Potential Consequences of Saltwater Intrusion Associated with Hurricanes Katrina and Rita

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Hurricanes Katrina and Rita pushed salt water from the Gulf of Mexico well inland into freshwater marsh communities in coastal Louisiana. This paper describes the spatial extent of saltwater intrusion and provides an initial assessment of impacts (salt stress) to coastal marsh vegetation communities.

Introduction

Katrina and Rita, two storms of exceptionally large size and strength, struck the northern Gulf of Mexico coast within a 1-month period in late summer of 2005 near the State borders of Louisiana-Mississippi and Louisiana-Texas, respectively. Catastrophic winds and waves had a direct and devastating effect on human lives, properties, and various infrastructures. Furthermore, the impacts of these two storms are expected to have major effects on coastal natural resources. Many conditions, such as salinity and storm surge, are transient in that their presence may be lost rather quickly unless rapid-response sampling takes place. While direct evidence of transient conditions may be temporary, they can be a catalyst for factors which may have long-term effects on the ecosystem.

Salinity is one of the transitory elements that are critical in understanding the long-term consequences of these storms on habitat change and coastal restoration.

Coastal saltwater and freshwater marshes were flooded with storm surge for weeks in some places, which increased the time for salt to diffuse into the pore water (i.e., interstitial water in the soil). Over time, porewater salinity should decline as it diffuses into overlying flood waters, provided that fresh water is available for flushing, either by precipitation or by mechanical introduction (e.g., freshwater diversions). If fresh water is not introduced, porewater salinity levels may continue to rise as a result of evapotranspiration and other processes. It is well documented that elevated porewater salinities can cause decreased productivity in wetland plants (Smart and Barko, 1980; Linthurst and Seneca, 1981; Howard and Mendelssohn, 1999). Thus, the hurricanes can affect primary and secondary production for an unknown time, with the duration of the effect depending on how long porewater salinity remains elevated.

The U.S. Geological Survey's (USGS) National Wetlands Research Center (NWRC), in cooperation with the U.S. Fish and Wildlife Service, has begun a posthurricane assessment of saltwater intrusion into coastal Louisiana's wetland habitats. It is the objective of this assessment to document the extent and duration of elevated salinities in vegetative communities and to identify potential consequences of this exposure on long-term environmental change.

Methods

Vegetation-salinity zones previously described (Chabreck, 1970) and mapped for coastal Louisiana include swamp, fresh marsh, intermediate marsh (less saline than brackish), brackish marsh, and saline marsh (Chabreck and Linscombe, 2001). To characterize the potential impacts of storm surge on Louisiana marshes, numerous Federal and State agencies collected surface-water salinity data at discrete locations throughout the coast and from continuously recording stations that were still operational after the storms. Measurements of storm-surge elevation, from high-water marks across coastal Louisiana and continuous water-level recorders in the Chenier Plain (see Barras, this volume, for descriptions of the Louisiana Chenier Plain, Marginal Deltaic Plain, and Deltaic Plain), were also conducted by the USGS Louisiana Water Science Center to assess storm-surge heights in response to Hurricanes Katrina and Rita (see McGee and others, this volume). The storm-surge and salinity data were overlaid on the vegetation-salinity zones to help identify whether the hurricanes caused salt water to be transported into traditionally fresher areas. These data are transitory in nature; however, they can provide some supporting information to help understand the spatial extent (primarily on a north-south gradient) and the severity of the salt pulse brought in by the storm surge.

Data on porewater salinity were collected on a quarterly basis in the Chenier Plain to support investigations of salt stress on vegetation communities. Porewater salinity is not as variable as surface salinity, and because it is measured in the plant's root zone, it provides a good measure of salt exposure to the vegetation. These data were collected at a 12-inch (30-cm) depth following procedures described in McKee and others (1988). Measurements of porewater salinity, vegetation cover, and species composition will provide an indication of vegetation impacts and recovery over time.

Coastwide Assessment

Storm Surge

Recorded storm surge from 21 continuous water-level recorders in western coastal Louisiana between the Louisiana-Texas border and Freshwater Bayou, La., ranged from approximately 5 ft (1.5 m) to greater than 14 ft (4.3 m). In eastern coastal Louisiana, high-water marks measured by the NWRC and the Louisiana Department of Natural Resources in Breton Sound after Hurricane Katrina were in excess of 15 ft (4.6 m). The data suggest that flood waters inundated significant acreage (hectares) of swamp and freshwater marsh communities throughout coastal Louisiana, transferring high-salinity waters into these areas, which are typically suited for no or low salt content.

