Wetland Loss and Land Subsidence Related to Hydrocarbon Production, South-Central Louisiana

Julie C. Bernier[1] and Robert A. Morton[2]

[1]The Environmental Careers Organization, St. Petersburg, FL and [2]U.S. Geological Survey, St. Petersburg, FL

Abstract

Extensive wetland losses have occurred in coastal Louisiana during the last half century, with estimated land-loss rates on the delta plain as high as 60 to 75 km^2/yr. Analysis of historic aerial photographs and satellite images suggests that the most rapid wetland loss and collapse of the delta plain occurred during the late 1960s and 1970s. Since 1956, the emergent land area at five wetland-loss hotspots in the Terrebonne-Lafourche region of the Mississippi River delta plain has, on average, decreased by 45 to 50%.

Formerly emergent marshes at the wetland-loss hotspots are now submerged beneath water that averages 0.5 to 1.0 m deep. Correlation of the shallow subsurface stratigraphy shows that land subsidence has been the primary physical process contributing to wetland loss. Subsequent erosion of the submerged delta-plain marsh has been relatively minor at most of the hotspots.

The widespread and nearly simultaneous collapse of marshes across the Mississippi delta plain appears to be an unprecedented event in the recent geological record. Average historical rates of subsidence, determined from analysis of leveling surveys conducted by the National Geodetic Survey between 1965 and 1993, range from 8 to 12 mm/yr. In contrast, average rates of subsidence inferred from radiocarbon dates range from 1 to 5 mm/yr over the last 5000 years.

Surface and subsurface data strongly indicate that the rapid subsidence and associated wetland loss were largely induced by the production of hydrocarbons and associated formation water. The areas of greatest wetland loss and highest subsidence rates show good spatial correlation with the location of large oil-and-gas fields; and the period of most rapid wetland loss (late 1960s to 1970s) is nearly coincident with the timing of peak oil-and-gas production. The most recent rates of wetland loss are substantially lower than the peak rates, which is also consistent with significantly lower rates of fluid production.

Introduction

Seaward progradation and accumulation of sediment on the Mississippi River delta plain is associated with the active delta-lobe distributary, whereas land and wetland areas adjacent to abandoned distributaries naturally compact, subside, and eventually become inundated over 100s to 1000s of years. In historic times, however, land loss on the delta plain has been widespread and very rapid.

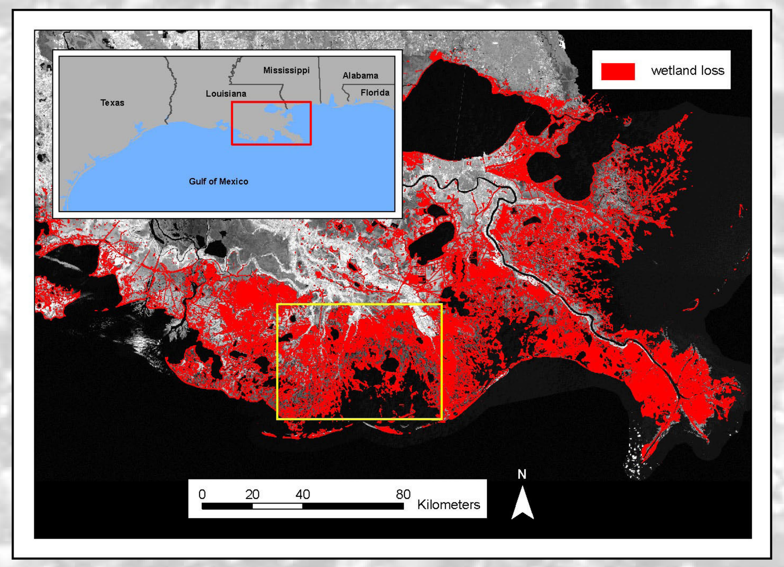

Figure 1. Since the 1930s, an estimated 4000 to 4500 km^2 of land and emergent marsh on the Louisiana delta plain has been converted to open water. Location of study area is shown by yellow box.

