U.S. Department of the Interior

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.

The Louisiana coastal zone encompasses approximately 37,780 square kilometers (km²) 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). changes. As glaciers retreated (from about 12,000 until 6.000 that compose coastal Louisiana today. Periodic floodwaters

Louisiana but throughout the Mississippi River catchment,

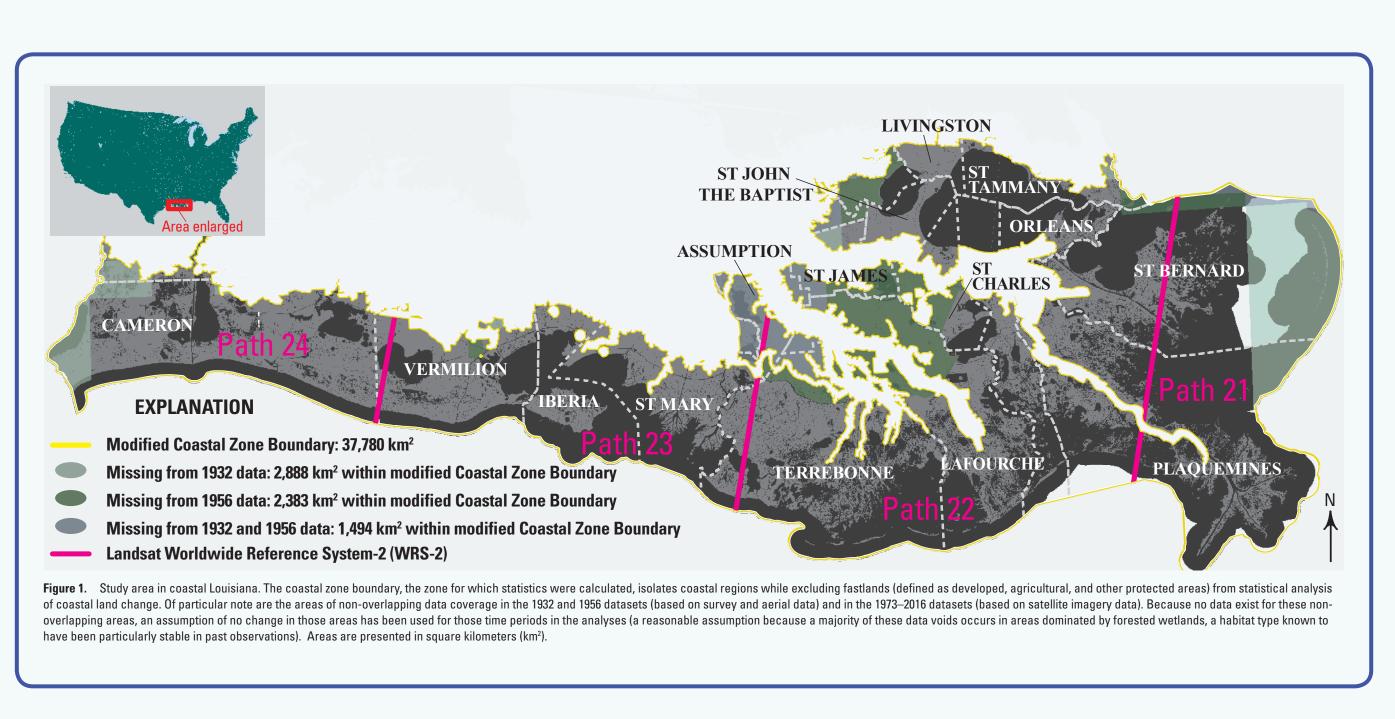
particularly after the flood of 1927. The construction of these

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

elevation in response to SLR and subsidence.



