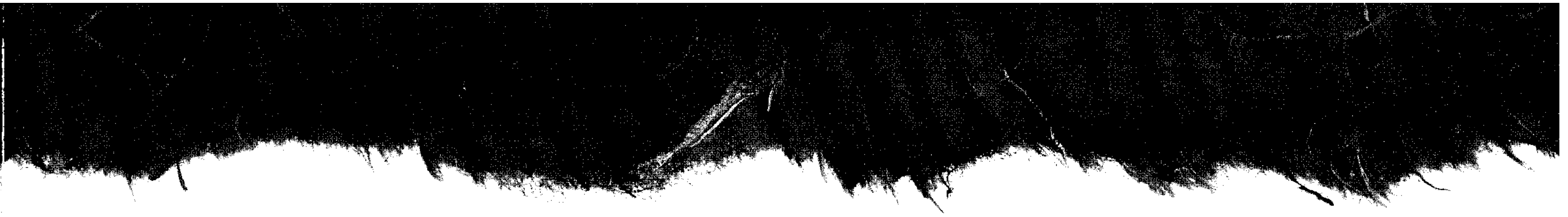

Willful Winds

HURRICANE ANDREW AND LOUISIANA'S COAST

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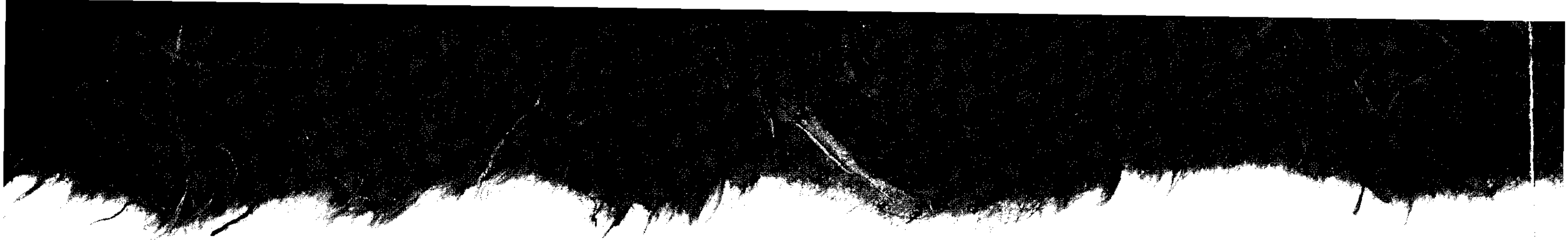


How Hurricanes Form

"Hurricane" is the term used to describe the strongest of the windy, circulating storms- or cyclones-in the Atlantic and eastern Pacific oceans; in the western Pacific these kinds of storms are referred to as typhoons. Most Atlantic hurricanes are born in the southern Atlantic Ocean, off the coast of Africa, in the months of June through November each year.

During this time, winds off the west coast of Africa sometimes converge, circulating counterclockwise. Often, these winds maintain a low speed and travel across the Atlantic Ocean as tropical waves, causing little more than rainfall on land masses they strike.

At other times, when water temperatures are warm enough and atmospheric conditions are correct, the wind speeds increase and begin to form around a center, or eye. Hot, moist air from the ocean is pulled up into the eye of the storm, which is now called a tropical storm. As the air rises and cools, moisture condenses and is released as heavy rain into the torrential winds circling the eye. The released energy is pumped into the rotating cloud mass, making it rise and spin even faster. By the time the winds reach speeds of 119 kph (74 mph), the storm has become a hurricane.

As the spinning storm moves across the ocean, unstopped by land, wind speeds increase. Hurricanes are commonly classified by the strength of their winds into five categories on the Saffir-Simpson Hurricane Intensity Scale. The weakest hurricanes, with wind speeds of 119-153 kph (74-95 mph), are referred to as Category I storms and cause minimal damage primarily to plants and trees. In 1992, Hurricane Andrew was a Category IV storm with sustained wind speeds of 225 kph (140 mph). Category V storms, such as Hurricane Camille in 1969, are the strongest and responsible for catastrophic damage. Hurricane Camille, with sustained winds of more than 320 kph (200 mph), was the most powerful hurricane ever recorded to hit the northern gulf coast.

Although difference in wind speed is one easy way to classify storms, hurricanes have other unusual characteristics. Some storms move quickly and produce little rainfall, while others are slow and generate torrential rain squalls with downfalls that often exceed 38 cm (15 inches). One characteristic that all storms share, however, is the location of the most powerful and dangerous winds. The forward right quadrant of a hurricane-12:00 to 3:00 on a clock face-is its strongest and most dangerous section, because it is fueled by the counterclockwise motion of the storm as well as its forward movement.

As the storm moves along the ocean surface, it becomes a complex, tight mass of wind and rain. The eye becomes perfectly clear on satellite pictures; larger hurricanes can have an eye as large as 56.3 km (35 mi) across. The hurricane's eye is the area around which the winds rotate and is actually a calm area in the center of the storm. People have often been deceived into thinking that a storm had ended when the eye passed over and were surprised when destructive winds began again.

Hurricanes can contain and release enough energy to supply electricity to the United States for a year. And hurricanes carry the ocean along with them, bringing storm surges as high as 7.6 m (25 ft) above sea level. Often the accompanying storm surge and associated floods are responsible for much damage in coastal areas.

Storms pursue unpredictable paths toward land. There is no set pattern in the journey from their birth places off Africa, although they frequently move northwesterly to the Gulf of Mexico and eastern coasts of North and Central America.

A Fierce Storm

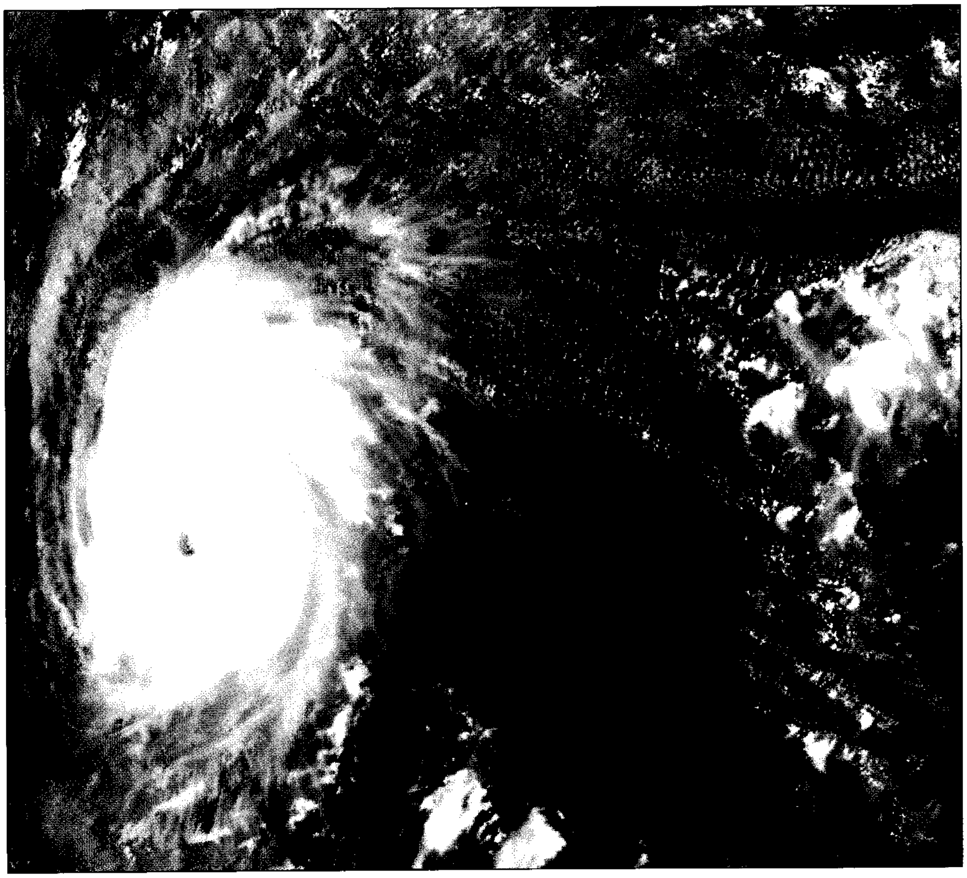


Figure l-Satellite image of Hurricane Andrew over the Gulf of *Mexico.*
NATIONAL BIOLOGICAL SERVICE, DATA FROM NOAA

In mid-August 1992, television and radio audiences were alerted to a potentially damaging hurricane that had formed in the Atlantic Ocean. Satellite imagery showed a large swirling mass of clouds rotating around an area of low pressure and heading toward the continental United States.

