Wind Damage and Salinity Effects of Hurricanes Katrina and Rita on Coastal Baldcypress Forests of Louisiana

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The frequency of hurricane landfall in a given coastal stretch may play a more important role in the ecology of coastal forests than previously thought because of direct and indirect impacts of fallen trees and the introduction of salt water that lingers long after the storm passes. Findings show that surge events can inundate interior freshwater forests many miles from the coast and elevate soil salinities twofold to threefold. These elevated salinities may contribute to delayed mortality of certain tree species and set the stage for eventual forest decline and dieback.

Introduction

Coastal forests along the Gulf of Mexico and along the Atlantic coast of the Eastern United States are increasingly vulnerable to ongoing forest dieback and decline from recurring droughts and hurricanes and altered freshwater flow. Most of this coastal impact on maritime forest and tidal freshwater swamps occurs within Federal and State parks and refuges where there is no monitoring activity to document current and future land-cover change. Baseline field research is needed to understand the process and pattern of saltwater intrusion that may be a leading cause of forest dieback. Subsequently, applied science and ecological models are needed to assist U.S. Department of the Interior (DOI) land managers with designing management strategies and restoration alternatives for controlling local hydrology, recovering habitat quality, and minimizing invasive species influx of degraded environments associated with hurricane impacts and other large-scale disturbances.

Land managers need to know whether current management practices and/or natural climatic variability and extremes may be threatening the long-term stability of certain plant and animal communities in their parks and refuges. More specifically, they need to know the degree to which the altered health and loss of coastal forest is attributed to increased tidal flooding as a result of regulated freshwater flow, drought severity, hurricanes, or relative sea-level rise. Coastal ecosystems are particularly at risk because they exhibit some of the highest land-subsidence rates, which will be further worsened by increasing eustatic (worldwide) sea-level rise (Stevenson and others, 1986; Cahoon and others, 1998). Some current case examples include extensive cabbage palm (*Sabal palmetto*) hammock die-offs that have been investigated in the Big Bend region of Florida and attributed to increased tidal flooding in recent decades (Doyle, 1998; Williams and others, 1999). Forest decline of pine populations in the Florida Keys has likewise been blamed on saltwater intrusion related to sea-level rise (Ross and others, 1994). While land-loss area of tidal wetlands in Louisiana has been estimated in numerous mapping studies (Sasser and others, 1986; Evers and others, 1992; Visser and others, 1999), process-based ecological studies of the factors and rate of coastal forest dieback are lacking.

Hurricanes Katrina and Rita

During the record-setting hurricane season of 2005, major Hurricanes Katrina and Rita made landfall across the coastal reaches of Louisiana in the eastern and western ends of the State, respectively. The central coast of Louisiana felt the impact of both storms, mostly backside winds from Katrina and a frontal assault of surge and salt water into interior freshwater wetlands from Rita. U.S. Department of the Interior lands managed by the U.S. Fish and Wildlife Service at Mandalay and Bayou Teche National Wildlife Refuges (NWRs) and by the National Park Service at Jean Lafitte National Historical Park and Preserve (NHPP) were impacted directly by high winds and a surge wave that resulted in tree damage and saltwater intrusion of coastal baldcypress (*Taxodium distichum*) forests normally considered freshwater habitat.

A hurricane windfield simulation model, HURASIM, developed by the U.S. Geological Survey (USGS) was used to predict windspeeds at study sites across the Louisiana coast to facilitate posthurricane reconnaissance and field studies. In addition, an ongoing USGS climate-change study to understand flooding and salinity conditions of tidal freshwater swamps at Mandalay NWR, Bayou Teche NWR, and Jean Lafitte NHPP provided both pre- and posthurricane observations of water levels and soil salinities. Continued monitoring will afford an understanding of the roles that hurricanes play in salinizing freshwater zones and augmenting forest dieback from episodic pulses of salt water that, with recurring storms, may lead to increasing soil salinities and vegetation change over time.