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 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 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 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. uses an automated process to align common landform features

Land area estimates can vary substantially because of 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,

> e from USGS Center for Earth Resources Observation and Science (EROS) ndsat imagery. Analyses presented utilized imagery from Landsat Multispectral anner System (MSS), Thematic Mapper (TM), and Operational Land Imager

Background imagery consists of average band 6 (mid-infrared) values from earl

Finite Difference Slope Approximation, 1932–2016

Table 3. Finite-difference approximation estimates of long-term wetland change rates including standard error (SE) estimates for each hydrologic basin and coastal Louisiana from 1932 to 2016. Units are in square kilometers per year

— — — 95 percent confidence band

2016 Landsat Operational Land Imager (OLI) satellite imagery.

Figure 4. Finite-difference approximation of land area change rates through time in coastal Louisiana, 1932–2016; negative measurements indicate a net land loss rate,

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

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 mNDWI = (Green-MIR)/(Green+MIR)

on error-prone classes such as floating aquatic vegetation (FAV), between datasets must be highly accurate. Misalignment of water-level variations on the date of acquisition (DOA) (table 2)

from fluvial and tidally redistributed deposits. The bulk of these Louisiana by using 21 datasets summarizing land and water used to derive the land area by date, basin area, and coastal area that of the 2010 estimate (Couvillion and others, 2011). 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 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

land change caused by misclassification or transient environmental

area change is similar to that of a third order polynomial (edf = Army Corps of Engineers land loss data (1932) (Dunbar and phenomena, two approaches were utilized. Changes must persist 2.903) (R²=0.923) (fig. 2). Within these data, 2005 and 2008 land years ago), meltwater inundated valleys and transported much of based on agrical photography (1056). (2) London Market and Survey (NWI) data and transported much of based on agrical photography (1056). (2) London Market and Survey (NWI) data and transported much of based on agrical photography (1056). (2) London Market and Survey (NWI) data and transported much of based on agrical photography (1056). 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 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 (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 land changes (2015 to early 2016) cannot yet be defined as persistent because data are not available to confirm that these

> trend in land area over the period of observation. The function of modeled), Mississippi River Delta Basin (-375 km² observed;
>
> 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 are an improved statistical analysis allowing for the observation called penalized regression splines by using the Mixed GAM
>
> or gain for a particular period can be less than or greater than the observed; -174 +/- 37 km² modeled) (table 1). Atchafalaya Delta 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. zero covariance between the model error and the independent variables, which leads to biased estimates. These data clearly violate this assumption because of differences in data-collection methods. To account for differences in methods across years,

> > 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020

1930 1940 1950 1960 1970 1980 1990 2000 2010 2020 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020

Finite Difference Slope Approximation, 1932–2016

 $-0.40 \quad -1.69 \quad 0.88 \quad -6.82 \quad -13.28 \quad -0.16 \quad -4.05 \quad -5.82 \quad -2.31 \quad -9.45 \quad -13.26 \quad -5.51 \quad -5.95 \quad -7.18 \quad -4.72 \quad -8.71 \quad -13.09 \quad -4.38 \quad -6.29 \quad -6.69 \quad -5.88 \quad -1.57 \quad -3.61 \quad 0.45 \quad -7.62 \quad -15.30 \quad 0.00 \quad -52.66 \quad -75.13 \quad -29.82$

 $2014 \qquad 1.66 \qquad 0.72 \qquad 2.61 \qquad -0.96 \qquad -5.42 \qquad 3.35 \qquad -7.78 \qquad -9.08 \qquad -6.50 \qquad -1.96 \qquad -5.88 \qquad 1.18 \qquad -0.19 \qquad 2.56 \qquad -6.20 \qquad -11.41 \qquad -0.96 \qquad -28.22 \qquad -44.57 \qquad -12.54$ $2015 \qquad 1.66 \qquad 0.72 \qquad 2.61 \qquad -0.85 \qquad -5.34 \qquad 3.51 \qquad -7.78 \qquad -9.09 \qquad -6.49 \qquad -1.96 \qquad -4.92 \qquad 0.87 \qquad -5.95 \qquad -7.18 \qquad -4.72 \qquad -3.61 \qquad -6.59 \qquad -0.60 \qquad -6.29 \qquad -6.69 \qquad -5.88 \qquad 1.21 \qquad -0.18 \qquad 2.60 \qquad -6.12 \qquad -11.37 \qquad -0.84 \qquad -28.06 \qquad -44.58 \qquad -12.26 \qquad -11.27 \qquad$

1930 1940 1950 1960 1970 1980 1990 2000 2010 2020 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020 the Louisiana Coastal Wetlands Planning, Protection and Restoration

R² 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 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).