Salinity

Surface salinities were measured at 821 locations across coastal Louisiana between September 26, 2005, and December 13, 2005 (figs. 1 and 2). A total of 1,174 discrete observations were gathered on different days and at different times over this period. Although the surface salinities are highly variable across hourly, daily, weekly, and monthly scales, these measurements do clearly show that Rita pushed salt water well into freshwater marsh and swamp areas across coastal Louisiana. The maximum discrete salinity concentration recorded by vegetation type and the normal salinity range as described by Chabreck (1970) for each of these vegetation types is given in table 1. The spatial distributions of salinity concentrations for western and eastern coastal Louisiana are shown in figures 1 and 2, respectively.

Limited continuous salinity and water-level data within the storm track and hurricane wind fields prohibit a proper examination of spatial and temporal influences of the storms on surface-water salinity. Stations outside of the direct impact areas of the hurricanes, however, illustrate the storm surge effects of Rita throughout the Louisiana coast. Stations TE28-03 and TE28-01 are located in the Terrebonne basin (central Louisiana) and represent a south-to-north transect with increasing distance from the higher salinity waters of the Gulf of Mexico (fig. 2). Station TE28-03 is located in an intermediate vegetation zone (see table 1 for typical salinity ranges in vegetation zones).

The effects of Katrina at this station were minimal, with only a slight reduction in salinities following the receding water levels (fig. 3*A*). After the passage of Rita, surface-water salinity concentration peaked at almost 23 parts per thousand (ppt), and high salinity levels continued for almost 2 months. The mean and range of observed salinities in October and November 2005 (after Rita) are greater than would typically be

