A Decade of Wetland-Loss Research at the USGS: Quantifying Trends, Processes, and Large-Scale Historical Accommodation Formation in Coastal Louisiana

Julie C. Bernier[1], John A. Barras[2], and Robert A. Morton[3]
[1]U.S. Geological Survey, St. Petersburg Coastal and Marine Science Center, St. Petersburg, FL [2]U.S. Geological Survey Eastern Geographic Science Center, Baton Rouge, LA [3]U.S. Geological Survey, retired
email: jbernier@usgs.gov http://coastal.er.usgs.gov/gc-subsidence/index.html

Abstract

Recent U.S. Geological Survey (USGS) research focused on better understanding the physical processes that contributed to historical wetland loss in coastal Louisiana and the spatial and temporal trends of that loss. The physical processes (land-surface subsidence and sediment erosion) responsible for historical wetland loss were quantified by comparing marsh-surface elevations, water depths, and vertical displacements of stratigraphic contacts that were correlated between short sediment cores at 10 delta-plain study areas and six sites at Sabine National Wildlife Refuge (SNWR) in the western chenier plain. The sequential development and two-dimensional extent of land loss at the study areas were described by comparing historical maps, aerial photographs, and satellite imagery. The total three-dimensional accommodation space that formed as the result of historical wetland loss was estimated by integrating the spatial data with emergent-marsh elevations and bathymetry from the study areas.

Results of our stratigraphic analyses indicate that subsidence greatly exceeded erosion at most upper delta-plain wetland-loss sites, whereas erosion was about equal to or slightly greater than subsidence at some lower delta-plain sites. Thick aggradational peat deposits were preserved at all delta-plain core sites. In contrast, erosion generally exceeded subsidence and the thinner chenier-plain peats were mostly eroded at the SNWR wetland-loss sites. In the upper delta plain, rapid subsidence led to collapse of the emergent wetlands before 1978 and larger volumes of historically formed accommodation compared to the lower delta plain and chenier plain, where slower subsidence led to greater marsh-sediment erosion and some wetlands did not become permanently submerged until after 1978. Wetland losses since the 1990s were mostly associated with recent hurricanes.

Despite differences in geologic setting, similarities in temporal and spatial trends of wetland loss indicate that historical accommodation formation was likely initiated by similar processes in both the delta and western chenier plains. The importance of land-surface subsidence to initiating delta-plain wetland loss and accommodation formation is underscored by the fact that erosion is totally contained within the peat section and does not penetrate the underlying clastic sediments, even at core sites where erosion exceeded subsidence and extant water depths are greater than the emergent-peat thicknesses. At SNWR, initial subsidence likely lowered the emergent marshes to a position where they were more susceptible to erosion. Analysis of tide-gauge and geodetic records indicate that delta-plain subsidence rates accelerated between the mid 1960s and early 1990s before declining to rates that are comparable to those averaged over geological time scales. The highest rates of subsidence and wetland loss partially correspond to the period of peak hydrocarbon production in coastal Louisiana.

We estimate that about 108 x 10^6 m^3 and 19 x 10^6 m^3 of accommodation formed locally on the delta and western chenier plains, respectively, as the result of historical wetland losses between 1956 and 2004. The differences are attributed to greater subsidence in the delta plain. These volumes provide a measure of the new sediment that would be needed at the study areas to restore the wetlands to their pre-1956 areal extent and elevations.

Objectives

(1) Describe the spatial and temporal trends of wetland loss in coastal Louisiana,

(2) Quantify the primary surficial processes contributing to wetland loss at selected study areas,

(3) Constrain historical subsidence trends and the most recent subsidence rates in coastal Louisiana,

(4) Quantify historic accommodation created where wetland loss in coastal Louisiana was rapid and extensive.

Geologic and Physiographic Setting

Delta Plain: The Mississippi River delta plain was constructed by sediment deposited in overlapping delta lobes that began prograding about 7,000 years ago. Thick aggradational peats that accumulated in interdistributary areas underlie much of the emergent delta plain wetlands.

Chenier Plain: Compared with the delta plain, the chenier plain consists of a thin wedge of Holocene sediments that unconformably overlie stiff over-compacted Pleistocene sediments and range in thickness from less than a meter to about 6 m. Beginning about 3,000 years ago, the chenier plain was constructed by primarily alongshore processes resulting in the progradation of broad mudflats capped by wetland vegetation with intervening narrow, sandy beach ridges (cheniers).