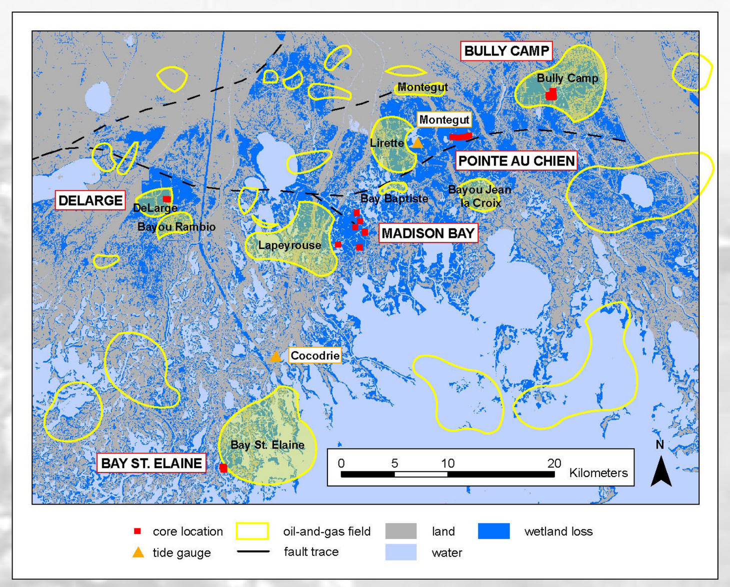

Figure 2. Map of study area showing the location of coring sites and reference tide gauges and the distribution of wetland losses (1956-2004) relative to producing oil-and-gas fields and regional subsurface faults.

Quantifying Historical Wetland Loss

Previous studies (Britsch and Dunbar, 1993; Barras et al., 2003) reported peak delta-plain land-loss rates of 60 to 75 km^2/yr from the 1960s to 1980s, with continued land loss to present at rates that are significantly higher than the 1930s to 1950s background rates. However, these rates are averaged over 10- to 20-year time periods. Improving the resolution of the land-loss curve will help to better constrain the timing and duration of peak wetland-loss rates. Five wetland-loss hotspots in the delta plain were identified from previous land-loss analyses and selected for further study. A time-series of images consisting of National Wetlands Inventory (NWI) habitat data (1956, 1978, and 1988), panchromatic (1969) and color-infrared (1974) aerial photographs, and Landsat Thematic Mapper (TM) satellites images (1983-2004) were analyzed by John Barras at the National Wetlands Research Center (NWRC).

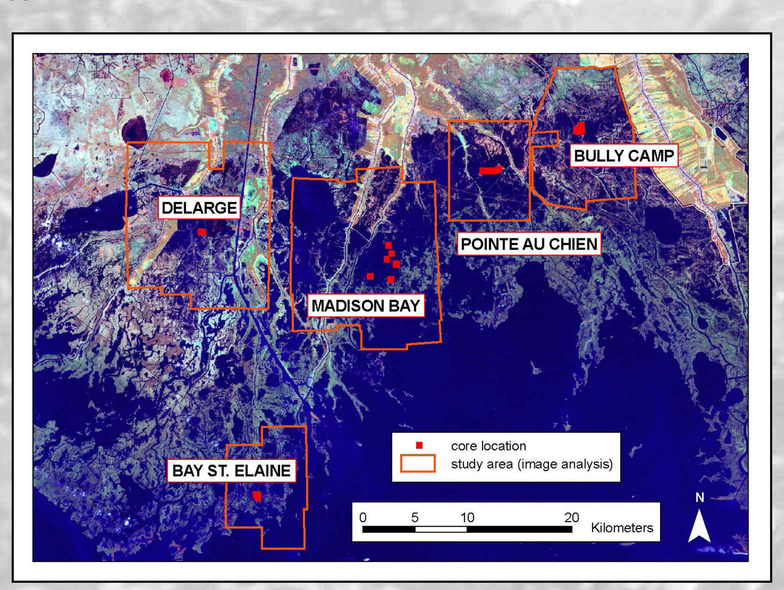

Figure 3. Location of five wetland-loss hotspots selected for analysis. Background is Landsat TM 5 image acquired Nov. 7, 2004 (R,G,B = 4,5,3).