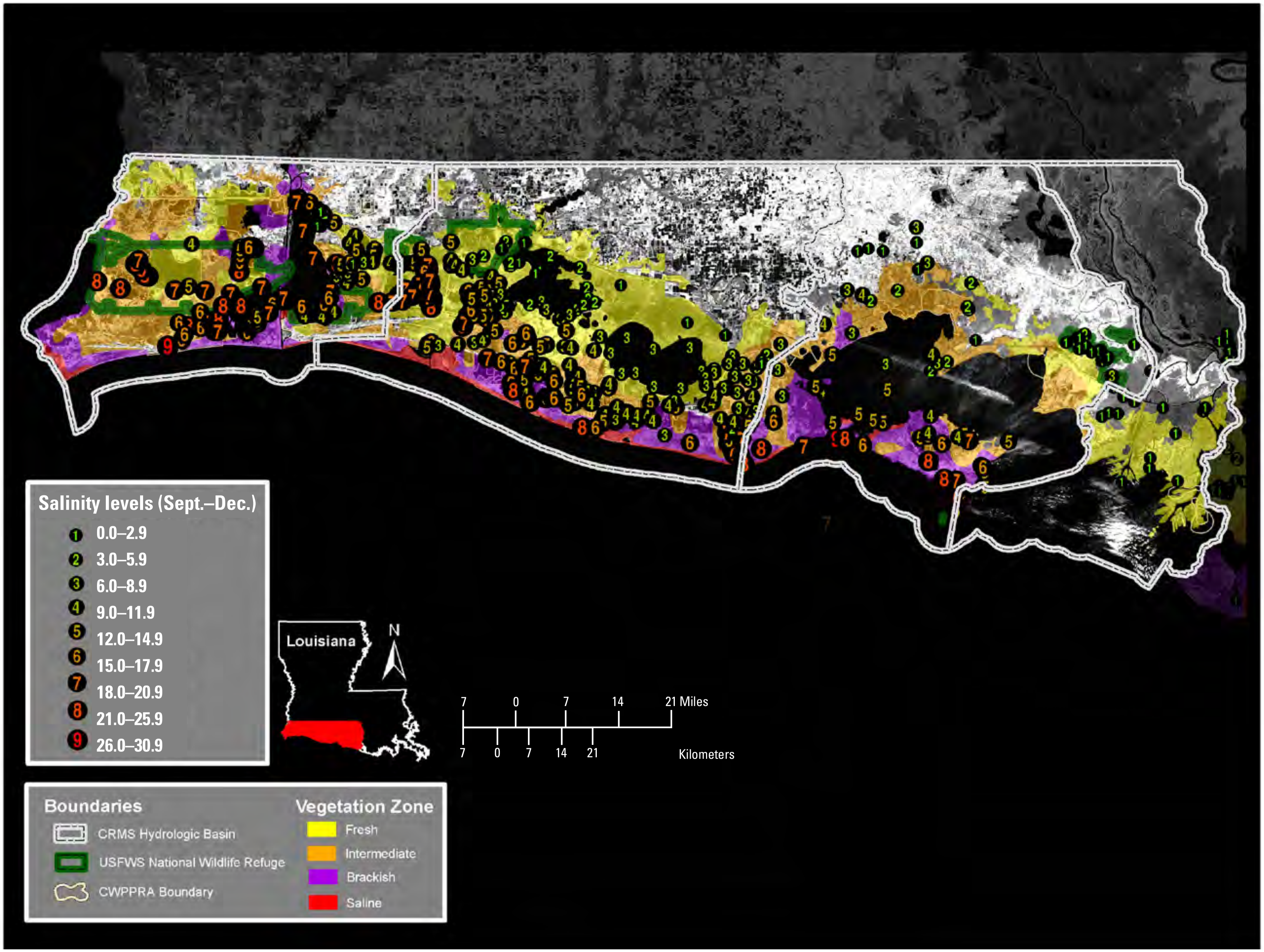

Figure 1. Western coastal Louisiana discrete surface salinity measurements (September–December 2005) with proximity to vegetation zones (Chabreck and Linscombe, 2001) and U.S. Fish and Wildlife Service (USFWS) national wildlife refuges. Regarding boundaries, CRMS refers to Coastwide Reference Monitoring System, and CWPPRA refers to the Coastal Wetlands Planning, Protection and Restoration Act.

