatial and temporal patterns of wetland change observed corresponds with the decrease in the rate of wetland loss. in this assessment reveal a dynamic landscape changing as a result Finally, restoration activities, such as marsh creation and

term trend. This increase in coastwide net land area may not yet be interpreted as "gain" because the persistence of said areas has yet to be assessed and much of this may be interpreted as recovery and 2008; however, specific areas of gain can be detected in the dataset, many of which are showing persistence throughout the newly added data points.

It is important to note that there is a difference between net The resulting land area data were summarized by time period modeled), Pontchartrain Basin (-472 km<sup>2</sup> observed; -529 +/- 30 km<sup>2</sup> land area change (figs. 2 and 3, table 1) and persistent losses and This assessment provides a comprehensive analysis of statistical platform (R Core Team, 2014). This method fits land modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land area across the entire period of record (table modeled) in total land

technique are smoothed and, as such, generalize trends over time. percent observed; -57 percent modeled), followed by Breton Sound in rates of wetland change through time by fitting data with non-The intent of this study is to provide long-term, coarse-scale rates Basin (-38 percent observed; -43 percent modeled), Barataria Basin linear models. Most of the models fit the coastwide and basin-level of change, and therefore these change rates are not appropriate (-29 percent observed; -31 percent modeled), Terrebonne Basin (-29 at finer spatial and temporal scales. The complexity smoothing percent observed; -30 percent modeled), Calcasieu-Sabine Basin In the Atchafalaya Delta Basin, a basin in which water levels are

> and Terrebonne Basins all have an  $R^2$  value at or exceeding 0.9. our changing environment. This analysis has shown decreasing rates of wetland loss after While recent trends have shown a reduction in the rate of the 1970s. The possible causes of this decline in land change rate wetland loss, it is important to note that past trends are not

after 1984. The goodness of fit is described by the coefficient of decreased from the peak loss rates observed in the 1970s which remaining, at some point the influence of this artifact should be determination ( $R^2$ ) statistic. Effective degrees of freedom (edf) can are known to have exceeded 80 square kilometers per year ( $km^2/$  considered. Similarly, many of the wetlands in the most precarious fit the models with and without weighting the data. As suspected, during the 1973–78 time period, followed by a steady reduction vulnerable and contribute to this reduction in loss rate; however, weighted models were more complex (larger edf) and had higher Barras and others (2008) observed a similar trend of decreasing cumulative episodic events over time (Morton and Barras, 2011). The lack of major storms since 2008 is likely the most influential factor causing the decrease in net loss rates. This period reduced bias and improved the robustness of the models. drastically over the period of record. Only two basins, Mermentau of relative calm has led to fewer disturbances in the form of wave energy, thereby reducing erosion-induced losses. The storm hiatus also allowed vegetation to colonize new areas of shallow water may have begun life as FAV but may have since attached to the substrate (Russell, 1942).