These analyses show that coastal Louisiana has experienced a net land area change of approximately -4,833 km² (modeled estimate: -5,197 +/- 443 km²) 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 area data from hurricane-induced effects are evident as low outliers. Also evident is a perceived "stability" in coastwide net land area in

experienced a net decrease in wetland area during the period of areas of persistent and consistent change. For this reason, recent observation (1932–2016) (fig. 3). In terms of total area, Terrebonne Basin has experienced the greatest decrease in wetland area $(-1,302 \text{ km}^2 \text{ observed}; -1,352 +/- 136 \text{ km}^2 \text{ modeled})$, followed by changes have persisted into the two following analysis periods.

Barataria Basin (-1,120 km² observed; -1,177 +/- 106 km² modeled), These unconfirmed changes are instead referred to as "new land Calcasieu-Sabine Basin (-517 km² observed; -578 +/- 100 km² investigation areas" and "new water investigation areas." modeled), Mermentau Basin (-488 km² observed; -500 +/- 90 km²

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 of the spline (edf = 1 is linear, edf = 2 is quadratic, and so on). We This analysis indicates wetland change rates averaged -83 km²/yr "at-risk" positions in the landscape which are consequently less 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, 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

calculated and displayed on the graphs.

Land Area Changes

All basins, with the exception of Atchafalaya Delta Basin, have and 2008; however, specific areas of gain can be detected in the

Computation Vehicle (MGCV) package (Wood, 2000) on the R

Basin experienced an increase (+16 km² observed; +51 +/- 39 km²

net land area change for that period. This effect occurs because for assessing coastal wetland change since 2010 (Couvillion statistical platform (R Core Team, 2014). This method fits land modeled) in total land area across the entire period of record (table persistent losses in a particular location can be offset by transitory across the span of years. Trends computed from this spline experienced the greatest percentage decrease in wetland area (-55 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 across the entire period of record (table 1).

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; 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

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

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 whereas figures 4 and 5 and table 3 display approximations of suggesting that the rate of change has not changed significantly also allowed vegetation to colonize new areas of shallow water 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, 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

in wetland loss rate since the 1960s, reaching a point of wetland Delta Basin experienced an increasing land area trend (positive

and a subaerial active delta emerged after the flood of 1973.

time, with the exception of hurricane-induced losses in 2005 and

2008. The Mississippi River Delta Basin experienced a reduction

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 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 longnew land or sustaining existing land, again contributing to a 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

dataset, many of which are showing persistence throughout the 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 km² observed; -529 +/- 30 km² land area change (figs. 2 and 3, table 1) and persistent losses and

This assessment provides a comprehensive analysis of features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease in the amount of sediment features has led to an overall decrease has led to an overall decr

> technique are smoothed and, as such, generalize trends over time.
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> percent observed; -57 percent modeled), followed by Breton Sound
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> 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 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 land area change data well, with a couple of notable exceptions. 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 spline, as determined by the dimensionality of its basis function, (-24 percent modeled), Mermentau Basin (-20 known to greatly influence assessments, the R² of the model is observed; -18 percent modeled), and Teche-Vermilion Basin (-10 which water levels affect our ability to assess land area, also had One of the assumptions of these modeling methods is that
>
> One of the assumptions of these modeling methods is that
>
> percent observed; -12 percent modeled). Atchafalaya Delta Basin
>
> one of the lower R² values (R² = 0.609) (fig. 3). The two Chenier
>
> loss that has occurred. These investigations will provide improved each data point provides equally precise information about the was the only basin to experience an increase (+3 percent observed; Plain basins, Calcasieu-Sabine (R²= 0.659) and Mermentau (R²= information to develop tools to monitor ecosystems, forecast response variable. When this assumption is violated, there is non+9 percent modeled) in land area, as a percentage of starting area,
>
> 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 and Terrebonne Basins all have an R² 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

determination (R²) statistic. Effective degrees of freedom (edf) can are known to have exceeded 80 square kilometers per year (km²/ considered. Similarly, many of the wetlands in the most precarious be interpreted as being related to the degree of the polynomial fit yr) (Britsch and Dunbar, 1993; Barras and others, 1994, 2003).