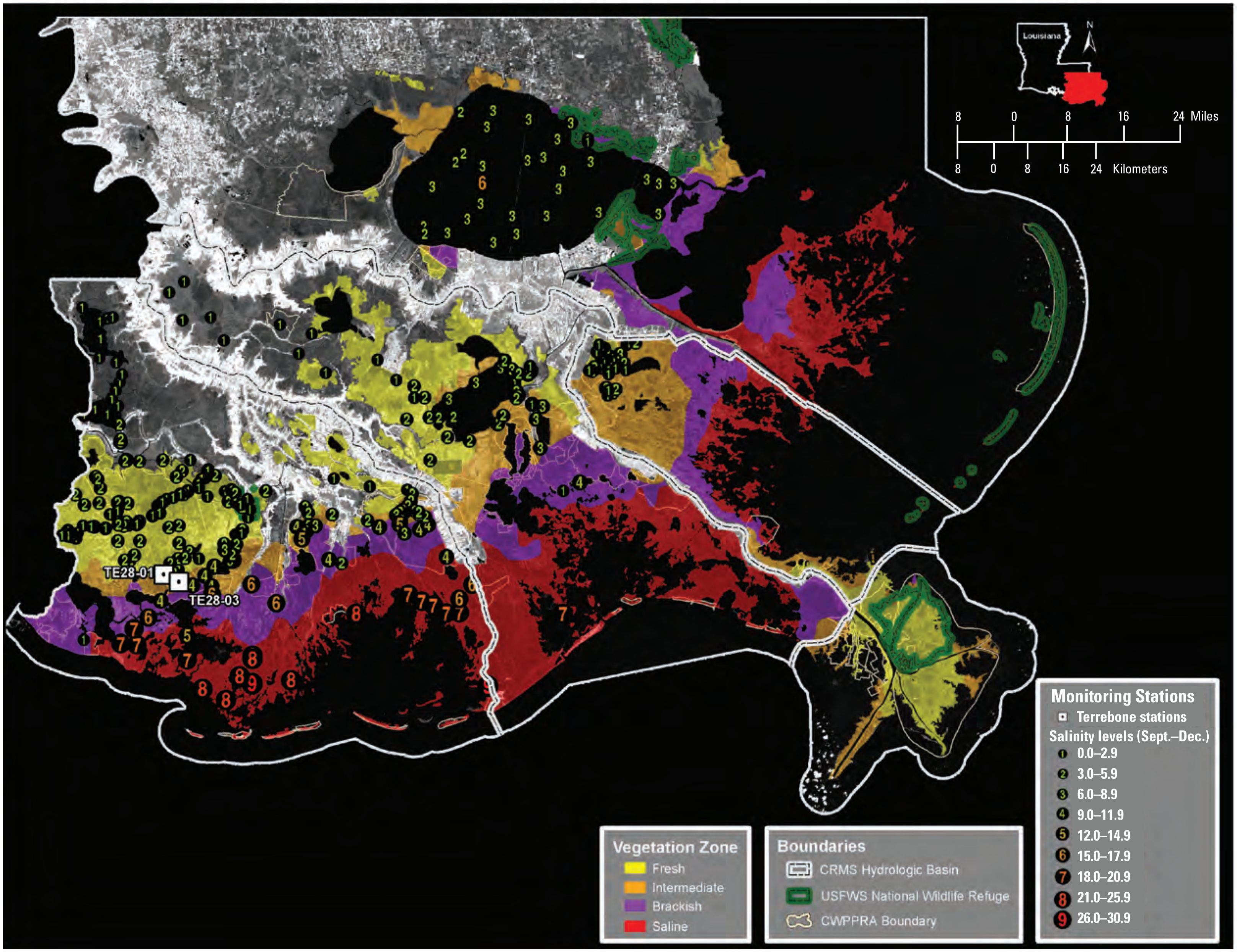

Figure 2. Eastern coastal Louisiana discrete surface salinity measurements (September–December 2005) with proximity to vegetation zones (Chabreck and Linscombe, 2001) and U.S. Fish and Wildlife Service (USFWS) national wildlife refuges. Regarding boundaries, CRMS refers to Coastwide Reference Monitoring System, and CWPPRA refers to the Coastal Wetlands Planning, Protection and Restoration Act.

Table 1. Typical salinity ranges found within various vegetation types in coastal Louisiana (Chabreck, 1970), and maximum discrete salinity measurements of surface waters recorded between September and December 2005.

[All salinities are reported in parts per thousand (ppt). Note that the salinity of ocean water is approximately 35 ppt]

Vegetation type	Typical salinity range	Maximum salinity measured
Swamp	0–0.5	8
Fresh marsh	0–3	26
Intermediate marsh	2–8	26
Brackish marsh	4–10	34
Saline marsh	8–29	30

expected in an intermediate vegetation zone (table 1). Station TE28-01 is located within a fresh vegetation zone. The effects of Katrina at this station were negligible (fig. 3*B*). Surface salinity concentration peaked at nearly 17 ppt following Rita and maintained levels above 6 ppt for the duration of the data record, which ended on December 6, 2005. The mean and range of observed salinities in October and November 2005 (after Rita) are much greater than would typically be expected in a fresh vegetation zone (table 1). Summary statistics and charts from continuous gage records for these stations are presented in table 2 and figure 3, respectively.