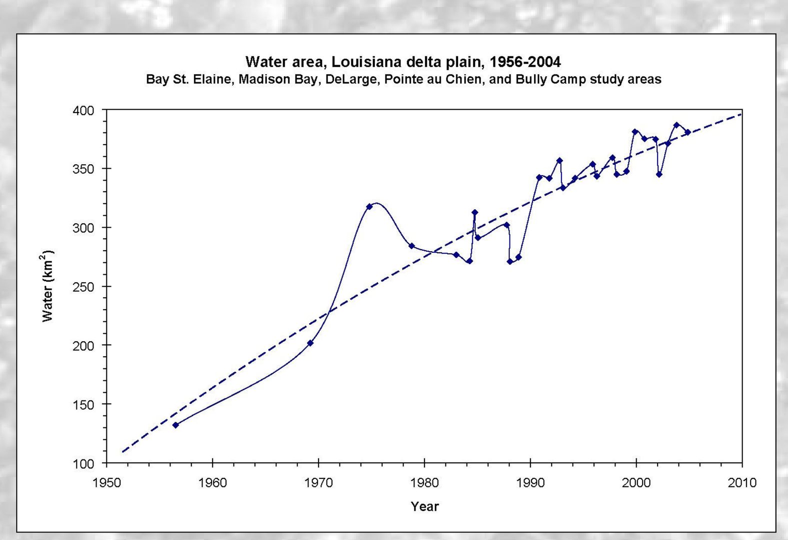

Figure 4. Land-change curve showing total water area from the five study areas through time. Almost 250 km^2 (46% of the total 1956 land area) of land and emergent marsh was converted to open water between 1956 and 2004. Much of this wetland loss occurred between 1956 and the mid- to late-1970s.

Subsidence vs. Erosion at Wetland-Loss Hotspots

Some recent studies (Penland et al., 2000; Day et al., 2000) attributed land loss around the shorelines of open-water bodies primarily to erosional processes, but Morton et al. (2003) showed that the magnitude of subsidence is significantly greater than erosion at the Madison Bay wetland-loss hotspot. Analysis of additional locations will help to identify whether subsidence or erosion is the more common delta-plain wetland-loss process.

At each study area, vibracores were taken from the emergent marsh and adjacent open-water sites. The water depth and surface elevation at each core site was corrected to the NAVD88 datum using water-level records from near-by tide gauges. At all coring sites, a similar succession of sediments was described, including two episodes of delta-plain marsh development represented by two peat deposits. The amount of subsidence is calculated from vertical offset of stratigraphic contacts between adjacent cores, and the amount of erosion is calculated from differences in thickness of the uppermost (modern or last marsh) peat deposit.