Wind Damage to Baldcypress Forest

Wind damage to trees in DOI parks and refuges within the central coast of Louisiana varied with species, stand exposure, and windspeed in relation to nearness of storm track. The predicted windspeeds from both hurricanes at each study site indicated that the Bayou Teche NWR site experienced the least winds of tropical storm strength, Mandalay NWR incurred hurricane-strength winds, and Jean Lafitte NHPP was most severely impacted with winds approaching category 4 (131 mi/hour (>211 km/hour)) strength from Katrina (fig. 1). Field observations of tree damage following each storm demonstrated minimal stem damage at Bayou Teche NWR and moderate stem damage at Mandalay NWR and Jean Lafitte NHPP concomitant with higher windspeeds and proximity to Katrina's path.

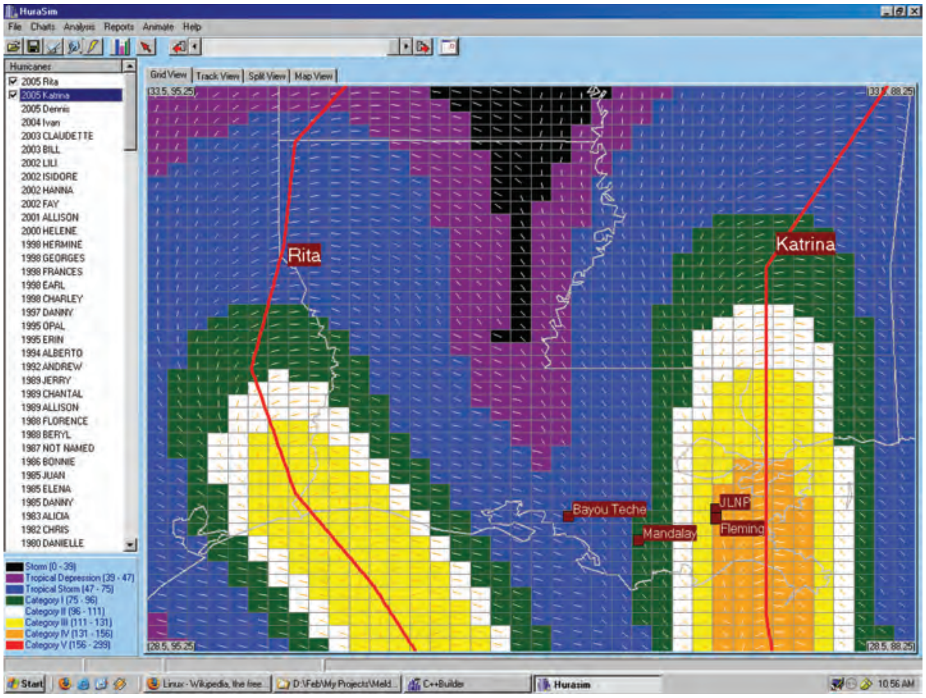

Figure 1. Simulated map of hurricane track and predicted wind fields of Hurricanes Katrina and Rita in relation to study site locations at U.S. Department of the Interior landholdings in Louisiana—Bayou Teche National Wildlife Refuge (NWR), Mandalay NWR, and Jean Lafitte National Historic Park and Preserve.