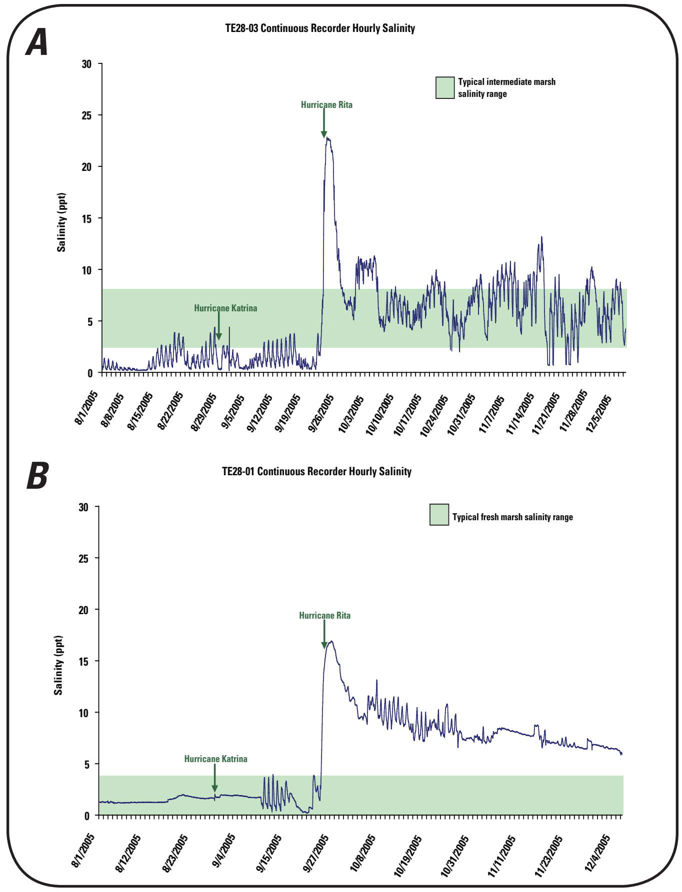

Figure 3. Hourly salinity (in parts per thousand (ppt)) from continuous recorders at the Terrebonne basin stations TE28-03 (*A*) and TE28-01 (*B*) from August 1, 2005, to December 6, 2005.

Chenier Plain Assessment

Porewater Salinity

Porewater salinity concentrations were measured at 30 locations within the Sabine basin on December 14 and 15, 2005, and March 27 and 29, 2006 (fig. 4). Porewater salinities ranged from 5.0 to 17.8 ppt with a mean of 11.1 ppt in December and ranged from 5.1 to 17.9 ppt with a mean of 12.2 ppt in March. The results suggest that the salt water is not being flushed from the system, and even more worrisome is that 38 percent of the sampling stations had salinities that increased by over 1 ppt from December 2005 to March 2006. These concentrations, measured at 3 and 6 months after Hurricane Rita, are outside the normal range described in Chabreck (1970) for the intermediate marsh plant species found within the study area, except for marshhay cordgrass (*Spartina patens*). Additional sampling of porewater salinity concentrations over time will provide a better assessment of impacts associated with salt stress.

Table 2. Posthurricane salinity range and mean by month from August to November 2005, and prehurricane mean salinity readings from 2002 to 2004 at stations TE28-03 (north of Bayou De Cade, La.) and TE28-01 (at Little Carencro Bayou, La.).

[All salinities are given in parts per thousand (ppt). Standard deviations are provided in parentheses]

	2005 salinity range	2005 mean salinity	2002–04 mean salinity
Station TE28-03			
Aug.	0.19–4.38	1.10 (0.93)	0.40 (0.54)
Sept.	0.25–22.83	4.24 (6.03)	1.70 (1.50)
Oct.	2.02–11.31	6.89 (2.05)	1.82 (2.24)
Nov.	0.68–13.18	6.63 (2.65)	2.05 (1.62)
Station TE28-01			
Aug.	1.14–2.02	1.47 (0.27)	0.42 (0.51)
Sept.	0.20–16.92	4.48 (5.45)	1.56 (1.48)
Oct.	6.57–13.13	9.15 (1.28)	2.35 (1.91)
Nov.	6.35–8.75	7.43 (0.63)	3.29 (2.50)

Figure 4. Sampling locations for porewater salinity concentration (in parts per thousand (ppt)) within the Sabine basin during December 2005 and March 2006. USFWS NWR, U.S. Fish and Wildlife Service National Wildlife Refuge; CWPPRA, Coastal Wetlands Planning, Protection and Restoration Act.

Figure 5. An aerial photograph showing the effects of tidal flushing on lowering salinity stress on adjacent marsh vegetation.

Vegetation

The dominant vegetation communities found at our sampling locations were marshhay cordgrass, California bulrush (*Schoenoplectus californicus*), and mixed communities of marshhay cordgrass, cattail (*Typha latifolia*), and common reed (*Phragmites australis*). Site-specific observations from all sampling locations generally showed the most severe impacts in cattail communities, followed by California bulrush, common reed, and marshhay cordgrass. Sampling stations that are further away from tidal influence generally appear to show greater signs of stress. Within many of these interior marsh stations, porewater salinities continue to increase because of evapotranspiration, and recovery of existing marsh species is limited. It is apparent, however, that when tidal flushing occurs as shown in figure 5, plant stressors are reduced, and this reduction facilitates vegetation recovery. Prehurricane versus posthurricane photographs of representative vegetation community types shown in figures 6–8 illustrate the short-term effects of Rita on marsh vegetation.