On August 24, this hurricane struck the eastern coast of Florida, passed over the Florida peninsula, entered the Gulf of Mexico, and moved north-westerly until it slammed into the Louisiana coast on August 26. Hurricane Andrew, as it was named by the National Weather Service, caused over $27 billion worth of damage in Florida and Louisiana. It was not only the costliest storm to strike the U.S. mainland but it was also one of the most intense. *Figure 1)*

Hurricane Andrew, with winds of 200 kilometers per hour (124 miles per hour), destroyed urban and other settled areas in Louisiana. It also swept across a variety of economically important natural ecosystems in south Louisiana, including barrier islands, coastal wetlands, and forested wetlands. A closer look at the life span of this storm shows that its path of destruction was inevitable.

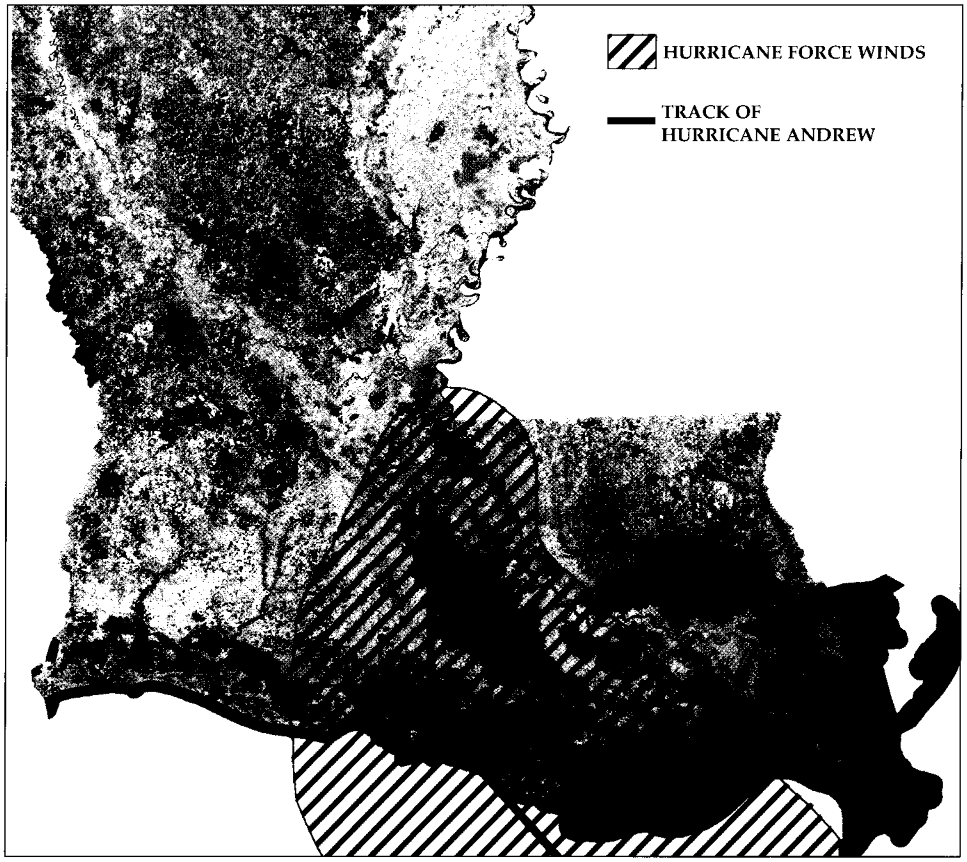
On August 14, satellite photography first indicated a strong tropical wave off the west coast of Africa. This weather pattern achieved tropical storm strength on August 17 and, by August 22, its winds had further strengthened to hurricane force-120 kph (74 mph). The storm rapidly intensified and by August 23 had become a Category III hurricane (see "How *Hurricanes Form," inside front cover)* with winds of 193 kph (120 mph). The next day, August 24, it struck the eastern coast of Florida and passed over the Florida peninsula in only six hours.

As an even stronger hurricane with winds of 225 kph (140 mph-a Category IV storm), Hurricane Andrew moved northwesterly across the Gulf of Mexico. As people all along the Gulf of Mexico tried to predict its course, the hurricane's second landfall was along Louisiana's coast August 26.

It first passed near the barrier islands along the central gulf coast of the state with 225-kph (140-mph) winds and a storm surge of 2 m (7 ft). A combination of these winds and the resulting strong waves and storm surge eroded 30-40 percent of Raccoon Island as well as the western arm of Whiskey Island. This erosion reduced the significant protection that those barrier islands could offer to coastal marshes and swamps from future storms.

Hurricane Andrew then moved across the water between the islands and the Louisiana mainland and struck coastal marshes near Cypremort Point. Large sections of marsh in western Terrebonne Parish received extensive physical damage.

Figure 2—Path of Hurricane Andrew over satellite image of Louisiana.
NATIONAL BIOLOGICAL SERVICE



Still very strong, the hurricane traveled through the swamps and forests of the Atchafalaya Basin. Aerial reconnaissance shortly after the storm revealed large tracts of downed and mangled forests. More than 40 percent of the bottomland hardwood forests in Iberia, St. Martin, and St. Mary parishes were severely damaged. By the time the storm neared Baton Rouge, its peak wind gusts were still near hurricane force 113 kph (70 mph).

About 24 hours after Hurricane Andrew struck Louisiana, it took a northeasterly track and was finally downgraded to a tropical depression. On August 28, it merged with an advancing cold front and died in Pennsylvania.

In just two weeks the hurricane created damages of $27.2 billion and affected the incomes of many Florida and Louisiana residents for years. Hurricane Andrew passed over a densely populated area in south Florida, which accounted for the bulk of the monetary losses and loss of lives. Its landfall in Louisiana was in a sparsely settled area, but storm damages in the state still reached $2.5 billion. The fishery and aquaculture industries suffered enormous losses. Although memories of the storm are now fading, its impact can still be seen and will be felt for years to come.

Storms such as Hurricane Andrew are significant forces in the evolution of coastal systems, helping alter the shapes of barrier islands, coastal marshes, and swamps and other wetland forests. Because scientists, fishermen, and foresters alike have become increasingly aware of the values of these systems, interest in understanding, protecting, and restoring them has been increasing as well. Recent passages of federal laws such as the Coastal Wetlands Planning, Protection, and Restoration Act of 1990 indicate that, among lawmakers and the people they represent, there is a growing appreciation of systems that hurricanes affect.

Three months after Hurricane Andrew, the U.S. Congress provided funds so that damages to Louisiana's coastal resources could be assessed and monitored. Headed by the National Biological Service's Southern Science Center, 23 studies of the ecological impacts of Hurricane Andrew were planned and completed. These studies examined the short- and long-term effects on coastal barrier islands, wetlands, and swamps and bottomland hardwood forests in Louisiana and their wildlife. *(Figure 2)*

Barrier Islands

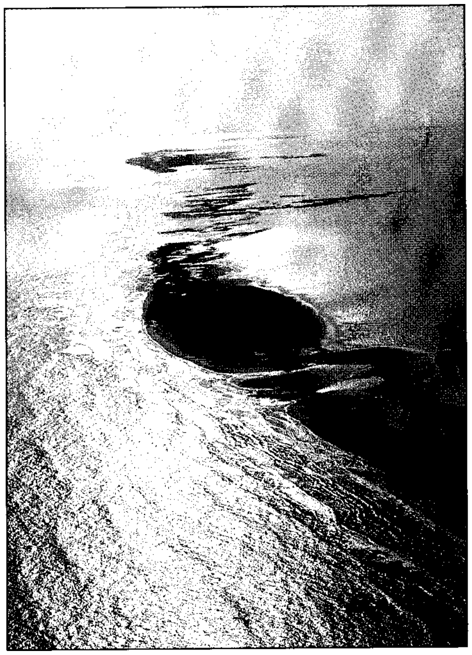


Figure 3-Overhead view of Isles Dernieres shows overwash and island break up.
UNIVERSITY OF SOUTHWESTERN LOUISIANA

As the outermost land exposed to hurricanes, barrier islands often lose significant areas of beach and marsh. Storm waves associated with cold fronts and tropical storms continuously alter the shapes of these islands, but large storms like hurricanes can cause significantly more erosion in one event than several years of cold front passages. Other disruptive forces such as subsidence, sea-level rise, inadequate sediment supply, and human disturbance work in concert with tropical and winter storms to degrade these islands. *(Figure* 3)

Among the first habitats of coastal Louisiana to experience the devastating effects of Hurricane Andrew were the barrier islands, Isles Dernieres. Over the past 130 years, nearly 78 percent of the land area in the Isles Dernieres chain had already been lost. The continuous island arc present in 1853 had deteriorated into a series of five narrow islands. Recent photointerpretation has documented that between 1990 and 1992 after Hurricane Andrew passed near them, the Isles Dernieres lost an additional 30 percent of their land area.