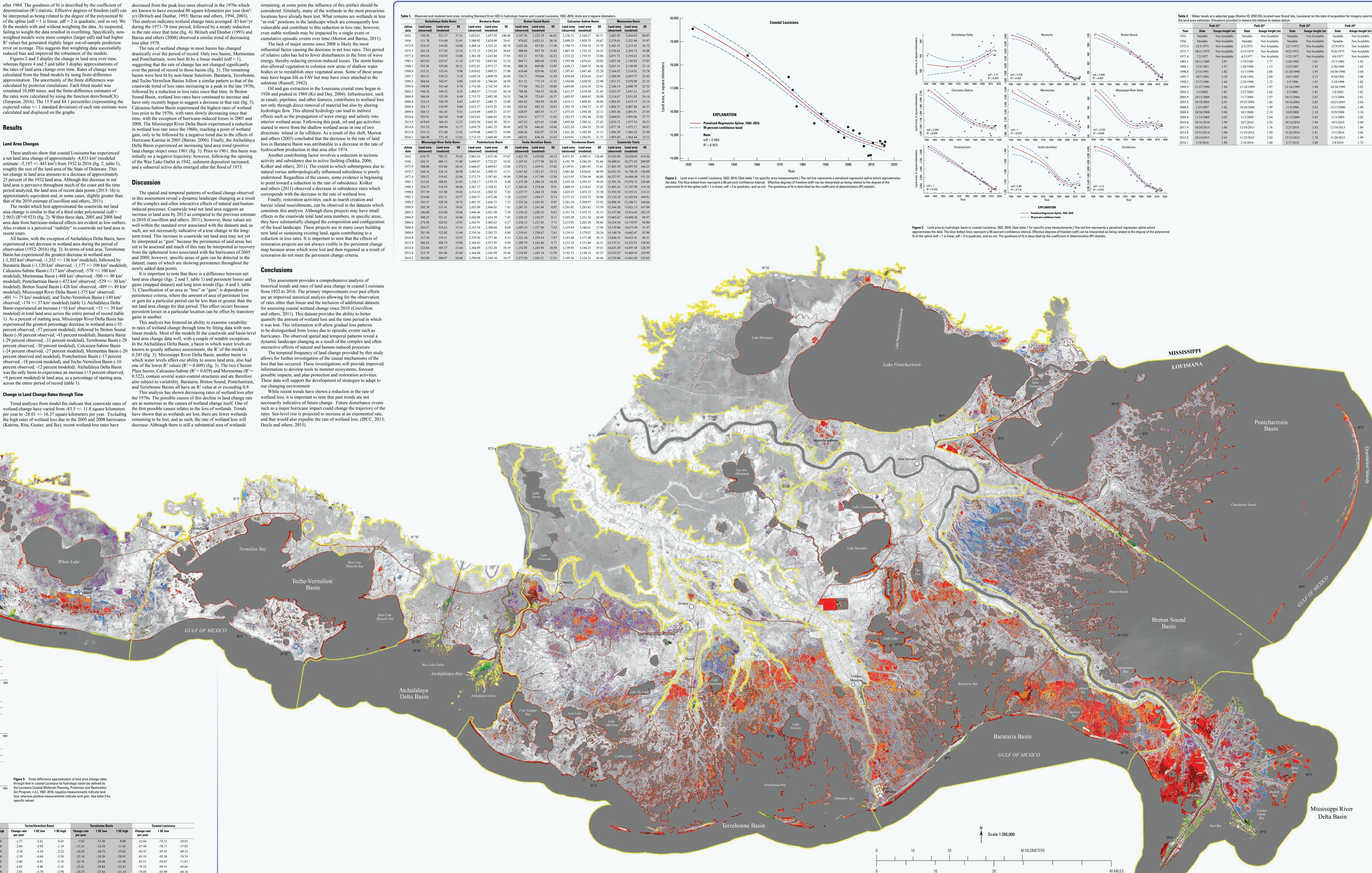
> Oil and gas extraction in the Louisiana coastal zone began in 1926 and peaked in 1969 (Ko and Day, 2004). Infrastructure, such as canals, pipelines, and other features, contributes to wetland loss not only through direct removal of material but also by altering hydrologic flow. This altered hydrology can lead to indirect effects such as the propagation of wave energy and salinity into interior wetland areas. Following this peak, oil and gas activities started to move from the shallow wetland areas in one of two gain, only to be followed by a negative trend due to the effects of directions: inland or far offshore. As a result of this shift, Morton Hurricane Katrina in 2005 (Barras, 2006). Finally, the Atchafalaya and others (2005) concluded that the decrease in the rate of land Delta Basin experienced an increasing land area trend (positive loss in Barataria Basin was attributable to a decrease in the rate of initially on a negative trajectory; however, following the opening Another contributing factor involves a reduction in tectonic Kolker and others, 2011). The extent to which submergence due to natural versus anthropologically influenced subsidence is poorly understood. Regardless of the causes, some evidence is beginning to point toward a reduction in the rate of subsidence. Kolker and others (2011) observed a decrease in subsidence rates which of the complex and often interactive effects of natural and human-barrier island nourishments, can be observed in the datasets which induced processes. Coastwide total net land area suggests an constitute this analysis. Although these projects may have small increase in land area by 2015 as compared to the previous estimate effects in the coastwide total land area numbers, in specific areas, in 2010 (Couvillion and others, 2011); however, these values are they have substantially changed the composition and configuration well within the standard error associated with the datasets and, as of the local landscape. These projects are in many cases building such, are not necessarily indicative of a true change in the long-new land or sustaining existing land, again contributing to a reduction in loss rates. It is important to note that the effects of

restoration projects are not always visible in the persistent change from the ephemeral lows associated with the hurricanes of 2005 map because areas which were lost and then regained as a result of restoration do not meet the persistent change criteria.