Potential Implications

Plant communities are defined by how individual plant species respond to salinity and other stressors and how these species interact under stressed conditions (McKee and Mendelssohn, 1989; Howard and Mendelssohn, 1999). Salt stress associated with elevated salinities following Katrina and Rita may influence the vegetation community throughout the study area; however, salt tolerance is species specific. Intermediate to brackish species such as marshhay cordgrass, cattail, California bulrush, and common reed respond

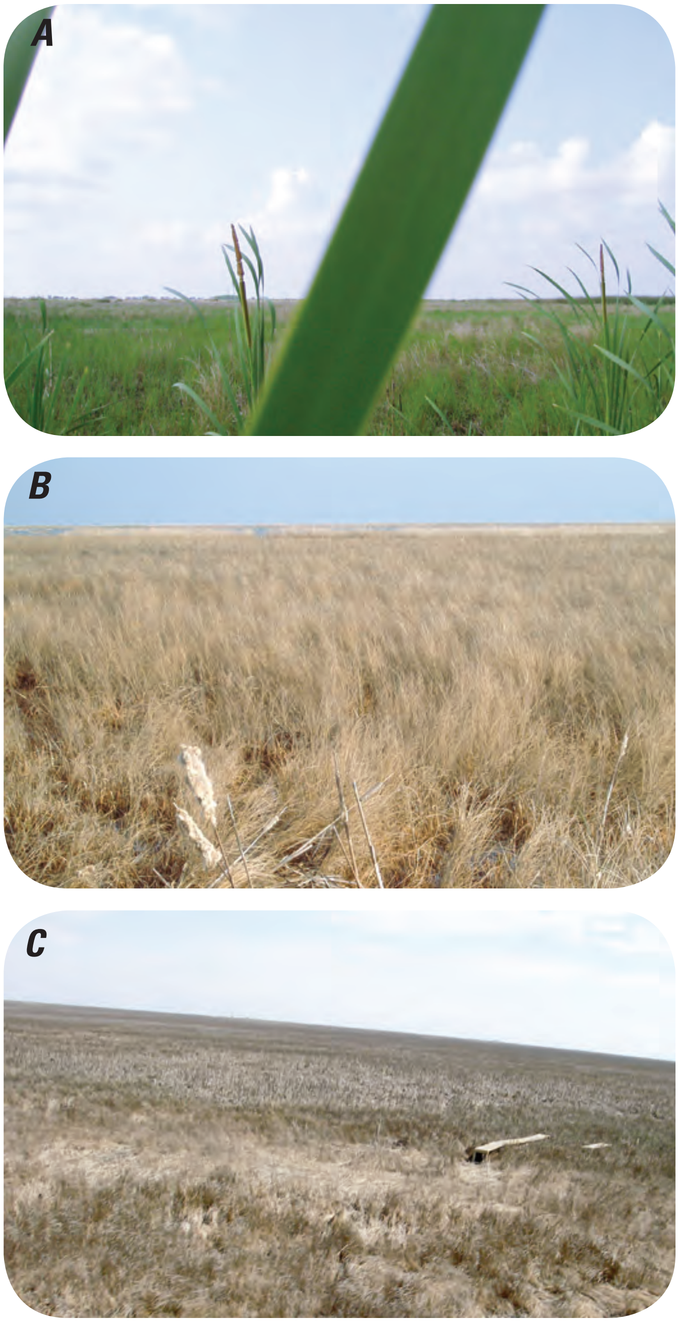

Figure 6. A community dominated by marshhay cordgrass (*Spartina patens*) and cattail (*Typha latifolia*): May 11, 2005 (*A*), January 12, 2006 (*B*), and March 27, 2006 (*C*).