Hurricane Andrew's impact on Isles Dernieres varied considerably, depending on the position of an island relative to the storm's path. Islands farther to the west and closer to the path of the storm suffered greater alterations in shape and size than did islands on the eastern end of the chain. The westernmost islands of the chain, Whiskey and Raccoon, were severely eroded. *(Figure* 4)

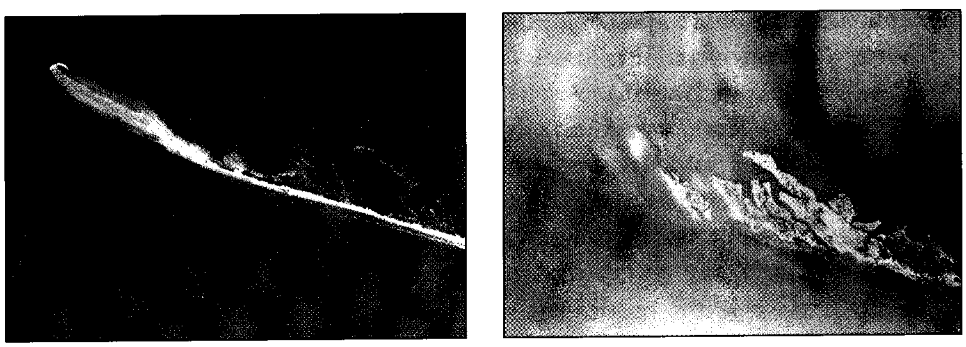


Figure 4—Two aerial photographs of Raccoon Island, Isles Dernieres, before and after Hurricane Andrew, show that the island's entire western spit was washed away. NASA AMES 1990, 1993

On Trinity Island, in the eastern part of the chain, large breaches of water up to 2 km (1 mi) long opened across the island. The shoreline receded 68 m (223 ft) in some areas, and there were significant overwashing and deposition of sand on back barrier wetlands. It is also likely that the entire island was submerged by the accompanying storm surge.

Overwash and sand movement from Hurricane Andrew damaged island plant communities that protect the underlying layers of sand from eroding, but in some areas the land was scoured and breached by waves, and the plant communities were essentially stripped away. In other areas, substantial overwash and sand deposition of 50-100 cm (20-39 inches) partially or completely buried plants.

Deposited sand partially or completely covered plant communities of Isles Dernieres and other Louisiana barrier islands. Low island marsh communities, dominated by smooth cordgrass, as well as marshes at higher elevations characterized by a mixture of mangroves, saltwort, saltgrass, glasswort, smooth cordgrass, and wiregrass were buried. In some cases, only the tops of the mangroves were still exposed to the air.

Because plants on barrier islands are generally adapted to sand movement, salt spray, and low levels of nutrients, it is not surprising that, despite burial by sand and exposure to the storm surge, the vegetation on Trinity Island is rapidly recovering. Throughout the recovery, both total plant cover and number of species have increased. The reestablishment and growth of these plant communities will help to stabilize the new sand surfaces created by the strong storm winds, which continuously eroded and transported the sandy dune and swale soils.

When Hurricane Andrew carried beach sand across Trinity Island and deposited it on the back barrier wetland plant communities, it created habitats with environmental conditions different from those present before the storm. Changes in salinity and elevation resulted in a redistribution of plant species. For instance, increased elevation from sand deposition caused a shift in species dominance from smooth cordgrass to wiregrass. Mangroves disappeared from higher sites but became established in the saltier lower sites.

Many barren areas had still not recovered from the hurricane three years later. Most recovery occurred when new shoots grew from the runners of adult plants that had survived the storm. Because runners have to grow from adult plants, barren areas

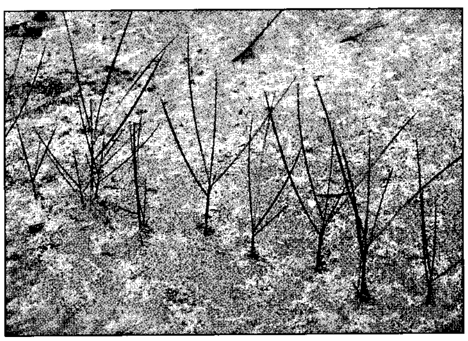


Figure 5-Revegetation of barrier islands through runner growth of plants that survived the storm. NATIONAL BIOLOGICAL SERVICE

distant from surviving vegetation will take a long time to regain plant cover. In addition, damage to new growth by nutria has been noted. This herbivore can damage new shoots and may play a major role in the future establishment of vegetation. (Figure 5)

Dispersal and germination by seeds on Trinity Island were minimal, as a persistent bank of seeds has not yet been established. The new sand deposits are barren surfaces swept by wind that continually resuspends the sands, making it difficult for seeds to accumulate and contribute to vegetation recovery Only in areas with existing adult plants were germinated seeds found, because these plants provided a windbreak that allowed both sediments and seeds to accumulate.

Barrier island beaches are also important habitats for benthic invertebrates, including ghost shrimp. Although not seen in the seafood markets of Louisiana, these burrowers are an important food for wading birds and are agents in nutrient cycling and other sediment development processes. These shrimp suffered mass mortalities during the passage of Hurricane Andrew near Isles Dernieres.

Within two years of the hurricane, shoreline populations of ghost shrimp had reestablished to prestorm levels, as had the populations of wading birds feeding in these habitats. Surprisingly, revegetation on the bay side of the islands was strongly correlated with the presence of shrimp burrows, suggesting that the shrimp influence the entrapment and growth of plant propagules. (Figure 6)

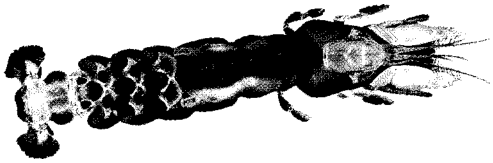
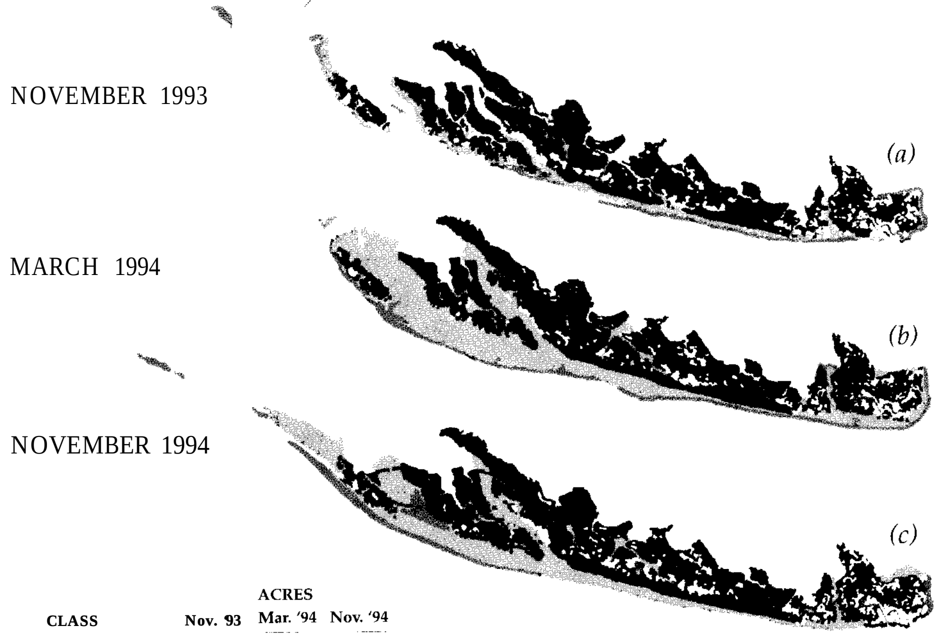


Figure 6- Wildlife such as shrimp actually helped to build back the barrier islands by overturning sediments as they burrowed.
UNIVERSITY OF SOUTHWESTERN LOUISIANA

Understanding how vegetation recovers from storms is important for land managers. The state of Louisiana began a beach restoration and nourishment operation to reestablish the portions of Raccoon Island swept away by Hurricane Andrew. The long-term stability of these newly restored areas may be significantly improved by the establishment of vegetative cover. *(Figure 7a, b, c)*

Natural resource managers must balance restorative sediment deposition with possible further decimation of reestablished ghost shrimp, which are important in the barrier island ecosystem. For the greatest success, there must be a combination of active management, including the planting of adult plants, and careful monitoring of benthic shrimp populations.



CLASS	Nov. '93	ACRES Mar. '94	Nov. '94
■ Bare Dunes	3 .58	4 7R	3.69
Beach	24.33	68.39	54.50
Flat/Beach Bar	4.20	5.70	6.77
□ Scrub Shrub	12.77	11.95	14.13
■ Vegetated Dunes	2.95	2.91	4.78
□ Water	3.23	3.06	3.24
■ Salt Marsh	59.75	57.55	61.59

Raccoon Island

***Figure** 7**a,b,c**- Geographic information system show restoration of Raccoon Island.*
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Coastal Wetlands

Hurricanes and other storms generally produce damaging winds, storm tides, and rain that flood inland coastal areas as well as erode beaches and barrier islands. Coastal wetlands help to dissipate the force of storm surges and can therefore lessen the impact of these storms on areas farther inland. Damage to these valuable coastal wetlands themselves, however, can be quite severe. The effects of high winds and storm surges are most apparent as continuous marsh is broken up into pieces, channels are filled with debris, and areas of marsh are converted into open water. *(Figure 8a, b)*

Other types of physical damage to coastal wetlands were evident following the passage of Hurricane Andrew. Most striking was the widespread lateral compression of marsh, resulting in a series of accordion-like folds with ridges rising 2 m (7 ft) above the normal surface level.