Table 1. Observed and modeled land area, including Standard Error (SE) in hydrologic basins and coastal Louisiana, 1932–2016. Units are in square kilometer The lack of major storms since 2008 is likely the most

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). influential factor causing the decrease in net loss rates. This period energy, thereby reducing erosion-induced losses. The storm hiatus may have begun life as FAV but may have since attached to the Oil and gas extraction in the Louisiana coastal zone began in

1926 and peaked in 1969 (Ko and Day, 2004). Infrastructure, such 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 loss in Barataria Basin was attributable to a decrease in the rate of land change slope) since 1961 (fig. 5). Prior to 1961, this basin was hydrocarbon production in that area after 1974. initially on a negative trajectory; however, following the opening

Another contributing factor involves a reduction in tectonic of the Wax Lake Outlet in 1942, sediment deposition increased, activity and subsidence due to active faulting (Dokka, 2006; 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

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.

1990.8 357.39 315.08 19.45 2,514.53 2,503.32 7.83 1,237.77 1,264.54 9.46 3,425.47 3,455.23 35.30 15,592.54 15,555.21 114.13

1995.7 354.60 325.11 18.77 2,420.37 2,472.48 7.38 1,235.07 1,249.57 9.13 3,271.51 3,353.72 34.08 15,132.18 15,243.84 109.91

1999.9 393.70 331.41 18.61 2,452.49 2,446.05 7.41 1,267.35 1,241.04 8.97 3,291.05 3,283.62 33.59 15,344.58 15,021.13 107.09

2002.2 346.00 332.60 18.06 2,446.46 2,431.58 7.59 1,258.42 1,238.35 8.67 3,351.74 3,252.32 32.53 15,197.04 14,916.65 103.35

2008.8 294.57 324.63 15.34 2,333.54 2,390.04 8.68 1,203.24 1,237.96 7.52 3,119.94 3,186.61 27.96 14,119.96 14,673.89 91.47

2009.8 281.50 322.02 15.44 2,339.36 2,383.75 8.90 1,219.41 1,238.67 7.61 3,119.51 3,179.07 28.24 14,140.76 14,642.67 92.96

2010.8 357.50 319.11 15.91 2,359.36 2,377.46 9.14 1,221.36 1,239.54 7.87 3,161.68 3,171.96 29.15 14,666.35 14,612.41 96.31

2013.9 306.83 308.79 19.88 2,364.85 2,357.95 9.94 1,289.79 1,242.86 9.77 3,213.18 3,151.80 36.31 14,737.51 14,522.81 118.92

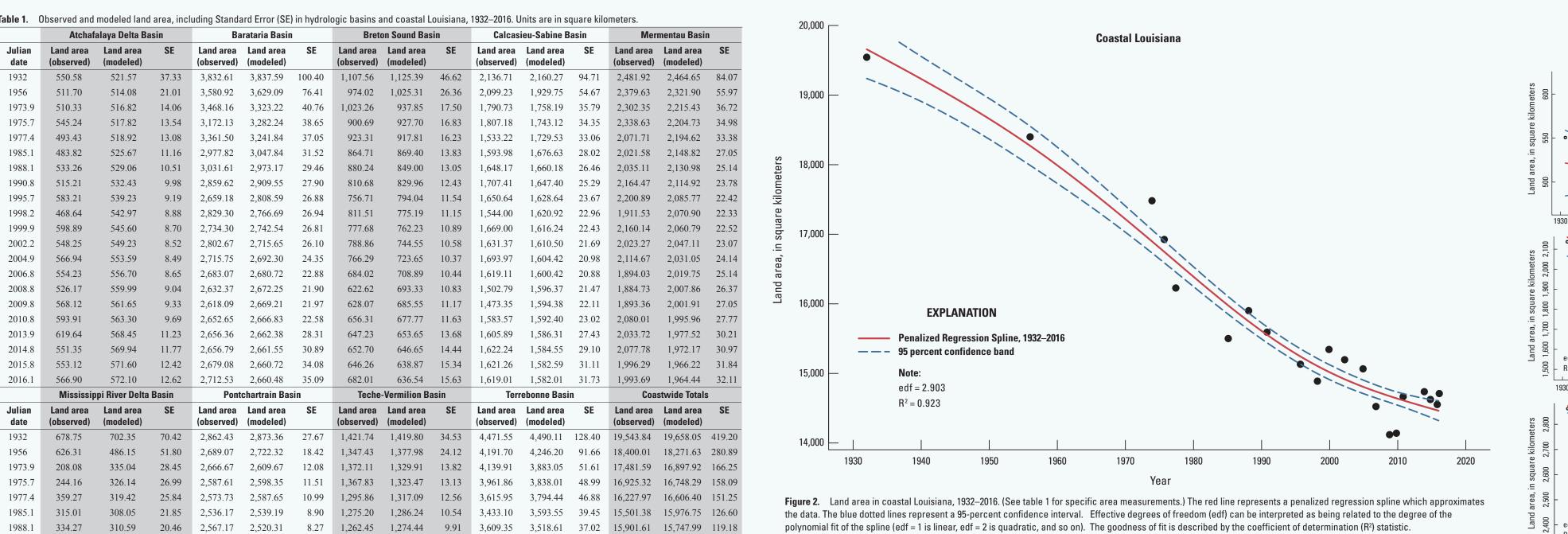
2014.8 324.68 305.57 21.64 2,366.89 2,352.28 10.19 1,232.92 1,243.94 10.59 3,139.95 3,146.25 39.41 14,625.29 14,497.48 128.39 2015.8 315.79 301.96 23.80 2,364.48 2,345.99 10.48 1,234.85 1,245.14 11.59 3,142.53 3,140.14 43.23 14,553.67 14,469.43 139.99