Bottomland hardwood sites at the Barataria Preserve unit of Jean Lafitte NHPP sustained major damage, with extensive downing of trees on the Bayou Des Familles ridge and moderate “windthrow” (trees felled by high wind) within baldcypress swamps and on forested spoil banks. Most of the bottomland hardwood forest was felled in partial and complete “blowdown zones” (wide areas of downed trees) with a majority of surviving trees composed of resilient live oaks (*Quercus virginiana*), many of which had significant branch pruning. Baldcypress is another tree species resilient to hurricane winds (Doyle and others, 1995), but excessive winds and exposure along forest edge accounted for single tree falls and partial blowdowns in baldcypress-dominated stands. A baldcypress swamp and research site at Jean Lafitte NHPP displayed typical swamp forest damage of toppled baldcypress and water tupelo trees (*Nyssa aquatica*) and downed branch debris as a direct result of high winds from Katrina (fig. 2). The backside winds of Katrina also impacted shoreline marshes along the southern periphery of the Barataria Preserve unit along Lake Salvador, causing severe erosion and marsh loss. Wind damage at Mandalay NWR included downed trees and branch debris but to a lesser extent than at Jean Lafitte NHPP concomitant with reduced windspeeds of category 1 hurricane strength. The compass angle (azimuth) of downed trees showed unidirectional patterns directly related to wind direction of backside winds from Katrina. Rita contributed tropical storm winds sufficient to cause leaf stripping and branch breakage across the field sites along the central Louisiana coast but, more importantly, pushed a long storm wave of salt water into interior freshwater wetlands.

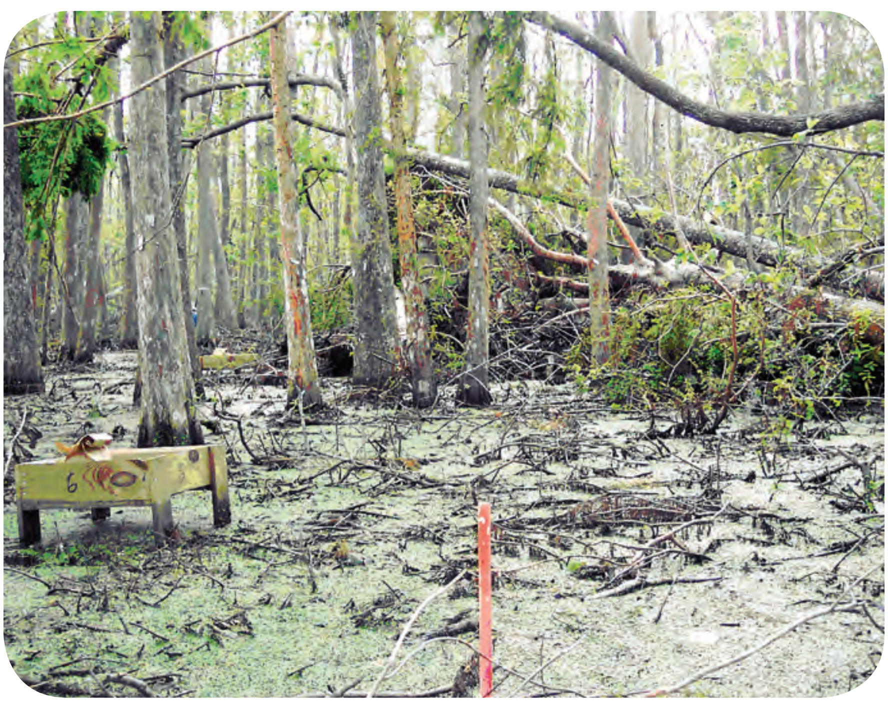

Figure 2. Downed baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) trees and branch debris within baldcypress swamp and established study plots at Jean Lafitte National Historic Park and Preserve in Louisiana.

Storm Surge and Saltwater Influx into Interior Freshwater Wetlands

All study sites were located in the backside circulation of Katrina and frontside circulation of Rita. Prior to Katrina, coastal Louisiana was experiencing drought conditions that fostered seasonal high salinities by normal tides into interior freshwater areas of the coastal zone. Water levels in the Barataria and Terrebonne basins of coastal Louisiana rapidly dropped in channeled waterways and open lakes during the passage of Katrina from backside or northerly winds that drained water out of the bayous and lakes toward the Gulf of Mexico. Conversely, interior marshes impounded by spoil banks and levees demonstrated a short-term rise in water levels of nearly 1 ft (25 cm) caused by the intense rainfall event associated with Katrina. Posthurricane porewater (interstitial soil space) salinities following Katrina actually decreased, counteracting seasonal drought effects by freshening these marshes. This decrease in salinities from Katrina was in contrast to Rita, which brought a large storm surge and saltwater overwash into interior freshwater marshes and baldcypress swamps.