In other areas, the marsh was scoured as portions were washed away, leaving open water. At some sites, large pieces of soil and vegetation were torn from the marsh and thrown to the tops of levees or deposited into oil and pipeline canals, effectively blocking them. Some of these pieces were as large as a small car. Other marsh sites were covered with 1.5-2 m (5-7 ft) of wrack (plant debris), which completely buried the existing vegetation. Areas that were not physically disrupted or covered with sediment or wrack also appeared to lose plant cover because the salty gulf waters driven onshore by the hurricane "burned" the tops of the plants, killing the aboveground parts.

Hurricane Andrew also introduced large amounts of sediment into these coastal marsh systems. In some cases, vegetation was completely buried while, in others, the sediment was deposited as a thin layer on the marsh surface but did not smother plants. Sediments were deposited over large expanses of the coast, and even sites as far as 130 km (81 mi) from the path of the hurricane received significant amounts.

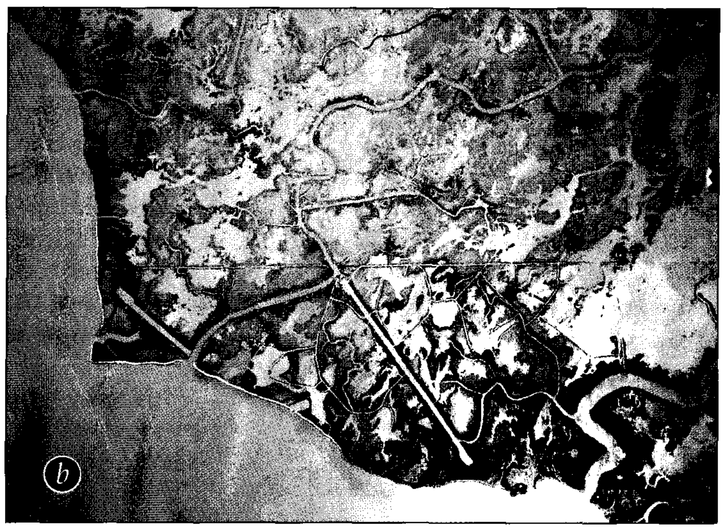
Where did these sediments originate? Careful measurements of sediment characteristics indicated that some were introduced from outside the coastal marsh system, while others were redistributed from the bottoms of shallow basins where the marsh substrate had eroded.

Coastal marshes closest to the path of the storm east of Atchafalaya Bay had the thickest deposit of storm-generated sediment, which was 10-16 cm (4-6 inches) deep and most probably came from the bottom of Atchafalaya Bay. As the storm approached, water was pulled from the bay by the force of the storm, exposing the sediments of the shallow bay bottom. As the storm passed the bay, this water rushed back in and the resulting storm surge of 1.8 m (6 ft) mixed these sediments into the water column. As the storm surge moved over the marsh, it deposited the sediments onto the surface.

Subsidence and lack of sediment are critical factors affecting wetland loss in coastal Louisiana. To remain stable, coastal marshes must grow

***Figure 8a,** b-Two aerial photographs* of *coastal Louisiana,* before *and after Hurricane Andrew, show marsh break-up into open water.*

NASA AMES 1990, 1993



in height as rapidly as they sink and sea level rises, but many portions of coastal Louisiana are isolated from renourishment by sediment. Events such as winter storms and hurricanes, which suspend sediments in the water column, may partially off-set the effects of subsidence and subsequent wetland loss by supplying needed sediment.

Not all hurricanes appear to contribute as much sediment to the coastal environment as Hurricane Andrew did. Whether they do depends on their idiosyncratic nature: wind velocity, storm tide height, angle of approach to the shore, and the availability of a source of sediments. And even if hurricanes do contribute much sediment, it may not ultimately help certain coastal marshes maintain their elevation relative to increasing sea level.

In studying the effects of Hurricane Andrew, scientists have found that, in certain areas of coastal Louisiana, even significantly increased contributions of sediment cannot completely counteract subsidence patterns, and marshes will continue to be drowned and lost. *(Figure 9)* In other areas, additional sediment resulted only in a temporary increase in elevation that was slowly lost in following years. The increases in elevation were short-lived phenomena and these sites are returning to prestorm conditions.

Proximity to the coast was not necessarily the primary factor that determined damage to wetland vegetation. In many cases, salt marshes closest to the path of the hurricane showed the least signs of damage. On the other hand, freshwater plants in interior marshes suffered most from exposure to the moderately saline water that accompanied the storm surge as it moved inland. At research sites 20-40 km (12-25 mi) from the coast, the

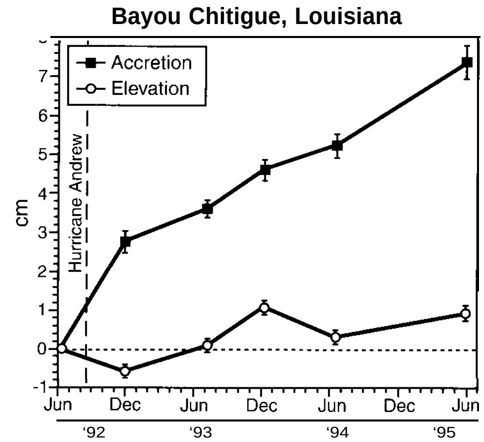


Figure 9-Although winter storms and hurricanes can deposit great amounts of sediments and wrack on marshes (accretion), the height and stability of the marsh (elevation) sometimes remain unaffected.
NATIONAL BIOLOGICAL SERVICE

hurricane-induced storm surge was still 1.7 m (6 ft) high with a salinity of 10-15 parts per thousand-about half the salt in seawater. This saltwater "burned," and in many cases killed, the aboveground portions of fresh marsh plants. This phenomenon was seen as far away as the Pearl River, located on the border of Louisiana and Mississippi, over 180 km (112 mi) from the storm's eye. Most of the plants affected, however, began to resprout within six weeks of the storm.

Five days after the hurricane, the salinity of some interior marsh sites was still eight times higher than it was prior to the storm and, at one site in western Terrebonne Parish, a wedge of saltwater was still evident below the marsh surface 55 days after the storm. Results from earlier studies of Louisiana wetlands indicate that impounded marshes suffer more extensive and long-term effects from saltwater than do marshes that drain freely. In one instance, the vegetation of an impounded marsh on the chenier plain in southwestern Louisiana required four years to recover from the entrapment of saltwater driven ashore by a hurricane storm surge.

At sites where researchers had prestorm data, they were readily able to see how Hurricane Andrew caused changes in plant composition. Areas with different types of storm damage, including sediment addition, wrack, lateral compression, and scoured marsh, were affected quite differently. *(Figure 10)*

Surfaces at the compressed-marsh sites were elevated, creating drier

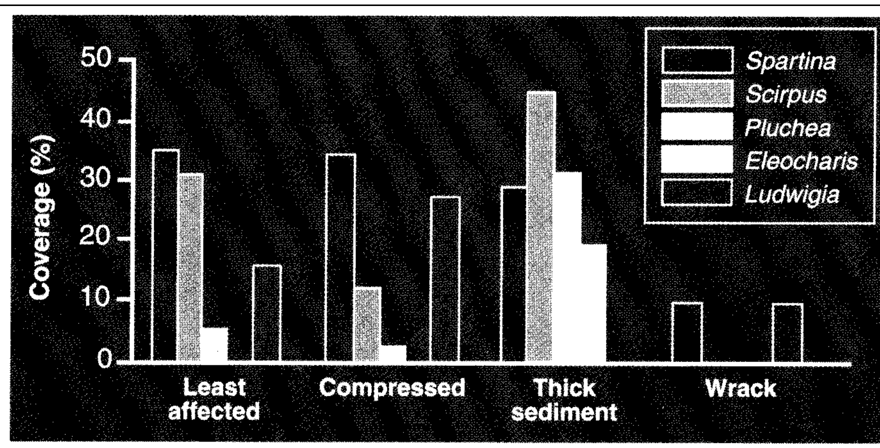


Figure 10-Depending on the type of damage suffered, coastal marsh plants recovered at different rates and some have yet to recover. NATIONAL BIOLOGICAL SERVICE

habitat. The most dramatic changes in species composition were in the compressed areas. Plants not typically found in coastal marshes increased significantly because of the drier conditions. Figure 11)

Areas where sediment was deposited did not change substantially in species composition. In these sites, it is likely that the sediment will act as a fertilizer, increasing the growth of the existing vegetation. In areas with wrack deposition, plants have recolonized very slowly because the wrack must first decay enough to allow plants to grow through the thick debris.