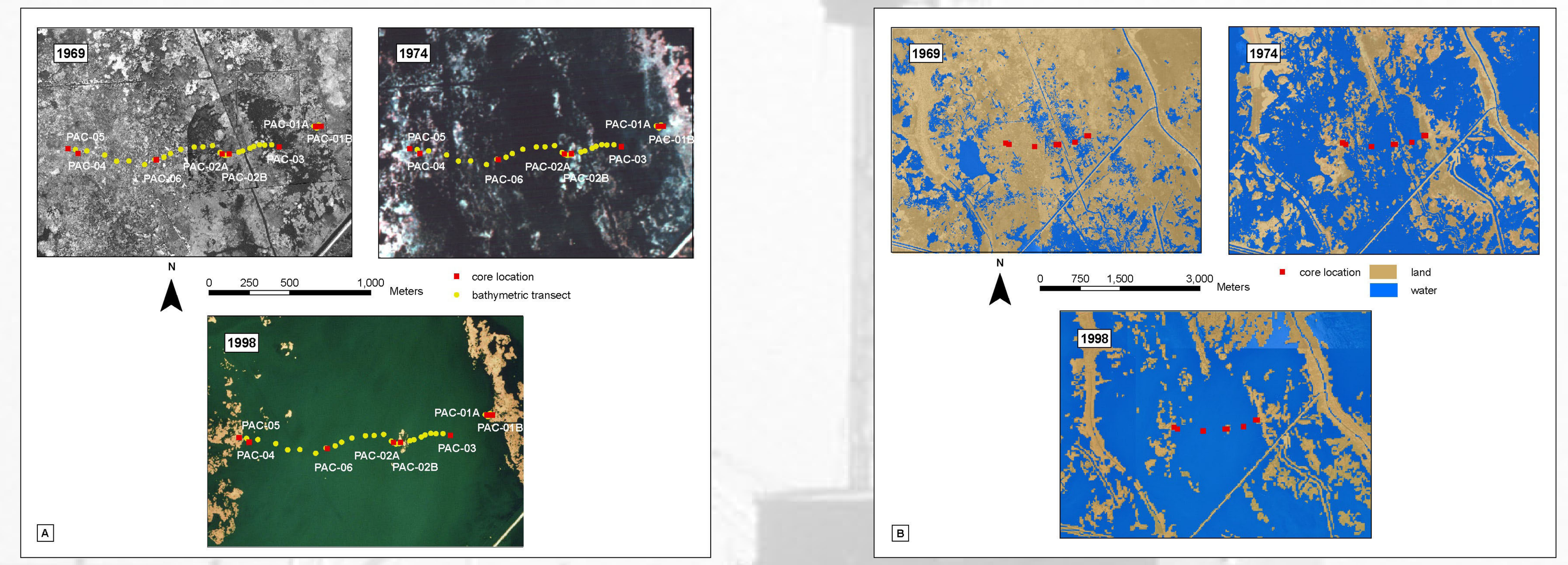

Figure 5. Locations of sediment cores at Pointe au Chien superimposed on (a) pre- and post-subsidence images and (b) results from image analysis (land-water classification). About 55% (26 km^2) of the total land loss (47 km^2 between 1956 and 2004) at Pointe au Chien occurred between 1969 and 1974.