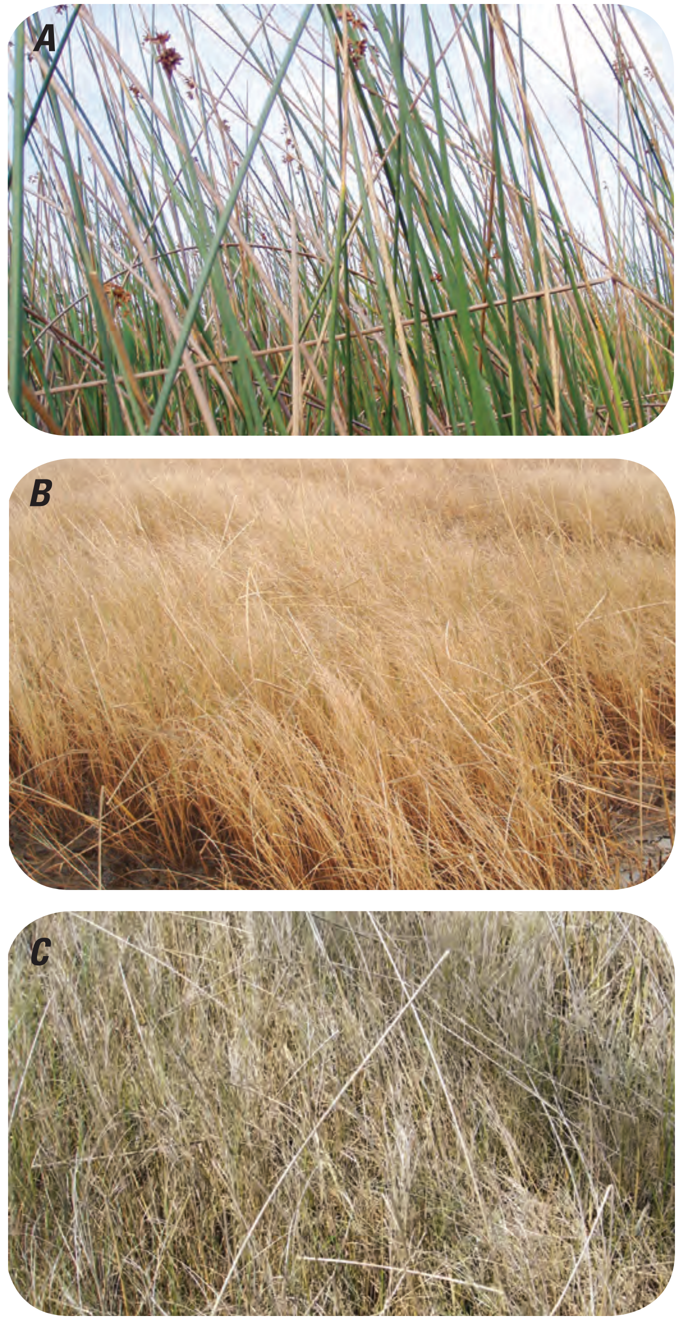

Figure 7. A community dominated by California bulrush (*Schoenoplectus californicus*) with marshhay cordgrass (*Spartina patens*): May 12, 2005 (*A*), January 12, 2006 (*B*), and March 27, 2006 (*C*).

differently to salt stress depending on duration of exposure, rate of salinity increase, mineral content of the soil, and submergence (Webb and Mendelssohn, 1996; Howard and Mendelssohn, 1999).

Marshhay cordgrass is the dominant marsh plant within the Chenier Plain of southwestern Louisiana (Taylor and Grace, 1995; Visser and others, 1999). Of the species found in our study area, marshhay cordgrass can tolerate a wide range of salinity and generally recovers quickly from environmental stressors. Common reed, another resilient species, has been shown to tolerate a wide range of salinity and inundation (Matoh and others, 1988); however, within the study area common reed stands browned by the saltwater surge had not fully recovered as of spring 2006.