Virtually all of the study areas in the coastal marsh had some degree of disturbance after Hurricane Andrew. Although the kinds of species present in many sites changed, this change is likely to persist only in areas of compressed marsh where increased surface elevations will last longer.

Ultimately, scientists have found that the vegetation of these coastal marshes recovers fairly quickly from the impacts of hurricanes and other tropical storms. Even areas where the vegetation dies back because of salt burn generally recover over time. Only in areas with dramatic changes,

Figure 11-Lateral compression caused the most significant damage and the longest recovery for coastal marshes.
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such as lateral compression, erosion, and wrack deposition, will long-term adverse effects be seen. *(Figure* 12)

Areas where the marsh was totally lost are unlikely to recover, worsening the existing problems of coastal marsh erosion and degradation. In other cases, sediment added to the marsh surface contributes to the health of these systems.

The overall firmness and "health" of the marsh strongly influence the degree to which it is affected by storms. Hurricane Andrew had a major impact on floating and weakly rooted wetlands, but a much smaller effect on firmly rooted marshes. In the future, areas of degraded marsh will be more susceptible to increased erosion from hurricane winds and associated storm surges.

Levees surrounding impoundments can also isolate marshes from available sources of sediment, which can promote subsidence and result in marsh loss. The sediment that enters an impounded marsh as a hurricane storm surge washes over the levee may be the only significant addition of sediment received by the marsh since its enclosure.

Hurricanes are valuable sources of sediment for coastal wetlands and may in the short-term be able to counteract subsidence and slow the process of the marsh's interior fragmentation and degradation. Although these sediments may not completely counteract the subsidence associated with Louisiana's coastal wetlands, they are an important addition in areas cut off from normal sediment supplies. Marsh managers should consider these often opposing effects when considering restoration and mitigation projects. The best way to protect wetlands from future hurricane destruction is to promote the inorganic and organic accretionary processes that encourage a "healthy" marsh.

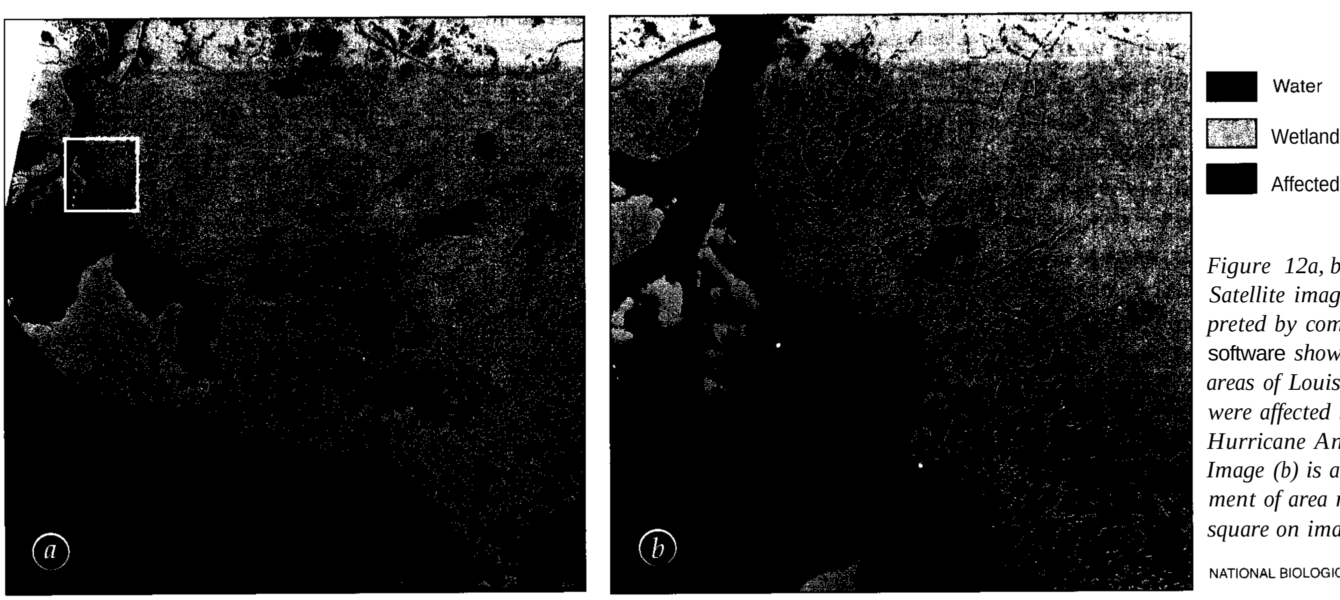

Figure 12a, b-Satellite images interpreted by computer software *show that large areas of Louisiana's coast were affected by Hurricane Andrew. Image (b) is an enlargement of area marked with square on image (a).*

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Forested Wetlands

Hurricane Andrew diminished in strength after it made landfall east of Cypremort Point. The storm turned to the north-northeast, passing over the Atchafalaya Basin where more than 450 km^2 (174 mi^2) of cypress-tupelo and bottomland hardwood forests were at risk. The storm stayed within the levee boundaries with wind speeds gradually weakening, but wind gusts of 112 kph (70 mph) were still recorded when the storm was 48 km (30 mi) west of Baton Rouge.

The Atchafalaya Basin contains 35 percent of the remaining bottomland hardwood forest and swamp forests of the lower Mississippi floodplain. The two dominant forest-cover types include cypress-tupelo swamps, primarily in the southeast part of the basin, and mixed bottomland hardwood forests. The southwest portion of the basin has been subjected to high rates of sedimentation since the construction of levees after the flood of 1927 and the diversion of sediment-laden Mississippi River water. The areas of new sediment are now dominated by black and sandbar willow, swamp cottonwood, and the exotic Chinese tallow.

The impact of Hurricane Andrew varied greatly with forest type, the species mixture, canopy (tree top) structure, and location relative to the storm's path. The zone of heaviest damage to the forest extended 20 km (12 mi) east from the hurricane eyepath in the southern portion of the basin and 10 km (6 mi) east of the eyepath in the northern part. Sites exposed to wind speeds less than 120 kph (75 mph) experienced lower levels of damage. *(Figure 13)*

Most of the initial loss in tree density and canopy cover was restricted to the bottomland hardwood forests. These stands lost 10 percent of their basal area-the volume of their trunks-in areas exposed to the weaker influence of the storm. Trees in areas exposed to the full strength of the storm lost over 60 percent of their basal area.

Bottomland hardwoods in the southwest portion of the basin, dominated by willows, were especially hard-hit, with more than 85 percent of the trees in this area damaged. These stands were growing on loose soils and were quite susceptible to being pushed over. Surprisingly, cypress-tupelo stands were largely unaffected because the canopy tree species have properties, such as extensive root systems, that make them resilient to hurricane-force winds. *(Figure 14)*

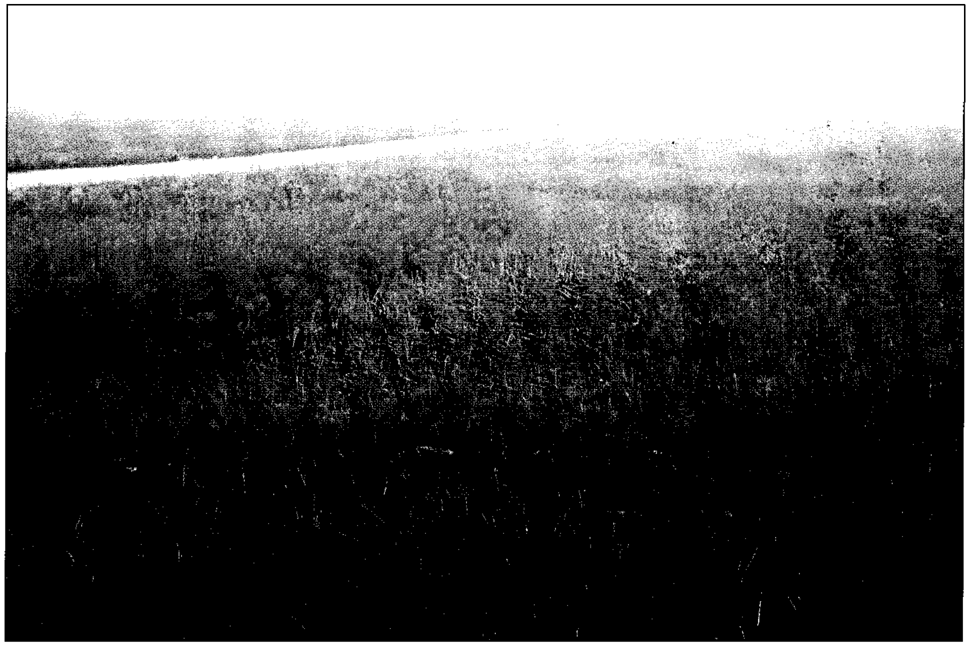

Figure 13-Hurricane Andrew's tree-toppling path in the Afckafalaya Basin.