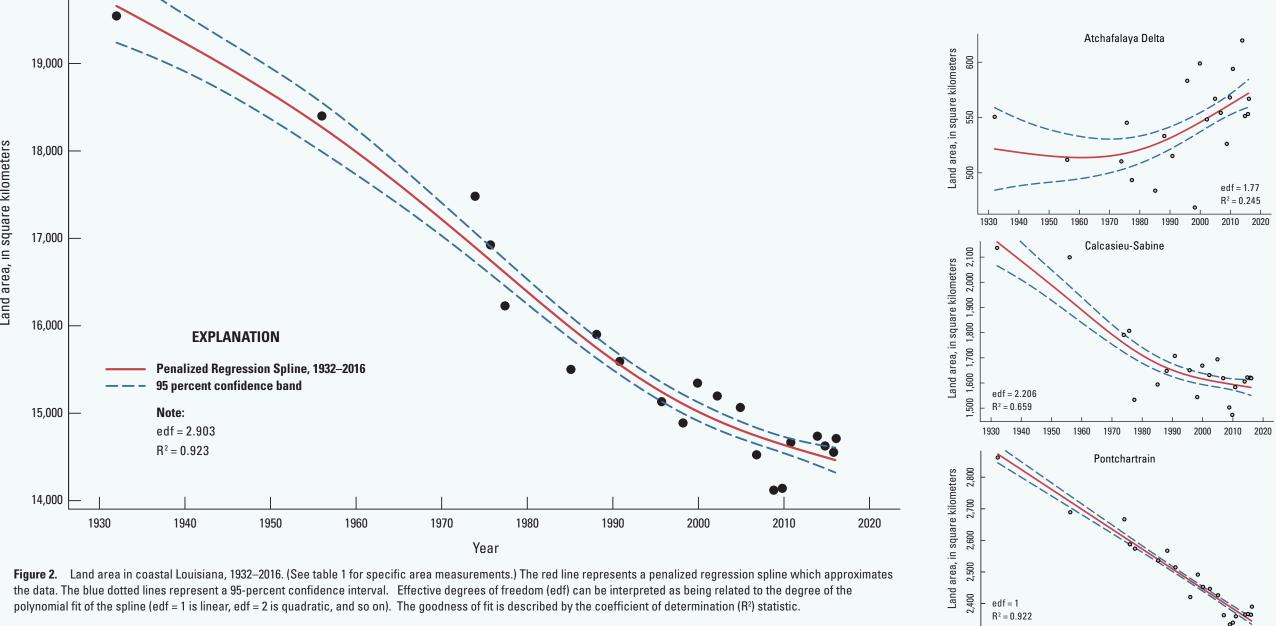
2016.1 303.98 300.87 24.48 2,390.08 2,344.10 10.57 1,272.90 1,245.51 11.91 3,169.56 3,138.31 44.44 14,710.66 14,461.03 143.65