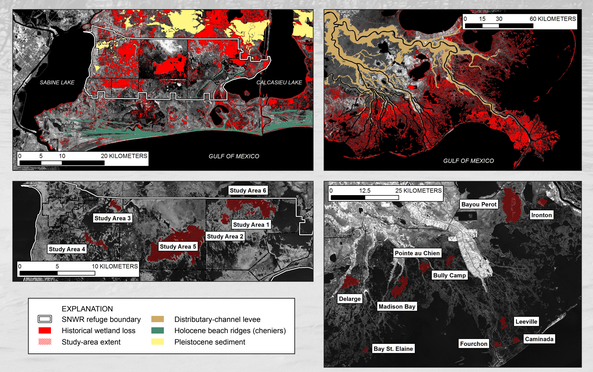


Figure 1. Geologic setting and location of study areas investigated in the western chenier and delta plains. The 10 delta-plain study areas encompassed several different physiographic and geologic settings, including: (1) an upper delta-plain levee flank of the Mississippi River (Ironton), (2) a pre-existing upper delta-plain interior channel (Bayou Perot), (3) four upper delta-plain interdistributary areas (Bully Camp, Pointe au Chien, DeLarge, and Madison Bay), (4) three lower delta-plain interdistributary areas (Bay St. Elaine, Leeville, and Fourchon), and (5) a lower delta-plain beach-ridge margin area (Caminada). The 6 western chenier-plain study areas were located in Sabine National Wildlife Refuge, which occupies a broad, shore-parallel, topographically low area that formed between the topographically higher beach ridges along the gulf shoreline to the south and Pleistocene upland areas to the north.

Historical Wetland Loss

At the upper delta-plain interdistributary study areas (Madison Bay, Pointe au Chien, Bully Camp, and DeLarge), extensive areas of formerly emergent marsh rapidly converted to open water before 1978 with little significant land-area change since. Analysis of historical aerial photography showed that the most rapid wetland loss at these study areas occurred during the late 1960s and 1970s. In comparison, at Leeville, Fourchon, and Caminada study areas in the lower delta plain, some wetland loss had initiated by the mid to late 1970s, but the majority of historical land loss occurred between 1978 and 1990. At these locations, some areas of formerly continuous marsh were alternately emergent or partially submerged on historical aerial photographs acquired prior to 1978 depending on whether the images were acquired under low or high water conditions, respectively. Between 1978 and 1990, most of these "wet marsh" areas became permanently submerged. At SNWR in the western chenier plain, most of the historical wetland loss occurred prior to 1978; however, some expanses of wet marsh surrounding Greens Lake in western SNWR persisted into the 1980s.

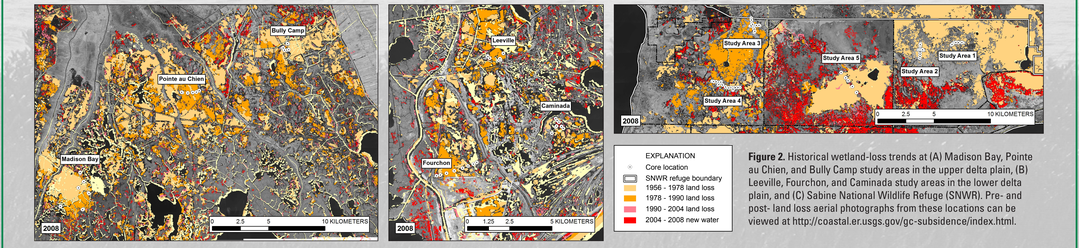


Figure 2. Historical wetland-loss trends at (A) Madison Bay, Pointe au Chien, and Bully Camp study areas in the upper delta plain, (B) Leeville, Fourchon, and Caminada study areas in the lower delta plain, and (C) Sabine National Wildlife Refuge (SNWR). Pre- and post- land loss aerial photographs from these locations can be viewed at http://coastal.er.usgs.gov/gc-subsidence/index.html.

Wetland Subsidence and Erosion

The two primary physical processes responsible for historical wetland loss in coastal Louisiana are land-surface subsidence and erosion. The magnitudes of subsidence and erosion at the wetland-loss core sites were estimated by comparing marsh-surface elevations, water depths, and vertical displacements of stratigraphic contacts that were correlated between short sediment cores. The predominance of subsidence or erosion at the study areas varied by physiographic and geologic setting. At the upper delta-plain interdistributary sites, subsidence greatly exceeded erosion; whereas at most of the lower delta-plain study areas, erosion was about equal to or greater than subsidence. Along the channel margins at Bayou Perot, erosion generally exceeded subsidence, but magnitudes of subsidence were greater than or equal to the largest magnitudes of subsidence at all study areas. At all of the delta-plain study areas, organic-rich marsh deposits (peats) were preserved at all core sites where formerly emergent wetlands have converted to open water. In contrast, erosion exceeded subsidence at most of the Sabine National Wildlife Refuge study areas, and the thin chenier-plain peat deposits were mostly eroded at the open-water core sites.