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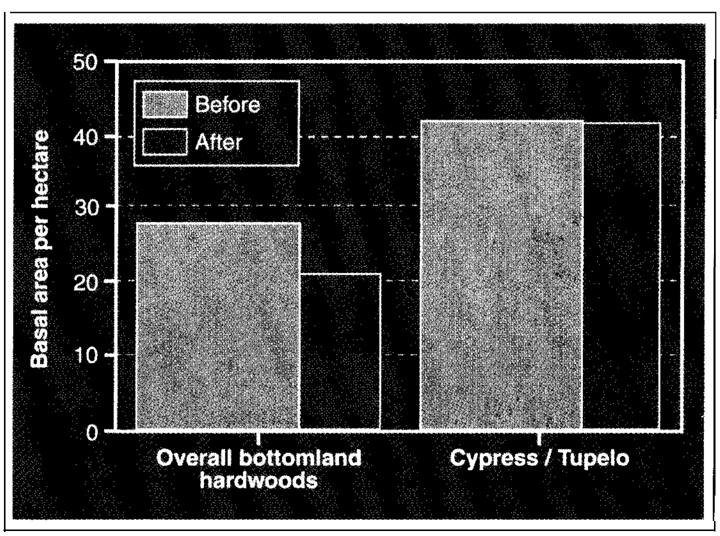

Figure 14—Although cypress-tupelo swamps remained almost unaffected by Hurricane Andrew, bottomland hardwood forests lost almost one third of their frees.

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Even though there were many fallen trees (about 10 percent of the forest volume, basinwide) overall tree mortality was initially low because, despite severe damage, many of the downed trees resprouted. Surveys conducted two years after Hurricane Andrew, however, revealed that there was a considerable amount of delayed mortality among certain tree species. Mortality for persimmon, swamp cottonwood, and sandbar willow increased from 5 to 7 percent during the first year to 25-61 percent the next year.

Despite the widespread destruction in the Atchafalaya Basin, not all tree species responded in the same manner to the catastrophic winds. *(Figure 15)* Some species were resistant to wind and lost only individual limbs; others were susceptible to windthrown or snapped tree trunks and died. Tree species that were susceptible to windthrow are prolific sprouters and have survived. Species that initially survived and sprouted, however, appear to be highly susceptible to delayed death.

A significant impact of the storm was the amount of plant material stripped and broken off the trees by the winds. This phenomenon was so widespread that it showed up on satellite imagery of the study area. Widespread defoliation (leaf removal) caused up to 41 percent of the normal seasonal leaf fall to occur in a single day. The decomposition of this large amount of organic material falling into the swamp in a short period led to extremely low levels of oxygen in the water column in the Atchafalaya Basin and a large die-off of fish. An estimated 182 million game and commercial fish died, an economic loss of $160 million. *(Figure 16)*

Table 1. *How Hurricane Andrew Damaged Specific Types of Trees in Bottomland Hardwood Forests*

Most damaged	Moderately damaged	Least damaged
Sandbar willow	Red mulberry	Pumpkin ash
Swamp cottonwood	Boxelder	Deciduous holly
Black willow	Swamp red maple	Water hickory
Waxmyrtle	Swamp privet	Baldcypress
Chinese tallow	Hackberry	Water elm
Sycamore	Various oaks	Buttonbush
Swamp dogwood	Various hawthorns	

Figure 15-One tree shows the haphazard damage a hurricane can cause.
NATIONAL BIOLOGICAL SERVICE

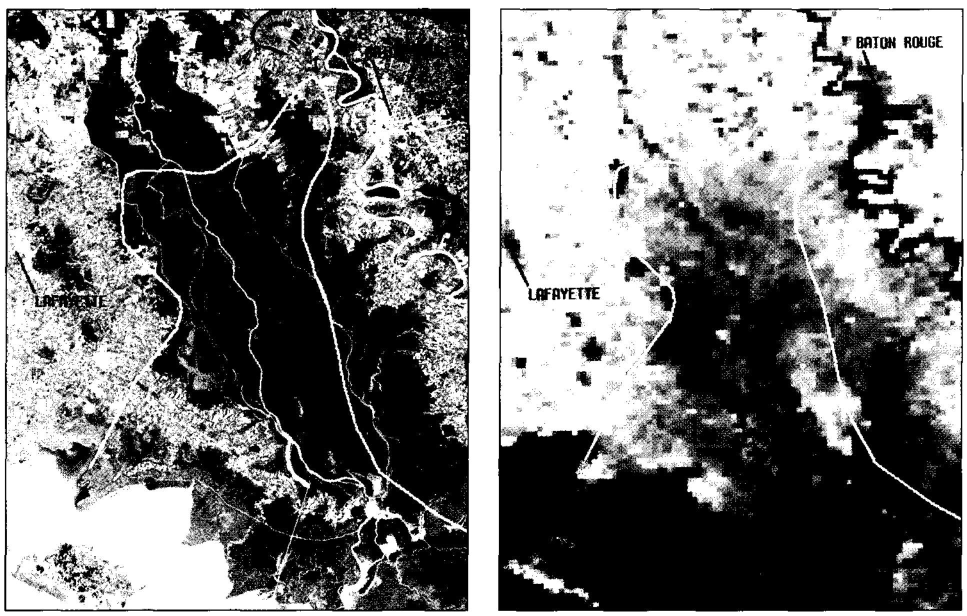

Figure 16—Landsat Thematic Mapper image of Atchafalaya Basin; red areas indicate green vegetation. Same area through Advanced Very High Resolution Radiometer at three different times in 1992. Normally, the area outlined would appear white or similar to the area above it. The pink-purple areas indicate new leaf cover just a few months after the storm.
NATIONAL BIOLOGICAL SERVICE

Can we predict how the forest will recover from such catastrophic disturbance? Forest recovery and the formation of a new canopy are accomplished in several ways. Defoliation of living trees by Hurricane Andrew, for instance, caused a surge of new leaf growth in the fall of 1992. Furthermore, many understory trees and saplings were unaffected by the hurricane despite the loss of the canopy trees. These survivors will grow rapidly and form the new canopy. In other cases, seeds and new tree seedlings will become established and eventually form the new forest. (*Figure 17*)

Initial surveys suggested that heavy-seeded species such as oaks were underrepresented in the ground layer, while other species such as Chinese tallow tree and water elm were more common. It is disturbing that an exotic species such as the Chinese tallow tree has such a high representation in the understory, while the more valuable oak species commonly found in bottomland hardwood forest sites are underrepresented. This suggests that exotic species may play more of a role in recovery from disturbance than they have historically and can alter the nature and function of these forests.

Hurricanes are an important agent of forest disturbance in coastal wet forests. The recovery of the forest will depend on the previous forest cover, the type of damage, and the specific environmental conditions affecting regeneration. The harvest of the virgin cypress swamps and the building of levees earlier this century caused widespread change in the forests of the Atchafalaya Basin. Increased sedimentation has resulted in the dominance of willow stands in the southwest portion of the basin, an area that was most heavily damaged by the hurricane because of the willow's susceptibility to hurricane-force winds.

Various climate change models suggest that under global warming, tropical storm intensity might increase as much as 50 percent. If so, then the forests of the Atchafalaya Basin will be at greater risk of damage, and intensive land management may be required to direct the developing forest toward more desirable forest cover. (*Figure 18*)

Figure 17-Resprouting in bottomland hardwood forest eight months after the storm.
NATIONAL BIOLOGICAL SERVICE

Figure 18-Ground view of damage in bottomland hardwood forest six months after the storm.
NATIONAL BIOLOGICAL SERVICE

Wildlife

Figure 19--White tail deer.
U.S. FISH AND WILDLIFE SERVICE

It is certain that a storm with winds of 225 kph (140 mph) will immediately kill some fish, birds, and other animals as it passes through their habitat. Surprisingly, however, studies have shown that the passing of Hurricane Andrew actually provided benefits to some wildlife species while barely affecting others. Sweeping through the Atchafalaya Basin, the winds of the storm cleared much of the canopy in the bottomland hardwood forest. This disturbance allowed more sunlight and other nutrients for a greater variety and number of plants to grow and, ultimately, provided small mammals like white-footed deer mice, and amphibians, and reptiles with more food.

Populations and growth of larger mammals in the Atchafalaya Basin, such as the white-tailed deer, seemed not to be affected at all by the hurricane. The mixed hardwood forest, sustaining more damage than the cypress-tupelo swamps, provided more forage opportunities for deer after the hurricane. Over time, however, this increased forage will decrease as mature canopy trees become reestablished and shade out the understory. Further research will show if alternative management, such as clearing debris in these forests after a hurricane, would enhance the habitat of white-tailed deer in years following storms. *(Figure 19)*

Birds in the Atchafalaya Basin were affected more significantly by Hurricane Andrew. Numbers of resident birds-those that live in an area year-round- dropped immediately after the hurricane, as individuals, their nesting places, and habitat were battered by the high winds. But studies have shown that any actual mortality caused by the hurricane was not a negative factor for long; surviving residents and birds from the surrounding forest soon began repopulating the empty areas.