#### Conclusions

features has led to an overall decrease in the amount of sediment this assumption was applied.) The areas missing from the 1932 and water and vegetation reflects MIR light more than green light (Xu, and by basin (fig. 3, table 1). Figures 2 and 3 display the long-term modeled), Breton Sound Basin (-426 km<sup>2</sup> observed; -489 +/- 49 km<sup>2</sup> gains (mapped dataset) and long term trends (figs. 4 and 5, table historical trends and rates of land area change in coastal Louisiana 3). Classification of an area as "loss" or "gain" is dependent on from 1932 to 2016. The primary improvements over past efforts historically stable, so the assumption of "no change" is correct in land/water categories by thresholds. Supervised and unsupervised  $-401 + 75 \text{ km}^2$  modeled), and Teche-Vermilion Basin (-149 km<sup>2</sup> are an improved statistical analysis allowing for the observation called penalized regression splines by using the Mixed GAM regression splines by using the Mixed GAM or gain for a particular period can be less than or greater than the observed; -174 +/- 37 km<sup>2</sup> modeled) (table 1). Atchafalaya Delta Computation Vehicle (MGCV) package (Wood, 2000) on the R Basin experienced an increase (+16 km<sup>2</sup> observed; +51 +/- 39 km<sup>2</sup> net land area change for that period. This effect occurs because for assessing coastal wetland change since 2010 (Couvillion quantify the amount of wetland loss and the time period in which it was lost. This information will allow gradual loss patterns to be distinguished from losses due to episodic events such as hurricanes. The observed spatial and temporal patterns reveal a dynamic landscape changing as a result of the complex and often spline, as determined by the dimensionality of its basis function, (-24 percent observed; -27 percent modeled), Mermentau Basin (-20 known to greatly influence assessments, the R<sup>2</sup> of the model is The temporal frequency of land change provided by this study observed; -18 percent modeled), and Teche-Vermilion Basin (-10 which water levels affect our ability to assess land area, also had allows for further investigation of the causal mechanisms of the percent observed; -12 percent modeled). Atchafalaya Delta Basin one of the lower  $R^2$  values ( $R^2 = 0.609$ ) (fig. 3). The two Chenier loss that has occurred. These investigations will provide improved Plain basins, Calcasieu-Sabine ( $R^2 = 0.659$ ) and Mermentau ( $R^2 =$  information to develop tools to monitor ecosystems, forecast 0.522), contain several water-control structures and are therefore possible impacts, and plan protection and restoration activities. also subject to variability. Barataria, Breton Sound, Pontchartrain, These data will support the development of strategies to adapt to

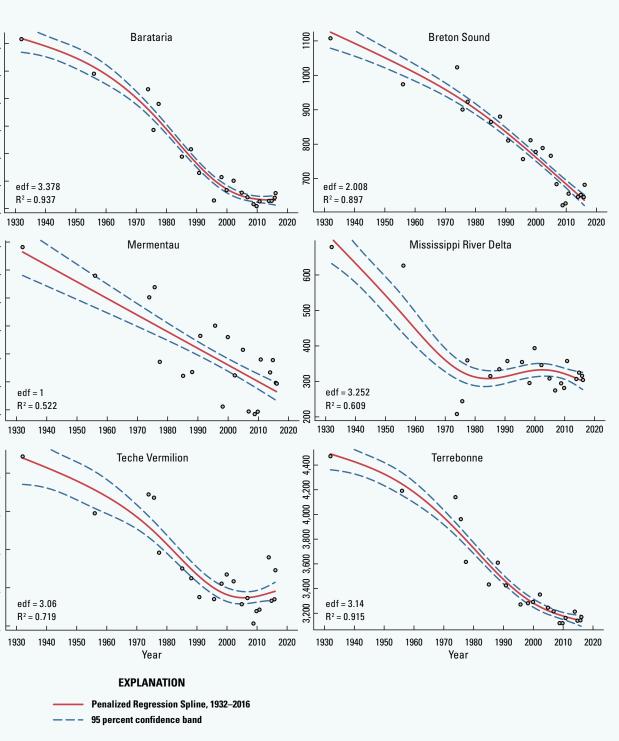
points were weighted differently on the basis of expert opinion of Trend analyses from model fits indicate that coastwide rates of are as numerous as the causes of wetland change itself. One of necessarily indicative of future change. Future disturbance events the uncertainty inherent in each method. The weights affect how wetland change have varied from -83.5 +/- 11.8 square kilometers the first possible causes relates to the loss of wetlands. Trends such as a major hurricane impact could change the trajectory of the strongly each point contributes to estimates of total deviation. Data per year to -28.01 +/- 16.37 square kilometers per year. Excluding have shown that as wetlands are lost, there are fewer wetlands rates. Sea-level rise is projected to increase at an exponential rate, before 1973 were given half the weight of data after 1984. Data the high rates of wetland loss due to the 2005 and 2008 hurricanes remaining to be lost, and as such, the rate of wetland loss will and that would also expedite the rate of wetland loss. (IPCC, 2013;



Land Area Change in Coastal Louisiana (1932 to 2016)