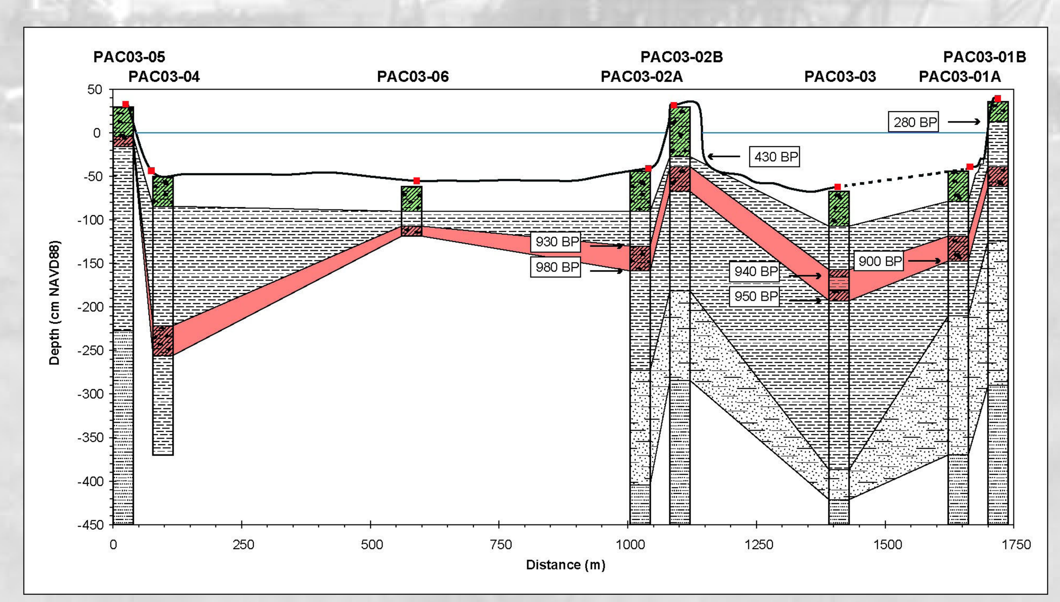

Figure 6. Combined bathymetric profile and stratigraphic cross section illustrates the magnitude of subsidence and wetland erosion relative to the modern emergent marsh at Pointe au Chien. Subsidence at the open-water sites ranged from 75 to 117 cm and averaged about 88 cm. In contrast, erosion of the last marsh peat ranged from 0 to 14 cm. The results were similar at all coring sites - the uppermost peat deposits are preserved at the top of the open-water cores, and a comparison of the relative magnitudes of subsidence and erosion suggests that subsidence is the primary process contributing to wetland loss.

Timing and Scale of Geological vs. Modern Wetland Loss

A delta-plain chronology was described for each study area based on ^{14}C ages at the base and top of the first- and last-marsh peat deposits (Fig. 6). Although the general stratigraphic section at each coring site is similar, the timing of peat development varies between study areas. For example, the first marsh peat is oldest (formed first) at DeLarge and is youngest (formed last) at Bully Camp. The timing and duration of peat formation at each study area reflects the timing of delta-lobe distributary progradation and abandonment. There is no evidence in the recent geologic past for the abrupt, regional-scale rapid burial and submergence of delta-plain marsh deposits that is occurring today.

There are several processes that affect the modern delta plain that are a direct result of human activity and are not representative of normal geologic processes. One major activity is oil-and-gas production. Direct impacts on the coastal wetlands include dredging, canal construction, and laying of pipelines. In addition, sharp declines in subsurface formation pressures commonly result from the extraction of large volumes of fluids. This pressure decline can cause reservoir compaction and settling of the overburden, which may be expressed at the surface as subsidence.

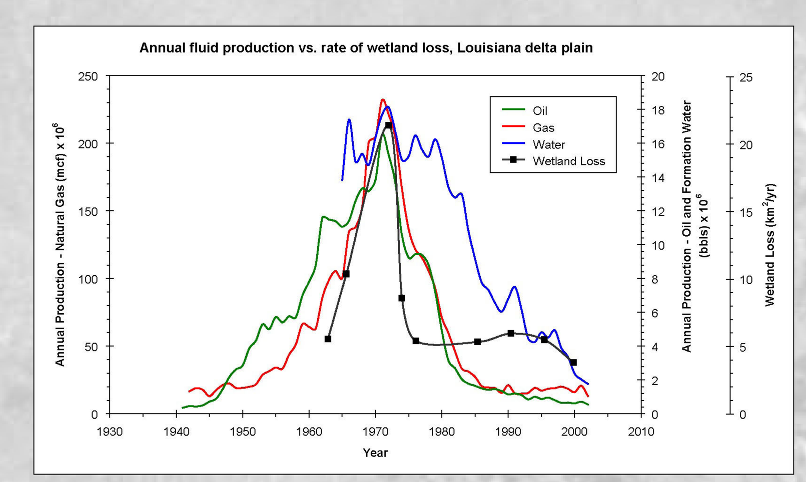

Figure 7. Composite histories of fluid production from oil-and-gas fields and wetland loss on the delta plain. Fluid production is for the Bay St. Elaine, DeLarge, Bayou Rambio, Lapeyrouse, Lirette, Bay Baptiste, Bayou Jean la Croix, Montegut, and Bully Camp fields (Fig. 2) that are closest to the coring sites. Wetland loss rates are based on the land-water classification at the five wetland-loss hotspots (Figs. 3 and 4). Peak wetland-loss rates in the late 1960s to 1970s are 2 to 4 times higher than the background rates for 1956 to 1969 and 1983 to 2004. The historical data shows close temporal correlation between the timing of most rapid wetland loss and the timing of peak oil-and-gas production.

Geological vs. Historical Delta-Plain Subsidence Rates

Geological subsidence rates can be estimated using aggradation rates calculated from ^{14}C ages as a proxy for subsidence. Forty-two subsidence rates calculated in this study range from 0.8 to 4.4 mm/yr and average 1.6 mm/yr. These rates are comparable to rates reported in previous studies (Kulp and Howell, 1998; Penland et al., 1988), which range from 0.1 to 7.0 mm/yr and average 1 to 5 mm/yr.