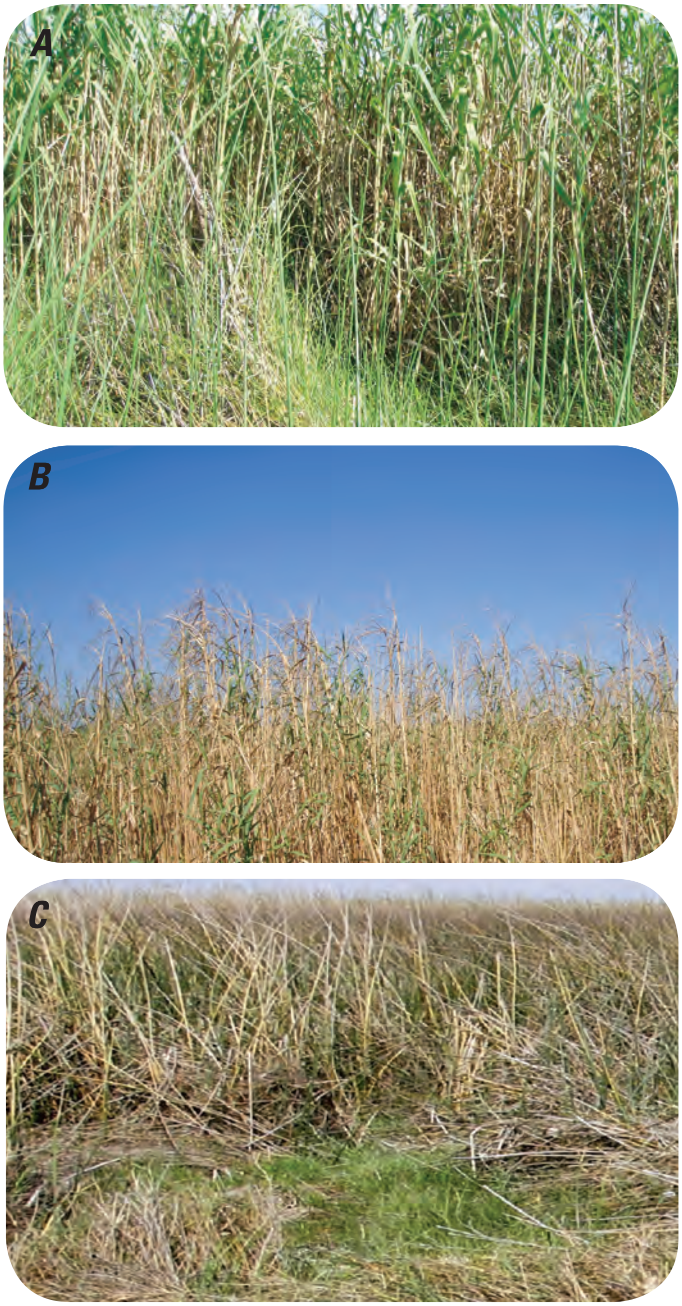

Figure 8. A community dominated by California bulrush (*Schoenoplectus californicus*) and cattail (*Typha latifolia*): September 16, 2005 (*A*), October 26, 2005 (*B*), and March 27, 2006 (*C*).

Common reed generally grows taller than the other mixed species and is particularly susceptible to physical damage from the hurricanes. This physical disturbance may be an additional factor contributing to the recovery time for common reed. Cattail is less tolerant of saline conditions and has shown reduced growth at salinities greater than 3–5 ppt (Hocking, 1981). Cattail's sensitivity to elevated salinities continued to be evident in the March 2006 sampling, as minimal recovery was observed in areas previously dominated by cattail.

It is too early to discern which plant species will recover and which will not. Climate will be an important factor in recovery. Rainfall or lack of rainfall will contribute to either flushing or intensifying porewater salinities. Duration and frequency of flooding will also influence the extent of salinity and other biogeochemical stressors. It is also unfortunate that coastal Louisiana was in an extended drought, beginning prior to the hurricanes of 2005, compounding the salinity problem.

Some of the potential consequences of continued exposure to high salinities may include (1) species-specific dieback and limited recovery; (2) shifts in species composition, possibly from less salinity tolerant species to more salinity tolerant species; (3) reduction in biomass production; and (4) reduction in germination rates. The Chenier Plain study will continue to track salinity and vegetation change over the 2006 growing season and provide additional evidence regarding long-term impacts and recovery.

Acknowledgments

We would like to thank all of the resource agencies that provided salinity data to support the broad coastwide assessment. They include the Louisiana Department of Natural Resources, Louisiana Department of Wildlife and Fisheries, USGS, U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, National Oceanic and Atmospheric Administration, and Natural Resources Conservation Service. We would also like to thank USGS researchers Tom Doyle, Beth Middleton, Wylie Barrow, and Steve Faulkner for contributing salinity data to this assessment. Lastly, we greatly appreciate funding through the U.S. Fish and Wildlife Service and the LCA Science and Technology Program to support this work as an integral part of a larger environmental assessment of the transitory effects of Katrina and Rita on the northern Gulf of Mexico coast.

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