The northern parula, a Neotropical warbler, was one bird directly affected by the storm. This bird uses Spanish moss to build its nest. In addition to the number of warblers lost during the storm, there was a continuing loss afterward, probably because the moss needed for new nests was blown off the trees and scattered throughout the basin, making it difficult for the birds to find. This bird also uses the canopy of trees as a feeding ground, and lack of canopy for forage could also explain a decrease in the number of birds. (Figure 20)

Other studies have shown some improvement of bird habitat in the Atchafalaya Basin. Birds that nest in tree cavities, for instance, did not lose their nests because the winds rarely completely toppled trees. The trunks remained standing, so the nest sites were not lost, even if a tree was heavily damaged. In fact, more nests were provided for cavity-nesting birds by the trees that were not toppled

Figure 20-Northern parula.
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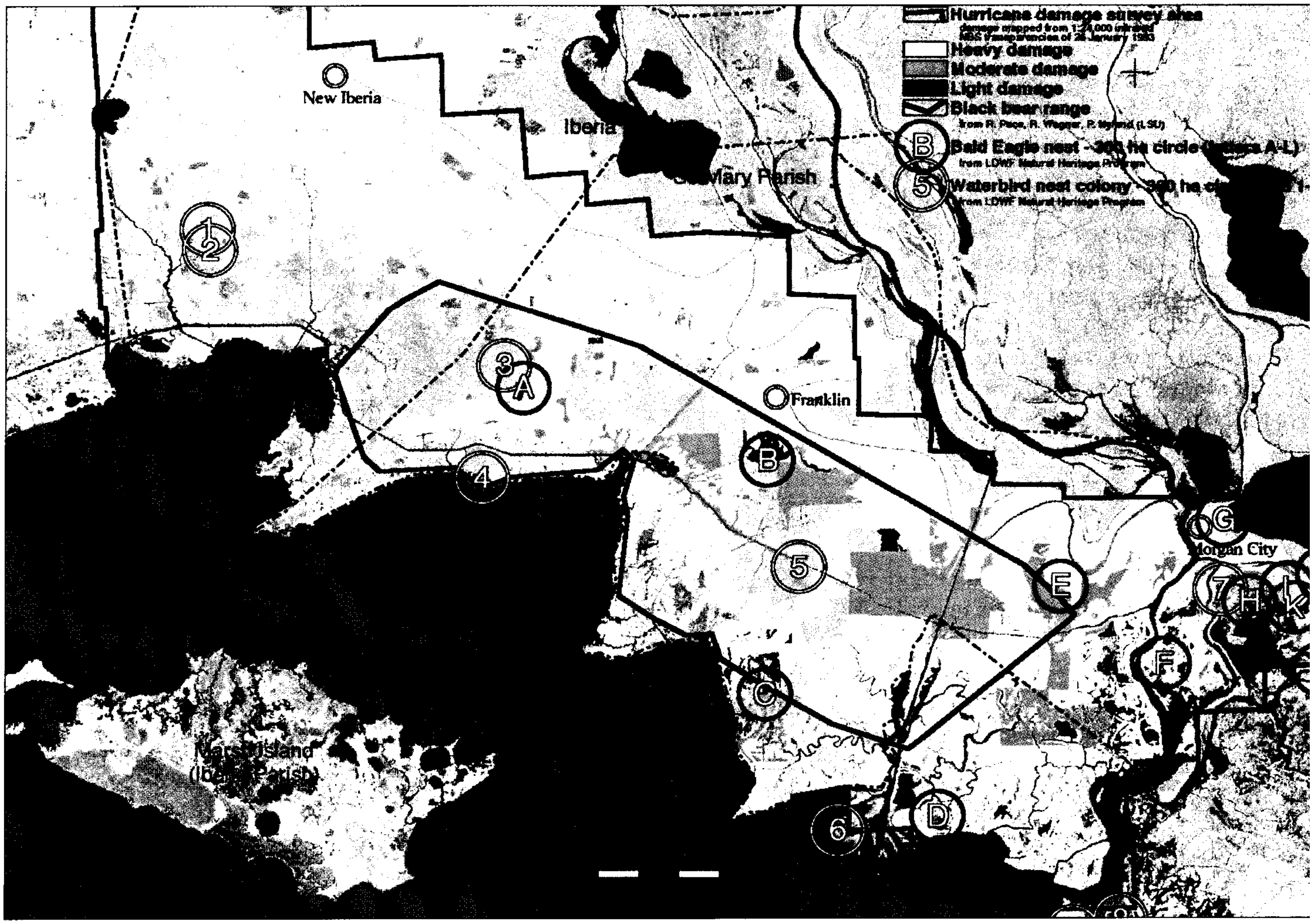

because new cavities were made when branches broke off.

While the number of resident birds dropped immediately after the storm, the broken forests provided some attraction for migrating birds like Neotropical warblers. These traveling songbirds visit the Louisiana forests on their migration through North America, but their new attraction to sites they usually ignored increased bird diversity in the basin right after the storm.

In Iberia, St. Martin, and St. Mary parishes, large areas of forest that provide important habitat for many species were affected by Hurricane Andrew. Scientists developed maps estimating damage to these forests and used a powerful computer tool known as a geographic information system to compare damaged areas with the known positions of bald eagle nests, colonial wading bird colonies, and the range of the Louisiana black bear. This analysis demonstrates the importance of maintaining multiple nesting sites and habitat for larger birds and mammals, though site or nest abandonment may result from other factors. (Figure 21)

Figure 21-Distribution of animals in areas of Iberia, St. Martin, and St. Mary parishes affected by Hurricane Andrew.
THE NATURE CONSERVANCY

Hurricanes Are Inevitable

We are only just beginning to appreciate the significance of hurricane effects on our biological resources. As we learn more from scientists about the frequency with which hurricanes can occur, the systems they affect, and how they interact with the evolution of our coastal ecosystems, we can better prepare ourselves and our environment for their onslaught.

Hurricanes have long affected the Atlantic and gulf coasts of North America. We can find chronicles of these storms in the New World experiences of Christopher Columbus and throughout the period of colonial settlement. Evidence is also imbedded in the growth rings of trees and in coastal geologic deposits, and it tells us that these storms have struck our coastlines with regularity. *(Figure 22)*

For instance, return times-how frequently hurricanes strike an area-along the northern gulf coast can average from five to 20 years, depending on location. Before 1995, the deadly nature of these storms had faded from the public consciousness because, even though Louisiana had been hit by other recent storms, the previous 25 years had been relatively inactive. The inactivity, however, seems to be changing.

Recent studies of hurricane activity and global weather patterns seem to indicate that hurricane activity comes in cycles of roughly 20 years. Meteorologists predicted 1995 to be one of the most active years for tropical storms in the last 50 years, and indeed by mid-October, a near-record 18 tropical storms and hurricanes had been named and tracked. Although these storms missed Louisiana that year, future storms will inevitably come this way. Most climatic computer models suggest a period of increased activity and a tendency toward stronger storms as we approach the new century.

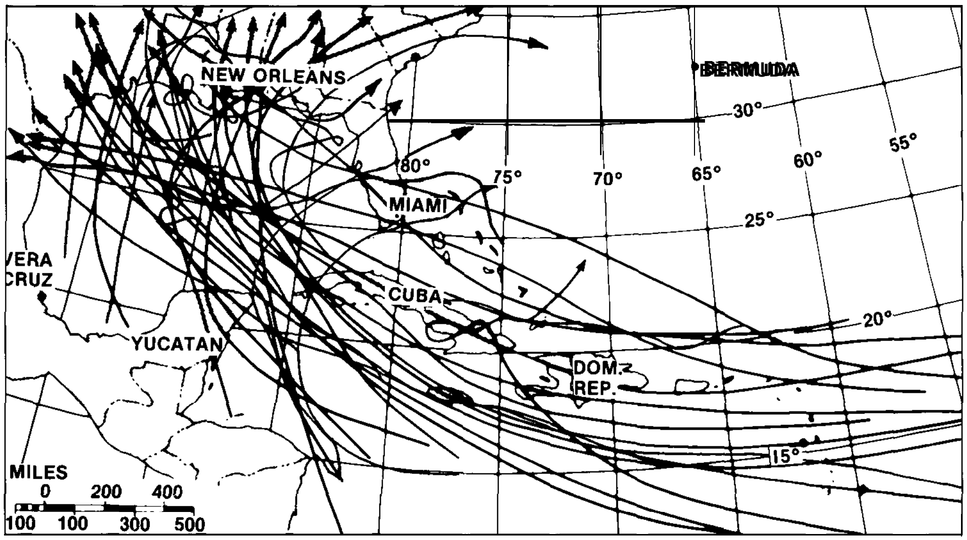

Figure 22-Tracks of cyclones *in the* Gulf of *Mexico this century.*

NATIONAL BIOLOGICAL SERVICE • SOURCE: AMER. SOCIETY FOR OCEANOGRAPHY, 1982 & NATIONAL WEATHER SERVICE, 1982-1988

Statistics compiled from storms this century indicate that while the number of deaths per hurricane decreased over time (Table 2), the costs of hurricane damage increased. In 1992, Hurricane Andrew was listed as the costliest natural disaster to occur on U.S. soil; total damage assessment for the storm was about $27.2 billion, but only 60 lives were lost.