Historical subsidence rates have been estimated using several different methods. The resulting rates are consistently much higher than geological subsidence rates determined from ^{14}C analyses. Subsidence rates calculated from young (< 100 years) ^{14}C ages range from 4.7 to 15.6 mm/yr and average 10.4 mm/yr (Penland et al., 1988). Subsidence rates calculated from repeat leveling surveys along natural levees range from 1.6 to 18.9 mm/yr and average 9.7 mm/yr (Shinkle and Dokka, 2004).

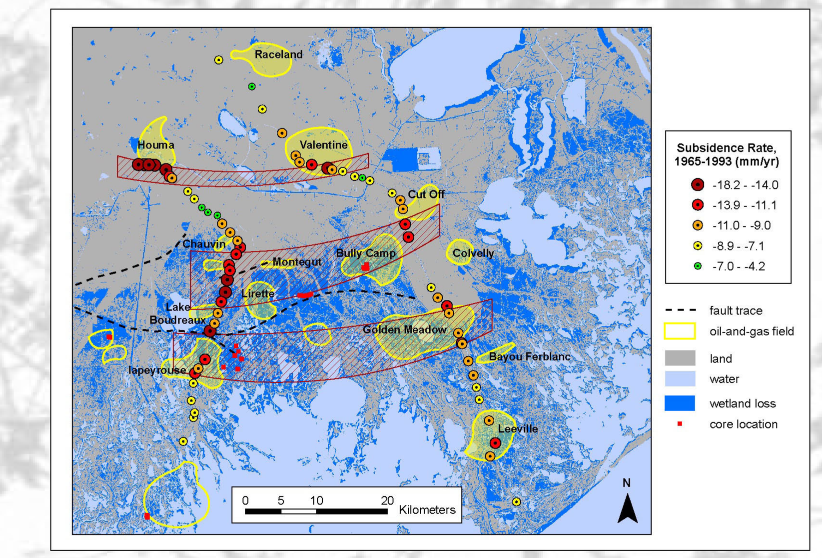

Figure 8. Map of subsidence rates calculated by the National Geodetic Survey (NGS) at benchmarks along Bayou Petit Caillou and Bayou Lafourche. Highest average subsidence rates (> 12 mm/yr) correlate closely with locations of oil-and-gas fields. Lowest average subsidence rates are located between major producing fields. Zones of highest subsidence rates projected between leveling lines correspond spatially with areas of greatest delta-plain wetland loss.