Brady R. Couvillion, Holly Beck, Donald Schoolmaster, and Michelle Fischer

# Scientific Investigations Map 3381



	Р	ath 21*	Pa	ath 22*	P	ath 23*	Path 24*		
Year	Date	Gauge height (m)							
1932	Variable	Not Available							
1956	Variable	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	4/15/1975	Not Available	9/25/1975	Not Available	9/26/1975	Not Available	
1977.4	7/2/1977	Not Available	6/3/1977	Not Available	1/23/1977	Not Available	4/6/1977	Not Available	
1985.1	10/11/1985	2.07	1/19/1985	1.77	1/26/1985	1.81	12/3/1985	1.92	
1988.1	12/4/1987	1.97	1/28/1988	1.53	12/2/1987	1.93	1/26/1988	1.82	
1990.8	2/14/1991	1.82	11/1/1990	2.00	11/24/1990	1.95	10/30/1990	2.04	
1995.7	10/7/1995	2.10	9/28/1995	2.09	10/5/1995	2.11	9/10/1995	2.08	
1998.2	2/17/1998	1.84	2/24/1998	1.72	3/3/1998	1.87	3/10/1998	1.88	
1999.9	11/27/1999	1.94	11/18/1999	1.97	11/16/1999	1.98	10/24/1999	2.05	
2002.2	1/3/2002	1.83	2/27/2002	1.66	2/2/2002	1.82	1/8/2002	1.83	
2004.9	10/15/2004	2.06	11/7/2004	1.97	10/13/2004	2.07	11/5/2004	2.01	
2005.8	10/18/2005	2.05	10/25/2005	1.86	10/16/2005	2.03	10/23/2005	2.04	
2006.8	1/25/2007	1.82	10/28/2006	1.99	11/4/2006	2.03	12/13/2006	1.90	
2008.8	10/26/2008	2.08	10/1/2008	2.10	10/8/2008	2.10	9/29/2008	2.10	
2009.8	11/14/2009	2.03	11/5/2009	2.04	11/12/2009	2.03	11/3/2009	2.05	
2010.8	10/16/2010	1.99	10/7/2010	1.92	10/14/2010	1.94	10/5/2010	2.09	
2013.9	10/24/2013	1.96	12/18/2013	1.76	2/27/2014	1.83	12/16/2013	1.80	
2014.8	12/14/2014	1.90	11/19/2014	1.99	11/26/2014	1.81	11/1/2014	2.06	
2015.8	10/14/2015	2.05	11/22/2015	2.02	12/15/2015	1.78	11/20/2015	1.99	
2016.1	1/18/2016	1.88	2/10/2016	1.80	2/17/2016	1.88	2/8/2016	1.75	

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#### EXPLANATION

1932–56 Persistent land loss<sup>2</sup> 1956–73 Persistent land loss<sup>2,4</sup> 1973–75 Persistent land loss<sup>2,4</sup> 1975–77 Persistent land loss<sup>2,4</sup> 1977–85 Persistent land loss<sup>2,4</sup> **1985–88 Persistent land loss<sup>2</sup>** 1988–90 Persistent land loss<sup>2</sup> 1990–95 Persistent land loss<sup>2</sup> 1995–98 Persistent land loss<sup>2</sup> **1998–99 Persistent land loss<sup>2</sup>** 1999–2002 Persistent land loss<sup>2</sup> 2002–04 Persistent land loss<sup>2</sup> 2004–06 Persistent land los 2006–08 Persistent land loss<sup>2</sup> 2008–09 Persistent land loss<sup>2</sup> 2009–10 Persistent land loss<sup>2</sup> 2010–13 Persistent land loss<sup>2</sup> 2013–14 Persistent land loss<sup>2</sup> 2014–15 New water area<sup>3</sup> 1932–56 Persistent land gain<sup>1</sup> **1956–73 Persistent land gain**<sup>1,4</sup> 1973–75 Persistent land gain<sup>1,4</sup> 1975–77 Persistent land gain<sup>1,4</sup> 1977–85 Persistent land gain<sup>1,4</sup> 1985–88 Persistent land gain<sup>1</sup> 1988–90 Persistent land gain<sup>1</sup> 1990–95 Persistent land gain<sup>1</sup> 1995–98 Persistent land gain<sup>1</sup> 1998–99 Persistent land gain<sup>1</sup> 1999–2002 Persistent land gain<sup>1</sup> 2002–04 Persistent land gain<sup>1</sup> 2004–06 Persistent land gain<sup>1</sup> 2006–08 Persistent land gain<sup>1</sup> 2008–09 Persistent land gain<sup>1</sup> 2009–10 Persistent land gain<sup>1</sup> 2010–13 Persistent land gain<sup>1</sup> 2013–14 Persistent land gain<sup>1</sup> 2014–15 New land area<sup>3</sup> **Basin boundary** ss is determined by the last date a particular pixel transitioned fr and remained water throughout the period of observa

<sup>3</sup>Because this date range has only one ending dataset, some of these effects may be temporary phenomena. date range contains at least one date in which the land/water data reated from Landsat Multispectral Scanner System (MSS). Publishing support provided by Lafayette Publishing Service Cente

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