Water levels rose abruptly above soil surface at the Bayou Teche NWR and Mandalay NWR baldcypress study sites during the passage of both Katrina and Rita (fig. 3). In contrast, Mandalay NWR demonstrated a slightly higher rise (about 6 inches (15 cm)) in water level after Katrina than did the more distant and westerly Bayou Teche NWR site as a result of rainfall, while Rita caused a much greater surge height at both sites and more so westerly than easterly. The baldcypress swamp at Bayou Teche NWR experienced a surge height of over 4.9 ft (1.5 m) during Rita, while Mandalay NWR exhibited a near 3.3 ft (1 m) rise. The higher water at Bayou Teche NWR receded more rapidly days after the storm but retained a higher stage thereafter for the period of record.

Porewater Salinities Before and After Storm Strikes

Porewater salinity is an important determinant of the plant species that can thrive and persist in coastal environments. Baldcypress is a tree species known for its tolerance of flooded soils and relative intolerance to saltwater settings. Coastal baldcypress forests are susceptible to saltwater pulsing in which chronic porewater concentrations average 3 parts per thousand (ppt) or more and acute intrusions exceed 10 ppt. Coastal baldcypress forests of Louisiana depend on a constant supply of fresh water to maintain growth and productivity. The current situation of land subsidence, sea-level rise, and recent hurricanes makes the coastal edge of baldcypress forest more vulnerable to dieback from increasing soil and surface-water salinities.

Hurricanes can be an important agent for introducing salt water into freshwater environments as a result of storm surge overwash and catchment. While Katrina introduced fresh rainwater into Barataria and Terrebonne basins of the central Louisiana coast, Rita pushed a long storm surge as far east as the Alabama coast. This storm surge brought not only high water levels but also increased salinity in many otherwise freshwater habitats. The degree to which given habitats retain salt water is a matter of how fast they shed surplus surface water and whether freshwater sources of overland flow or precipitation act to dilute and flush impounded salt water. Weather conditions in coastal Louisiana before and since the hurricanes have been rather dry and below normal for rainfall.

Soil salinities showed an abrupt increase following Rita's storm surge at exposed sites—Lafitte (Fleming) and Mandalay NWR—in contrast to protected control sites at Jean Lafitte NHPP and Bayou Teche NWR for posthurricane sampling runs in September and October 2005 (fig. 4). Prehurricane observations show that the exposed sites at Lafitte (Fleming) and Mandalay NWR had higher residual soil salinities year round and similar seasonal fluctuations around 1 ppt greater than their respective control or protected sites at Jean Lafitte NHPP and Bayou Teche NWR. The Bayou Teche NWR endured a high surge effect from Rita but is also at the outlet of the Atchafalaya River outflow, where large volumes of fresh water mix with estuarine water, accounting for the modest saltwater effect.

Hurricane Rita inundated two of the more exposed sites (Fleming and Mandalay) with surge overwash of up to 12 ppt salinity. Baldcypress has been shown to tolerate salinities of 3 ppt, but only if intermittently exposed (Pezeshki, 1990; Conner, 1994; Allen and others, 1996). Results vary on how long baldcypress can survive if continuously flooded by water with salinity higher than 3 ppt. Despite an apparent decrease in salinity in the control sites at Jean Lafitte NHPP and Bayou Teche NWR for the second month (October 2005) following the storms, porewater salinities on surge overwash sites—Lafitte (Fleming) and Mandalay NWR—remained high for all posthurricane readings. The storm surge from Hurricane Rita may have left a lingering effect of higher than normal salinity because of a prolonged drought following the hurricane and lack of fresh water to dilute the ground water and flush out the salt water.