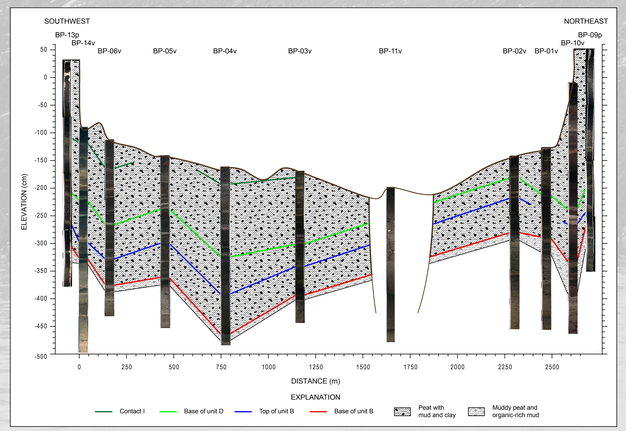
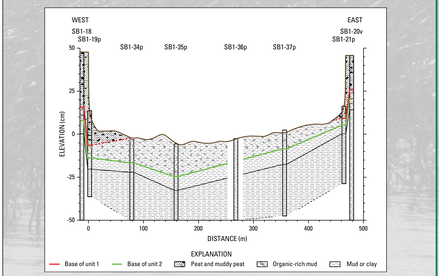


Figure 3. Combined bathymetric profile and stratigraphic cross section illustrating the magnitude of subsidence and wetland erosion at (A) core sites BP-13 to BP-09 at Bayou Perot study area in the upper delta plain and (B) core sites SB1-18 to SB1-20 in Sabine National Wildlife Refuge in the western chenier plain.

Historical Subsidence Rates

Analysis of tide-gauge records, elevation changes at benchmarks between repeat leveling surveys, and Global Positioning System (GPS) vertical velocities at Continuously Operating Reference Stations (CORS) showed that historical subsidence rates on the delta plain accelerated from less than 5 mm/yr to more than 10 mm/yr between 1965 and 1993 and then deccelerated to about 5 mm/yr after 1993. Several lines of evidence suggest that accelerated historical subsidence and wetland loss were induced by onshore hydrocarbon production. The period of accelerated subsidence correlates with the period(s) of greatest historical wetland loss as well as the period of peak hydorcarbon production in coastal Louisiana. In addition, subsidence rates measured at benchmarks were generally higher near oil-and-gas fields and lower between the producing fields. Although compaction of unconsolidated Holocene delta-plain sediments is a component of total subsidence, time-averaged subsidence rates derived from radiocarbon dating of delta-plain peats and numerical models of sediment compaction are generally less than about ~5 mm/yr, which is an order of magnitude less than the highest observed historical rates. Similarly, it is unlikely that natural tectonic processes, which operate on geologic time scales, can explain the observed decadal-scale acceleration and deceleration of historic subsidence rates. In addition, neither compaction of Holocene sediments nor tectonic processes adequately explain the temporal similarities in wetland-loss trends across coastal Louisiana despite regional differences in geologic and physiographic setting. However, if accelerated historical subsidence rates and wetland loss were induced by hydrocarbon production, then the most recent reductions in subsidence rates likely reflect a balancing of subsurface stresses and a return to near-equilibrium conditions.



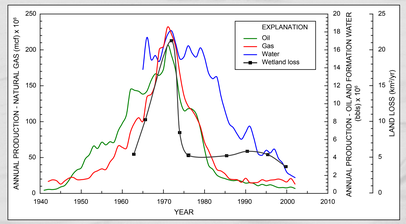


Figure 4. Composite annual fluid production (oil, gas, and formation water) from delta-plain oil-and-gas fields with wetland-loss rates measured at five representative delta-plain hotspots.

Historical Accommodation Formation

Accommodation is the space available for sediment accumulation as a result of a rise in sea level and/or land subsidence. Historical conversion of coastal-plain wetlands to open water is an example of accommodation formed at the decadal scale. Bathymetric data acquired at the study areas were integrated with the extent of historical (1956 to 2004) wetland loss to estimate the total accommodation volume that formed historically on the western chenier and delta plains. Magnitudes of historical accommodation that formed locally at the western chenier plain study areas (about 19 x 10^6 m^3) were significantly less than formed at the delta plain study areas (about 108 x 10^6 m^3). The differences are attributed to greater subsidence and, consequently, greater 1D accommodation in the delta plain, and these volumes provide estimates of the new sediment that would be needed just at the study areas to restore the coastal-plain wetlands to their pre-1956 areal extent and elevations.