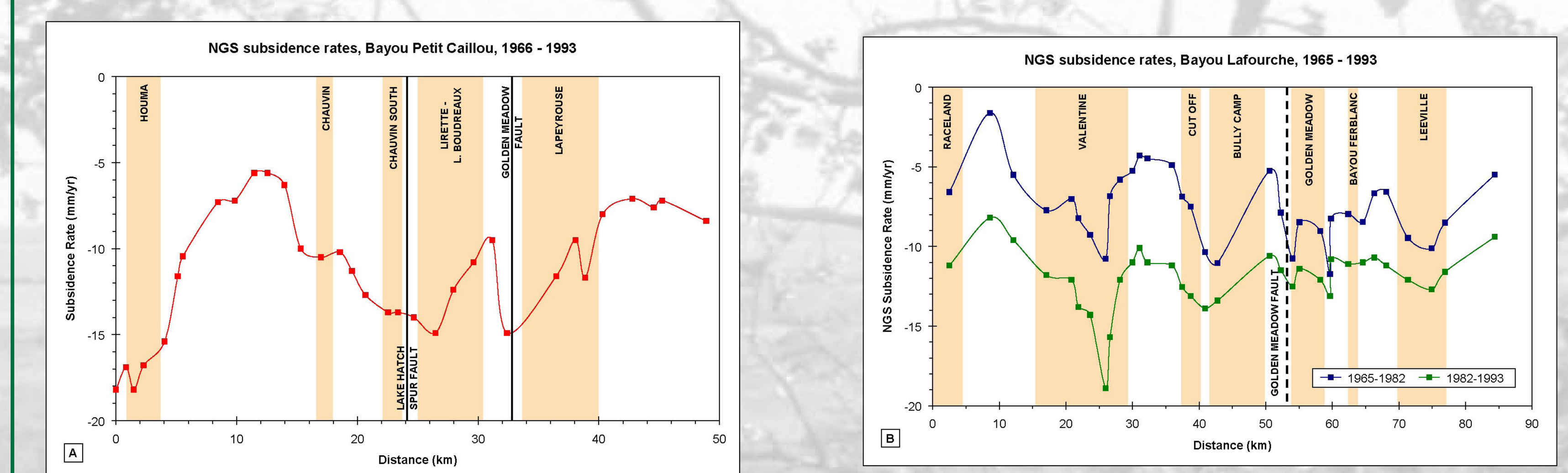

Figure 9. Plots of historical subsidence rates calculated by NGS from repeat leveling surveys of benchmarks along (a) Bayou Petit Caillou and (b) Bayou Lafourche. The plots show good spatial correlation between highest subsidence rates, hydrocarbon-producing fields (Fig. 8), and the projected intersection of deep regional faults.

Summary

- Image analysis at five wetland-loss hotspots indicates that most of the wetland loss occurred very rapidly during the late 1960s and 1970s. The most recent wetland-loss rates are similar to the 1950s to 1960s background rates.
- Subsidence is the primary physical process contributing to wetland loss at the coring sites. Erosion of the uppermost peat unit is minimal.
- Wetland loss on the delta plain was likely induced by hydrocarbon production. This is indicated by (1) good temporal correlation between the timing of peak wetland-loss rates and the timing of peak hydrocarbon production and (2) good spatial correlation between areas of greatest wetland loss and highest subsidence rates and the location of large oil-and-gas fields.

Future Implications

If subsidence and wetland loss was largely induced by the rapid production of large volumes of hydrocarbons and associated formation water, then the observed decrease in production volumes should be accompanied by a similar decrease in subsidence rates and wetland loss over time. This is consistent with the observation that the most recent wetland-loss rates are substantially lower than the peak rates.

Selected References

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

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

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

Kulp, M.A., and Howell, P.D., 1998, Assessing the accuracy of Holocene subsidence rates in southern Louisiana as indicated by radiocarbon-dated peats: Geological Society of America, Abstracts with Programs, v. 30, p. 142.

Morton, R.A., Bernier, J.C., Barras, J.A., and Ferina, N.F., in review, Rapid subsidence and historical wetland loss in the Mississippi delta plain: likely causes and future implications: U.S. Geological Survey Open-File Report, 125 p.

Morton, R.A., Tiling, F., and Ferina, N.F., 2003, Primary causes of wetland loss at Madison Bay, Terrebonne Parish, Louisiana: U.S. Geological Survey Open-File Report, no. 03-60, 44 p.

Morton, R.A., Tiling, G., and Ferina, N.F., 2003, Causes of hot-spot wetland loss in the Mississippi River delta plain: Environmental Geosciences, v. 10, p. 1-10.

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

Penland, S., Wayne, L., Britsch, L.D., Williams, S.J., Beall, A.D., and Butterworth, V.C., 2000, Process classification of coastal land loss between 1932 and 1990 in the Mississippi River delta plain, southeastern Louisiana: U.S. Geological Survey Open-File Report 00-418, 1 sheet.

Penland, S., Ramsey, K.E., McBride, R.A., Mestayer, J.T., and Westphal, K.A., 1988, Relative sea-level rise and delta-plain development in the Terrebonne Parish region: Louisiana Geological Survey, Coastal Geology Technical Report No. 4, 121 p.

Shinkle, K.D., and Dokka, R.K., 2004, Rates of vertical displacement at benchmarks in the lower Mississippi Valley and the northern Gulf Coast: National Oceanic and Atmospheric Administration, Technical Report 50, 135 p.