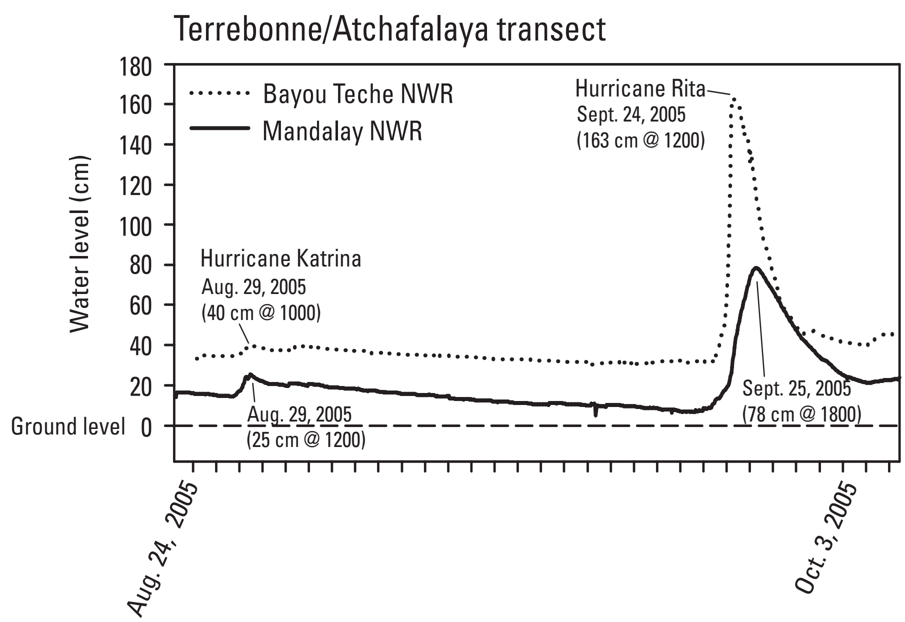

Figure 3. Water levels above ground level within coastal baldcypress (*Taxodium distichum*) swamp sites at Bayou Teche National Wildlife Refuge (NWR) and Mandalay NWR in Louisiana for summer and fall 2005, preceding Hurricane Katrina and following the onshore surge effects of Hurricane Rita.

Implications of Hurricane Science on Coastal Forest Management

Coastal forests of the Gulf of Mexico and of the Atlantic coast of the Eastern United States encounter tropical storms and hurricanes on a periodic basis and as a result are subject to recurring high winds and surge effects. Baldcypress is resistant to windthrow and modest saltwater overwash that may explain its longevity and resilience in coastal environments, particularly in river outlets with freshwater outflow. In some locales, coastal baldcypress forests have undergone decline from apparent saltwater intrusion. Katrina and Rita acutely impacted coastal baldcypress forests of the central Louisiana coast with wind and surge, but little is known of the long-term effects of saltwater introduction from surge overwash into these freshwater habitats. Long-term monitoring is needed to determine the fate of elevated soil salinities following