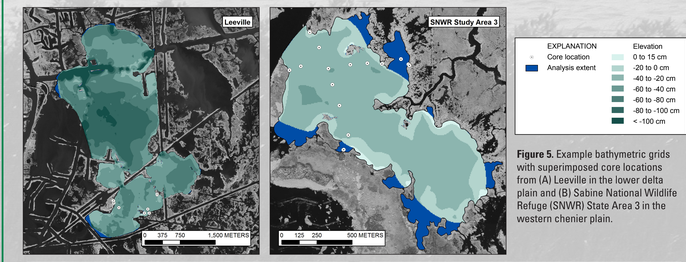


Figure 5. Example bathymetric grids with superimposed core locations from (A) Leeville in the lower delta plain and (B) Sabine National Wildlife Refuge (SNWR) State Area 3 in the western chenier plain.

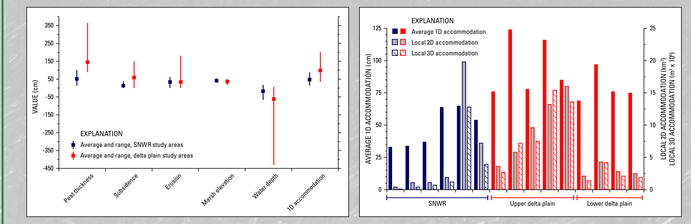


Figure 6. Comparison of accommodation parameters and measurements at Sabine National Wildlife Refuge (SNWR) and delta-plain study areas.

Conclusions and Implications

Despite differences in geologic setting, similarities in temporal and spatial trends of wetland loss indicate that historical accommodation formation was likely initiated by similar processes in both the delta and western chenier plains. The importance of land-surface subsidence to initiating delta-plain wetland loss is underscored by the fact that erosion was totally contained within the peat section and did not penetrate into the underlying clastic sediments, even at core sites where erosion exceeded subsidence and extant water depths were greater than the thicknesses of the organic-rich marsh sediments. In addition, the expanses of wet marsh that were identified on the historical aerial photography in both the lower delta plain and the western chenier plain also indicates that subsidence was the process that initiated historical wetland loss in those areas. Wet marsh is an intermediate stage in the progression from emergent wetlands to open water and represents nearly uniform drowning of large sections of marsh. At SNWR and the Caminada headland sites, initial subsidence likely lowered the emergent marshes to a position where they were more susceptible to erosion.

The results of this study provide the first comprehensive analyses of the three-dimensional aspects of historical wetland loss in coastal Louisiana and characterize the likely causes of those losses. Incorporating these results into project plans may improve wetland restoration strategies. For example, the volume of sediment used to create vegetated earthen terraces around Greens Lake in SNWR (about 0.7 x 10^6 m^3) is an order of magnitude less than the total accommodation that formed in the same area between 1956 and 2004. Similarly, at sites where wetland loss was driven primarily by subsidence, structures designed to mitigate shoreline erosion may not be effective. Considering recent and historical land-loss trends, and given that historical subsidence was not driven entirely by natural processes that would be expected to persist in the future, rates of future accommodation formation in coastal Louisiana will likely be low except for losses associated with episodic storm impacts.

Selected Publications

- Barras, J.A., Bernier, J.C., and Morton, R.A., 2008, Land area change in coastal Louisiana--A multidecadal perspective (from 1956 to 2006): U.S. Geological Survey Scientific Investigations Map 3019, scale 1:250,000, 14 p. pamphlet.
- Bernier, J.C., Morton, R.A., and Kelso, K.W., 2011, Trends and Causes of Historical Wetland Loss, Sabine National Wildlife Refuge, Southwest Louisiana, U.S. Geological Survey, Open File Report 2011-1169, 36 p., plus app.
- Morton, R.A. and Bernier, J.C., 2010, Recent subsidence-rate reductions in the Mississippi Delta and their geological implications: Journal of Coastal Research, v. 26, p. 555-561.
- Morton, R.A., Bernier, J.C., Kelso, K.K., and Barras, J.A., 2010, Quantifying large-scale historical formation of accommodation space in the Mississippi Delta: Earth Surface Processes and Landforms, v. 35, p. 1625-1641.
- Morton, R.A., Bernier, J.C., and Kelso, K.W., 2009, Recent subsidence and erosion at diverse wetland sites in the southeastern Mississippi delta plain: U.S. Geological Survey Open-File Report, no. 2009–1158, 39 p., plus app. (p. 41-221).
- Morton, R.A., Bernier, J.C., Barras, J.A., and Ferina, N.F., 2005, Rapid subsidence and historical wetland loss in the Mississippi delta plain: Likely causes and future implications: U.S. Geological Survey Open-File Report, no. 2005-1216, 116 p.