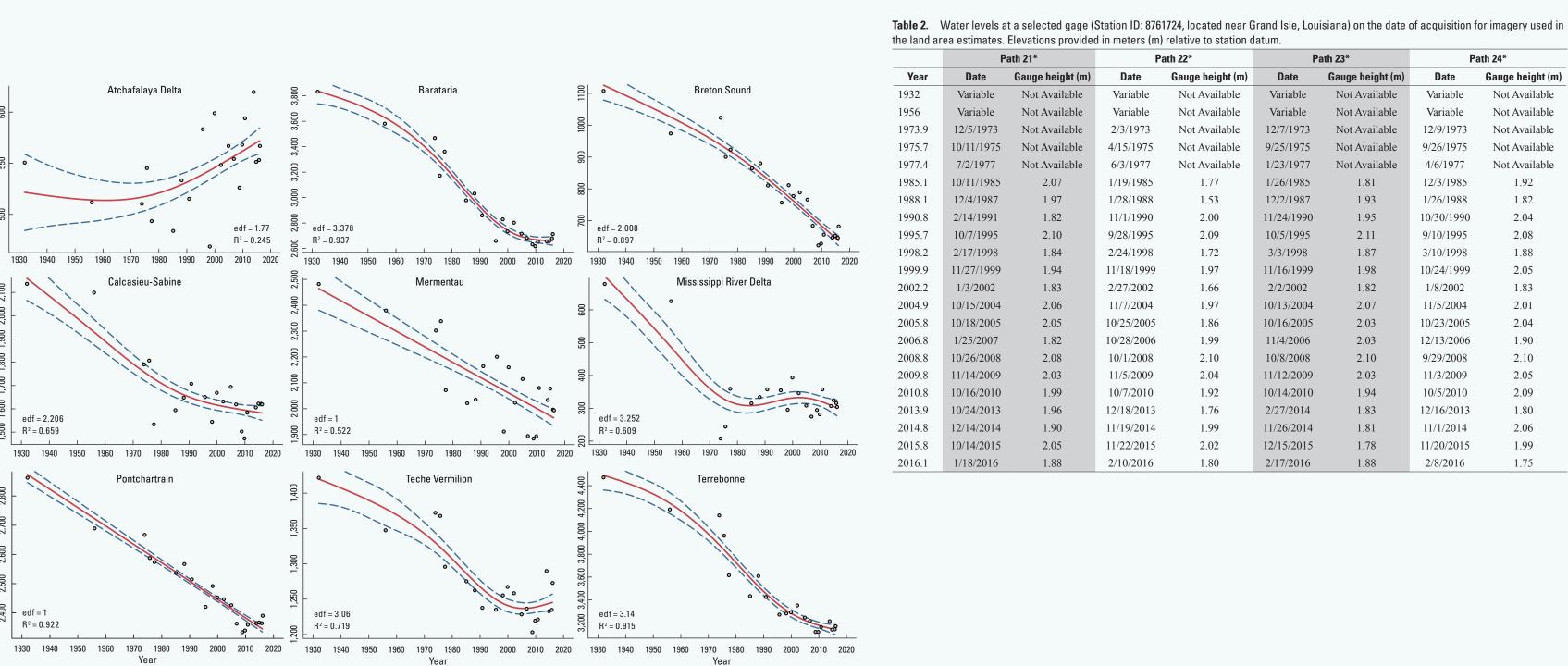
1998.2 295.37 329.39 18.75 2,491.55 2,456.75 7.35 1,255.36 1,243.95 9.07 3,281.10 3,309.97 33.93 14,888.36 15,106.21 108.66

quantify the amount of wetland loss and the time period in which it was lost. This information will allow gradual loss patterns hurricanes. The observed spatial and temporal patterns reveal a dynamic landscape changing as a result of the complex and often The temporal frequency of land change provided by this study

the 1970s. The possible causes of this decline in land change rate wetland loss, it is important to note that past trends are not