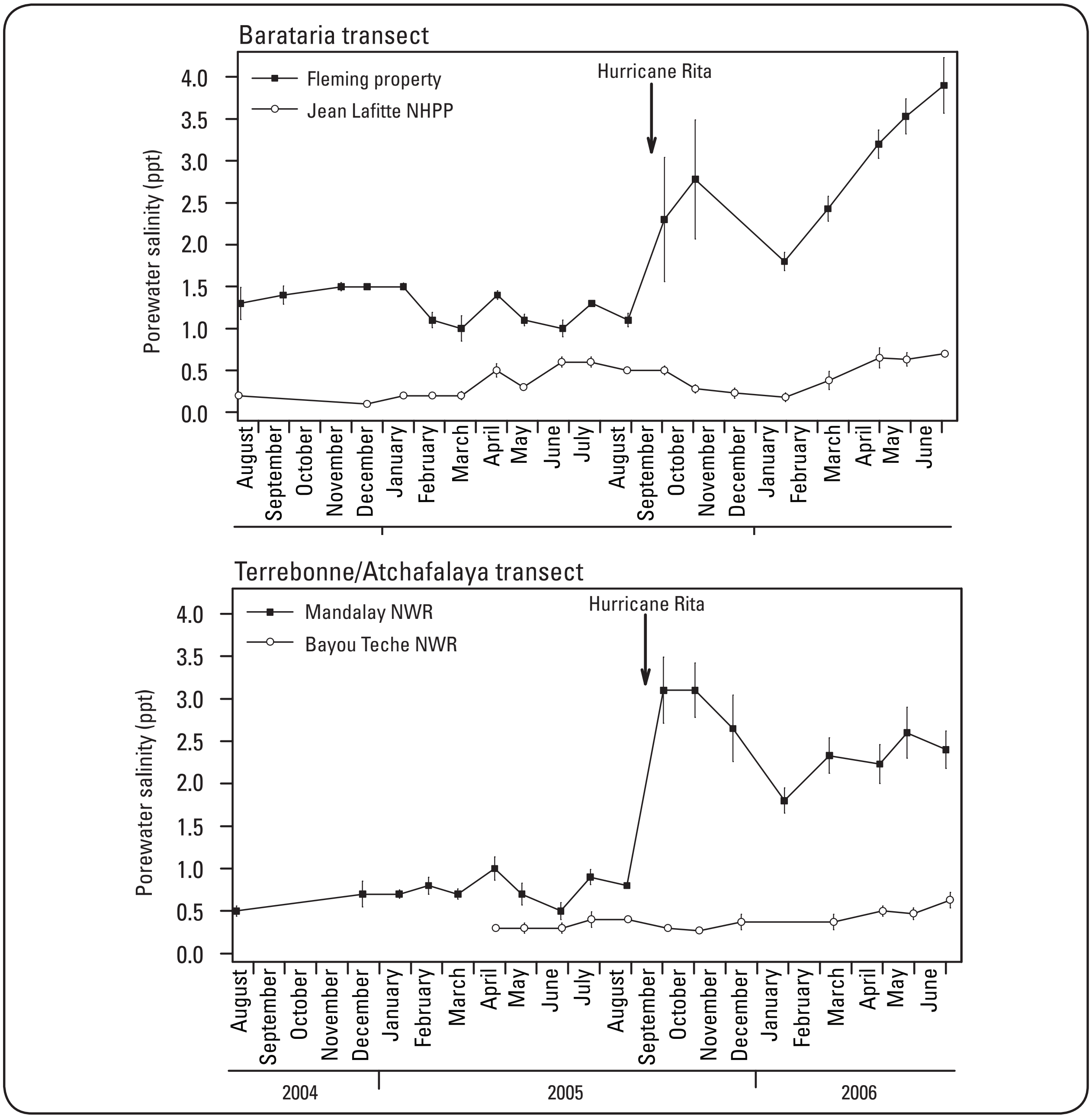

Figure 4. Monthly averages of porewater (interstitial soil) salinities in parts per thousand (ppt) for 2004 and 2005, before and after Hurricanes Katrina and Rita, at coastal baldcypress (*Taxodium distichum*) swamp sites at Jean Lafitte National Historic Park and Preserve and Lafitte (Fleming) in the Barataria basin and at Mandalay National Wildlife Refuge (NWR) and Bayou Teche NWR in the Terrebonne and Atchafalaya basins of coastal Louisiana.

hurricanes and the possible interaction of altered freshwater flow and drought that may contribute to forest dieback in these coastal environments. The potential increase in sea-level rise and hurricane incidence and intensity under climate change may accelerate the demise of coastal forests from saltwater intrusion and impact science priorities and management alternatives for coastal restoration.

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