How is it that the cost of storms has increased over the years while their deadliness has decreased? One reason is that people are building and living in coastal areas much more so than in the past, and these areas are the ones hit hardest by hurricanes. Over half the nation lives and works in coastal counties, which represent only about 10 percent of the U.S. land mass. At the same time, however, the advent of aerial reconnaissance and satellite imagery has warned people about the approach of such storms, leading to prompt evacuations and a reduction in deaths. But we still have much to learn before we can understand whether human activities in the coastal zone are making these ecosystems more vulnerable to hurricane effects.

Table 2. Hurricanes Affecting Coastal Louisiana Earlier This Century (Data From the U.S. Army Corps of Engineers)

Year	Effect
1909	$6 million in damage; 353 deaths; winds 200 kmh (124 mph); 5-m (16-ft) storm surge
1915	$13 million in damage; 275 deaths; flooding in New Orleans 0.3-2 m (l-8 ft) deep; 3-m (10 ft) storm surge covered Grand Isle
1947	$100 *million* in damage; 34 deaths; flooding in New Orleans 0.3-2 m (l-8 ft) deep
1957	*Hurricane Audrey: $150* million in damage; 500 deaths; 4-m (12-ft) storm surge
1965	Hurricane Betsy: $1.4 billion in damage; 81 deaths; 3-m (I0-ft) storm surge covered Grand Isle

Value of Louisiana's Coastal Barrier Islands and Wetland Systems

It is estimated that every 1 km (0.6 mi) of barrier island shoreline protects 30 km^2 (12 mi^2) of wetland-estuarine habitat. The islands that fringe the coastal wetlands can limit the height of hurricane storm surges, reduce wave energy, reduce the potential for erosion of landward wetlands, and retard saltwater intrusion. The continued degradation of these islands, however, has diminished their ability to protect the wetlands, bays, and estuaries that support Louisiana's coastal fisheries.

Coastal wetlands offer an important buffer from flooding and salinity intrusion associated with the hurricane's storm surge. However, Louisiana's coastal wetlands are also at risk. The current rate of wetland loss in Louisiana averages some 65.6 km^2 (25 mi^2) each year. Since the 1930s, an estimated 3,950 km^2 (1,525 mi^2) of coastal wetlands and barrier islands have been lost. Subsidence, human impacts, and erosion caused by storms have all been implicated in these high rates of loss. A hurricane such as Hurricane Andrew can result in a year's worth of loss in a single day.

Besides offering great protection to cities and upland areas, Louisiana's coastal and forested wetlands also have an important impact on the state's economy. The state's coastal ecosystems provide the natural resources for a $1-billion-per-year fish and shellfish industry. The fisheries industry in southern Louisiana relies on coastal marshes for crucial nursery habitat. A powerful hurricane damages the livelihoods of people who rely on fisheries. After Hurricane Andrew, for example, $15 million was granted to the gulf commercial fishing industry to help recover from those losses. Farther inland, forested wetlands provide crucial habitat for wildlife and a renewable resource for the timber and paper industries. The Atchafalaya Basin holds the largest single parcel of forested wetland left in the United States, about 1.5 million acres.

Monitoring, Protecting, and Restoring Coastal Louisiana

Although many natural habitats were devastated by the hurricane, research is showing that most of these systems will recover in time. Physical destruction was limited to an area near the path of the storm, but the secondary effects of Hurricane Andrew were noticed at sites quite distant from its path. Some of the barrier islands were severely eroded. Hurricanes such as Andrew can only accelerate a trend towards their disappearance, although efforts to restore those islands are already seeing some success.

Vegetation has recovered in Louisiana's coastal wetlands, but in certain areas wetland loss was accelerated and distinct physical changes—such as the compression of coastal marshes-resulted. The forested wetlands of the Atchafalaya Basin will probably be as resilient as the coastal wetlands despite damage and loss to the canopy trees. Despite initial losses, wildlife populations have generally recovered.

Our conclusions must be tempered with the realization that these coastal ecosystems are increasingly at risk from various natural and human-caused factors. The forested wetlands are being rapidly reduced in area and are experiencing changes in the composition of their woody species. Over time, Louisiana has lost nearly 60 percent of its forested wetlands. Barrier islands are eroding at alarming rates, and Louisiana leads the nation in wetland loss.

We must continue to monitor the long-term effects of hurricanes and make note of which species are present as well as establish permanent study plots that can be followed over time. Without continued research into how both nature and humans affect Louisiana's coast, we may one day arrive at a point where we find that willful winds are agents of total destruction. Hurricane Andrew's damage was tempered by its part in the continued evolution of the coast, but that may change with future, fiercer storms and continued degradation of our coastal resources.

Technology Advances But So Do Old-Fashioned Techniques

Pieces of trees and sediment, carefully extracted and preserved, provide a historical view of the environment. Analytical techniques carry names like dendrochronological (dendro=tree, chrono=time) and cryogenic (cryo=frost, genic=generation) core sampling. Tree samples reveal the impacts of past hurricanes on tree growth, as do sediment samples of the life of a marsh, both offering valuable information about the present environment.

Wetland scientists have made use of these technological advances to develop tools that assist their research efforts and offer more detailed information about the resources to be managed. In the studies undertaken after Hurricane Andrew, these tools were used to assess the damage to the coastal environment and predict the long-term effects on valuable coastal resources.

For instance, data loggers for the continuous recording of water elevation, wind speed, and other information had been placed at various marsh sites prior to the hurricane to evaluate marsh management methods. These computers recorded the hurricane as it passed over the sites. They showed that, on August 26, Jug Lake, Louisiana, received wind gusts of 162 kph (101 mph) that were responsible for the extensive tearing of the brackish marsh and its conversion to open water, which is specific, on-the-spot information scientists would not have had otherwise.

Aerial photographs, satellite imagery, and predictive models are also techniques used in studying natural resources. Aerial photographs, taken from airplanes right after the storm, showed immediate loss of spits on barrier islands, the accordion folds in marshes pushed together by winds, and the defoliation and breaking of trees in bottomland forests. Comparisons of aerial photographs taken before the storm, classification of damage type and entry of these classifications into digital data bases, and the use of geographic information systems allowed researchers to generate color maps that clearly showed damage that the human eye can miss. Furthermore, similar delineation of images taken from satellites allowed the same kind of damage assessment and will help lead to large-scale analyses of land cover trends. *(Figure 23)*

With field data and digital data bases, scientists can develop computer models that simulate the effects of different types of hurricanes on different habitats. Models developed can actually use historical data on wind strength and direction of past hurricanes to predict the probability of hurricane return frequency, as well as the intensity of the winds at remote locations.

But these hurricane studies were also aided by some old-fashioned techniques. Site-specific damage surveys throughout the coastal zone were made by people who actually use the coastal marshes: trappers, hunters, and camp lessees. They provided detailed information about damage to sites that they were most familiar with, and almost all of them knew within a week of the storm exactly what had happened in their areas. The information also helped land managers in setting priorities for repairing storm damage. More information about past storms will presumably be provided by the compilation of oral histories of the Atchafalaya Basin. To balance technology and tradition is fitting because, ultimately, it is the tie between the people and the land hurricanes affect that will teach us the most about the willful winds.

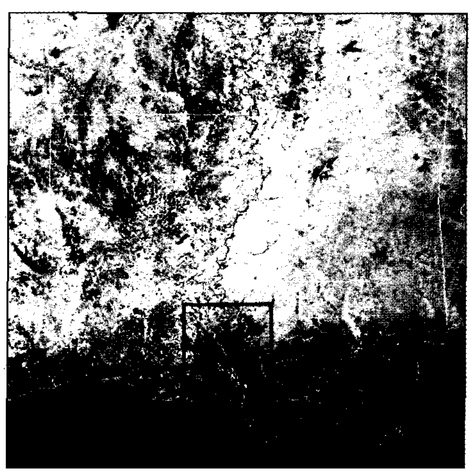

Figure 23-Louisiana depicted through Advanced Very High Resolution Radiometer at three different times in 1992. Normally, the area outlined would appear white or similar to the area above it. The pink-purple areas indicate new leaf cover just a few months after the storm.
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