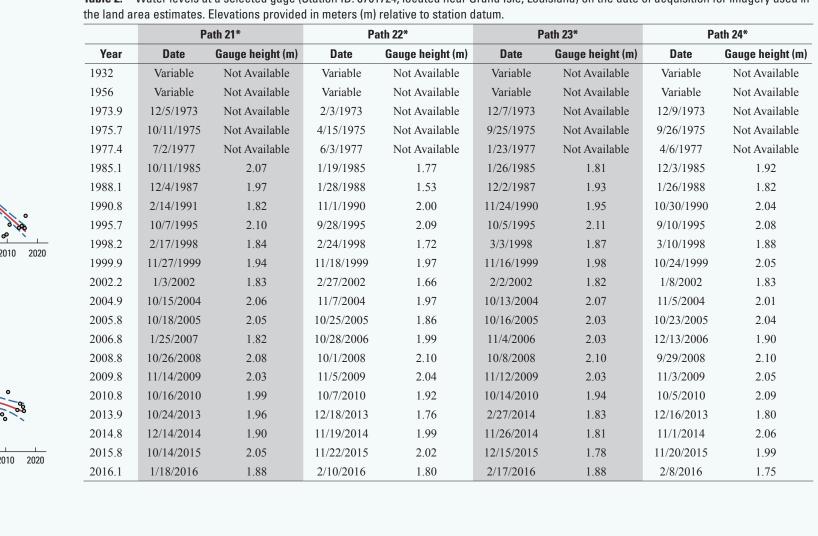
Penalized Regression Spline, 1932–2016

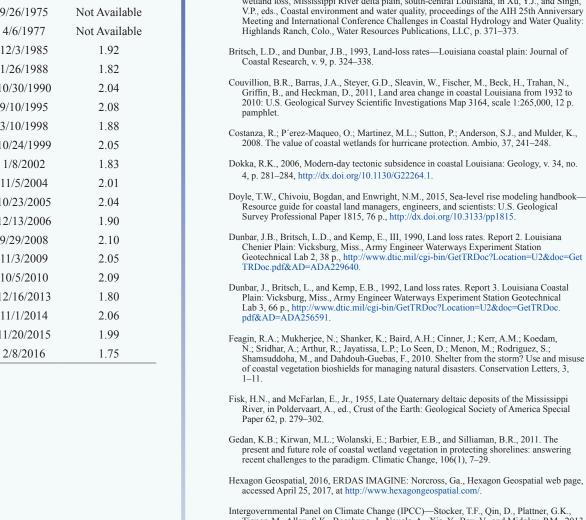
— — 95 percent confidence band

approximates the data. The blue dotted lines represent a 95-percent confidence interval. Effective degrees of freedom (edf) can be interpreted as being related to the degree of the polynomial

Figure 3. Land area by hydrologic basin in coastal Louisiana, 1932–2016. (See table 1 for specific area measurements.) The red line represents a penalized regression spline which

fit of the spline (edf = 1 is linear, edf = 2 is quadratic, and so on). The goodness of fit is described by the coefficient of determination (R2) statistic.





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1988–90 Persistent land loss² 1990–95 Persistent land loss² 1995–98 Persistent land loss² 1998–99 Persistent land loss²

1999–2002 Persistent land loss² 2002–04 Persistent land loss² 2006–08 Persistent land loss²

2008–09 Persistent land loss² 2009–10 Persistent land loss² 2010–13 Persistent land loss²

2013–14 Persistent land loss² 2014–15 New water area³ 1932–56 Persistent land gain¹

1975–77 Persistent land gain^{1,4} 1977–85 Persistent land gain^{1,4} 1985–88 Persistent land gain¹

1988–90 Persistent land gain¹ 1990–95 Persistent land gain¹ 1995–98 Persistent land gain¹ 1998–99 Persistent land gain¹

1999–2002 Persistent land gain¹ 2002–04 Persistent land gain¹ 2004–06 Persistent land gain¹ 2006–08 Persistent land gain¹

2008–09 Persistent land gain¹ 2009–10 Persistent land gain¹ 2010–13 Persistent land gain¹ 2013–14 Persistent land gain¹

2014–15 New land area³

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